WATERING THE ROMAN LEGION

Gabriel Moss

A thesis submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Department of History.

Chapel Hill
2015

Approved by:

Richard Talbert
Fred Naiden
S. Thomas Parker
ABSTRACT

Gabriel Moss: Watering the Roman Legion
(Under the direction of Richard Talbert)

This thesis investigates how ancient Roman legions provisioned fresh water while on campaign, arguing that water logistics were an important limit on Rome’s ability to defend the empire. Using comparative data, this thesis estimates the hefty water requirements of a Roman army in the field and argues that the limits of preindustrial transportation technology compelled commanders to stick close to local water supplies except in the most urgent circumstances. After a discussion of what water sources ancient armies could tap, this thesis turns to investigate how the reliance on local water sources limited the strategic maneuverability of Roman forces. Through GIS analysis of water sources along the Roman frontier in Tripolitania, it demonstrates that large swaths of nominally “Roman” territory were inaccessible to Roman troops, and that the strictures of water logistics made it challenging for the Roman Empire to adequately secure its desert frontiers.
ACKNOWLEDGEMENTS

This thesis could not have been produced without the generous contributions of many people and organizations. My thanks to professors Richard Talbert, Fred Naiden, S. Thomas Parker, and John Chasteen for their valuable feedback and guidance, to Ryan Horne for technical assistance in all things GIS, and to Philip McDaniel and the UNC GIS Library for directing me to invaluable mapping datasets. Work on this thesis was funded in part by the James K. and Georgia C. Kyser Fellowship in History. The GIS portions of my work were made possible by the support of the UNC Ancient World Mapping Center.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>vi</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2. QUANTITATIVE ESTIMATES OF ROMAN WATER NEEDS</td>
<td>3</td>
</tr>
<tr>
<td>3. THE POSSIBILITY AND IMPROBABILITY OF TRANSPORTING WATER</td>
<td>13</td>
</tr>
<tr>
<td>4. WATER “FORAGING” AND LOCAL WATER SOURCES</td>
<td>29</td>
</tr>
<tr>
<td>5. TRIPOLITANIA, WATER LOGISTICS, AND STRATEGIC LIMITATIONS</td>
<td>39</td>
</tr>
<tr>
<td>6. CONCLUSION</td>
<td>55</td>
</tr>
<tr>
<td>MAPS</td>
<td>57</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>67</td>
</tr>
</tbody>
</table>
# LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Author</th>
<th>Abbreviation</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appian, B.Civ.</td>
<td>B.Pun.</td>
<td>Bellum Civile / Civil Wars</td>
</tr>
<tr>
<td></td>
<td>BAtlas</td>
<td>Barrington Atlas of the Greek and Roman World</td>
</tr>
<tr>
<td>Caesar, B.Afr.</td>
<td>B. Alex.</td>
<td>De Bello Africo / On the African War</td>
</tr>
<tr>
<td></td>
<td>B. Civ.</td>
<td>Commentarii de Bello Civili / Commentaries on the Civil War</td>
</tr>
<tr>
<td></td>
<td>B. Hisp.</td>
<td>De Bello Hispaniensi / On the Spanish War</td>
</tr>
<tr>
<td>Enc.Berb.</td>
<td></td>
<td>Encyclopédie Berbère</td>
</tr>
<tr>
<td>Enc.Brit.</td>
<td></td>
<td>Encyclopedia Britannica</td>
</tr>
<tr>
<td>Frontinus, Strat.</td>
<td>HA</td>
<td>Strategemata / Stratagems</td>
</tr>
<tr>
<td>HA</td>
<td></td>
<td>Historia Augusta / Augustan History</td>
</tr>
<tr>
<td>Josephus, BJ</td>
<td></td>
<td>Bellum Iudaicum / Jewish Wars</td>
</tr>
<tr>
<td>OSHA</td>
<td></td>
<td>Occupational Safety and Health Administration</td>
</tr>
<tr>
<td>Pliny, NH</td>
<td></td>
<td>Naturalis Historia / Natural History</td>
</tr>
<tr>
<td>Plutarch, Ant.</td>
<td>Crass.</td>
<td>The Life of Antony</td>
</tr>
<tr>
<td></td>
<td>Luc.</td>
<td>The Life of Crassus</td>
</tr>
<tr>
<td></td>
<td>Luc.</td>
<td>The Life of Lucullus</td>
</tr>
<tr>
<td></td>
<td>Paul.</td>
<td>The Life of Aemilius Paulus</td>
</tr>
<tr>
<td></td>
<td>Pomp.</td>
<td>The Life of Pompey</td>
</tr>
<tr>
<td></td>
<td>Sert.</td>
<td>The Life of Sertorius</td>
</tr>
<tr>
<td>Sallust, Jug.</td>
<td></td>
<td>Bellum Jugurthinum / Jugurthine Wars</td>
</tr>
<tr>
<td>Tacitus, Ann.</td>
<td></td>
<td>Annales / Annals</td>
</tr>
</tbody>
</table>
——, Hist. Historiae / Histories

Vitruvius, De Arch. De Architectura / On Architecture
1. Introduction

At its height, the Roman Empire’s borders stretched for thousands of kilometers around the Mediterranean world. Roughly half of these borders abutted deserts. From Gibraltar to Mesopotamia, the Roman frontier brushed against the vast arid zone stretching from the Sahara eastwards into Asia. As a result, the Romans’ ability to win and defend the huge sectors of territory to their south and east depended to a great extent on the ability of imperial armies to function in areas where water was scarce.

Given the importance of desert operations to imperial security, it is remarkable that no scholars have thoroughly addressed Roman military water logistics. Only two consider the question at all: Jonathan Roth briefly discusses water requirements and water provisioning methods as part of a longer monograph on Roman military logistics.¹ Experimental archaeologist Marcus Junkelmann provides valuable estimates of the amount of water required by Roman legionaries, but does not explore the implications of his figures at any length.² A third scholar, Donald Engels, analyzes water logistics and military geography, and their combined effect on the strategy of Alexander’s eastern campaigns; though not about the Roman military, his work provides valuable comparanda and largely influences the methodological approach of

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¹Roth (1999).

²Junkelmann (1997), pp. 172-175.
Beyond the works of these three men, the historiography of ancient military water supply is deserted.

My thesis seeks to address this critical gap in our understanding of Roman military water logistics. Using a variety of modern comparative evidence, it will estimate the volume of water required by Roman units in the field. Analyzing literary sources and the quantitative limitations of ancient technology, it will evaluate the ability of Roman armies to operate independently of the water landscape by carrying large quantities of water with them. Concluding that Roman campaigns, particularly by large forces, were generally limited to areas where water was locally available, I discuss what types of water sources Roman troops could use, arguing that only rivers and springs could typically meet the water requirements of an ancient army. Finally, having constructed a general model of the techniques and limitations of Roman military water supply, I apply that model to an actual geographic landscape; using GIS analysis of water sources in Roman Tripolitania (the arid northwestern corner of modern Libya), I argue that the water requirements of a Roman army severely limited its ability to defend the empire’s desert frontiers.

\[^3\)Engels (1978).\]
2. Quantitative Estimates of Roman Water Needs

Our first question is a scientific one: how much water did Roman troops (and their animals) require to remain fit for service? In principle, these figures should be simple to calculate. After all, Roman men and animals were not notably different from their modern counterparts in biological terms. Yet our calculations are complicated by the essential physiology of dehydration. To put it bluntly, in order to know how much water a Roman soldier needed to drink, we need to know just how heavily he sweated.

