Finding the site of Boudica's last battle: Roman logistics empowered the sword.

Steve Kaye, March 2013.

Note: this is an updated version of an earlier essay issued in 2012. The updates largely relate to a complete re-computation of the hydrology of Britain, the inclusion of insights gained from a study of Roman marching camps and, subsequently, a reworking of the statistics to produce a weighted listing of possible Boudican battle sites. This essay is one of a series based on the core work related to terrain analysis, hydrology and Roman marching camps, all of which can be found on the author's website at www.bandaarcgeophysics.co.uk/arch_intro.html .

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Introduction

In a brutal conflict in the summer of either 60 or 61 AD approximately 100,000 humans struggled for the control of the seventeen-year-old Roman Province in southern Britain. The Boudican uprising saw rebels and Romans march and fight in numbers probably never seen since, across a land where resources of water, food and fodder for the huge numbers of men and supporting animals were crucial determining factors in the outcome. In this essay these under-appreciated resources, mistakenly perceived as mundane, are calculated and examined to try to further narrow down the search for the site of Boudica's last battle.

Napoleon famously said: “An army marches on its stomach”; he might have said, with equal certitude that: “An army walks on water”. Sadly for his Grand Army of c.500,000 marching to Moscow in 1812, which was essentially destroyed by lack of sustenance, he did not practice what he opined. However, the Russians did; they withdrew before the vast Napoleonic onslaught, leaving barrenness in their wake, until the pitiful rump, c.20,000 men of the Emperor’s army, crawled back across the river Niemen. This story of destruction by logistical weakening contains 2000-year-old echoes.

In an earlier Empire, Roman army commanders also understood that a victorious campaign was determined as much by logistics as by the sword. Hundreds of years of bloody conquest had created a body of military knowledge and practice that was not matched until the modern era.

Knowledge of logistics was used as a weapon by applying it to the enemy's needs and weaknesses, hence:

"*I follow the same policy toward the enemy as did many doctors when dealing with physical ailments, namely, that of conquering the foe by hunger rather than by steel*", so cites Frontinus (in Strategemata, VII,1) of Julius Caesar.

Roman strategy regarding the use of logistics as a weapon would not have been limited to food – the availability of firewood, fodder and most especially water - would have been understood to control many aspects of a conflict. Additionally, conquering by the denial of logistical elements implies that Roman armies were structured to be immune from the same stratagem. In this essay these factors will be measured, calculated and applied to the deadly struggle between empire builders and the emancipator of tribal rebels.

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**/b**oudica-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.

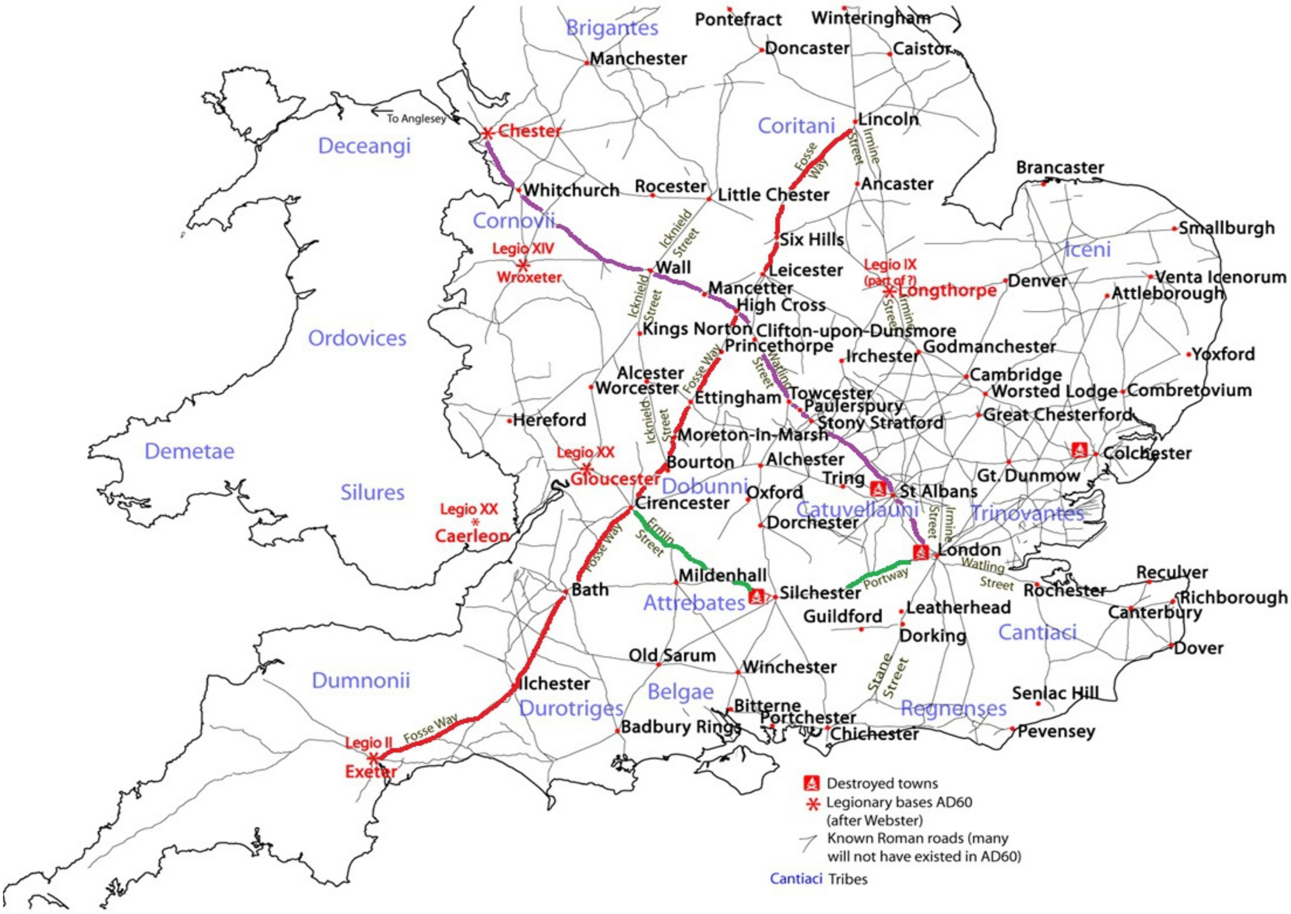


Figure 1: Location map. Significant roads are colour highlighted. Please note that not all the roads depicted would have existed at the time of the rebellion. Elements of this image are © Crown Copyright. All rights reserved 2013.

Review of Events

A précis of events in 60/61AD, based on Tacitus, would mention that Caius Suetonius Paulinus was the Roman Governor in Britain who commanded the 2nd, 9th, 14th and 20th Legions, together with an unknown number of auxiliary and cavalry units, and that he was interrupted in his conquest of the Druidic stronghold on Anglesey by news of a rebellion by the Iceni, a tribe in modern East Anglia led by Boudica, a woman driven by revenge for grievous slights by Roman oppressors. The Iceni, together with other local allies, including the Trinovantes located in modern Essex, stormed and destroyed Colchester, the principle Roman town in Britain. Meanwhile, the veteran cohorts of the 9th Legion, led by their commander Petillius Cerialis, marched from their fort (probably Longthorpe near Peterborough) to suppress the revolt and possibly to save the Romans in Colchester but were met en route, at an unknown location, by the already victorious Britons. The veteran infantry of the 9th Legion were destroyed and Cerialis retreated, with his surviving cavalry, back to their fort.

This news would probably have reached Suetonius as he marched from Anglesey towards London with cohorts and auxiliaries from the 14th and the veterans of the 20th Legions who numbered, according to Tacitus, 10,000 armed men. This bad news would be more than doubled when Suetonius heard that the 2nd Legion, probably based in Exeter, was not marching to join him as he had ordered. Suddenly, Suetonius had lost something approaching half of his effective combat strength; he was marching the 14th and 20th Legions through hostile territory towards London and faced the possibility of meeting a horde of Britons, possibly numbering in the hundreds of thousands. On reaching London he decided to abandon the proto-city and marched his men, plus any civilians who could keep up, away from the Britons who were about to destroy the town.

A less destructive fate befell St. Albans to the north of London. The horde of Britons followed Suetonius as he attempted to march away from the greatest danger to his army but circumstances forced him to offer battle. The Roman legionaries, auxiliaries and cavalrymen were victorious, apparently killing tens of thousands of Britons for little loss.

Summary of the earlier terrain analysis work

The author's earlier analysis of terrain, and how this limits the location of possible battle sites, coupled with Tacitus' written account, was explained in the documents referenced above.

In summary, once Suetonius had arrived in London with his army he was no longer the prospective destroyer of the rebellion, but a surprised fugitive from Boudican revenge and annihilation. Suetonius had to choose the direction of march out of London; for various reasons (Fig.14) it was concluded that he marched westwards, towards Silchester, using the shortest and quickest route to the Fosse Way and safety in the camps at either Cirencester, Gloucester, or even Exeter. It is possible he had an alternate strategy, namely joining forces with the missing 2nd Legion and giving battle.

This earlier work speculated that, for whatever reasons – Tacitus does not explain - Suetonius turned and gave battle somewhere within, or close to, the Kennet river valley.

Logistics of the Roman army

After the reforms of Gaius Marius, c. 100BC, the Roman army became professionalised: soldiers from all classes enlisted for decades; equipment was largely standardized; huge and slow moving baggage trains were reduced, and individual soldiers were trained to carry much of their armour, equipment and food.

Roman legions could now march for 29km each day (as a comparison the US Army marches 20-32km/day), with bursts of forced-marching if required, and may have been capable of approximately 22 days of independent operation before additional supplies were needed. These figures are based on the use of a troop baggage train, essentially mules closely associated with each unit, rather than an army baggage train. The latter would have been larger, made use of wagons and mules, carried more supplies and heavy weapons, was slower and would have supported the whole army, not just individual fighting units as did the troop train. The troop baggage train is selected as the primary transport unit in this essay because it is thought likely that the army baggage train would have remained with the fighting units left behind in North Wales and Anglesey, while Suetonius, and units of the 14^{th} and 20^{th} Legions, moved rapidly south along Watling Street to London.

To place the 22 days of operation into the Boudican context it can be calculated that this would allow the legionaries to march 638km at 29km/day – enough to travel the 540km from Anglesey to London, then onwards to Silchester, Cirencester and finally Gloucester, and leave 3-4 rest days, i.e. roughly one in five. However, we have no evidence that Suetonius' legionaries and mules did have this capacity, but the figures are illustrative of the capabilities of the legions, and suggest that, allowing for foraging and requisitioning from local forts and London merchant-warehouses, that Suetonius probably had little difficulty feeding his men during the campaign. Of course the actual marching rate during the Boudican campaign would have been variable, for example falling lower than 29km/day when harassed by rebels, but attempting to match this variability to recorded events is fraught with uncertainties and, ultimately, pointless. Nevertheless, as we shall discuss, the Roman army will be shown to have been the significantly quicker unit of the two combatants.

The core unit of a legion was the eight man *contubernium* which shared a single tent, probably one servant, or slave, and two mules. The servants cared for the general needs of the legionaries, fetched water, cooked, cared for the mules and were an essential and integral element in the effectiveness of the eight man fighting unit. Each legionary carried all his clothing, armour, weapons, sundry essential items (such as a sickle) and could carry rations for 17 days. The total weight came to 43.4kg; in comparison, British army soldiers during the 1982 Falklands conflict typically carried 54kg, while US Army riflemen in Afghanistan regularly carried 40 to 58kg. The Roman mules carried shared, larger and heavier units of equipment such as the tent and cooking pots, together with their own fodder and additional food stuffs for the men. Crucially the mules were fast and rugged enough to match the pace of the trained legionaries, and did not lag behind the marching units, or slow them down.

It is estimated that a Roman era mule could carry 135kgs. The two mules could carry 145kgs of non-food stuffs (tents and the like) and at least 17 days, or 38.5kgs, of mule-grain. The remaining mule capacity of 86.5kgs could be taken up with five more days of legionary and mule-grain – hence the figure of approximately 22 days of independent operation by the legion.

Historical accounts state that the marching legions supplemented their carried-rations with food acquired by purchase, requisition, foraging and pillaging, the method being determined by varying circumstances. Foraging was essential to the maintenance of the marching units, especially for firewood, water and fodder, and was conducted in a daily, disciplined and practised manner.

Fodder was the main staple for the mules and horses; the animals could be released to pasture and/or the legionaries would use their sickles to gather fodder for immediate consumption or later transport. Roman commanders knew how crucial fodder was to any campaign; for this reason they would delay their marches until the grass-growing season and retire to winter quarters once fodder was insufficient. The importance of gathering fodder is further emphasised by each legionary carrying a sickle, although it was also used for harvesting grain.

It is also thought that each legionary carried a saw for the gathering of firewood, another crucial requirement of the marching legion. Without fire wholesome meals could not be prepared, wet men would become sick, spirits and morale would fall and could lead to a general feeling of wretchedness.

The water needs of the marching legionary

An adequate water supply was essential for the well-being, independent efficiency and effectiveness of the legions. Furthermore, Jonathon P. Roth, in his excellent: 'The Logistics of the Roman Army at war (264 B.C. - A.D. 235)', states that: “Caesar measured his marches and set up his camps in order to assure an adequate water supply.” Estimating the water requirements of the marching man is notoriously difficult today; even more so for a Roman legionary. Although there a number of statements in the historical texts concerning the amount of water consumed by a legionary, none are thought to be sound, certainly not empirical, and cannot be relied upon. Consequently the scientifically sound studies of the water consumed by modern soldiers, conducted by the medics and professionals of the modern US Army, were examined for this study: this empirical data is, therefore, a proxy for the water required by a legionary.

Figure 2 is of a graph of the water needs of US Army soldiers operating under varying climatic conditions and at varying work-rates. The work-rates are calibrated to energy expenditure, such that a sedentary soldier expends 2,500 kilocalories a day (kcal/day) – the lower purple band in Figure 2 – while a hard-working soldier expends 5,000 kcal/day – the blue band. The average work-rate for all measured US Army, US Marine and Israeli personnel is 4400 kcal/day.

One of Suetonius' legionaries marched at 29km/day, carried approximately 43kg of clothing, equipment, arms, armour and food, and before night-fall helped build a marching camp which he then took his turn to guard. He had probably repeated this labour since the start of the campaign to suppress the Druids in Anglesey in the early Spring, and continued to do so as he marched from that island to London and then on to a battle site; a distance in excess of 400km.

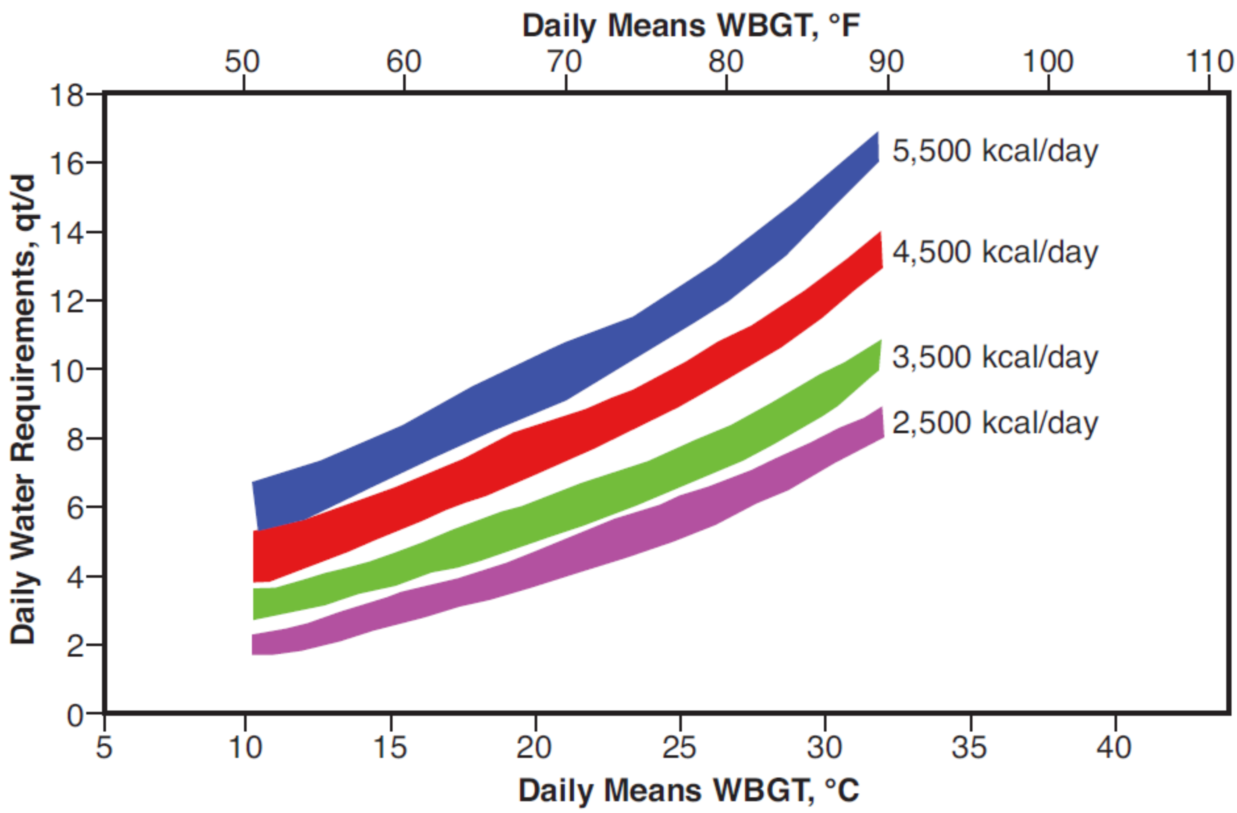


Figure 2: Estimates of daily water needs for a range of environmental conditions and energy expenditures. From: S.J.Montain and M.Ely, Water Requirements and Soldier Hydration, Borden Institute Monograph Series. Primary data source: Sawka MN, Wenger CB, Montain SJ, et al. Heat Stress Control and Heat Casualty Management. Washington, DC: Headquarters, US Department of the Army and Air Force; 2003: 13. TB MED 507/AFPAM 48-152.WBGT: wet-bulb globe temperature.