A Roman soldier, like any other human, must consume enough water through food and fluids to match the water lost through urination, defecation, and perspiration. In the context of Roman desert warfare, we may safely ignore all factors except fluid intake and perspiration. Though the diet of Roman soldiers in garrisons included fruits, vegetables, and other water-rich foods, troops on desert marches carried “iron rations” of hardtack and pork-fat, foods which contributed little in the way of hydration.\(^4\) Except in cases of dysentery, water loss through defecation is minor, while urine output will drop below .5 L/day for humans in the desert heat.\(^5\) Thus, we may simplify our calculations by assuming that the small amounts of water taken in through food will cancel out the small amounts lost through urination and defecation.

Desert hydration, therefore, is a relatively simple matter of matching water intake to perspiration. When this balance is not maintained, dehydration begins. Even before the onset of

\(^4\)Davies (1971).

any symptoms, dehydration may be evaluated by measuring weight loss: a soldier who sweats 2 L but drinks only 1 L will have lost 1 kg and have a 1 L water deficit. However, to judge the severity of dehydration it is necessary to measure weight loss as a percentage of total body mass: thus an 80 kg person who has lost 2 kg of water through perspiration will have roughly the same level of dehydration as a 40 kg person who has lost 1 kg.6

The symptoms of dehydration appear as the percentage of weight loss increases. Dehydration up to 10% of body weight can be severely unpleasant but not fatal.7 However, dehydration incapacitates around 10%. By 12% weight loss, humans become unable to swallow and can recover only through the medical administration of fluids. Dehydration is fatal when weight loss reaches between 15% and 25% of body weight; at these levels, the human body becomes unable to regulate its temperature through perspiration. Core temperature spikes above 100° F with fatal results.8

Given the physiology of dehydration, it is difficult to calculate a precise water requirement for the Roman soldier in the field. After all, this requirement depends on the soldier’s rate of perspiration, which is itself dependent on his level of exertion, on his armor and equipment, and on the climate in which he operates. Moreover, all evidence for the legionaries’ water needs must come by necessity from modern comparative data, all of it collected from subjects who were not (with a couple notable exceptions) working under the conditions of a Roman military campaign.

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7Schmidt-Nielsen (1964), ch. 1. Though not technically related to dehydration, it is worth noting that the levels of perspiration high enough to produce 10% dehydration can also cause severe salt deficiency with its own debilitating symptoms. See Atkinson & Morgan (1987).

8Schmidt-Nielsen (1964).
In the face of these methodological challenges, we should hardly fault Engels and Roth (the only major analysts of ancient military logistics to address water at all) for not adequately exploring their estimates of ancient water needs. Both historians claim that a soldier required two liters of water per day, with that requirement increasing with high temperatures and activity levels.\(^9\) This figure is problematic both in its scientific grounding and its general utility: in the deserts where water supply posed its greatest logistical challenge to ancient armies, soldiers required significantly more than 2 L/day.

Backtracking Engels and Roth’s citations reveals three sources for their 2 L/day figure. Engels cites the estimate in a 1930 *Journal of Hellenic Studies* article, in which Frederick Maurice analyzes the logistics of Xerxes’ 5th century invasion of Greece.\(^10\) Maurice gives no citation for his claim that slightly over 2 L of water would suffice for men marching in the heat of the Turkish summer; he presumably draws upon personal experience in the region during World War I.\(^11\) Roth takes his 2 L figure primarily from Engels himself, though it is tentatively suggested by two more sources. U.S. Army nutrition guidelines from the 1960s recommend that servicemen drink only 1 L/day (though this assumes that the soldier’s diet provides an additional 1.5 L of fluids).\(^12\) Based on estimates from our other sources, this figure must have been intended only for relatively inactive troops in very temperate weather. Atkinson and Morgan, reporting on their experiments with Roman military reenactors, also suggest that 2 L/day would

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\(^{10}\)Maurice (1930), 223.

\(^{11}\)With Maurice (who gives his figure as 2 quarts) and all other sources, I have converted all measurements to metric equivalent. Individual water requirements have been rounded to the nearest whole or half.

\(^{12}\)U.S. Army (1961), pp. 5-6.
be an acceptable water ration for a Roman legionary.\textsuperscript{13} However, both sources indicate that troops performing strenuous work in hot environments would require far more than 2 L/day of water; Atkinson and Morgan found 2 L inadequate at temperatures over 70° F, while the Army stated that troops in hot environments could require up to 2.5 gallons (9.5 L) of water per day.

Of Engels’ and Roth’s sources on ancient water requirements, one (Maurice) is of questionable scientific validity. The other two readily admit that their numbers are not accurate for troops marching in the hot and dry environments where water logistics would present a serious problem to ancient generals. A more reasonable figure comes from Marcus Junkelmann, the leading German scholar of Roman military logistics, who claims that a Roman legionary on the march required between 4.5 and 8.5 L of water per day, with the higher figure holding true in high temperatures.\textsuperscript{14} Furthermore, he states that 2 L would only be sufficient for a soldier not engaged in strenuous activity such as marching, construction, or combat. Junkelmann bases these figures on his famous experimental recreation of a legion on the march, in which he led a small band of volunteers outfitted in reconstructed Roman equipment some 500 km from Verona over the Alps to Augsburg.\textsuperscript{15} As a result, his estimates should reflect the needs and circumstances of the ancient Roman soldier more accurately than those based on the experiences of British soldiers in Asia Minor or American G.I.s in Korea.\textsuperscript{16}

Junkelmann’s work suggests that Engels and Roth’s 2 L/day figure may be inadequate even for troops in temperate climes. A more recent nutritional report from the U.S. Army leads

\textsuperscript{14}Junkelmann (1997), pp. 172-175.
\textsuperscript{15}Junkelmann (1986).
\textsuperscript{16}Referring to Maurice (1930) and U.S. Army (1961).
to similar conclusions, stating that soldiers engaged in “light to moderate activity in a temperate climate” require 1 quart (.95 L) of water for every 1000 calories burned.\textsuperscript{17} By Roth’s own estimate, the average legionary burned 3000 calories per day, and thus would require just under 3 L of water even in cool temperatures.\textsuperscript{18}

Leaving water requirements in moderate climates aside, we may be quite sure that 2 L of water per day is woefully inadequate for troops on desert campaigns. Steven Sidebotham’s work on the ancient inhabitants of Egypt’s Eastern Desert indicates that 4-6 L/day is necessary in the Egyptian summer; more than 6 L may well have been necessary to maintain strenuous levels of physical activity (and marching under arms should certainly fall into this category).\textsuperscript{19}

Sidebotham’s estimate is supported by a particularly valuable set of ostraka from Mons Claudianus which lists the water rations for a community of 916 people at an early 2\textsuperscript{nd} Century BCE mining site in the Eastern Desert. Rations ranged from 6.5 L to roughly 2 L per day; the lower numbers are presumably for children, and since the ostraka appear to give the water rations for winter months, summer water requirements may well be higher.\textsuperscript{20}

Modern comparative data indicates that a 4-6 L/day water requirement for desert survival is, if anything, still too low for our study of Roman legionaries. The 2001 U.S. Army nutrition report cited above states that troops in warm environments require roughly 4-6 L of water per day, but that higher temperatures and activity levels can drive this number up.\textsuperscript{21} The