Furthermore, Tacitus tells us that Suetonius marched to London: “amidst a hostile population to Londinium”, an observation that indicates that legionaries were probably also defending themselves against skirmishing tribesmen. All-in-all, it seems reasonable to assume that the legionary was expending a considerable amount of energy over a protracted period of time, and at the height of Summer.

Therefore, it is estimated that the legionary would probably have expended at least 4,500kcal/day while marching which, at a temperature of 25C, gives a daily, total water requirement of 10 US quarts or 9.46353 litres/legionary/day. However, this figure may be too high for a Roman legionary, a shorter, lower-weight, hardier and more rigorously-trained individual than the modern equivalent. Hence, in this essay a figure of 9 litres per day has been estimated as reasonable. It should be borne in mind that this is a conservative measure: the energy expenditure may well have exceed 4,500kcal/day, and does not include additional water required for cooking, washing, cleaning clothes etc..

The raw statistics, discussed in this and the preceding section, clearly show how vital the management of logistics was to the Roman army. It allowed the Romans to deploy an independent, self-sufficient, self-sustaining, rapidly-moving, well-trained fighting force into the field for weeks at a time. It is difficult to assign these attributes to the Boudican rebels – probably an ill-disciplined and ill-prepared, amorphous mass of tribal warriors, youths, agricultural workers and their followers.

Logistics of the Boudican rebels

It is important to make clear at the outset that there is no firm evidence of the Boudican rebels management of logistical supply. However, it is known from Tacitus' account, that the rebel force included an unknown number of wagons filled with supporters and wives. This seems to follow common European tribal tradition and may be, in part, related to summer travel to religious and trading sites. Therefore it seems reasonable to assume that 'camping equipment', and food and fodder was transported for the warriors in the wagons. There were probably transportation mules and donkeys, but assigning numbers is difficult. Wagons drawn by oxen were probably common, but these beasts move slowly, typically only 2km/hour for a maximum of six hours/day; a substantial limiting factor on the speed of march. The Iceni, Boudica's tribe, seem to have favoured horses; they appear on their coins, and might have been used in large numbers as transport, but probably not as cavalry in the strictest sense – the majority of warriors might have ridden to battle, either in chariots, or mounted, and then fought dismounted. Elite warriors may have used their chariots as ancient tanks, or weapon platforms, but they would have been relatively few in number. These may have been common traits amongst the tribes of Eastern England and elsewhere.

Preparing for a campaign, or raid, probably amounted to gathering as much food etc. as could be spared from the home, farm or village, and supplementing this by foraging and pillaging as the warfare progressed. Centrally-controlled and managed foraging, or food-sharing, was probably minimal. Tacitus tells us that the tribesmen bypassed defended places but violently plundered other habitations. Stealing valuable, or otherwise desirable, objects was probably one motive for this activity, but acquiring foodstuffs and fodder and transporting it back to the wagon train to feed the mass of the tribal horde was just as important. One consequence of this sort of raiding activity is the spreading of tribal forces across a large area. There may have been a compact mass of travelling people, wagons and animals directly following the Romans out of London, but many fast-moving younger warriors would have travelled far, not least for reconnaissance and harassing purposes. In contrast, the Roman system held all units in close proximity, except possibly for cavalry sent to screen the main army, or on reconnaissance.

The tribal practice of extracting supplies from the local population, towns and farms would work well for short raids in the more agriculturally-rich lowlands of southern Britain. However, it would pose considerable provisioning difficulties if attempted in the harsher, drier, less populated chalk and limestone uplands of the same region. The water-poor uplands would have supported pastoral agriculture - raising sheep, cattle, goats, and horses - with arable cultivation being possible only in the narrow river valleys where most settlements occurred. Of course, finding enough fodder or grazing land for transport animals might not have been too problematic (assuming the Romans did not scorch the earth). However, finding sufficient food for the tribal horde would have posed great difficulties. Firstly, the thin, high river valleys had little area for growing crops; secondly, the locals, being few in number, would not have grown much beyond their own needs; thirdly, what food was available in quantity was also mobile – the grazing animals would probably have been driven away from the horde, as they probably had been for millennia; fourthly, although we have no evidence, written or otherwise, it is possible that the retreating Romans used a scorched earth policy, using the prevailing eastward blowing winds to burn settlements, fodder and crops. In this case the Romans would have continually moved into fresh land while the rebels marched consistently into a scourged landscape. The overall result of moving from the rich lowlands to the poor uplands, might have been a forced concentration of the Boudican horde into the river valleys as it sought water, and probably acute strain as food supplies ran down or became exhausted.

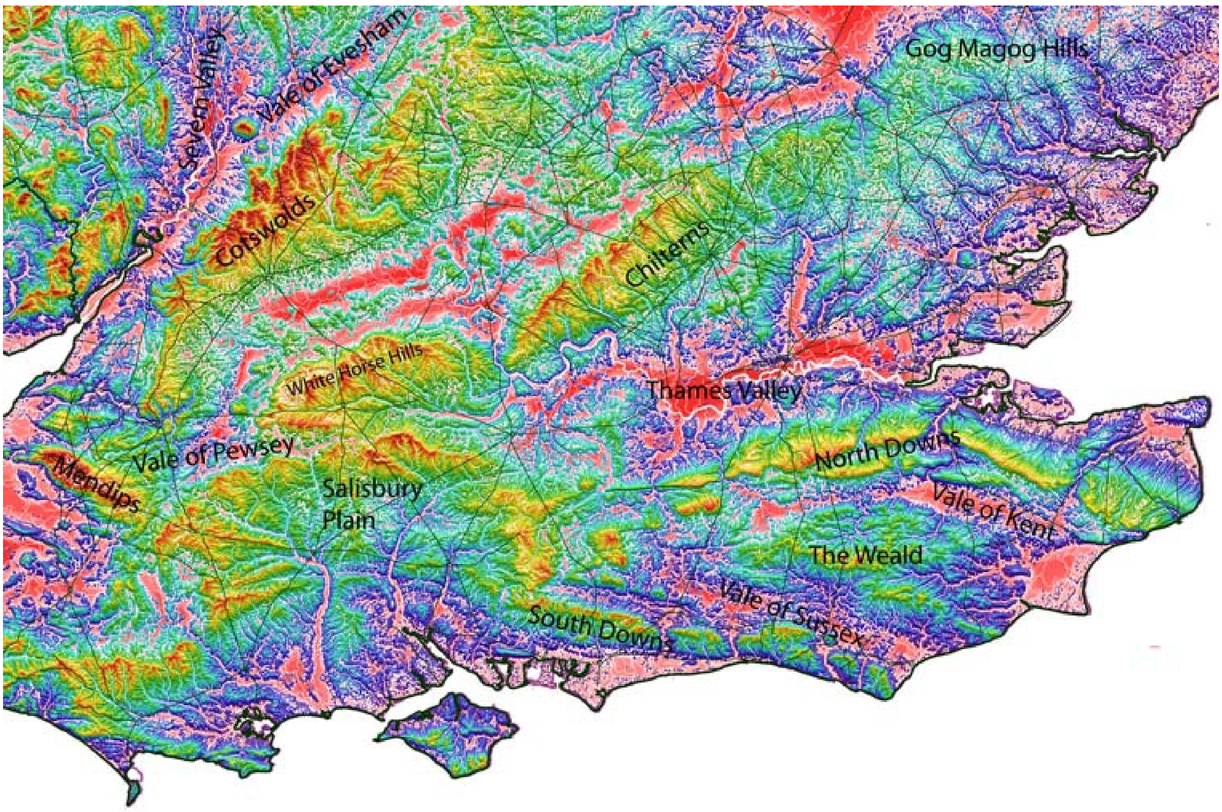


Figure 3: geographical areas of Southern Britain. Elements of this image are © Crown Copyright. All rights reserved 2013.

The mixed use of mules, horses and oxen for transport, coupled with the need to forage or pillage to feed the assembled rebel horde, probably reduced the marching rate to 16km per day. This figure is thought to be the mean during the Mediaeval period when armies used similar transport means and food gathering tactics, and is probably a reasonable one for the Boudican rebels. This is not to suggest that there were not fast-moving rebel units capable of matching the Roman army. Nevertheless, there are at least two consequences of this slow marching rate: firstly, the Roman army on leaving London, and assuming a westwards-march using the road system, could have consistently outpaced the horde by approximately 13km per day; secondly, the horde following the Roman army, and entering the chalk uplands beyond Silchester, would have taken between four and six days to clear the uplands. However, in following the Romans, who would only have taken three to four days to cross the chalk uplands, the rebels would have entered a land probably depleted of food-stuffs, where nearby fodder had already been consumed or destroyed, and where the water supply would be diminished and probably polluted. The stress imposed upon the rebel horde by these factors might have caused enough strain to slow it even further which would compound the stress. Additionally, if the rebels had not been able to replenish their food supplies since leaving their homelands, possibly because the Romans had either consumed or destroyed it in London and elsewhere, then starvation may have been evident, or at least a possibility, severely damaging morale, fighting effectiveness and possibly causing some tribesmen to abandon their cause.

In conclusion, the crucial point is that the Romans could sustain their forces in the field for weeks, including within the relatively water-, food- and fodder-poor regions, such as the Chilterns, Cotswolds, White Horse Hills, Salisbury Plain and the Weald (Figure 3): the Boudican rebels could not.

Roman and British water requirements

Attempting to place firm numbers on the amount of foodstuffs, fodder and firewood required by the two combatant groups is very difficult and open to inaccuracies in the amount available and consumed. However, as we have already discussed, in the 20th and 21st centuries military authorities have measured the water requirements of soldiers to enable adequate logistical support. In addition, hydrologists in Britain and elsewhere have extended great efforts to measure the available water in catchments and rivers. This modern knowledge can be retrofitted to the situation in 60/61AD, enabling the assessment of available and consumed water, and how these parameters may have influenced the outcome of the revolt. The situation and the number of combatants is described by Tacitus writing in c.109AD. Tacitus was the son-in-law of Agricola who was serving in Britain as a tribune at the time of the uprising; he may have been present at the final battle. The author takes Tacitus' numbers of combatants at face-value: better to accept 1st century AD inaccuracies or political spin, than to introduce additional 21st century AD unsubstantiated bias.

In the remainder of this section we will make an assessment of the water requirements of the combatants before examining the hydrology of southern Britain in the following section.

	Soldiers	Servants	Citizens	Horses	Mules
Numbers of >	10,000	2,500	2,500	937	3,000
Water/day	9 litres/day	9 litres/day	9 litres/day	70 litres/day	30 litres/day
Unit total litres	90,000	22,500	22,500	65,625	90,000
	Total army litres/day	Total army cubic metre/day	Minimum river flow cubic metre per second	Minimum river flow (daylight corrected)	
Total for army per day	290,625 litres	290.63 cubic metres	0.00336 cumec	0.00447 cumec	

Table 1: Roman Army Water Requirement.

Table 1 is an estimate of the water requirements for the soldiers, servants and slaves, mules and horses in Suetonius' army. They are based on generally accepted numbers for Legionary forces, specifically the legionary cohort system of the early Roman Empire of the 1st and 2nd centuries AD. There is no attempt to vary these legionary numbers due to the presence of auxiliary soldiers, siege equipment or additional cavalry units, beyond those cavalry normally assigned to a legion. In emphasis therefore, the number of soldiers etc. in Table 1 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 1st *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. It should be stated that these numbers exclude officers, their servants and supernumeraries.

The figure of 10,000 soldiers in Table 1 is taken from Tacitus. The 2,500 number for citizens is the author's estimate based on the evacuation of London, Romano-British refugees joining the army as it marched, and possibly large numbers of friendly Britons, e.g. Atrebates, also seeking shelter.

These figures are considered to be reasonable, probably an under-estimate, and based on the supposition that the main army baggage train was left behind in North Wales. Figures for the water needs of animals, working hard either marching and/or carrying loads in a temperate climate in summer, are taken from a number of sources.

In the lower half of Table 1 are figures for the total water requirement of the Roman army expressed in a number of units. Each day the army required a total of 290,625 litres, or 290.63 cubic metres. To satisfy this need the rivers or streams the army was extracting from would need a minimum flow, in each 24 hour period, of 0.00336 cumec (cubic metre per second – i.e. the volume of water, passing through a river cross-section in one second). However, it would of course have been extremely dangerous and foolish to extract water after nightfall, therefore, in the final column of Table 1, the 24 hour figure is adjusted for the number of daylight hours in August to give 0.00447 cumec.

However, the figure of 0.00447 cumec is the *minimum* required by Suetonius' army; it is probably not the amount a Roman army surveyor would have in mind when selecting a suitable river to satisfy the demand of a marching camp or army prior to battle. To discover that amount we must turn to an examination of Roman marching camps.

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 based on the number of new occupiers. The camps may have been used for days or weeks at a time, especially when the Roman army was campaigning, and not at always by the same unit.

The author has written another essay which fully describes the method used to examine 374 *known* marching camps in Britain and the use they can be put to predict *unknown* camp locations. This essay can be found at:

www.bandaarcgeophysics.co.uk/arch/roman_marching_camps_uk.html

For our immediate purpose of estimating the amount of water the surveyor might have thought suitable we can extract Figure 4 from that essay.

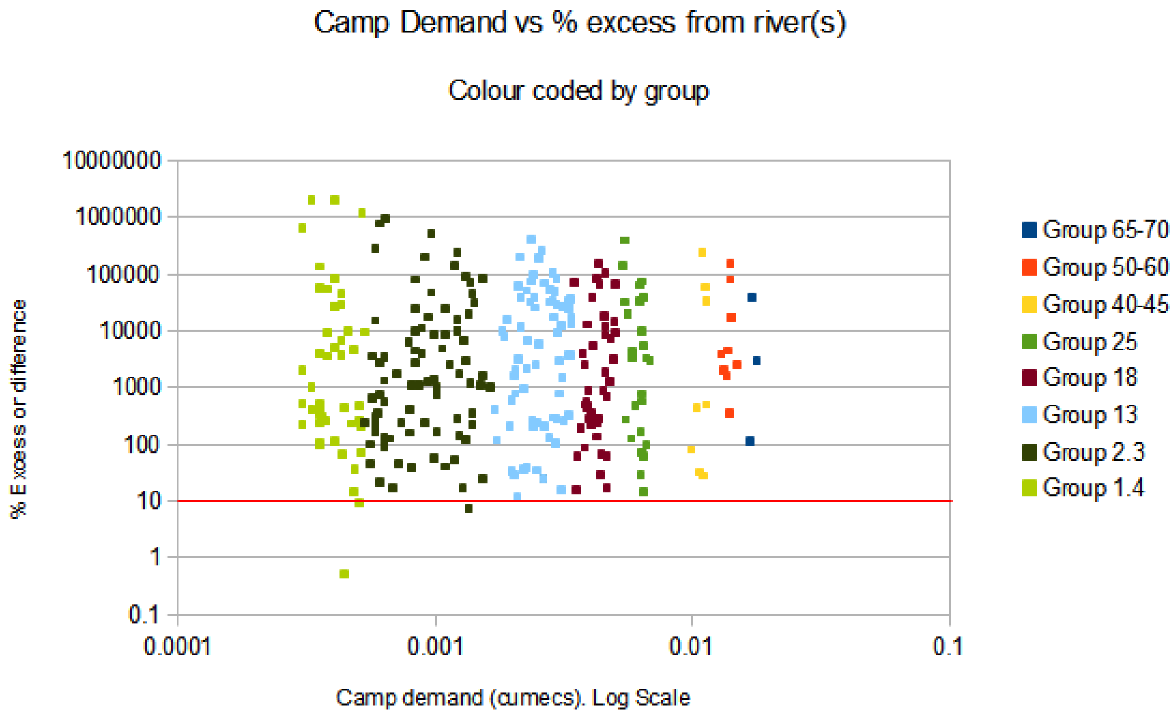


Figure 4: Plot of the percentage difference, or excess, between the demand and supply. 307 marching camps displayed within colour coded Groups. See text for further details. River flow rate calculations are for August. Log scale on both axes. Elements of this image are © Crown Copyright. All rights reserved 2013.

This image shows for each of 307 marching camps the percentage difference, or excess, in August between the supply (flow-rate of rivers) and the demand (water requirement for the force occupying the camp). One of the striking details is the base line (red) which marks the 10% excess mark on the Y axis, i.e. 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 supplied an excess greater than 10% of what was demanded. It is thought unlikely that the Roman camp surveyor would have thought that a 10% excess was sufficient, and for that reason, it is postulated that 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 4.

Therefore, the minimum river flow figure from Table 1 of 0.00447 cumec should be doubled to 0.0089 cumec; it is this figure that has been used to determine which of the rivers across Britain could have sustained Suetonius' army, both as it marched and as it camped prior to battle.

	Warriors	Citizens	Oxen, horses and mules	
Numbers of >	60,000	20,000	25,000	
Water/day	9 litres/day	9 litres/day	60 litres/day	
Unit total litres	540,000	180,000	1,500,000	
	Total army litres/day	Total army cubic metre/day	Minimum river flow cubic metre per second	Minimum river flow (daylight corrected)
Total for army per day	2,220,000 litres	2,220 cubic metres	0.02569 cumec	0.03417 cumec

Table 2: Boudican Rebels water requirement.

Turning to the Boudican rebel force, Table 2 displays, in the same manner as that for the Romans, estimated and calculated figures of water consumption. The final figure, of 0.03417 cumec of minimum river flow adjusted for daylight is, self-evidently, a result of the larger numbers of humans and animals marching in the rebel horde.

To be consistent these figures require an explanation. The Roman army figures are rooted on the figure of '10,000 armed men' given by Tacitus, an author not given, experts contend, to much exaggeration, embellishment or theatrical posturing (some would say in contrast to Cassius Dio, who also gave an account of the Boudican rebellion). Similarly, the figures in Table 2 are rooted in Tacitus' account when he claims 80,000 rebels were killed in the final battle. Tacitus states that women were also killed: presumably these were on the wagons supporting the warriors. One can find speculative methods to parse Tacitus' figures in a number of ways, but this author supposes that the simplest approach is to accept his figures. Therefore, this study divides the 80,000 figure into 60,000 warriors, supported by 20,000 women, and sundry other non-combatants. Of course, not all defeated attendees at a battle die: many escape or become captured and later sold into slavery. This study does not estimate the number of such survivors. The figure of 25,000 animals includes horses, mules, donkeys and oxen: it is an estimate based on a third used as mounts, the rest as pack-animals and hauling the rebel wagon train. Like the figures for rebel humans, it is probably too low, rather than too high. In summary, the rebel numbers are based on Tacitus' figures, exclude the body of survivors and may be too low.

The result is that the rebels needed 0.03417 cumec (Table 2), but if they were following Suteonius along a single river course then supply increases to a minimum of 0.04 cumec (rounded down) – a whole order greater than Suetonius' needs.

The Hydrology of Britain

Southern Britain, the operational region for the Boudican revolt, can be generalised as a small, low-elevation landmass with commensurate drainage basins and rivers. The general consequence is of many rivers and streams with relatively small flows in comparison to those in Europe. For decades the hydrologists at the Centre for Ecology and Hydrology (CEH, formerly the Institute of Hydrology, Wallingford) have measured, calculated and attempted to produce models to predict the flow within rivers. Of late, much effort has been made to understand and model low flows, usually by statistical inference based on measured gauged values and catchment parameters, which has produced a number of key papers of the methods employed – it is these that have been utilised within this study to produce the values and maps depicted.

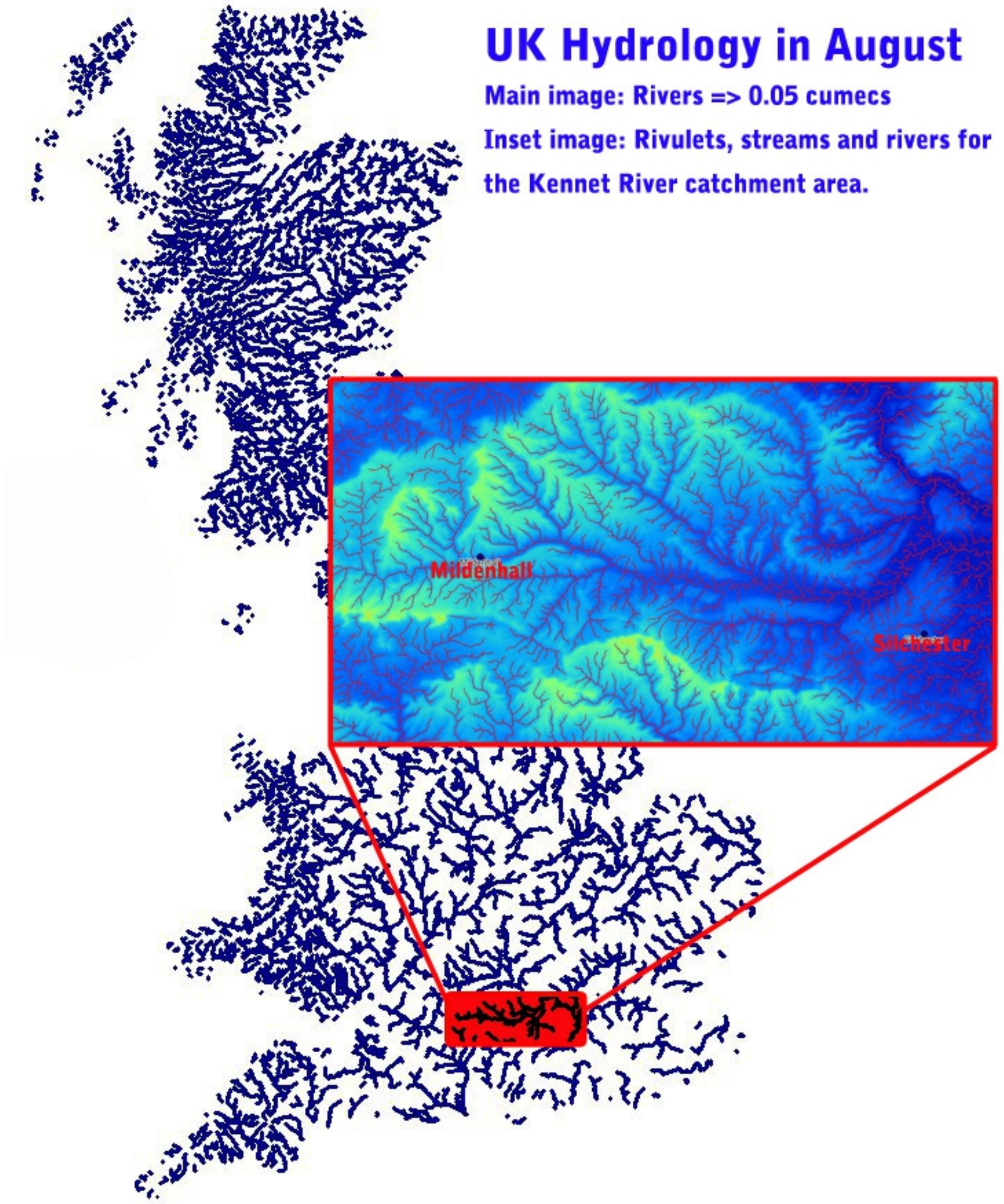


Figure 5: The rivers of Britain greater or equal to 0.05 cumec of flow as calculated for this study. Inset: Rivers and streams of the Kennet river catchment (calculated lower-order streams and rivers shown).

In outline, the catchment water balance methodology was used in this study for the whole of Britain (Figure 5). This involves calculating the mean flow in rivers by use of rainfall, potential evapotranspiration losses, and catchment characteristics such as area sizes, topographic and geological descriptors and models of the river systems. All these investigations, and other supporting statistical and mathematical calculations, were conducted within SAGA (**S**ystem for **A**utomated **G**eoscientific **A**nalyses), a GIS and calculation engine, that contains the key hydrological modules used in this study.

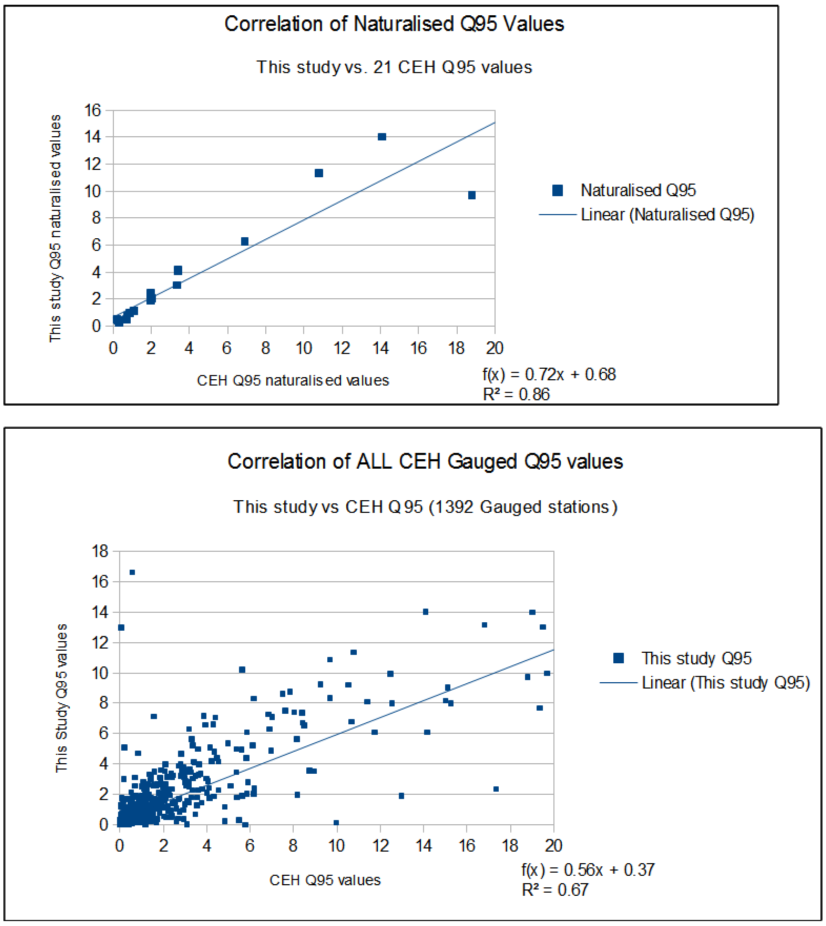
We are interested in river flows in the summer of 60/61AD, especially those within and on the margins of the chalk and limestone uplands of southern Britain. Therefore, the values of the Q95, for the period 1961-2006, have been computed for August and for naturalised catchment and river systems. Essentially these Q95 values - at the height of summer, when rainfall, surface runoff, aquifer discharge and consequently river flows are at a minimum – tells us where these large armies could march and give battle.

It should be made clear that the calculation of low flows is fraught with difficulties and uncertainties, especially when examining flows in the ranges required for this study. The results are imperfect, have unknown error ranges, but are generally representative of the flows the protagonists would have experienced in marching across southern Britain.

It is in part due to these hydrological uncertainties that the numbers of humans and animals was kept low, and the water requirement for humans lowered to 9 litres/man/day rather than use the larger figure from the investigations of the US Army.

The base data used in the for-mentioned calculations were:

> 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 ,
>
> Rainfall, long term average per month for years 1961-2006 from the Meteorological Office - http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/download/longterm/fivekm_monthly.html ,
>
> Evapotranspiration figures from MODIS 16; a NASA/EOS project to estimate global terrestrial evapotranspiration from the earth land surface by using satellite remote sensing data. http://www.ntsg.umt.edu/project/MOD16/ .



21 CEH Gauged Q95 values

RIVER_NAME	LOC. NAME	Q95
Thames	Kingston	18.8
Tweed	Norham	14.1
Tweed	Sprouston	10.77
Tweed	Boleside	6.9
Thames	Sutton Courtenay	3.42
Thames	Days Weir	3.4
Tweed	Peebles	3.36
Tweed	Lyne Ford	2.05
Thames	Eynsham	1.98
Ettrick Water	Lindean	1.97
Lee	Feildes Weir	1.58
Yarrow Water	Philiphaugh	1.12
Whiteadder Water	Hutton Castle	1.11
Tweed	Kingledores	0.91
Yarrow Water	Gordon Arms	0.88
Yarrow Water	Craig Douglas	0.74
Lyne Water	Lyne Station	0.69
Megget Water	Henderland	0.32
Manor Water	Cademuir	0.31
Vyrnwy	Vyrnwy Reservoir	0.25
Ale Water	Ancrum	0.22

Figure 6: Comparison of Q95 flow values from this study with those of the Centre for Ecology and Hydrology (CEH). See text immediately below for description. Elements of this figure are the copyright of the Natural Environment Research Council (NERC). All rights reserved.

Due to the uncertainties resulting from the method it was thought prudent to compare this study's results with those of the CEH.

The CEH publishes 21 naturalised values of Q95 (Figure 6, table on the right) at various gauging stations across the UK and these were correlated with the equivalent values from this study (Figure 6, top graph). The linear regression line gives a coefficient of determination (R squared) of 0.86, a high “goodness of fit” value. The lower graph is of all 1,392 Q95 CEH gauge station values throughout the UK correlated with this study's values; the coefficient of determination is 0.67, a fairly high level of “goodness of fit” considering that only 21 of the CEH stations are naturalised compared to all of them for this study.

Figure 5 shows the river systems calculated within SAGA and used as a base for all other calculations and river displays. Figure 7 shows the same river system but with the removal of all channel sections with flows less than that required by the Romans (0.0089 cumec at the minimum). This clipping action removes many sections, especially those in the chalk and limestone uplands (Figure 3).

Figure 8 represents the minimal water available to the Boudican horde as it followed the Roman army. Here the base river system (Figure 5) is limited to 0.04 cumec which produces a dramatic reduction in the number of river sections available to the horde, essentially to those of the major rivers and their main tributaries. The difference between Figures 7, rivers capable of supplying the Romans, and 8 is stark, and clearly shows how constrained the horde might have been by its need for adequate water.

History relates that the Romans left London, marched for some days, and then offered battle. The tribal leaders would have known that their only chance of a successful rebellion was to destroy Suetonius' Roman army in the field, before tackling the legionary forts. Consequently the main rebel force had to follow Suetonius as he marched away from London and therefore had to contend with damaged river systems already depleted and probably polluted. Similarly, any wells would have been rendered unusable, either by Roman consumption or deliberate act. As we have already discussed, food stuffs and fodder would probably have suffered similarly.

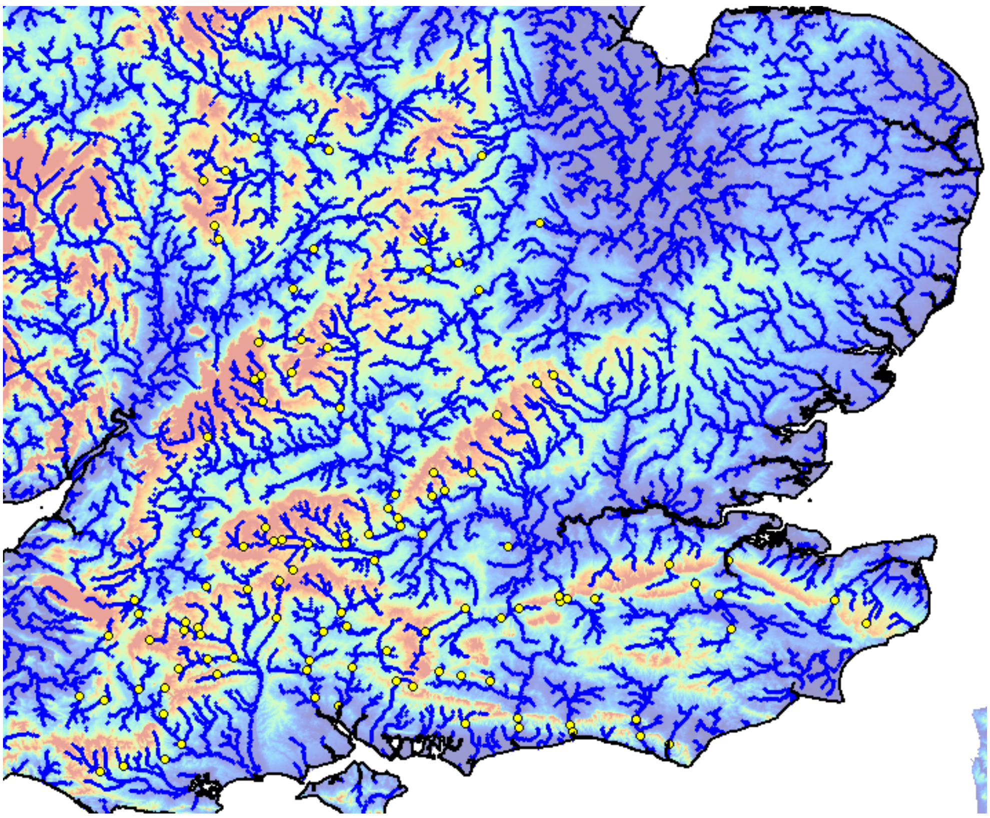


Figure 7: River channels with minimum water flow required by the Roman army (0.0089 cumec). Yellow dots are the 110 possible battle sites from this study.

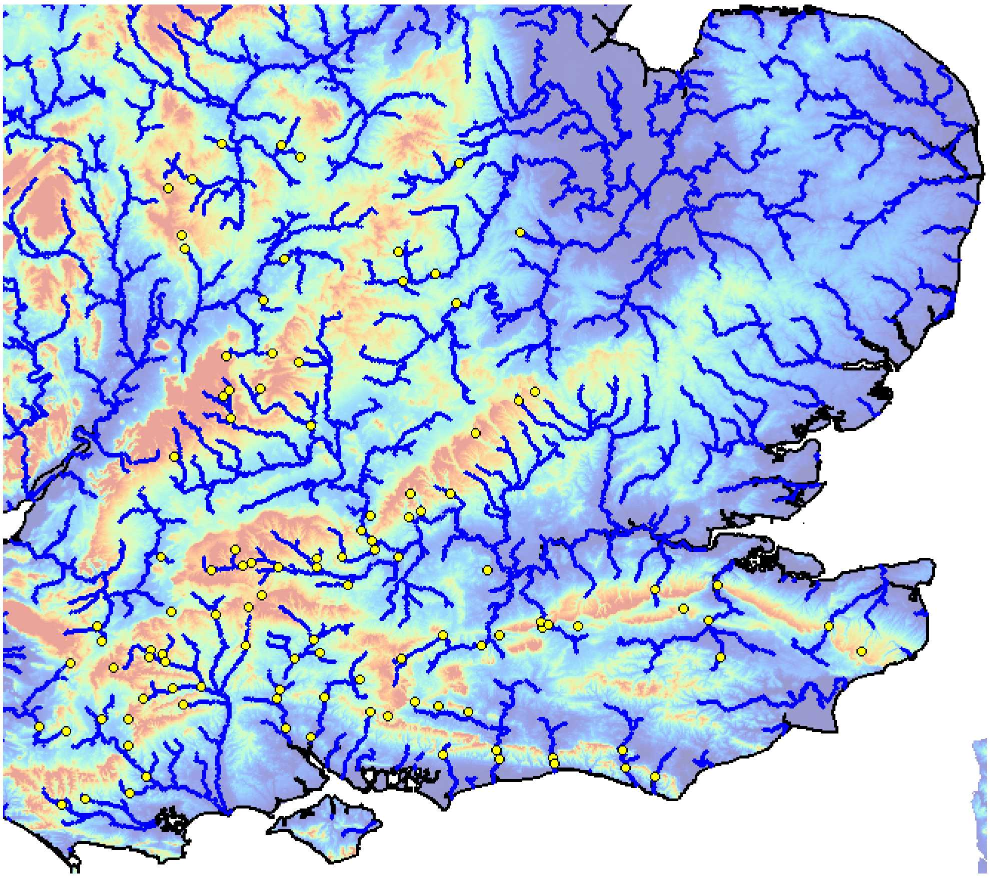


Figure 8: River channels with the minimum water required by the rebels following the Romans (0.04 cumec). Yellow dots are the 110 possible battle sites from this study

Figure 8 suggests that the vast numbers of rebels, with their slow moving (16km/day) wagon train, would have tried to remain adjacent to the main rivers of southern England. The horde's natural tendency might have been to remain within the river valleys and off the Roman roads, but that would have slowed the main body even further. Consequently, the tribal leaders would probably have enforced the need to move as quickly as possible, to stay close to Suetonius, and to follow using the Roman road system. However, that system was built to serve well-organised, legionary units (typically 1000s of men), not a huge horde of ill-disciplined tribesmen numbering tens of thousands. The combination of the demand to follow the Roman road system, together with a high water replenishment rate, created a situation even more unfavourable to the advancing horde.