\textsuperscript{17}U.S. Army (2001), p. 4.
\textsuperscript{18}Roth (1999), p. 12.
\textsuperscript{20}Cuvigny (2005); Sidebotham (2011), ch. 7; \textit{BAtlas} (2000), 78 C4.
\textsuperscript{21}U.S. Army (2001), p. 5. Note that U.S. Army (1961) claims that troops in hot environments can require up to 9.5 L/day of water.
U.S. Occupational Safety and Health Administration (OSHA) recommends that manual laborers working in temperatures over 80° F consume roughly 1 L of water each hour, for a daily water requirement of 8-12 L.\(^2^2\) Schmidt-Nielsen draws a similar conclusion in his study of human physiology under high-temperature desert conditions. He records human perspiration rates (as noted above, the most important cause of water loss in the desert) of roughly 1 L/hour, producing a daily water requirement of about 12 L.\(^2^3\)

In the face of these conflicting estimates, how may we best proceed to evaluate the water requirements of a Roman legionary? As argued above, we may safely claim that Engels’ and Roth’s 2 L/day figure is far too low for soldiers in hot climates, and probably too low even for troops in cooler conditions. Upon consideration of the available scholarship, 4-8 L/day seems a more adequate estimate, with the actual amount of water required depending on temperature and activity level. In accord with Sidebotham and the more recent U.S. Army Nutrition guide, we may suspect that 4-6 L/day would be enough for legionaries under most circumstances.\(^2^4\) That said, expanding the range up to 8 L (after Junkelmann) includes the water needs of soldiers operating in particularly high temperatures or at particularly high levels of activity.\(^2^5\) In addition, water needs greater than 8 L/day are certainly possible. 4 L/day is a relatively hard “floor”: less

\(^{2^2}\)OSHA (2014).

\(^{2^3}\)Schmidt-Nielsen (1964).


\(^{2^5}\)Junkelmann (1997).
water will not suffice except for inactive troops in cool climes. But legions under the most
grueling conditions of high-temperature combat could certainly surpass the 8 L/day “ceiling.”

Though the bottom half of our 4-8 L/day range was usually sufficient to meet the
legionaries’ water requirements, wise Roman commanders would have “played it safe” and
planned to provision more than 4-6 L of water per day. Ancient generals could not predict the
weather with anything near modern accuracy; on an unseasonably hot day, a commander who
had only provisioned 4 L of water per man could rapidly find himself commanding a parched
and ineffective army. Then as now, a general could not necessarily predict when combat
would occur; he would need to be prepared for the exertion of melee fighting to sharply increase
the water needs of his men. In short, an army’s water supply always needed to be adequate for
exceptional conditions, not for typical ones. Out of necessary caution, Roman generals facing
even the slightest threat of heat or combat would have been prudent to plan to provision at least
6 L if not 8 L/day of water.

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Thus far we have focused on the water requirement of the Roman soldier. However, a
Roman general needed to provision water not only for his men, but also for the sizeable
contingent of animals that accompanied his forces. An imperial legion was typically
accompanied by a contingent of 1,000 mules or donkeys and about 330 horses. The water

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26 The upper ranges of the Roman water requirement are suggested by Engels (1978), whose source in the
Quartermasters Corps gave a water requirement of 10 L/day for desert campaigns. See also, OSHA
(2014); Schmidt-Nielsen (1964); U.S. Army (1961) gives 9.5 L/day as its maximum requirement for
troops in high temperatures.

27 As illustration of this danger, see Plutarch, Ant. 47.

28 Hyland (1990), p. 38. These figures assume a legion travelling without auxiliaries or camp-followers.
On the possibility that Roman armies employed camels as pack-animals, see below, pp. 22-25.
 requirements of these animals dwarfed that of their human masters. Engels reports that equines (whether horse, donkey, or mule) have an average water requirement of 35 L/day.\textsuperscript{29} Roth gives figures of 15-30 L/day for horses and 20 L/day for mules and donkeys.\textsuperscript{30} Similarly, two monographs on the Roman cavalry estimate the water requirement of a Roman horse at between 20 and 30 L/day.\textsuperscript{31} As with human water requirements, these estimates could certainly be inadequate for mounts and pack-animals in hot climates.

If we take these figures at face value, the water requirements of a legion’s animals seem as pressing of those of its men. Although soldiers outnumbered mounts and baggage animals by perhaps five to one, each beast’s water requirement far outstripped human needs. Yet equine physiology may have lightened the burdens animals placed on Roman military water logistics. Despite the high water requirements suggested above, some evidence suggests that horses and pack-animals may have proved quite resistant to dehydration. Anecdotal evidence from the First World War reports that British horses and mules could operate for impressive periods without water: near Darfur, one regiment “marched 90 miles in three nights and two days” without watering its mules. In Gaza, at least one unit “marched and fought for nine consecutive days, during which its horses were only watered three times.”\textsuperscript{32} Schmidt-Nielsen’s experiments on donkeys in desert conditions support these claims, observing that donkeys can work for up to

\textsuperscript{29}Engels (1978), p. 127. This figure, which also appears in Maurice (1930), originates in Army Veterinary Department (1908), p. 129.


\textsuperscript{32}Preston (1921), p. 314.
four days without drinking.\footnote{Schmidt-Nielsen (1964), p. 89. Army Veterinary Department (1908), p. 270 similarly remarks that donkeys and mules are “tolerant of thirst.”} Equine physiology provides some explanation for this remarkable tolerance of thirst: donkeys can withstand dehydration up to 20\% of their body weight without observable adverse effects, and can survive dehydration of up to 30\% of body weight (as opposed to humans, who suffer at less than 10\% and perish starting at 15\%).\footnote{Schmidt-Nielsen (1964), p. 89.}

Equines’ ability to work without water for relatively long periods could have impacted the logistical calculations of Roman commanders. We should by no means assume that generals planned to water their beasts only once every 2-4 days, even though the evidence above suggests this might have been possible. As of yet, we have scanty evidence on how dehydration affected equine performance, and no evidence on whether an infrequent watering schedule was sustainable in the long term. At least one ancient manual on agriculture and veterinary medicine gave advice for treating heat exhaustion and dehydration in overworked horses.\footnote{Varro, 2.1.22-23. Also see McCabe (2007), p. 89.} Yet the resilience of donkeys and mules in particular may have added much needed flexibility to the Roman logistical apparatus in desert campaigns. Roman commanders who needed to cross wide stretches of waterless terrain could load multiple days’ worth of water onto pack-animals, delaying their need to replenish their water supply in the field.\footnote{See below, pp. 21-22.} As I argue below, this tactic was incredibly costly and difficult, requiring the fullest exertion of the Romans’ logistical capacities. Yet carrying water across deserts must have been more manageable if a commander did not need to account for the water requirements of his pack-mules, trusting that the hardy
beasts could survive until the next water source without tapping into the very water-skins they carried.