In leaving London before the horde arrived, Suetonius might have realised that he was not only withdrawing, but also gaining a strategic advantage: his was the choice of the direction of march; he could lead the rebels where he wished and in doing so, place them at a logistical disadvantage.

Water Replenishment

One of the powerful attributes of a GIS system, such as SAGA, is its ability to extract multiple datasets from different layers, determine some new variable and display the results in another layer. In this section the data layers to be acted upon were the Roman road system (Figure 1) and its conjunction with rivers of sufficient water quantity for the Romans and rebels (Figures 7 and 8). The result is a series of maps showing points where the protagonists could replenish their water to meet minimum needs along their line of march.

It is important to re-emphasise that not all the Roman roads shown in the following images would have existed in 60 or 61AD.

The Roman replenishment map is shown as Figure 9, where the intersections of the roads with a river that could supply the minimum need (0.0089 cumec), are shown as green blocks.

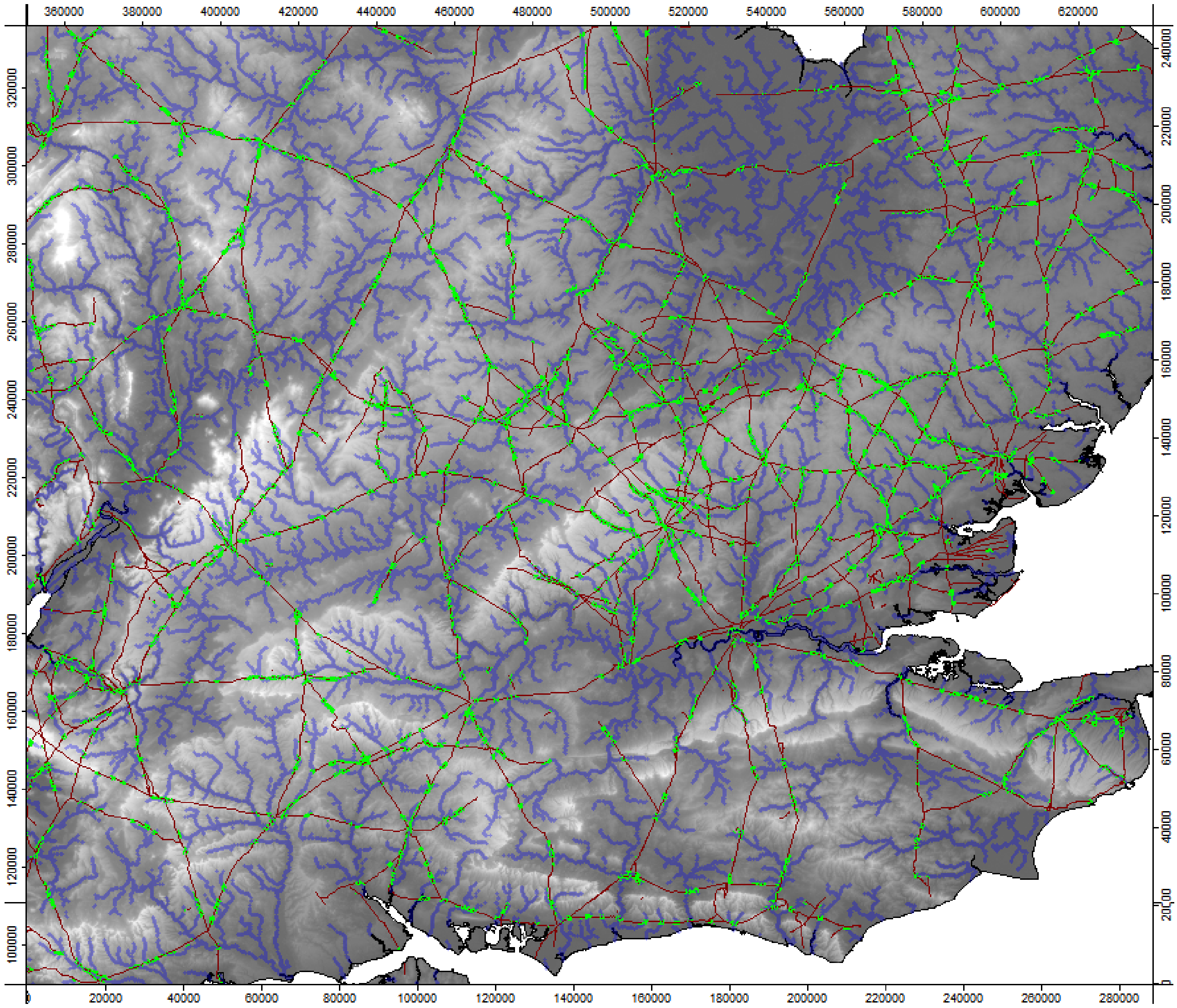


Figure 9: The Roman army replenishment map. The green areas are locations on the road system (maroon strings) that intersect rivers (blue strings) capable of supplying the minimum water required (0.0089 cumec). Background is of the general topography. Elements of this image are © Crown Copyright. All rights reserved 2013.

The distribution of Roman replenishment sites is such that nearly all sections of road could have been be traversed within one day (at approx. 29km/day) and also have minimally adequate water at both ends of the section: this is a result of design.

This aspect of Roman road engineering is displayed in Figure 10 along the route known as the Portway between London and Silchester. The road must cross the Thames at some point and this is achieved at Staines where the river is thought to have been crossed by a Roman causeway and bridges – hence the Roman name of *Ad Pontes* – 'at the bridges'. Multiple bridges might have been required to not only cross the Thames, but also the river Coln which joins the Thames in this location. The road is not well-located directly west of Staines but is thought to arrive at Virginia Water after 6.5km. At this point Suetonius would find sufficient water for his army but thereafter, for a distance of approx. 24km, is a section of road without adequate water until the river Blackwater is reached south of Farley Hill. The approximate distance between Staines and the

Blackwater is 30km, close to the standard legionary marching rate of 29km/day: as elsewhere on the Roman road system, the marching day rate was apparently matched to night-stops with adequate water.

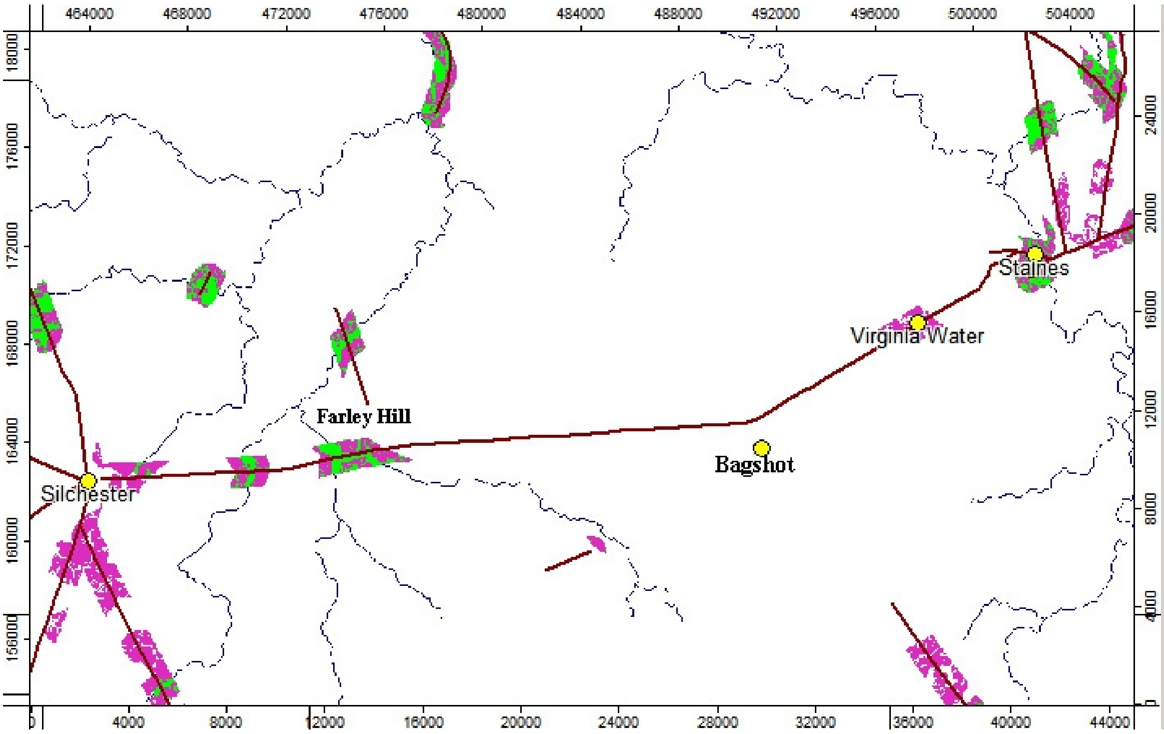


Figure 10: The Portway between Staines and Silchester (maroon). Rivers shown (blue) can supply 0.04 cumec, sufficient for the Boudican horde. Purple coloured areas are Roman replenishment sites; the same for the horde in green. Elements of this image are © Crown Copyright. All rights reserved 2013.

The postulated deliberate routing of roads to provide water is possibly demonstrated by another feature of the Portway between Virginia Water and Silchester: the kink in the road north of Bagshot. There is no topographical reason why the road should take this route, which extends the distance between Virginia Water and Silchester, but an hydrological one does exist, i.e. the kink is located at its junction with the headwaters of the Windle Brook and its tributaries. Here Suetonius would find insufficient water but there would have been enough for smaller marching units and civilian traders, and enough to slake the thirst of Suetonius' legionaries.

The principal points of this example (Figure 10) are that the Roman road engineers' design allowed for not only the rapid covering of distances, but also ensured there was an adequate water supply at marching camps.

Returning to the story of the uprising, Figure 10 shows that the Boudican horde would not have found sufficient water along the road between Staines and Farley Hill, a distance of approximately 30km, or a march of two days, but without sufficient water.

As one might expect, Figure 9 shows that for most of the road system water supply would have been adequate, with only a few stretches across the high chalk and limestone regions, e.g. Salisbury Plain, the Cotswolds and the chalk downs north of the Kennet river valley, causing some concern for a lack of water. However, this would have been mitigated by the knowledge that legionaries were trained and disciplined in the use of water-skins and possibly amphorae (or similar) transported on mules. Keeping the men adequately hydrated was very important, equally so the mules and horses of the army: no transportation equates to no provisioned march, and all that that would have entailed.

Much more could be said about these maps and what it may tell us about the planning and use of the Roman road system. However, for brevity's sake, a small and simple example will be given of how water might have influenced one possibility.

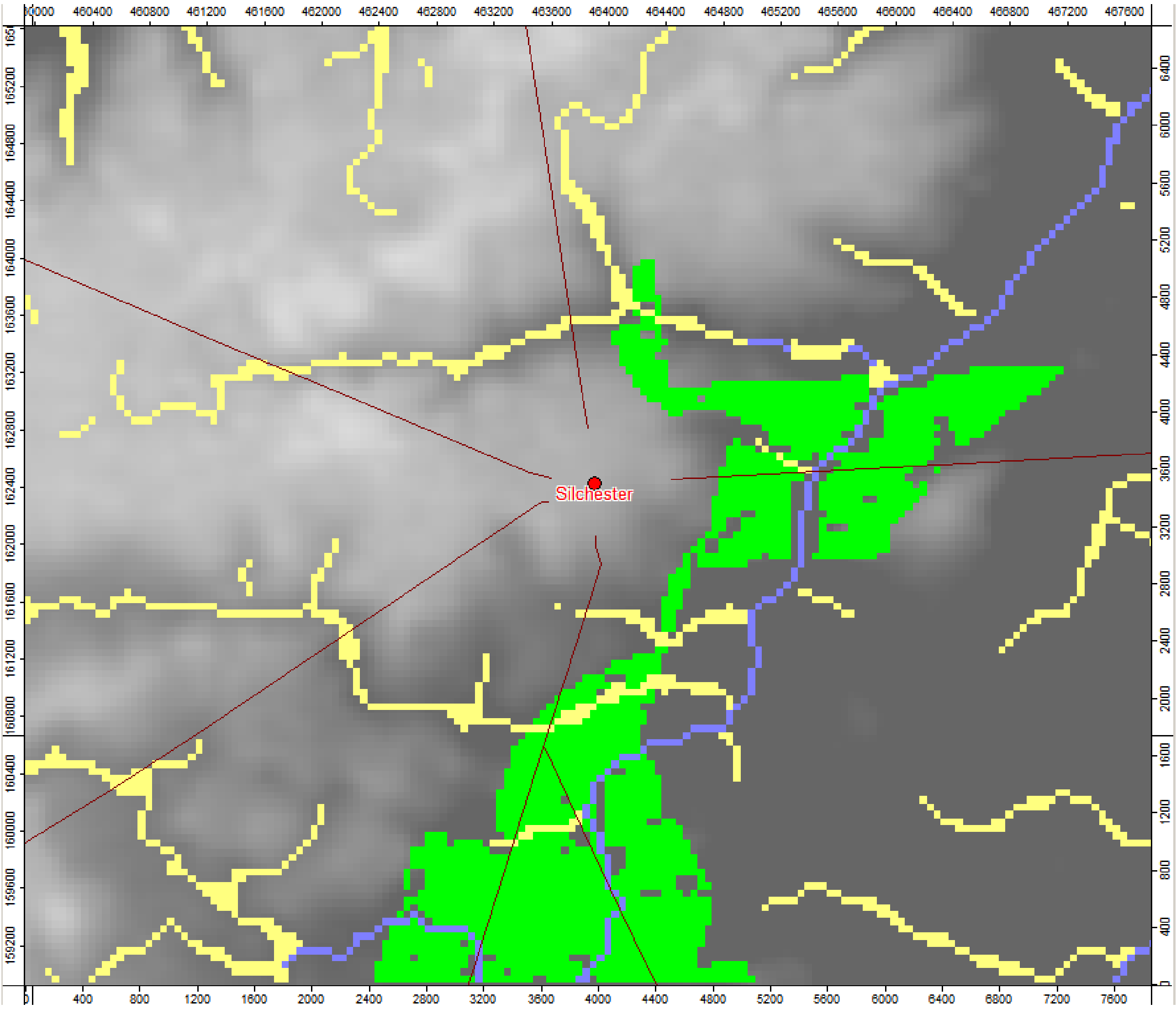


Figure 11: A map of Silchester and the local, surrounding rivers/streams. Rivers greater than 0.0089 cumec = blue string: less than 0.0089 cumec = yellow strings. Maroon lines are Roman roads. Green areas are Roman replenishment points and favourable marching camp areas adjacent to the road system. The graticule is in metres. Elements of this image are © Crown Copyright. All rights reserved 2013.

Cogidubnus, the King of the Atrebates, was an ally of the Romans and probably had his capital at Silchester, the site of extensive burning and a 20 year building hiatus between 50 and 80AD as reported by Professor Mike Fulford and his team of archaeologists from Reading University. The suggestion is that this burning might be attributed to the Boudican uprising, possibly by the rebel horde as it followed the Roman army westwards, or even by the Romans using a scorched earth policy. It is instructive to ask why Silchester could not be defended by the Romans. The answer lies in two observations. Firstly, Silchester, although on locally raised terrain, is a poor site for building defences robust enough to withstand an attack by a large body of tribesmen. Secondly, as Figure 11 shows, the Romans would have had an impossible task to defend a perimeter, greater in radius than 1km, to safeguard sufficient water for themselves if they were besieged (this ignores the use of polluted wells and small springs, which are known to exist within Silchester, but would not have provided enough water for the Roman army and Atrebates). If Suetonius did rest for the night near

Silchester, then the bulk of his army would probably have camped approx. 1.5km to the east alongside the river with more than sufficient water for his men and beasts – the green areas in Figure 11.

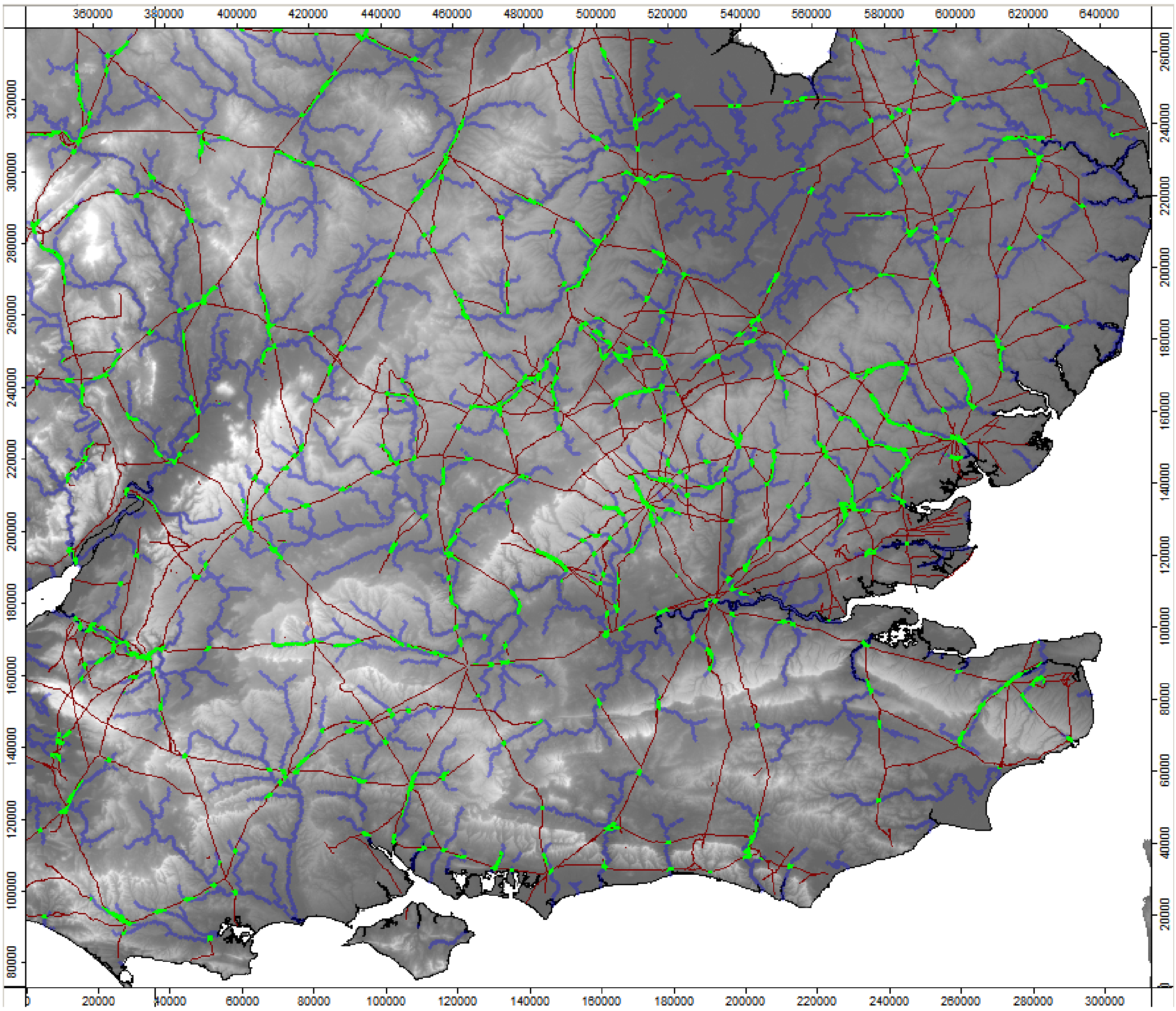


Figure 12: The Boudican horde replenishment map for the case when it follows the Roman army. Green areas are locations on the road system (maroon strings) that intersect rivers (blue strings) capable of supplying the minimum water required (0.04 cumec). Background is of the general topography. Elements of this image are © Crown Copyright. All rights reserved 2013.