In and of themselves, the human and equine water requirements presented above may not seem particularly challenging. Even in the desert, a knowledgeable and resourceful human can obtain the 4-8 L of water required to sustain life. Indeed, small groups of farmers and herders did just this in some of the most hostile locales along Rome’s southern frontier. Yet it was the sheer size of a Roman legion that made procuring adequate water in the desert such a daunting logistical challenge. The general of an imperial legion needed to provide water for some 5,000 legionaries, plus any auxiliary troops and noncombatant camp followers. As mentioned above, a single legion also travelled with some 1,330 mules, donkeys, and horses. Using the figures estimated above, a legion in the desert (even without auxiliaries or noncombatants) has a daily water requirement of 51,500-71,500 L/day, with more prudent commanders planning to have supplies of water closer to the higher volume. For the sake of scale, this is equivalent to 55-75 industrial pallets loaded with bottled water, and weighs roughly as much as an American M1 Abrams tank (roughly 65 metric tons). Such a vast quantity of water must have weighed heavily on the mind of any ancient commander; constrained by limited time and ancient technology, how would Roman armies best meet such imposing water requirements?

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37Barker et al. (1996).
39Calculations based on a water requirement of 30 L/day for horses, 20 L/day for mules, and 4-8 L/day for men. Calculations rounded to the nearest 500.
3. The Possibility and Improbability of Transporting Water

In terms of strategic flexibility, the best option was for a Roman army to carry several days’ worth of water with it, thereby removing its dependence on local water sources and operating (at least for a time) independently of the hydro-geographic landscape. Indeed, there is trustworthy textual evidence that on occasion sizeable Roman forces operated in areas without local sources of drinking water. However, such episodes of desert campaigning are ultimately exceptional. Both a preponderance of literary evidence and a quantitative analysis of ancient logistics technology suggest that while a Roman force could transport water over long distances to fulfill particularly crucial missions, it generally operated in near-constant proximity to potable water sources.

A Roman general at war faced the prospect of desert campaigning under two circumstances: either his army needed to march across a desert to reach its objective, or the enemy forced him to fight in a location with little or no available water. Ancient texts recount episodes in which Roman legions operated successfully in both situations. For desert crossings, Roman armies were certainly capable of carrying several days worth of water on the march. According to Sallust, in the late 2nd Century BCE the Roman general Metellus, while pursuing Jugurtha to the desert town of Thala, jettisoned all equipment save food and water from his pack animals and entered the wastes: “although he knew that between Thala and the nearest river lay fifty miles of dry and desolate country, yet in hope of ending the war by getting possession of so
important a town he undertook to surmount all the difficulties and even to defeat Nature herself.”

When Metellus successfully reached Thala, Jugurtha was so overawed that he fled from the city rather than fight a man capable of such a feat. Later, Sallust recounts Marius’ forced march across the Numidian desert to the town of Capsa; like Metellus, Marius ordered his troops to abandon all their equipment and load themselves and their pack-animals with water alone. Ammianus reports a similar desert crossing by the emperor Jovian on the eastern frontier. At the desert city of Hatra, “we learned that on a plain extending for seventy miles through dry regions only water that was salt and ill-smelling could be found…”

Filling water vessels, the Romans crossed the wastes for six days before reaching the city of Ur.

In addition to transporting their own water supplies for desert marches, Roman legions sometimes conscripted their subjects and allies to provide water along their route. Soldiers rushing to the battle of Metaurus in the Second Punic War may well have had their canteens refilled by the grateful citizens along their march. Metellus used just such a strategy in his aforementioned march to Thala: “he ordered all the people who dwelt near by (they had

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40Sallust, Jug. 75: “quamquam inter Thalam flumenque proxumum in spatio milium quinquaginta loca arida atque vasta esse cognoverat, tamen spe patrandi belli, si eius oppidi potitus foret, omnis asperitates supervadere ac naturam etiam vincere aggreditur.” BAtlas (2000), 33 C1 Thala.

41Sallust, Jug. 76.

42Sallust, Jug. 91; BAtlas (2000), 33 C4 Capsa (Iustiniana). Although Sallust reports that Marius ordered that his men and mule’s carry nothing except water, food was presumably transported as well, since Sallust himself reports in section 90 that there would be little chance for foraging on the desolate march to Capsa.

43Ammianus, 25.8.6: “cognito per porrectam planitiem ad usque lapidem septuagensimum in regionibus aridis nec aquam inveniri posse praeter salam at faetidam.” BAtlas (2000), 91 D2 Hatra.

44Ammianus, 25.8.7; BAtlas (2000), 93 C3 Ur(i).

45Livy, 27.45; BAtlas (2000), 42 D1 Metaurus. Though Livy makes no specific reference to water supplies here, locals donated all manner of supplies to the Roman troops, potentially including fresh water.
surrendered to Metellus after the flight of the king) to bring each as much water as he could, naming the day and the place where they were to appear.”⁴⁶ According to Josephus, King Herod provided a similar service to Octavian during his campaigns in Egypt, providing “an abundance of water” for legions on the march near Pelusium.⁴⁷

Whether by their own resources or by outside aid, Roman armies could evidently venture relatively brief desert crossings, operating at a distance from potable water sources for days at a time. Ancient authors also provide a handful of cases in which stationary legions in hostile and waterless areas (typically conducting siege operations) imported water to their positions over long distances. When Caesar was fighting in Alexandria and the Egyptian general Ganymedes rendered his water supplies undrinkable, he reassured his nervous troops that fresh water could be imported by sea: “since they held unfettered command of the sea, while their enemies had no fleet, they could not be prevented from seeking water daily in their ships.”⁴⁸ Pompey relied on similar tactics shortly before the Battle of Dyrrhachium during his civil war against Caesar; when

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⁴⁶Sallust, *Jug.* 75: “Ad hoc finitimis imperat, qui se post regis fugam Metello dederant, quam plurumum quisque aquae portaret; diem locumque, ubi praesto fuerint, praedicit.” Though Sallust is somewhat unclear on this point, it appears that Metellus compelled locals to build a makeshift reservoir several days into his march, establishing a depot to replenish his water supplies.

⁴⁷Josephus, *B.J.*, 1.394-395: “προφυνοσθησαν δὲ καὶ διὰ τῆς ἀνύδρου πορευομένοις μέχρι Πηλουσίου παρασχεὶν ὕδωρ ἀφθόνον ἐπανουσία τε ὁμοίως.” *BAtlas* (2000), 74 H2 Pelusium. According to Herodotus, the Persians employed a similar strategy in Egypt, compelling the inhabitants of Memphis to fill amphorae with water and transport them to the Syrian desert in the north, thereby providing drinking water along the desiccated routes from the Persian core territories into Egypt. Herodotus, 3.6; *BAtlas* (2000), 75 E1 Memphis.

⁴⁸Caesar, *B.Alex.*, 8: “quoniam mare libere tenerent, neque hostes classem haberent, prohiberi sese non posse quo minus cotidie navibus aquam peterent.” *BAtlas* (2000), 74 B2 Alexandria. As it happened, Caesar was able to secure an adequate water supply by digging wells and did not resort to dispatching ships to obtain water.
Cesarean troops prevented his fleet from landing to take on fresh water, “they were obliged to bring up by merchant-ships from Corecyra supplies of wood and water as of other stores…”

Romans and their contemporaries were also capable of importing water by land, though the effort involved must have been prohibitive. When Herod built his eponymous fortress of Herodium on the Arabian frontier, “he had, at immense expense, an abundant supply of water brought into it from a distance.” Roman troops as the siege of Masada, the last major action against the Jewish Rebellion in the first century C.E., faced a similar logistical challenge, “for not only were supplies conveyed from a distance, entailing hard labor for the Jews told off for this duty, but even water had to be brought into the camp, there being no spring in the neighborhood.” Even relying on conscripted labor, this water provisioning strategy must have been prohibitively difficult, a testament to the Roman commitment to crush the last remaining Jewish rebels.

This textual evidence indicates that in urgent situations it was certainly possible for Roman legions to overcome the logistical challenges of water provisioning in desert environments. After all, Ammianus, Caesar, and Josephus are relatively reliable narrators with military experience. Sallust is less so, but even his accounts seem plausible. That said, we should not conclude that the campaigns recounted above were standard practice for the Roman military. Roman commanders in these instances braved the desert in pursuit of crucial


objectives. Metellus crossed the North African desert in a bid to capture Jugurtha and avenge an embarrassing string of Roman defeats.\textsuperscript{52} Caesar considered importing water by sea while battling for Alexandria, jewel of the Nile and the granary of Rome.\textsuperscript{53} And Roman forces besieged waterless Masada in a bid to end five years of catastrophic, intractable rebellion.\textsuperscript{54} These were missions that justified the greatest exertion of the legions’ logistical capabilities. For less important missions, the inefficiency of ancient technology and the strategic risks involved with transporting water supplies in desert areas compelled commanders to stay close to local water sources.

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Above, we estimated the vast water requirements of even a single Roman legion. The transportation resources necessary to carry such a volume of water would have been massive, and the literary descriptions of desert campaigns suggest that the army’s pack-animals would have borne the burden.\textsuperscript{55} How many pack-animals would a Roman general need to load down with water in order to march across waterless tracts of desert? Relying on a mix of modern and ancient evidence, Roth estimates the carrying capacity of a Roman mule at 135 kg and the capacity of a Roman donkey at 100 kg, although both figures would probably decrease on desert marches.\textsuperscript{56} Since each liter of water weighs one kilogram, a mule could carry 135 L of water, a

\textsuperscript{52}Sallust, \textit{Jug.} 75.

\textsuperscript{53}Caesar, \textit{B.Alex.}, 8.

\textsuperscript{54}Josephus, \textit{BJ}, 5.276-279.

\textsuperscript{55}Sallust, \textit{Jug.} 75, 91.

\textsuperscript{56}Roth (1999), pp. 198-208.
donkey could carry 100. For the purposes of this simulation, we will be generous and assume that the Romans were using the more efficient mules.

Suppose that our hypothetical desert crossing is undertaken by only a single imperial legion, travelling without auxiliaries or camp-followers. As described above, this legion consists of some 5,000 men, 1,000 mules, and 330 horses. Its daily water requirement on desert campaign is somewhere between 51,500 L and 71,500 L, depending on temperature and activity level. To clearly demonstrate the calculations involved in estimating the transportation requirements for this legion, let us begin with a very simplified simulation: our imperial legion is operating in a geographically anomalous desert, one which offers adequate supplies of food and fodder but no potable water. Therefore, pack-animals need only transport enough water to sustain the legion for the duration of its crossing.

To transport its water requirement for a single day, our legion would require between roughly 380 and 530 mules loaded solely with water skins. Since the 1,000 mules typically assigned to a legion were already loaded with the army’s other gear, a general would need either to acquire 380-530 extra mules, or to repurpose 380-530 of his own pack-animals by abandoning the fifty- to seventy-thousand kilograms of equipment those mules would otherwise carry. Obviously, multiple days of desert operations would increase the legions’ pack-animal requirement accordingly: a general would require 760-1,060 mules for two days’ water supply, 1,140-1,590 for three, and so on.

Though daunting, these figures could certainly be achieved. Roman generals in the field had few qualms about requisitioning local resources; as long as our theoretical desert campaign

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58Roth (1999), ch. 2.
was launched from a reasonably well-populated area, its commander could potentially acquire the beasts he needed. However, as Engels points out in his study of Macedonian logistics, the math behind transporting consumable supplies is significantly more complicated than the simplified calculations above.\textsuperscript{59} After all, the mules carrying our legion’s water would themselves need to be provisioned with water from the very water skins strapped to their backs. As a result, the actual carrying capacity of a mule decreases the longer it travels away from water. A mule crossing a desert for a single day can deliver 115 L of water (135 L – 20 L drunk along the way).\textsuperscript{60} A mule crossing for two days can deliver just 95 L, and so on.

Since mules drink a portion of their carrying capacity each day they spend away from water, the number of mules (N) necessary to provision an army during a desert march is expressed by the following equation, where D is equal to the number of days the legion spends away from water supplies, W is equal to the total daily water ration of the legion, and M is equal to the daily water requirement of a pack mule:

\[ N = \frac{D \times W}{135 - (D \times M)} \]

Using 60,000 L/day as a moderate figure for the legion’s daily water requirement produces the following equation:

\[ N = \frac{D \times 60,000}{135 - (D \times 20)} \]

The following table represents the relationship between D and N:

\textsuperscript{59}Engels (1978), pp. 18-25.

\textsuperscript{60}On the daily water requirements for mules, see above, pp. 9-11.
Table 1: Mules Required for Water Transport in Desert Operations

<table>
<thead>
<tr>
<th>Duration of Desert Operations in Days (D)</th>
<th>Number of Mules Required (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>521</td>
</tr>
<tr>
<td>2</td>
<td>1,263</td>
</tr>
<tr>
<td>3</td>
<td>2,400</td>
</tr>
<tr>
<td>4</td>
<td>4,364</td>
</tr>
<tr>
<td>5</td>
<td>8,571</td>
</tr>
<tr>
<td>6</td>
<td>24,000</td>
</tr>
<tr>
<td>7</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>

These numbers begin to indicate the scale of the logistical challenge posed by desert operations, particularly for longer campaigns. Thanks to the exponential growth in N, even two-day desert crossings presented significant difficulties, while longer treks rapidly became prohibitive. Moreover, according to this simulation it was physically impossible for a Roman legion to operate for more than six days without somehow replenishing its water supplies; after roughly six days and 18 hours in the desert, each pack-mule would have consumed all 135 liters of water it set out with.

Moreover, it must be remembered that the numbers presented in Table 1 represent the requirements of a march through a very strange desert, one which provides adequate food and fodder but no potable water. Suppose that our legion ventures into more realistic terrain, a desert that offers neither water nor adequate supplies of food and fodder. The legion’s 5,000 soldiers could perhaps carry their own food requirements as prepared biscuit rations. However, mules would be required to carry sufficient fodder for themselves and the 330 cavalry mounts (horses

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61This formula and calculations based on Engels (1978), p. 22.