The replenishment map for the Boudican horde (Figure 12) is far more sparsely populated with green replenishment areas than the Roman equivalent (Figure 9) – an unsurprising result given the difference in water required, i.e. 0.04 versus 0.0089 cumec, respectively. Once the horde had left the Thames river basin - the area bounded by the Chilterns, the chalk uplands of Salisbury Plain and White Horse Hills, and the North Downs (Figure 2) – its water-strain increased significantly. Of course, the rebels could have moved off the Roman roads, possibly using the more ancient track-ways across Britain, hence covering a larger area with a greater water supply. However, as has already been mentioned, this would have slowed the rebels in their advance and given the Romans an advantage. Additionally, covering a larger upland area in search of water results in a break-up of the horde as it is fragmented by individual units following different rivers. Coalescing these units on command, for example to give battle, would have been slow and difficult.

Compounding these difficulties would have been the horde's lack of preparedness. The Roman army practised marching in all conditions and made provision for carrying water. This cannot be said of the rebel tribesmen: they would have had water skins and the like, but probably not enough capacity to cover large distances between replenishment points.

Further more, as the horde followed the Romans upstream there may have been even less water flowing, more pollution and probably a destruction of the river banks and other physical characteristics. Of course, these observations are most applicable to roads that parallel rivers, for example, the Kennet, Wye, Avon (from Bath) and Great Stour (Canterbury to Ashford).

As an aside, the Romans would extract water from a river in a controlled, disciplined manner so that, for example, animals did not pollute potable water. The tribesmen probably knew of such practices, but it is hard to imagine a huge volume of humans and animals descending on a river after a hard day of marching, maintaining extraction discipline and not destroying the water source they all craved.

Camp grounds and marching camps adjacent to rivers

So far we have examined the locations where rivers, with sufficient flow for either rebels or Romans, intersected Roman roads; however, both protagonists could have made use of camp grounds (rebels) and marching camps (Romans) that were adjacent to rivers. In the case of the rebels this would have allowed them to seek additional water, other than that along roads, and to have broadened their marching front, possibly allowing a degree of flanking of the withdrawing Romans. For the latter the additional use of river locations would have conferred a level of tactical surprise and much more importantly, allowed Suetonius to choose a battle site situated off the road network. However, it should be re-emphasised that Suteonius would probably have used the road system for most of his march from London, only leaving the network once he had arrived at the battle site location: to do otherwise would have diminished his advantage regarding the differential in marching rates, i.e. estimated at 13km/day.

To examine the Roman possibilities we can again turn to the study of *known* marching camps in Britain and use a range of statistical and GIS techniques to predict the locations of *unknown* camps sites elsewhere in Britain. This essay will extract some of the findings and predicted sites from a detailed description of the method in an essay available at:

www.bandaarcgeophysics.co.uk/arch/roman_marching_camps_uk.html

The same essay contains detailed information relating to the finding of the rebel camp grounds. Additionally, although this essay displays maps of these techniques along the Portway, similar UK-wide maps in Tiff format can be found at the URL above.

In summary, the predictive technique involved the extraction of key topographical and hydrological attributes for 374 *known* marching camps across Britain. These attributes were statistically examined and a range of values discovered that are thought to represent a description of a suitable camp ground, that is, the description might match the thought processes of a Roman surveyor tasked with selecting marching camp locations. The range of values place a limit, from good to bad, on the various attributes, for example, the examination of ground water saturation gives an indication of the level of bogginess that a camp surveyor might have thought acceptable. The statistical description of the *known* marching camps was then searched for across the rest of Britain resulting in the location of areas thought to be the location of *unknown* camp locations.

Figure 13 displays the results of these techniques centred on Silchester. Here the most favourable marching camp areas alongside rivers capable of supplying the Roman demand are displayed, and show that Suetonius could have marched his army of 15,000 humans up most river valleys in the region. He also had the capability of marching across-country from one river valley to another.

There are some river stretches that are not so favourable to the Romans, i.e. those areas adjacent to rivers in Figure 13 which are not coloured red; these have attribute values that, in combination, lack the full level of acceptance that a Roman army surveyor might have demanded of the location.

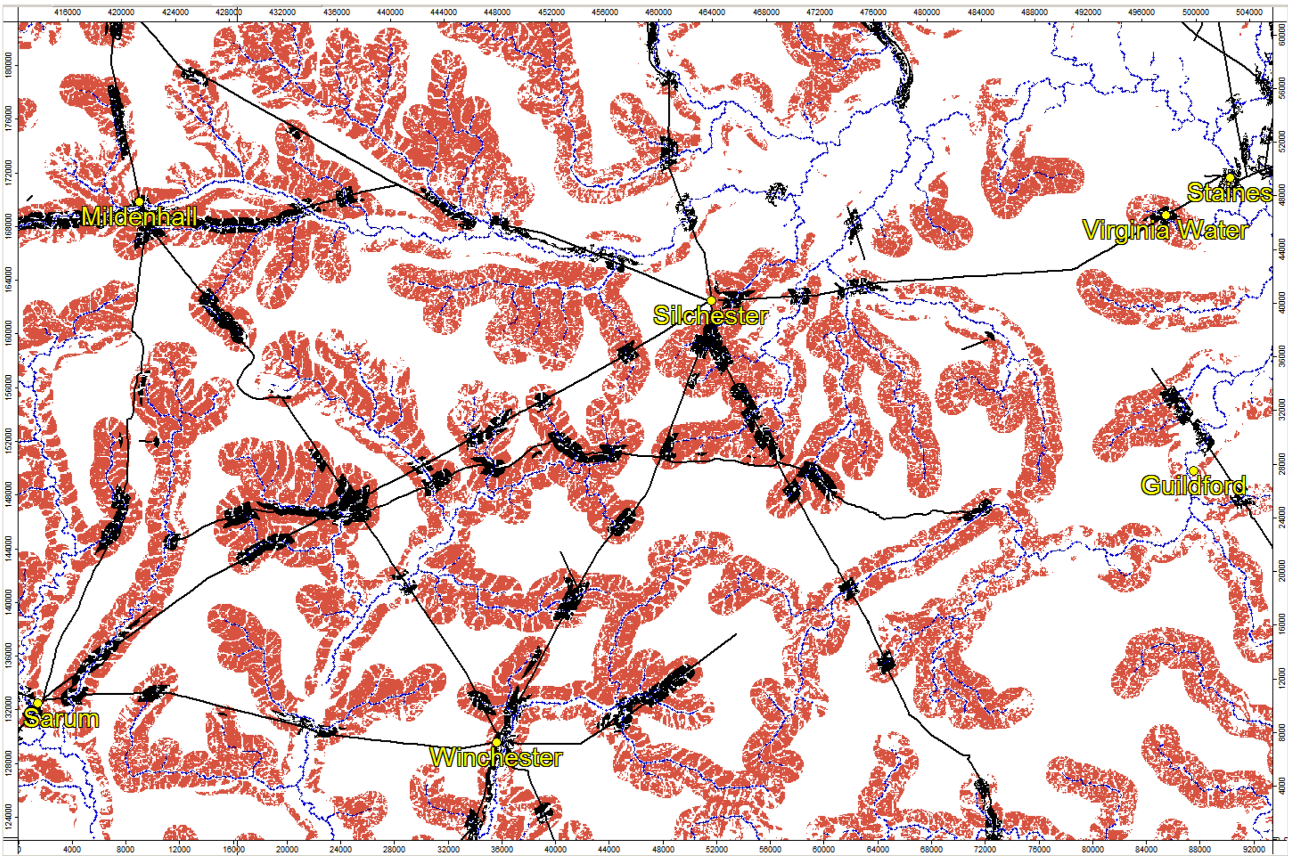


Figure 13: Most suitable Roman Marching camp locations along rivers and roads. Suitable camps at river-road intersections = black, most suitable camps along rivers = red. Elements of this image are © Crown Copyright. All rights reserved 2013.

As an example, much of the lower stretches of the Kennet Valley, between Silchester and Mildenhall, are not suitable for the Romans: partly because the ground is too boggy and water-logged to make a good camping ground.

The red areas in Figure 13 also indicate where Suetonius could have camped his army in preparation for the final battle. As already mentioned, Suetonius would probably have kept to the road system for most of his march from London, but he might have left it on arriving at the river valley along which he knew he would find his preferred battle site.

Figure 14 displays the case for the river-side camps grounds thought suitable for the Boudican horde as it followed Suetonius. In comparison to Figure 13, the Roman case, the horde's camping options are more limited: there are far fewer suitable camps grounds adjacent to roads (black areas) and the number of suitable river valleys is much lower, coupled with a lack of deep penetration up the river valleys. Of course, the latter is largely the consequence of the lack of sufficient water. This observation also suggests that, for rivers flowing away from the Roman front line towards the horde, Suetonius could have selected a battle site in the upper reaches of a river, and have himself found sufficient water: for the rebels there would have been insufficient.

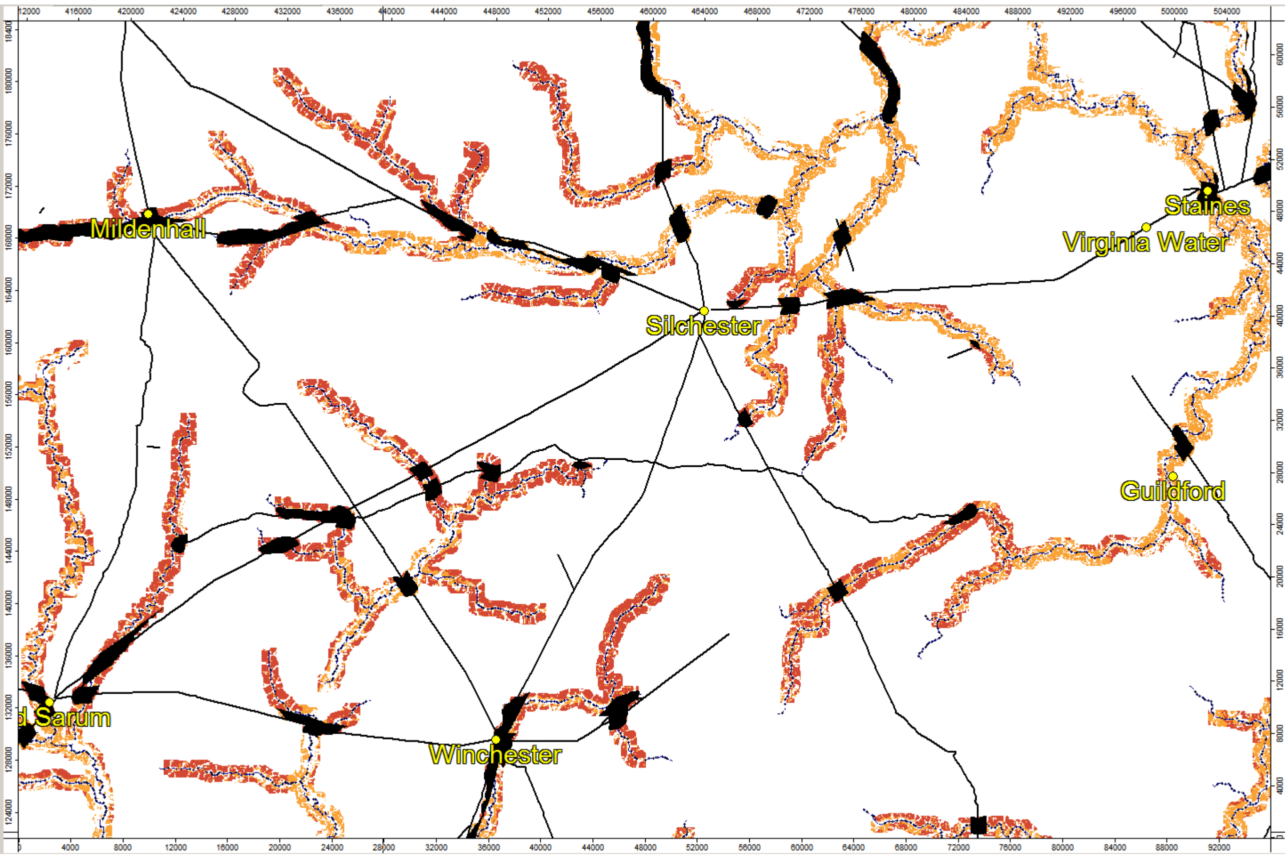


Figure 14: Boudican horde camp grounds alongside rivers and roads. Most suitable river-side camps = dark brown, less suitable = light brown. Suitable camp grounds at river-road intersections = black. Elements of this image are © Crown Copyright. All rights reserved 2013.

The Boudican rebels need to follow the Romans, matched to their negative disparity in discipline, experience, march-rate and preparedness, coupled with the stress imposed by a lack of food, fodder and water, and all further compounded by the diminution of morale as the horde marched further from its homeland, can be estimated as strain rates (Figure 15). In this image, the suitable camp grounds in Figure 14 are weighted by the factors just described such that, the blue areas show where the horde is least strained, typically in lower river reaches, while the red areas indicate maximum strain. The latter are most often found in the upper reaches of smaller rivers where the effects of a lack of water, food, fodder, etc. compound to produce the greatest strain. Here the rebel horde would have been most disadvantaged relative to Suetonius' army: at its weakest in locations most favourable to Suetonius' choice of battle site.

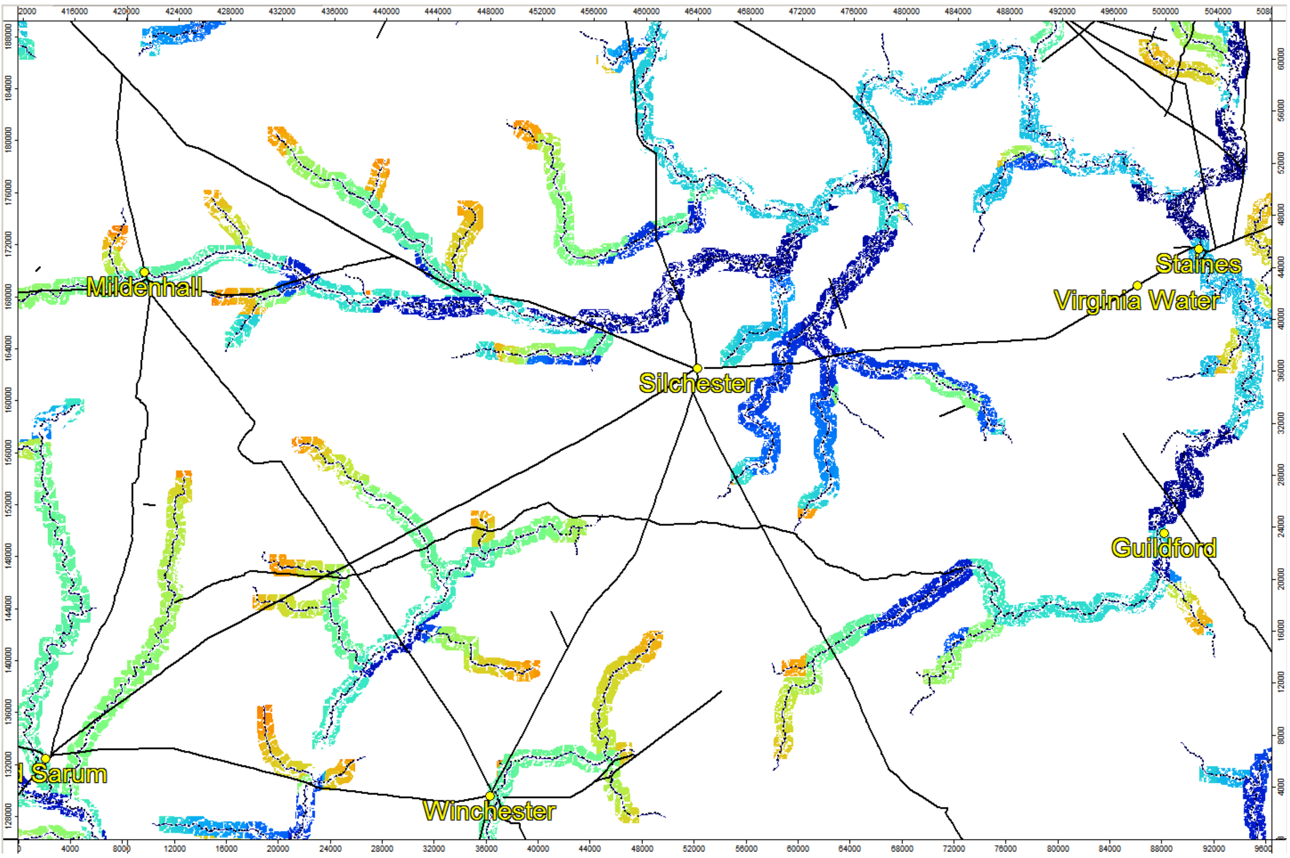


Figure 15: Boudican horde camping grounds alongside rivers, colour graded for strain. Highly strained = red-brown, moderately strained = green-cyan and least strain = blue. Strain levels are computed from elevation, amount of food and fodder, shortness of adequate water and distance from London. The values for the strain due to the lack of food and fodder is proxied by a calculation based on elevation and local hydrogeological parameters.