62Roth (1999), pp. 43, 51-53. Roth estimates a daily biscuit ration at .57 kg, providing 1,950 calories. Unsupplemented, this provides significantly less than the 3,000 calories required daily by a Roman legionary (Roth, p. 12), but could perhaps have sustained operations for short periods of time.
require 9.5 kg of fodder per day, while mules require roughly 7.5 kg of fodder per day). For this more complex (but more accurate) simulation, we can recalculate the required number of pack-animals through a modified version of the previous formula, where D is the number of days spent in desert operations, W is the daily water requirement for the legion’s men and animals, F is the fodder requirement for 200 cavalry mounts and the 1,000 mules already loaded with the legion’s equipment, $M_w$ is the daily water requirement of a mule, and $M_f$ is the daily fodder requirement of a mule:

$$N = \frac{D \times (W + F)}{135 - (D \times (M_w + M_f))}$$

Substituting in the correct figures (again using 60,000 L/day as the legion’s water requirement) produces the following formula:

$$N = \frac{D \times (60,000 + 10,635)}{135 - (D \times (20 + 7.5))}$$

The following table provides a more realistic calculation of the number of mules our legion would require for a desert campaign:

<table>
<thead>
<tr>
<th>Duration of Desert Operations in Days (D)</th>
<th>Number of Mules Required (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>657</td>
</tr>
<tr>
<td>2</td>
<td>1,766</td>
</tr>
<tr>
<td>3</td>
<td>4,036</td>
</tr>
<tr>
<td>4</td>
<td>11,301</td>
</tr>
<tr>
<td>5</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>

These figures are significantly more imposing. Desert campaigning for more than four days becomes impossible; Jovian’s water supplies during the six-day crossing from Hatra to Ur

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63These figures are admittedly problematic. Roth is very hesitant to estimate animal rations even when grazing is available. Roth (1999), pp. 62-67.

64As above, this formula and calculations based on Engels (1978), p. 22.
(see above, p. 14) must have been supplemented by scattered wellsprings or local assistance.\textsuperscript{65} Any desert march longer than one day would surpass the carrying capacity of our legion’s standard contingent of mules. Even a single day of desert operations would require two thirds of the legion’s mules, requiring the commander to abandon vast quantities of materiel. The figures produced by this simulation suggest that transporting water for desert campaigns was not merely a daunting prospect, but a prohibitive one.

That said, the ability of horses and mules to work without water for several days at a time (tenuously suggested above, pp. 9-10) would potentially have made it much easier for Roman generals to transport water for their troops. Leaving out animal water needs, the legion’s 5,000 men need between 20,000 and 40,000 L of water per day. As such, one day’s supply of water could be carried by roughly 150-300 mules, two days’ supply could be carried by 300-600, and so on. These figures certainly look more attainable; a commander willing to temporarily dehydrate his animals could campaign with more freedom in desert environments. Yet as I suggested above, we should be very cautious before suggesting that such a policy of deliberate dehydration was a matter of general practice. First, this tactic could only be used for perhaps two days, four at the most.\textsuperscript{66} Second, repeatedly pushing animals up to their physiological breaking point could hardly be sustainable over the long term. Would a Roman general be willing to risk the health and productivity of his animals for a couple days of desert operations? In general, we may safely assume that he would not. Again, the difference between crucial missions and routine missions is key. Metellus or Marius may have tolerated the dehydration of

\textsuperscript{65}Ammianus, 25.8.6-7.

their pack-mules in their exceptional cross-desert marches.\textsuperscript{67} Under more typical circumstances, such a risky strategy would probably have been avoided.

Though Roman commanders would be loath to intentionally dehydrate their pack-animals, some might have struck upon an alternative method of water-transportation better suited to desert campaigning: camels. Camels can survive on far less water than equines; even in high temperatures, camels can easily go without water for more than a week provided there is adequate grazing, and there are some reports of camels surviving 16 days of waterless marching.\textsuperscript{68} Even if grazing is impossible (bearing in mind that camels can consume desert plants inedible to equines), camels can work for 5-7 days without needing to drink.\textsuperscript{69} Moreover, camels can bear heavier loads than mules and donkeys, carrying roughly 250 kg compared to the mule’s 135.\textsuperscript{70} For these reasons and more, the use of camels as desert pack-animals had obvious advantages.\textsuperscript{71}

The Romans would certainly have encountered domesticated camels along the arid fringes of their empire.\textsuperscript{72} And in several cases, Roman generals employed these dromedaries as pack animals in order to survive long marches across the desert. Corbulo used pack-camels in his campaign against the Parthians, while Jovian used the same tactic while returning from defeat.

\textsuperscript{67}Sallust, \textit{Jug.} 75, 91.
\textsuperscript{68}Gauthier-Pilters and Dagg (1981), p. 53.
\textsuperscript{69}Irwin (2010), p. 19.
\textsuperscript{70}Irwin (2010), p. 24; Zimmerle (2012). Irwin estimates 273 kg, Zimmerle estimates 240. Both estimates are for the one-humped dromedary camels that the Romans would have encountered. Bactrian camels, which dwell further east, could carry significantly more.
\textsuperscript{71}For a more complete list of the camel’s virtues on a desert campaign, see Carbuccia (1853), pp. 12-13.
\textsuperscript{72}Bulliet (1975), ch. 1, 4-5; Irwin (2010), ch. 6; Toplyn (2006); Wilson (1984); Zimmerle (2012).
in Persia.\(^73\) According to Ammianus, the notorious Romanus demanded 4,000 camels from the citizens of Lepcis Magna, presumably for use in desert campaigning.\(^74\) The notoriously unreliable *Historia Augusta* provides a third account of Roman pack-camels, claiming that Alexander Severus employed them in the early 3\(^{rd}\) century.\(^75\) In each case, the camels’ prodigious ability to work without water must have significantly eased the burdens of water logistics.

One last set of calculations suggests just how useful camels would have been. Supposing that a legion replaced its entire contingent of pack-mules with camels, its daily water requirement would drop to between 30,000 and 50,000 L.\(^76\) This daily water ration could be carried by between 120 and 200 camels. Moreover, because camels can survive without drinking from their own water-skins, the number of pack-camels required for multi-day desert crossings scales linearly, rather than exponentially. 240-400 camels can carry two days’ worth of water, 360-600 can carry three, and so on. Though these are not insignificant totals, they appear far more manageable than the logistical requirements of an army using pack-mules.

Despite their evident strengths, the Romans do not seem to have made camels their default beasts of burden for desert campaigns. With the exception of the four passages cited above, I have found no literary evidence that the Roman military used camels as pack-animals. Even the passages that mention this practice suggest its rarity: on Corbulo’s campaign, Tacitus writes, “Accompanying the army—apart from the usual war apparatus—was a large number of

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\(^73\)Ammianus, 25.8; Tacitus, *Ann.* 15.12.

\(^74\)Ammianus, 28.6.

\(^75\)HA *Alexander Severus*, 47.

\(^76\)This total based on 5,000 men consuming 4-8 L/day, and 330 horses consuming 30 L/day. For simplicity’s sake, I have left out the 3,135 kg of fodder which the legion’s 330 horses would also require.
camels laden with grain, so Corbulo could ward off both hunger and the enemy."\textsuperscript{77} Clearly, in Tacitus’ experience camels were not standard issue for the Roman baggage train. Similarly, both Ammianus and the \textit{Historia Augusta} indicate that camels were used to supplement, not replace, traditional equine pack-animals.\textsuperscript{78} Even in situations where camels might have been more effective, pack-mules held on to their customary position in the Roman army—the men responsible for baggage trains took the title \textit{muliones}, and "Mules were the most esteemed transport animals of the roman army."\textsuperscript{79} Camels may certainly have been employed more frequently by detachments of auxiliaries, who were more familiar with its use—Trajan and Hadrian evidently established auxiliary camel-cavalry units in Syria and Egypt.\textsuperscript{80} Yet in the large, legionary armies which waged the empire’s major wars, pack-camels appear to have been rare.

It is impossible to say for certain why the Romans did not make more frequent use of camels. The high purchase price of dromedaries may have played a role; papyri from Egypt suggest that a camels cost twice as much as mules, if not more.\textsuperscript{81} Institutional inertia may also have dissuaded innovation. An army that had soldiers experienced in handling mules, that had systems in place to procure and care for mules, and that by long tradition had grown accustomed to mules in its baggage train was not likely to adopt pack-camels except in situations of direst need. Whatever the reason, camels were rarely the Romans’ preferred baggage animal. In the

\textsuperscript{77}Tacitus, \textit{Ann.} 15.12. “comitabantur exercitum praeter alia sueta bello magna vis camelorum onusta frumenti ut simul hostem famemque depelleret.” Translation is from Yardley’s 2008 Oxford World Classics edition, not from the badly archaic Loeb. Emphasis is my own.

\textsuperscript{78}Ammianus, 25.8; \textit{HA Alexander Severus}, 47.


\textsuperscript{81}Johnson (1936), pp. 230-232.
absence of specific evidence, we cannot be certain that any given desert campaign did not employ camels. At the same time, however, we should not imagine that the use of pack-camels was widespread, and that Roman armies could easily launch desert campaigns as a result. The Romans remained firmly bound by pre-industrial limits on the transportation of water, and shied away from all but the most critical desert campaigns as a result.

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This reconstruction of the harsh quantitative limits on ancient water transportation is reinforced by an array of textual evidence suggesting that Roman commanders avoided desert warfare even to the detriment of their military objectives. In a number of cases, generals retreated rather than risk water shortages. Faced with the threat of thirst during his North African campaigns, the normally decisive Julius Caesar was vacillating and ineffectual. Contemplating a siege of Thysdra in 46 BCE, “Caesar studied the characteristics of the town, and the lack of water discouraged him from attacking it: he then set out forthwith and pitched a camp some four miles away near water, only to quit it at the fourth watch.” Shortly thereafter, he retreated again despite the jeers of his foes: “realizing that it was equally impossible for him to pitch his own camp closer to the enemy owing to the poor supply of water, and perceiving that his opponents…were led to hold him in contempt by their reliance on the dearth of water, Caesar left Aggar on April 4th at the third watch.”

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83 Caesar, B.Afr., 79: “neque ipsus hostem castra ponere propter aquae penuriam se posse animadvertebat, adversarios non virtute eorum confidere sed aquarum inopia fretos despicere se intellexit, II Non. Apr. tertia vigilia egressus ab Aggar XVI milia nocte.” BAtlas (2000), 33 G1 Aggar?
Other passages describe certain towns as inaccessible to Roman troops due to a lack of water in their surrounding hinterlands. In Spain, Ursao was thoroughly isolated from military incursions: “apart from a single fountain in the town itself, there was no water to be found anywhere in the neighborhood under eight miles from the town; and this was a great advantage to the townsfolk.”\textsuperscript{84} The town of Singara on Rome’s eastern frontier was similarly inaccessible thanks to its waterless surroundings, though Ammianus reports that this isolation worked against the beleaguered townsfolk, since “even in former days no one had ever been able to aid Singara when in trouble, since all the surrounding country was dried up from lack of water.”\textsuperscript{85} If desert operations were commonplace, Caesar and Ammianus (two of our more strategically knowledgeable authors) would hardly have considered Ursao and Singara beyond the reach of Roman legions.

The evidence above directly testifies to legionary commanders’ refusal to launch desert campaigns. It is obliquely supplemented by a wide variety of sources indicating the care that Roman commanders took to ensure their water supplies, and the likelihood that generals would not readily run the risk of desert operations. The threat of thirst motivated several maneuvers during Caesar’s civil wars: in North Africa, Scipio was forced to give battle when Caesar’s troops threatened the town of Uzitta, “on which [Scipio’s] army had been accustomed to rely for its water supply and all other means of support.”\textsuperscript{86} Three centuries later in a speech reported by

\textsuperscript{84}Caesar, \textit{B.Hisp.}, 41: “Huc accedebat ut aqua praeter quam in ipso oppido unam circumcirca nusquam reperiretur propius milia passuum VIII; quae res magno erat adiumento oppidanis.” \textit{BAtlas} (2000), 27 A4 Urgao/Vircao.


Ammianus, the Emperor Julian tried to temper his troops’ bloodlust just before his victory at Strasburg, worrying that thirst would handicap their performance: “the country is fairly ablaze with heat and relieved by no supply of water....What strength can we have, when our limbs are enfeebled with hunger, thirst, and toil, to offer resistance?n87

Commanders would rush or delay battle to secure their water supplies. They would forego military goals for fear of thirst. While so clearly aware of the importance of water provisioning, would they blithely undertake desert campaigns for anything less than the most crucial objectives? The answer must be no. A Roman general would have thought long and hard before leaving riverbanks or oases, weighing the cost and risk of desert campaigns. Except in the rare cases when the desert promised exceptional rewards, Roman legions stuck close to water sources, replenishing their water stores at least once a day, and desert campaigns remained a logistical possibility only rarely undertaken.

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4. Water “Foraging” and Local Water Sources

Since transporting water was not a strategy the Romans were generally willing to undertake, under normal circumstances the empire’s troops could only operate in areas with local water sources adequate to meet their needs. Before we attempt to locate such sites on a map, it is necessary to examine what types of water sources were actually available to a Roman army.

A thoroughly deficient literary record limits our understanding of what water sources legionaries could exploit. Ancient accounts of the Roman military understandably prefer narratives of cunning generalship and glorious combat to the humdrum technicalities of routine water provisioning. The few descriptions of water logistics we possess tend to discuss exceptional cases, episodes in which remarkable Roman military ingenuity, “undertook even to defeat Nature herself.” Nevertheless, ancient literature is littered with scattered evidence for more routine water provisioning. The utility of this evidence is undeniably limited. It cannot say how any particular force gathered water at any particular location during any particular campaign. What this evidence can do, however, is lay out a set of preferences and possibilities. It suggests a general practice of Roman water supply, what most legions and their commanders

88Sallust, Jug. 75. See above, p. 13.

89A large number of these references do not mention what type of water source troops were exploiting. Nevertheless, these reports stress that in situ water gathering was a quotidian practice for the Roman army, and support the argument of this paper that areas without local water sources were generally inaccessible to Roman forces: Caesar, B.Afr., 24; B.Civ., 1.66, 73; B.Hisp., 21; Cassius Dio, 65.4; Frontinus, Strat., 1.8.9, 3.9.3; Josephus, B.J., 3.85-86; Plutarch, Sert., 7.3; Polybius, 6.27.3; Sallust, Jug., 93.
would choose to do under most circumstances. More importantly, this evidence illuminates the physical and physiological limits to the possibilities of Roman warfare: the *in situ* availability of drinking water was a critical factor in determining where a Roman army could campaign without incurring the heavy costs and risks of water transport.

As a general rule, Roman legions preferred water sources that were flowing and aboveground, namely rivers (and smaller watercourses) and naturally occurring springs. In Polybius’ account of the First Punic War, a giant serpent attacks Roman soldiers gathering water at an African river.\textsuperscript{90} Less colorful sources on the late Republic show Metellus securing a riverine water supply during the Jugurthine wars, Crassus’ army watering at a stream in Parthia, and Pompey’s forces seeking river water in Asia Minor.\textsuperscript{91} Finally, Trajan’s Column contains an image of a legionary filling a vessel with water at a riverbank; in what may well have been a standard practice, the soldier kneels upon wooden planks laid down at the bank to keep his boots from stirring up mud.\textsuperscript{92}

Accounts of legions collecting spring-water are somewhat more rare than mentions of rivers, though not by enough to imply that legionaries definitely preferred one to the other. Nero’s general Corbulo, while fortifying the banks of the Euphrates, took care to secure local springs in order to both provision his forces and deny water to the enemy.\textsuperscript{93} Later in the first century during the siege of Jerusalem, the future emperor Titus relied on springs surrounding the

\textsuperscript{90}Polybius, 4.12.