Terrain analysis and water availability

The availability at the battle site of an adequate water supply would have been more crucial to the Romans than when on the march. When marching a temporarily inadequate water supply would have been an inconvenience, as long as it was not prolonged. When waiting for battle such a situation would have been disastrous. And, given the disparate marching rates of the Romans and rebels, the waiting time may have been 4-5 days at, for example, Mildenhall-Cunetio (116km from London). Therefore, it is considered inconceivable that Suetonius did not choose a battle site with an adequate water supply that could be safeguarded and, most probably, flowed away from his front-line towards the rebel line.

The earlier terrain analysis work (www.bandaarcgeophysics.co.uk/arch/boudica-terrain-analysis.pdf) created a list of 263 possible battle sites across the study area (Figure 16), with those most likely to be the actual battle site located within, or near, the Kennet river valley. For the present work the 263 were examined and all those not having sufficient water to maintain the Roman army were eliminated. A few former sites were moved slightly to more appropriate positions, and some new sites added. The overall result is a new list of 110 possible battle sites, a significant reduction based largely on the hydrology study.

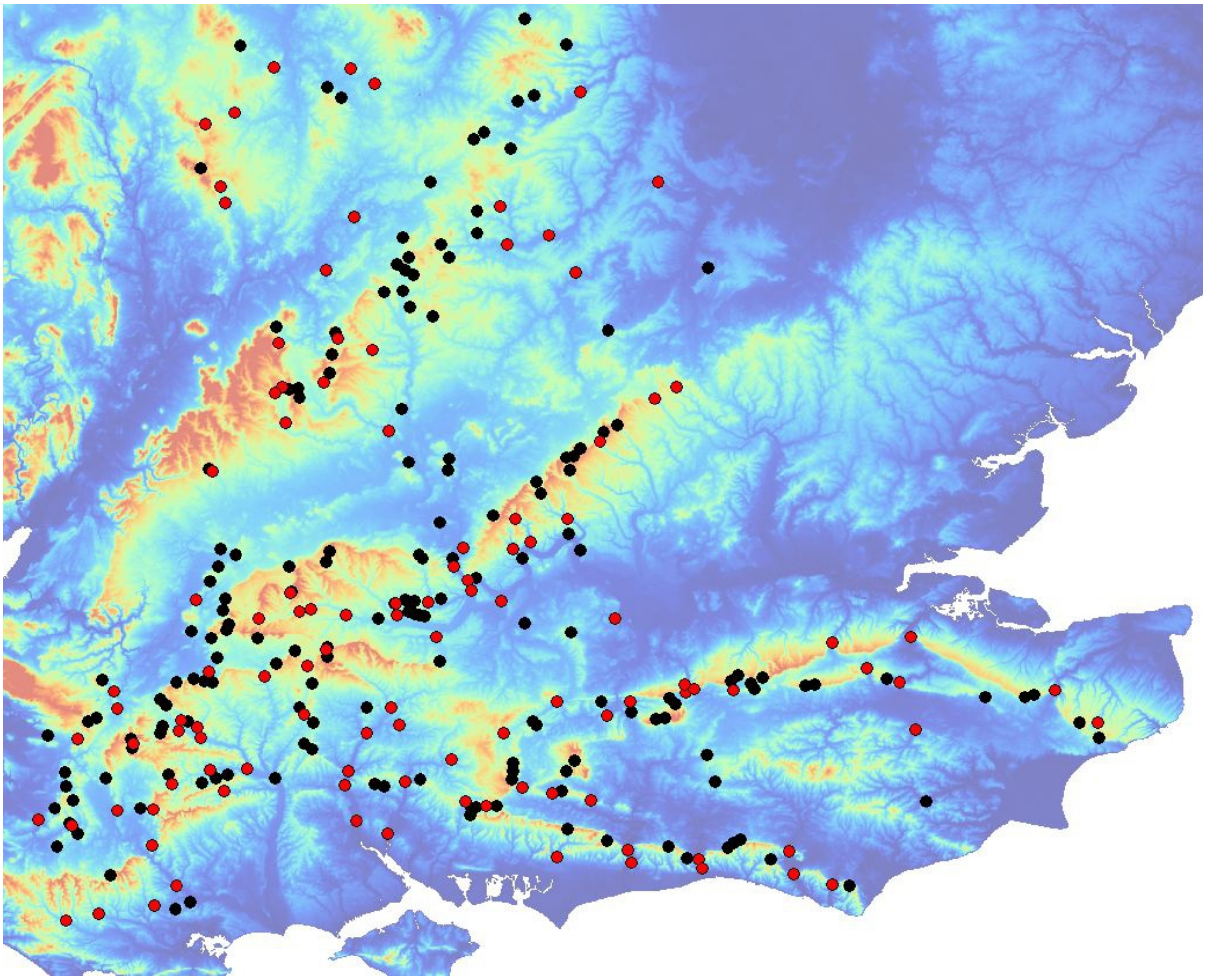


Figure 16: New (110 and red) and old (263 and black) possible battle site locations overlying terrain. The new sites may overlie the old. The black dots are old, deselected sites, i.e. those no longer suitable because they lack adequate water for the Roman army.

Many old sites have been removed in the East Midlands area, while elsewhere there has been a general thinning of possible battle sites. Of special note is the removal of many sites along the eastern, lower stretches of the river Kennet, the preferred location for the battle in the terrain analysis work, due to the effects of small water catchments and the bourne-like nature of the local streams, i.e. there is not enough water.

For clarity, Figure 17 only shows the locations of the 110 new sites. As with the old study, few sites are located west of the Fosse Way (Figure 1) because there is no evidence of the destruction of towns or forts on or beyond that road, for example at Cirencester, and also because it is thought likely that if Suetonius had reached the Fosse Way he would probably have marched immediately to a legionary fort at Gloucester or Exeter.

As an aside, the old study's battle site at Dadlington, now thought to be the site of the Battle of Bosworth, is still in the new list – a good battle site, meeting the terrain and water needs of a waiting army, seems to have permanent qualities.

The new hydrology work clearly demonstrates the critical importance of water supply to large bodies of marching men and beasts, not only during the Boudican revolt, but also other Roman era campaigns, for example, the invasion in 43AD, and the Agricolan and Severan in Scotland. Of course, the same truth applies to later periods.

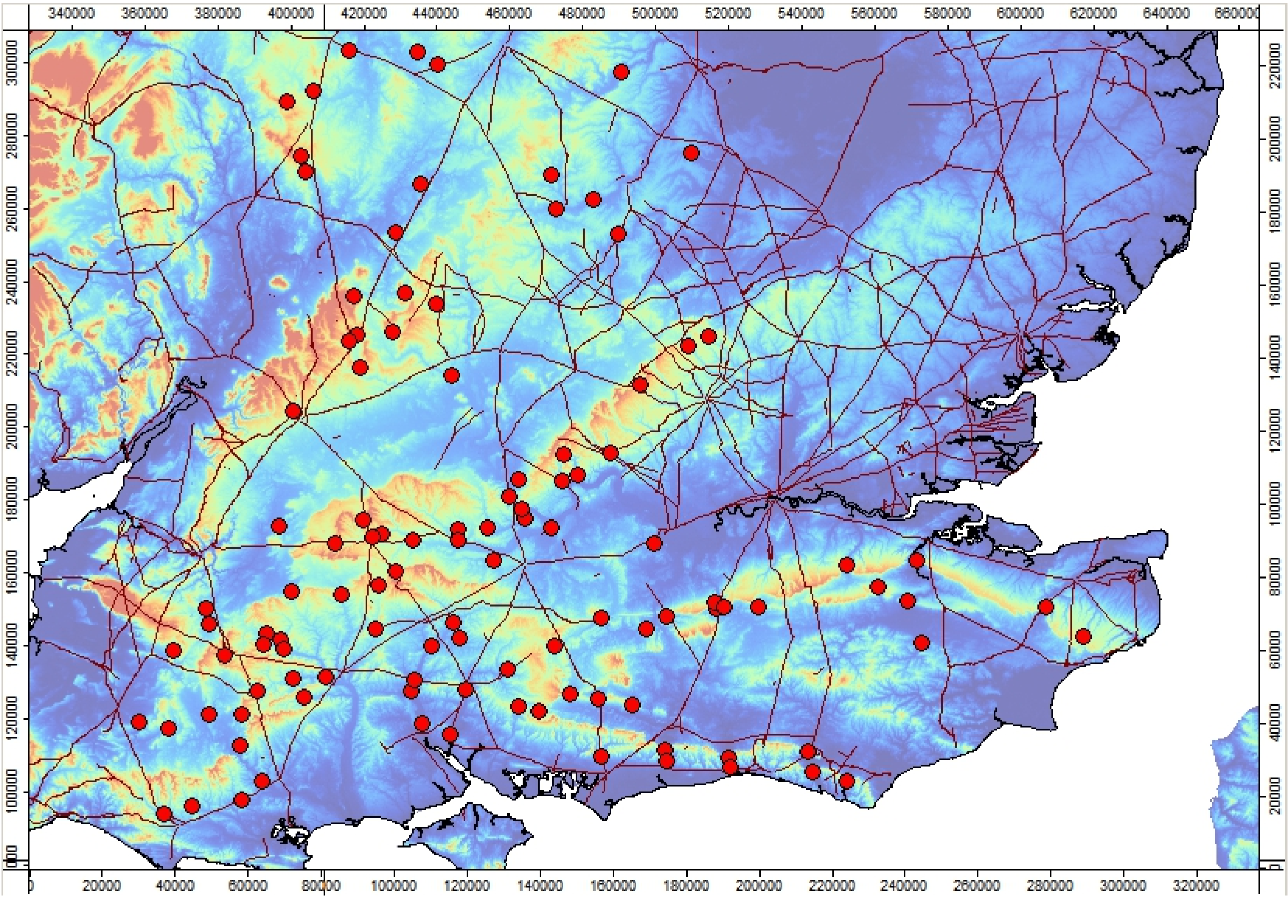


Figure 17: The locations of 110 possible battle sites based on the former terrain analysis and the new hydrology work. Elements of this image are © Crown Copyright. All rights reserved 2013.

Weighting and ranking of battle sites

As already mentioned, the earlier terrain analysis work did not empirically differentiate between the possible battle sites: any one was as likely to be the *actual* site as another. However, for this study a weighting of various factors, followed by a ranking exercise, was performed on the 110 possible battle sites in order to remove some subjectivity, but not all, in the selection of a site thought more likely to be the *actual* site. The key term is 'more likely' because - although the author has endeavoured to remain objective in the interpretation of Tacitus' script, terrain features, the hydrology, marching camp calculations and weighting factors - some other worker would indisputably create a different ranking order.

Each weighting factor was derived using GIS techniques in SAGA and then weighted for each site according to the following formula for unity-based normalisation:

$$X_{i,\,0\text{ to }1} = \frac{X_i - X_{Min}}{X_{Max} - X_{Min}}$$

Where:

X_i = Each data point i

X_{Min} = The minima among all the data points

X_{Max} = The maxima among all the data points

$X_{i, 0 \text{ to } 1}$ = The data point i normalized between 0 and 1

All normalised weighting numbers were then summed, divided by the number of factors, and finally ranked 1 to 110, with 1 being the more likely to be the actual battle site of this listing.

The overall aim of the exercise is to use the determining factors so that the battle site is ranked so that the Romans gain the greatest empirical advantage from the battle site, and the Boudican rebels the reverse. This strategy is thought most appropriate given that Suetonius chose the *actual* battle site, and therefore probably had sufficient time, understanding and knowledge not to locate the battle to his disadvantage. Hence, the normalised range was organised such that zero was the most advantageous to the Romans and, of course, vice versa.

Six factors were used for weighting and ranking: each will be described below.

Distance of the battle site from a Roman road

The Roman road system conveyed many benefits to the marching Roman army – speed of traverse, adequate water, good camping ground and communication with the rest of Britain being most important. Selecting a battle site that traverses a road would maximally maintain these benefits, if only in potential. A morale dimension might also be invoked, namely, the legionaries might have thought they had an escape route if the battle was lost. Therefore, the distance of each possible battle site from a Roman road was calculated within SAGA, and the resulting kilometre values normalised as described above.

As an aside, there is another advantage to be gained by following the road system: the use of previously constructed marching camps. Archaeologists have shown that *known* camps in Britain were re-occupied by other units at later dates. This often resulted in an alteration of the camp margins, or a smaller sized camp built within and utilising some of the pre-existing ramparts and ditches. The Boudican uprising takes place only 17 years after the start of the campaigns to conquer southern Britain. It therefore seems reasonable to assume that marching camps built during the conquest, and probably within the 17 years thereafter, would still be extant. Most would be located along the road system. For Suetonius' men, as they retreated in front of the Boudican horde, re-occupying these old camps would have saved them considerable energy and time. Marching towards an existing refuge might have had a substantial, positive impact on legionary morale; however, this has not been modelled.

Distance the Boudican horde was from an adequate water supply

The Boudican horde required a minimum of 0.04 cumec of water if its camp ground was located downstream from the Roman front line. Although it could augment its need from local, smaller streams within the vicinity of the battle site, nevertheless it would have still needed a river of that capacity to fully maintain itself. Therefore, the distance of the battle site to such rivers was measured and normalised. However there is a twist to this factor.

If the Boudican horde took its water supply from a source that had already passed through Roman lines, then the Romans would probably have interfered with the supply and maybe polluted it with their effluent. This possibility would further strain the rebels but, because there is no evidence of such an event or a simple method of assessing the results, this consequence has not been calculated, or allowed for, but should be borne in mind when examining each battle site.

As a further aside, if the Boudican horde was, while on the march and moving constantly onto fresh ground, already strained by water shortage, then that debilitation would be magnified by halting prior to battle, thereby draining the immediately available water. This may have been part of Suetonius' logistical planning, i.e. significantly weaken the horde by the route taken, before destroying it in battle.

Boudican strain rates: a multi-attribute factor

A multi-attribute factor was calculated to measure the supposed strain experienced by the rebels as they marched along river valleys or used roads across southern Britain. The attributes were: distance from London, elevation, the availability of sufficient water and foraging. For each battle site these were summed and normalised; Figure 15 is based on this multi-attribute approach, but only for rivers. The calculation of the first three strain attributes - distance, elevation and water – do not require further explanation: not so, that for foraging.

As we have discussed, as the rebels marched after the Romans they may have moved into land where food and fodder resources were limited and water in short-supply. This would be particularly true for the upland chalk and limestone regions. In lowland regions this stress would be lessened by larger local populations producing surplus food in richer farmland. As a strain indicator related to foraging, the distance travelled since leaving London might be thought to be significant but, because the horde probably had little carrying capacity, or practice, what food was entrained would have run out after perhaps three to four days. After that time, and for the remaining length of the campaign, the general provisioning method would have been by foraging, requisition and pillage. Under these circumstances the distance travelled is not relevant, i.e. the horde would have experienced a constant, background strain due to foraging etc. after 3-4 days no matter how far it had already travelled. However, there would have been an element of declining morale due to the distance travelled from London, and it is for this reason that this was calculated separately as a strain indicator.

To continue, assigning a constant, background, foraging strain to the lowlands allows the differentiation of increased strain due to travelling in upland areas where food and fodder are more scarce. Therefore, the stress on the horde due to foraging can be represented by a measure of elevation and hydrogeological parameters: these in combination act as a proxy for the foraging stress. Consequently, the weighting method employed was to simply multiply elevation by a hydrogeological parameter called the Mean Annual 7 Day Minimum (MAM(7)), maps of which have been produced covering the UK. MAM(7) is essentially a statistical measure of low-flows in rivers and can be assigned, crucially for this exercise, to varying lithological and soil classes. Lowland areas were ignored in this process by identifying their predominant rock types, e.g. sandstones, shales, mudstones, while upland areas were identified by their rock type – typically either chalk or limestone. The result was a measure of foraging strain but only for the upland chalk and limestone regions.

Terrain ruggedness

Tacitus tells us that Suetonius chose a battle site located in a defile, with a plain in front and woodland behind. The previous terrain analysis study used these basic descriptors to assist in the finding of the 263 battle sites across southern Britain.

Such descriptors were constrained by criteria (Table 3) but these can still result in a range of morphological surfaces – for example of defile shape, height, depth, width, bounding slopes and gradients etc. – which vary considerably in form, from subdued to robust. Accepting that the most robust form is the most defensible, then those of the 110 might have been more favoured by Suetonius.

1	a defile of approximately 1km width set within an elevated area
2	an adjacent, lower elevation plain (less than 4 degrees of slope) or an extensive, lower elevation flat area with gentle slopes
3	a plain of at least 1km diameter to accommodate the British horde and wagons
4	a defile whose flanks rise at least 30 metres higher than the bottom of the defile and have a steep slope (generally > 8 degrees)
5	the flanks extend at least 1.5km in both directions to discourage mass flanking movements by the Britons. These flanks could be a mix of high and broken ground.
6	A gentle, positive slope (< 5 degrees) exists between the Britons and Romans.
7	a river or stream, sufficient to water 10,000 men and 1,000 horses and capable of protection by the Roman force (note: this water requirement was not calculated)
8	the Roman army must be able to march radially away from London using roads to reach the site vicinity
9	a general requirement that the site cannot be easily flanked, for example by an adjacent road or valley
10	the battle site should not so intimidate the Britons that they would not offer battle but instead besiege the Romans – it must be inviting to the Britons and appear to be a trap for the Romans

Table 3 The selection criteria used in the earlier, terrain analysis study

To measure this desirable defensiveness, the Terrain Ruggedness Index (TRI) was utilised. This uses elevation changes within neighbouring grid nodes/cells to determine the heterogeneity of a terrain. Typically this heterogeneity is characterised by type, e.g. level terrain, slightly rugged and highly rugged. SAGA was used to characterise the ruggedness of terrain within a 1km radius of possible battle sites. The resulting values were then normalised, 0 to 1, with 0 being the most rugged and, therefore, the most advantageous to the legionaries, and the most likely to have been chosen by Suetonius.

Weighting due to limiting factors associated with battle sites

The body of 110 possible battle locations contain some that have limiting features, unfavourable to the Romans, that cannot be readily measured by calculation and must be visually evaluated.

Such features are:

1) retrograde battle sites which the Romans could only have reached by performing a marching u-turn. The assumption is that the Romans marched radially away from London, but to reach retrograde battle sites would have had to reverse, to varying degrees, their line of march. This action would have exposed their marching and battle-line flanks to attack from the following rebels. For example, such sites are common along the western-facing scarp of the Chilterns. In these cases Suetonius might have marched north out of London along Watling Street, continued beyond the NW face of the Chiltern escarpment and then turned south-westwards, parallel to the escarpment, and marched towards his pre-chosen battle site, the defile, ensconced within the NW facing escarpment. This convolution of manoeuvre was considered during the phase of the investigation when objectivity in selecting terrain analysed sites was paramount, i.e. these sorts of sites (there are quite a few throughout the southern Britain) match the terrain description/criteria and should not be dismissed, but instead down-weighted as likely battle sites.

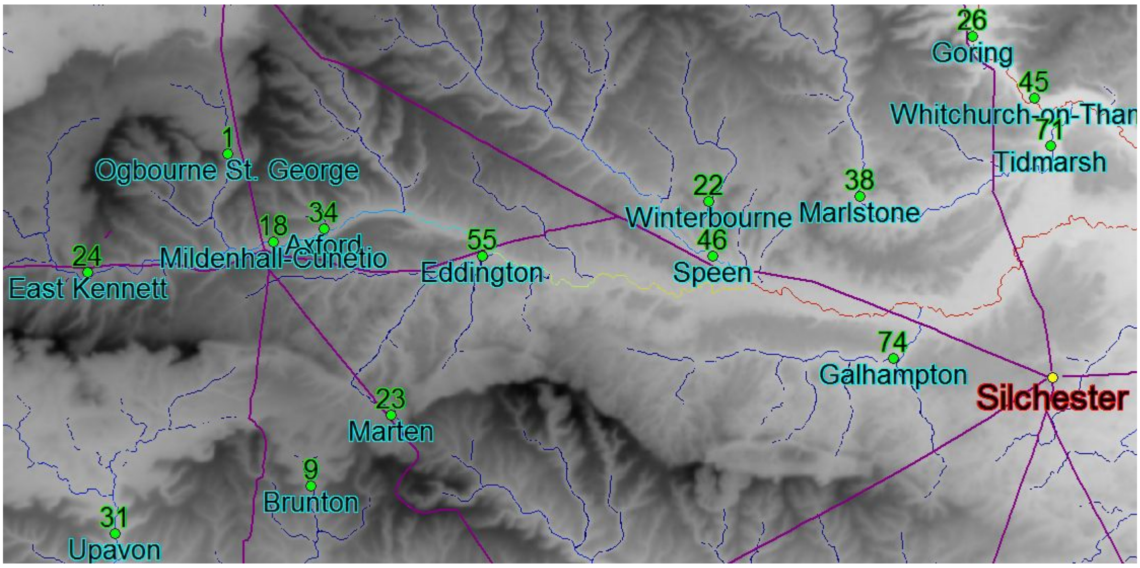


Figure 15: Battle sites within, and adjacent to, the Kennet river valley. Elements of this image are © Crown Copyright. All rights reserved 2013.

2) the possibility of the Romans being flanked. Depending on the local terrain, marching routes and other factors, some sites have been weighted negatively due to the possibility of flanking by the rebels. To be clear, this flanking relates to local outmanoeuvring at the battle site and to flanking approach-marches by the rebels that may take place over a number of days. To aid the discussion we will examine a region of the Kennet river valley (Figure 15). The Kennet river is that shown running through Eddington, Axford and Mildenhall-Cunetio. An example of sites that had little danger from flanking are Eddington, Mildenhall-Cunetio and Ogbourne St. George because the rebel horde would have had to approach the Roman battle lines along the line of march. However, Axford being in the river valley, could have been flanked by rebels taking the road to Mildenhall-Cunetio. In contrast, at Mildenhall-Cunetio the same road and river valley converge, both could be blocked by a defensive line which might have enabled the Romans to force the rebels to march directly towards them. The sites at Marten and Brunton could be flanked, both requiring an element of eastwards, retrograde rotation from the Roman line of march. However, because Marten could have been more readily reached by rebel units cross-country marching from the main Roman road than Brunton, it is weighted down more heavily. All 110 possible sites were examined in this way and each weighted accordingly from 0, no flanking possibility, to 1, high chance of flanking.

3) If a battle site has a river that flows *towards* the Roman front lines then it has been down weighted.

Weighting due to direction of march from London

London is the last named location given by Tacitus for Suetonius and his army. The obvious question is which direction of march did he take? The answer is the primary supposition of any study of Boudica's last battle site, and of course, delimits the region in which to search.

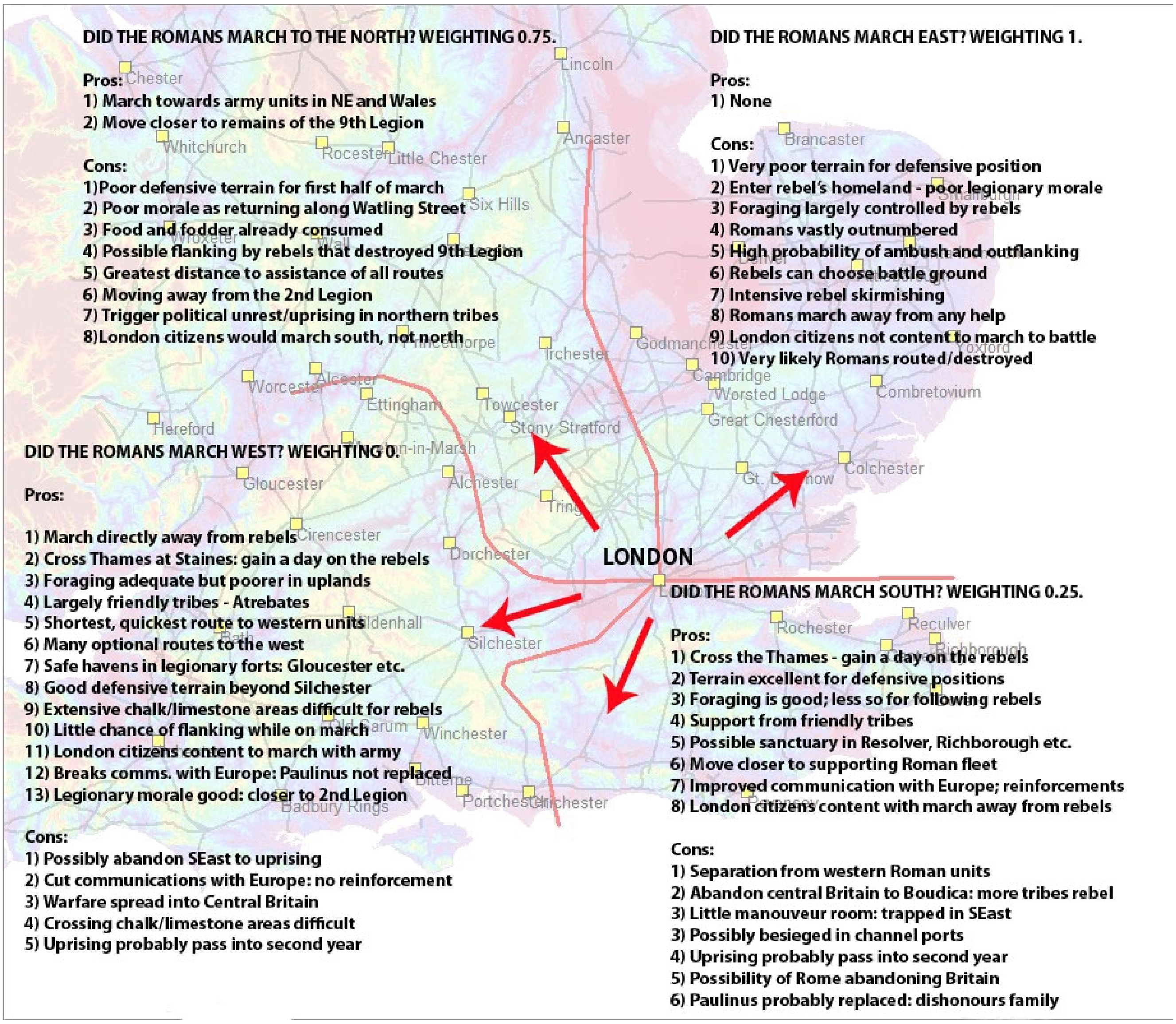


Figure 16. Which direction from London did the Romans march? Answer: west to Silchester. The red lines separate the differing directions Suetonius could have marched.

The earlier terrain analysis work examined this question in depth, its results are itemised in Figure 16. In summary, it is thought that Suetonius while retreating would have marched his army directly westwards, crossed the Thames at Staines, thereby probably gaining at least a day on the horde, before moving quickly along the Portway to friendly Silchester (Figure 1). At some point west of Silchester, but not necessarily directly west there being four westerly roads out of the town, he chose to alter his strategy of retreat, or withdrawal, and offer battle. This last point we are told implicitly by Tacitus when he writes, "*when he* [Suetonius] *prepared to break off delay and fight a battle.*"

The weighting assigned to regions (Figure 16) is 0 for a westwards march from London, 0.25 for marching south, 0.75 for marching north, and 1 for an eastwards march. This weighting is a reflection of the author's combined suppositions (text in Figure 16), with the lowest value thought most likely, i.e. westwards. The southern route is also quite likely, and so is given a weighting of 0.25. The northern route is considered very unlikely, reflected in a weight of 0.75. The eastward, suicidal route, is thought to be highly improbable and given a weight of 1. However, of the 110 sites, none are in the east.

The ranking process and list of likely battle sites

The six normalised weightings described above were summed for each possible battle site, divided by six and then ranked 1 to 110, with 1 being the more likely - of this study's selection of criteria, weightings and suppositions - to be the *actual* battle site (see Table 4 and Figure 17).

1 Ogbourne St. George
2 Norton Ferris (north)
3 Wigginton
4 Upper Slaughter
5 East Meon
6 Lower Swell
7 Lower Assendon
8 Milland
9 Brunton
10 Bowyer's Common
11 Piddlehinton
12 Daglingworth
13 Alton
14 Stratton
15 Winterborne Kingston
16 Hambledon
17 Ottinge
18 Mildenhall-Cunetio
19 Codford
20 Ibstone
21 Broad Chalke
22 Winterbourne
23 Marten
24 East Kennett
25 Cornwell
26 Goring
27 Box Hill
28 Cockernhoe
29 Heytesbury
30 Alfriston
31 Upavon
32 Batcombe
33 Arrowfield Top
34 Axford
35 St. Cross
36 Corton
37 Walton
38 Marlstone
39 Bossington
40 Blatchbridge
41 Botolphs
42 Teffont Evias
43 Stockton
44 Shoreham-by-Sea
45 Whitchurch-on-Thames
46 Speen
47 Hanborough
48 Littleton Panell
49 Houghton
50 Murtry Aquaduct
51 Winchet Hill
52 High Wycombe
53 Wilton
54 Godalming
55 Eddington
56 Iwerne Courtney
57 Cann
58 Wiggington
59 Swaythling
60 Hints
61 Spetisbury
62 West Humble
63 Bordesley
64 Oldbury
65 New Alresford
66 Lewes
67 Dorking
68 Spratton
69 Romsey
70 Chilbolton
71 Tidmarsh
72 Claygate Cross
73 Blockley
74 Galhampton
75 Brington
76 Mottisfont
77 Warningcamp
78 Perry Bar
79 Southease
80 Lavant
81 Wouldham
82 Virginia Water
83 Stourton
84 Semley
85 Olney
86 Godmersham
87 Sherborne
88 Sheepy
89 Warnford
90 Farnham
91 Chilworth
92 Redhill
93 Reading
94 Shipton Bellinger
95 Upper Bullington
96 Ipsden
97 Harringworth
98 Tufton
99 Fifehead Magdalen
100 Dadlington
101 Studley
102 Lodsworth
103 Eynesford
104 Nene Valley
105 Luton
106 Trent
107 Sherborne
108 Northampton
109 Nettlestead
110 Offchurch

Table 4: The 110 possible battle sites ranked in order, with 1 the more likely.

The weightings for each site ranged from 0 to 1 except for ruggedness, the measure of terrain fitness best suited to the Romans, which was increased by 50% to match its probable importance in Suetonius' selection process.

1	Ibstone
2	Cockernhoe
3	Ogbourne St. George
4	Norton Ferris (north)
5	Wigginton
6	Arrowfield Top
7	Upper Slaughter
8	East Meon
9	Ottinge
10	Lower Swell
11	Lower Assendon
12	Milland
13	High Wycombe
14	Box Hill
15	Brunton
16	Bowyer's Common
17	Piddlehinton
18	Wiggington
19	Daglingworth
20	Alton
21	Stratton
22	Hints
23	Winterborne Kingston
24	Hambledon
25	Bordesley
26	Oldbury
27	Mildenhall-Cunetio
28	Codford
29	Broad Chalke
30	Winterbourne
31	Marten
32	Alfriston
33	East Kennett
34	Cornwell
35	Goring
36	Spratton
37	Botolphs
38	Brington
39	Perry Bar
40	Shoreham-by-Sea

Table 5: Top 40 rankings after removal of weighting due to direction of march from London.

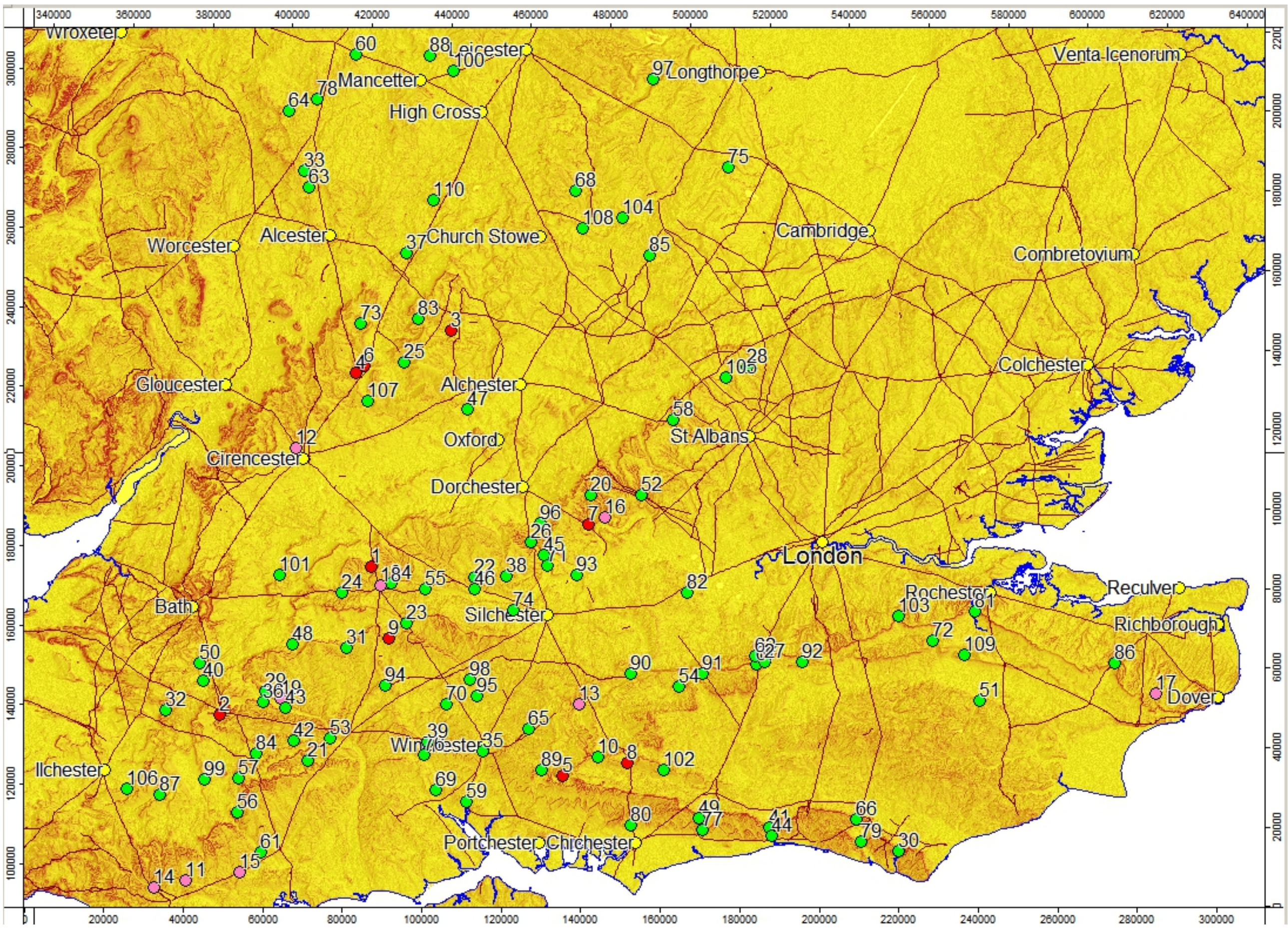


Figure 17: Ranked battle sites overlying terrain and Roman roads. Top ten sites are in red, 11 to 20 in magenta. Cross-reference the ranking numbers with Table 4 to identify the locations. Elements of this image are © Crown Copyright. All rights reserved 2013.

As already discussed, the primary supposition of any study such as this, is the direction Suetonius took when leaving London. If this weighting is removed from the ranking process then a new listing (Table 5, top 40 sites only, and Figure 18) of possible battle sites is created.

Ibstone in Buckinghamshire is sited in the northern march region (Figure 16) but, once this weighting is removed (Table 5 and Figure 18), it displaces Ogbourne St. George as number 1 which is relegated to number 3. Overall, the removal of the weighting for direction of march still leaves a predominance of western sites at the top of the listing.

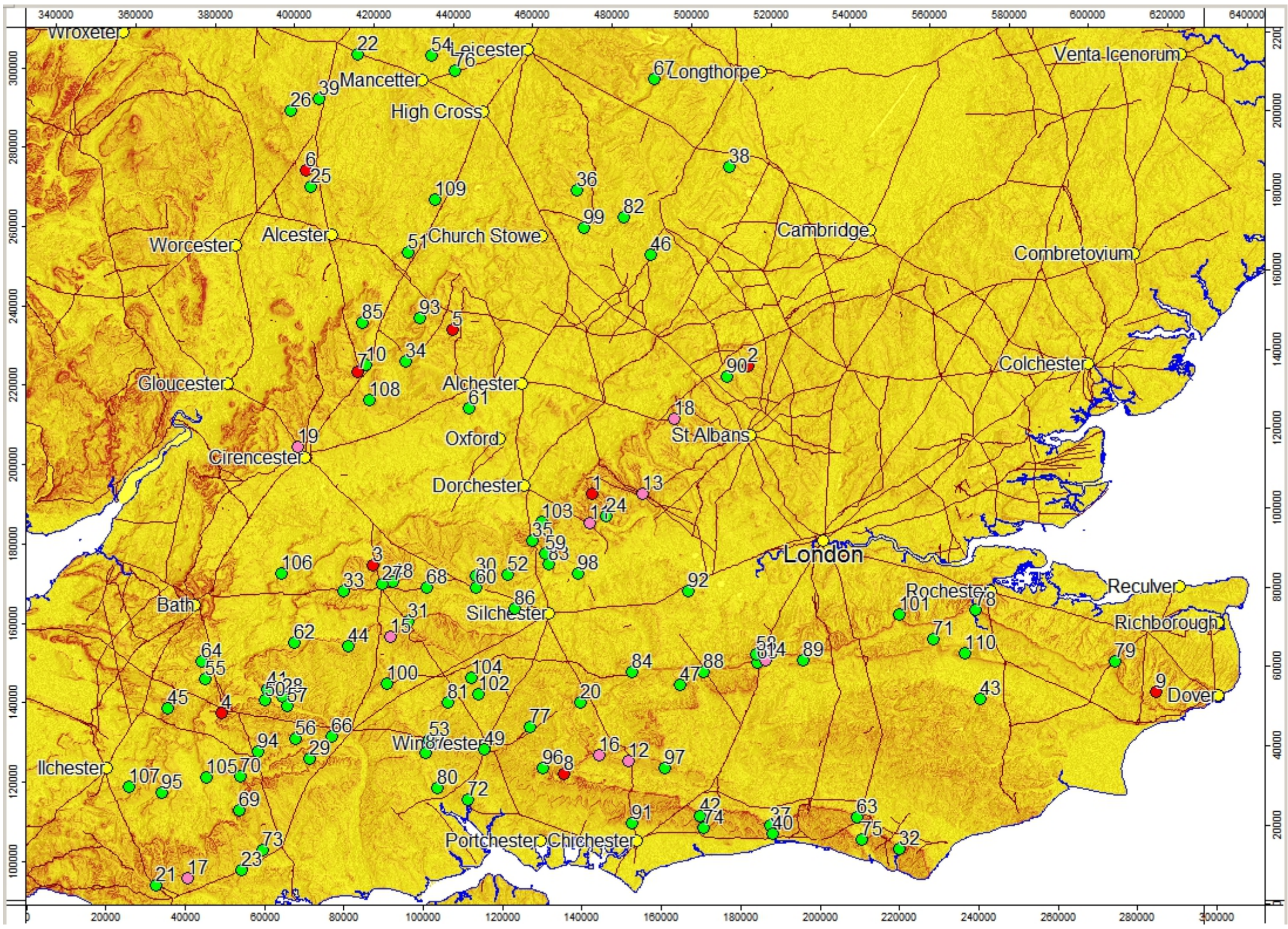


Figure 18: The battle site rankings where the weighting due to the marching direction from London has been removed. Background as Figure 17. Top ten sites are in red, 11 to 20 in magenta. Cross-reference the top 40 ranked numbers with Table 5 to identify the locations. Elements of this image are © Crown Copyright. All rights reserved 2013.

Discussion

We have now examined the combined results of the earlier terrain analysis, the water needs of the legionary and rebel forces matched to the available water supply, and an examination of the marching camp data that places limits on where Suetonius might have marched and camped and, hence, the location where the final battle might have taken place.

The highest ranking battle sites (Figure 17) occur in an area from the Kennet valley region through to the Chilterns, and also in the high Cotswolds, within and near the Evenlode and Windrush river valleys (Figure 19). Elsewhere groupings are found within the South Downs of West Sussex (East Meon, Milland and Bowyer's Common) and in the south facing valleys of the hills north of Dorchester (Piddlehinton, Stratton and Winterbourne Kingston). The former are thought less likely to be highly probable sites because of their distance from London; however, if Suetonius had marched in this direction, with the intention of reaching the ports at Portchester and Chichester, then their likelihood increases; this probability is tinged with doubt when considering Suetonius' probable nature, i.e. would this man consider a strategy which might lead to flight to the continent? The latter are fine examples, but again, probably too far from London to be seriously considered as likely sites; however, they should not be discounted entirely, especially if it is thought Suetonius had been manoeuvring in the direction of support from the 2nd Legion probably located in Exeter.

The high Cotswolds locations (Wiggington, Lower Slaughter and Upper Swell) pose a difficulty with the favoured westwards march out of London because they imply a London - St Albans –

Bicester (*Alchester*) – Cirencester marching route as being more probable. Indeed, passing through St. Albans would match Tacitus' account, and archaeological evidence, of destruction. It is equally possible, and preferred by the author, that St. Albans was devastated by the rebel unit that had earlier destroyed the 9th Legion and then followed Suetonius as he marched to London.

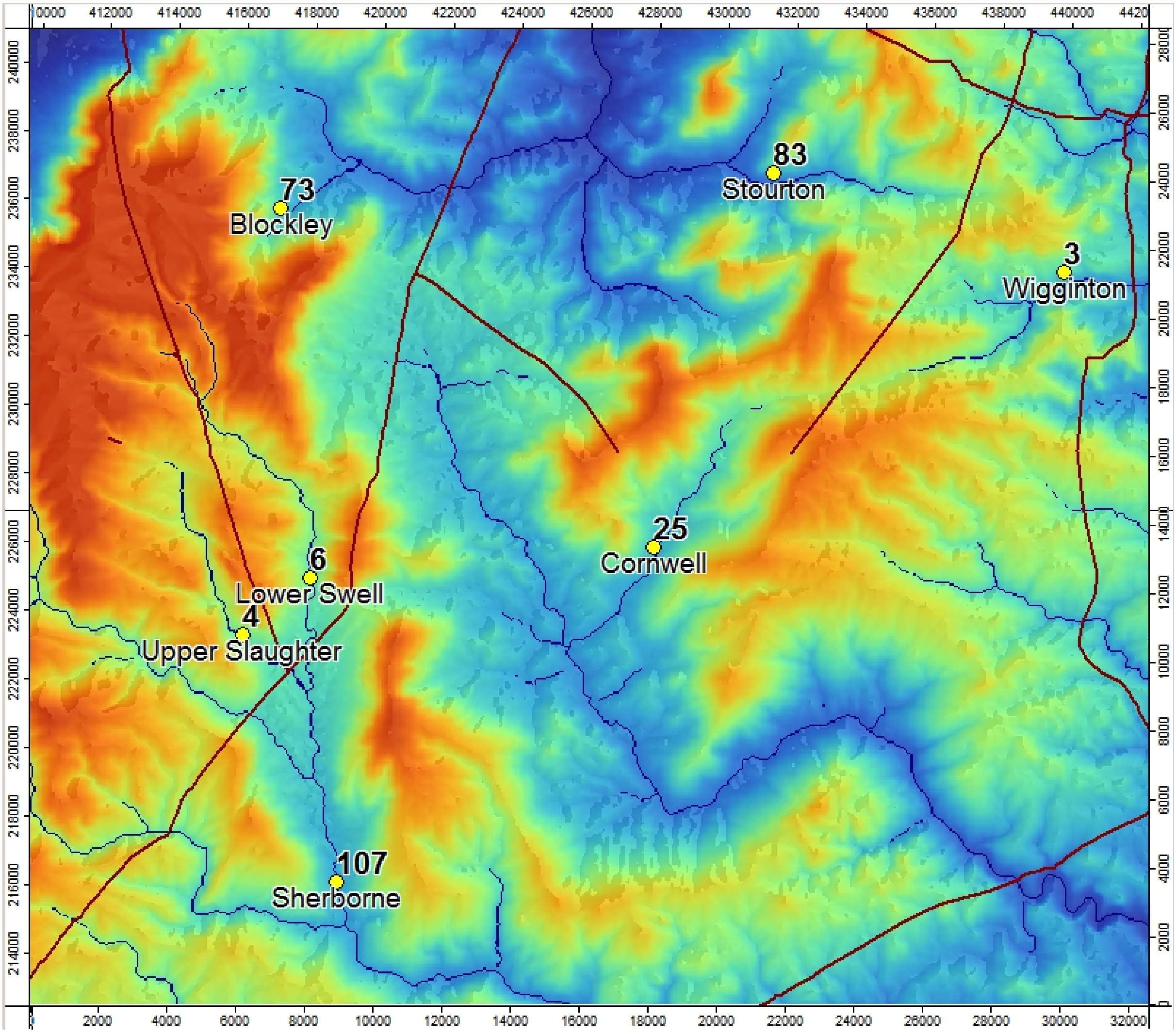


Figure 19: High ranking battles sites in the high Cotswolds. Numbers are ranks. Elements of this image are © Crown Copyright. All rights reserved 2013.

Another route Suetonius may have taken was London – Silchester – Goring Gap – Bicester – Cotswolds, with the initial intention of moving on to Cirencester, before terminating at Gloucester, the legionary fort for the area.

These high ranking sites in the high Cotswolds, West Sussex and Dorset result from the same measurements, weightings and calculations as those in the Kennet valley region and should not be dismissed, even if that implies a route taken that is contrary to this author's preferred westwards marching route.

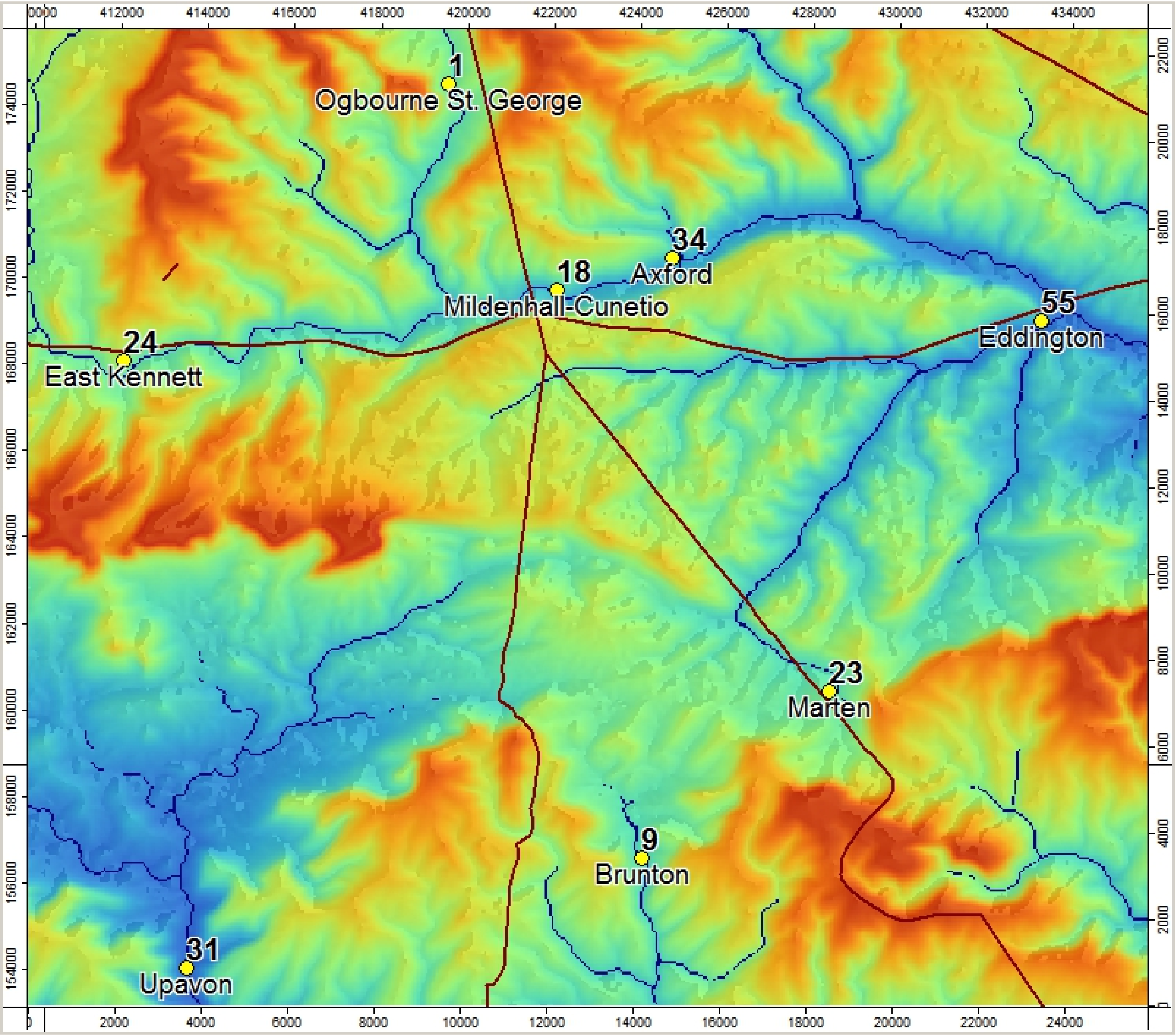


Figure 20: High ranking battles sites around Mildenhall-Cunetio. Numbers are ranks. Elements of this image are © Crown Copyright. All rights reserved 2013.

Within a 17km radius of Mildenhall, in the Kennet valley region (Figure 20), are eight possible battle sites, including Ogbourne St. George at number one. This might be considered a remarkable outcome of the work described in this essay, but might have already been fully appreciated by Suetonius. But not only Suetonius: the East Kennet battle site was also the precise location of a battle in 1006 between Vikings and Anglo-Saxons, while the Kennet Valley at Newbury saw two battles of the English Civil War in 1643 and 1644.

Suetonius, Governor of Britain, probably selected for his military prowess and experience, turned impending disaster into victory, securing the Roman province for the next 350 years. It is instructive to compare this outcome to Varus' defeat in the Teutoberg in 9AD: Germany does not become a province, nor its inhabitants Romanized, while southern Britain is pacified and Romanized. It might be argued that Suetonius' achievements have been underestimated.

Similarly his handling of the Boudican campaign might not be fully appreciated. Admittedly, his probable original plan, of containment of the uprising in eastern England, went badly wrong when the 9th Legion was routed and the 2nd refused to obey his orders; the first disaster might have been the Governor's responsibility, but the second could not have been foreseen. However, after leaving London it seems Suetonius made all the right decisions.

He may have called upon his experiences of fighting tribal units in the arid regions of Mauritania and the Atlas Mountains to realise that the size of the Boudican horde, coupled with its inexperience of distance-marching in regions with a scarcity of food, fodder and water, might eventually result in victory.

Suetonius would have realised that the rebel leaders had to destroy him in battle before he found refuge in a legionary fort, or support from the 2nd Legion. They therefore had to follow him, even if they were placed in logistic jeopardy. Suetonius might have reasoned that marching his superior and well-trained, -practised, -provisioned, -equipped and faster legionaries into high and dry land would strain his adversaries far more than his units. He might have planned that eventually the Boudican horde would be so weakened that it could be destroyed in battle. But, if not weakened sufficiently, his quicker army would still be able to escape to a legionary fort in the west country, and then plan the re-conquest.

In summary, it is postulated most likely that Suetonius led his soldiers out of London along the Portway (Figure 1), crossed the Thames at Staines, and marched on to his kingly ally, Cogidubnus, at Silchester. From Silchester he marched directly westwards, taking the Ermin Street spur towards Mildenhall and Bath, and into the high and dry chalk uplands of the White Horse Hills (Figure 3) and an already identified battle site. His decision to offer battle would have been influenced by many factors, but surely amongst the foremost might have been the planned, debilitating and destructive effect on the Boudican horde of marching over 116km from London to Mildenhall-Cunetio, that is seven to eight days at 16km/day (probably longer as the logistical strain progressed).

The faster marching rate of the legions confers another advantage on the Romans, namely, being approximately four to five days at the battle site before the slower Boudican rebels arrive. Time enough to rest, recuperate, repair equipment, gather or consume the fodder in front of the lines and prepare the ground, water-supply and defences for either a siege, or battle. Long enough to again emphasize the critical importance of having sufficient water. Unfortunately for the rebels, if they came off the march in a battle location without sufficient water, fodder or food, then their already strained state would be compounded.

Which leads to one striking oddity of the battle: why did the Boudican rebels frontally attack and not besiege and weaken, or extensively flank, the Romans? To answer that definitively is not yet possible, however, if Suetonius chose a battle site where he controlled the water supply, had already consumed or gathered the local foodstuffs, or the rebels had insufficient nearby water, then they may have been forced to quickly attack in their march-weakened state, or disperse. It is possible to envisage Suetonius, a man probably well-versed in Julius Caesar - "*conquer*[ing] *the foe by hunger* [and thirst] *rather than by steel"* - deliberately choosing such a site, knowing that his legionaries would use their steel to finish the foe already weakened by his logistical cunning.

In support of the preceding paragraphs are insights into the experience and character of the Roman commander, so critical to the outcome of the uprising, given by Tacitus in his Histories when describing the battle of Cremona during the Civil War of 69AD, "*for he was naturally inclined to delay, and a man who preferred cautious and well-reasoned plans to chance success. So he kept issuing orders to fill up the ditches, clear the fields, and extend the line, thinking that it was soon enough to begin to conquer when they had made provision against defeat*."

Finally, it cannot be reasonably denied that the study of terrain analysis, hydrology, marching camps and logistics is beneficial when cautiously applied to the enigma that is the Boudican uprising: to what extent is debatable - for now.

These comments go to the heart of what the author is attempting, that is, to narrow down the search for the battle site by combining archaeology and historical accounts with modern data and computing techniques. However, not one site, or any listing, is sacrosanct as the data, methodology and results are improved.

What is undoubtedly true is that the merciless objectivity of the archaeologist's trowel will, hopefully, end the search.

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Primary software:

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

Copyright:

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).