\textsuperscript{91}Respectively: Sallust, *Jug.* 50; Plutarch, *Crass.*, 23.4-5; Caesar, *B.Civ.* 3.66.

\textsuperscript{92}Webster (1985), p. 169. The image can also be viewed online via the Cheiron Project at McMaster University (cheiron.mcmaster.ca/~trajan), Scene 107.

\textsuperscript{93}Tacitus, *Ann.* 15.3.
city; Josephus reports that these normally temperamental water-sources flowed particularly strongly due to Titus’ abiding good fortune.  

The advantages of flowing surface-water, whether from watercourses or springs, are self-evident. These sources provide high volumes of water and require minimal labor on the part of the water-gatherer. Unlike wells, rivers and spring-fed oases can be accessed by many people and animals simultaneously, allowing water to be gathered quite efficiently. As I discuss below, gathering water for any sizeable force was a time-consuming chore, but the local availability of aboveground water made this task relatively manageable. For this reason, Hyginus’ military manual recommends that commanders locate their nightly camps near a spring or river.

Though rivers and springs were evidently the legions’ preferred water source, they were not without their drawbacks. Not all rivers and springs are potable, and a Roman army operating in foreign territory would not necessarily know the quality of a given water source until it was too late. Thus Marc Antony suffered grievous casualties in his Parthian campaign when his troops, parched from a long and waterless march, found that the desperately needed river at the end of their journey was poisonous. In addition, since rivers and streams lie aboveground, they were easy for an enemy to poison. Jugurtha contaminated springs in Metellus’ path during Rome’s second century BCE wars in North Africa, and African locals used a similar tactic some

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95 The labor involved in scooping drinking water into vessels was certainly not negligible, but paled in comparison to digging wells or transporting water over long distances (see below, pp. 31-33).

96 Pseudo-Hyginus, 57. The authorship of this manual is uncertain, and it is ascribed here to Hyginus by convention only.

97 Plutarch, Ant., 47.
years later against Caesarean forces in the civil wars.98 A general with greater ambition (and more skilled engineers) could reroute watercourses entirely. Julius Caesar most famously employed this tactic shortly before the Battle of Dyrrhachium. As he himself recounts, “all the streams and all the rivulets which ran to the sea Caesar had either diverted or blocked by great works; and as the district was hilly and rugged he had damned the narrow defiles by sinking piles into the ground and heaping up the earth, so as to keep in the water.”99

Despite their vulnerability to enemy action, flowing surface water remained the Romans’ primary source of drinking water. What then of wells? More flexible in their location, wells tapped reserves of groundwater which were nearly impossible for an enemy to pollute or disrupt. We could reasonably expect them to play a significant role in Roman water logistics. However, literary evidence suggests that the legions avoided well-digging if at all possible.

To be sure, our sources indicate that the Roman army was technically capable of provisioning water by digging wells. According to Caesar’s own account of the civil wars, Pompey sunk numerous wells as the two opponents jockeyed for position before the Battle of Dyrrhachium.100 Plutarch writes that Pompey used a similar tactic during the Mithridatic Wars, while Caesar evidently used wells on campaign in Alexandria and Africa.101 Finally, both Livy

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98Sallust, *Jug.*, 55; Appian, *B.Civ.* 2.7.44.


100Caesar, *B.Civ.*, 3.49.

101Plutarch, *Pomp.*, 32.2; Caesar, *B.Alex.*, 8-9; *B.Afr.*, 51. The Alexandrian and African Wars, along with Caesar’s commentary on the wars in Spain, are generally regarded as pseudonymous.
and Plutarch report that Aemilius Paulus sunk wells to assuage his troops’ thirst during the Republic’s wars against Perseus.\textsuperscript{102}

Although such evidence indicates that well digging was a possible method of water-provisioning in Roman warfare, we may be quite certain that it was not the legions’ preferred option. Indeed, Caesar’s commentary on Dyrrhachium (first discussed above) notes that Pompey turned to wells only because Caesar’s troops had diverted or dammed the streams flowing to his position, and that the labor of well-digging strained the Pompeians’ endurance.\textsuperscript{103} Appian comes to a similar conclusion on the undesirability of wells in his own history of the civil wars. Narrating Antony’s campaign against the Republicans, he contrasts Cassius and Brutus’ outstanding campsite with Antony’s poor situation: “the former were on elevated ground, the latter on the plain; the former procured fuel from the mountains, the latter from the marshes; the former obtained water from a river, the latter from wells freshly dug.”\textsuperscript{104} Evidently, wells were the legion’s water-source of last resort, not of choice.

Ancient sources never explicitly explain why the legions preferred not to utilize well water, but we may hazard some reasonable guesses. The quality of well water could be suspect, particularly since troops digging a shaft for one night’s use could hardly be expected to properly line it with wood or stone so as not to muddy its water.\textsuperscript{105} Compared with rivers or springs, wells provide a small volume of water at a low rate of speed: little over 15 L/minute according to

\textsuperscript{102}Livy, 44.33; Plutarch, \textit{Paul.}, 14.1.

\textsuperscript{103}Caesar, \textit{B.Civ.}, 3.49.

\textsuperscript{104}Appian, \textit{B.Civ.}, 4,107; Gilliver (1999), p. 71.

\textsuperscript{105}On poor quality well water, see Appian, \textit{B.Pun.} 7.40. The “villainous” (\textit{deterimma}) water in Horace (\textit{Satires}, 1.5.7-9) probably also came from local wells. It should be noted that Pliny praises the quality of well water (\textit{NH}, 31.38-39). On lining wells, Vitruvius, \textit{De Arch.}, 8.6.12-15; Humphrey, Oleson, and Sherwood (1998), ch. 8; Wikander (2000), I.3.
modern estimates.\textsuperscript{106} Most importantly, well digging was labor intensive; note the fatigue of Pompey’s diggers at Dyrrhachium.\textsuperscript{107} Encamping at the end of a day’s march, legionaries already bore the burdens of foraging, food-preparation, maintenance of weapons and armor, and the fortification of the camp itself. Added to this list, the labor of well-digging would have been onerous.

The strenuous effort of well-digging limited the areas in which armies could feasibly sink wells. To conserve time and labor, wells could be dug only in spots with extremely shallow water tables. For a temporary well built under the time constraints of the campaign, a water table even a couple meters deep would have been out of the legions’ reach: according to Peace Corps training manuals, an experienced team of laborers using hand tools alone can sink only one meter of well-shaft in a day’s work.\textsuperscript{108} Determining where water could be struck at such a shallow depth strained the capacities of ancient science.\textsuperscript{109} Indeed, both Aemilius Paulus and Pompey are praised for their ability to “read” the landscape and locate sites where wells could easily hit water.\textsuperscript{110} We should not assume that the typical Roman commander was so skilled (or so lucky); in many areas well-digging would have proved both laborious and fruitless.

For all the reasons above, Roman commanders preferred not to dig wells on campaign.

But what of preexisting wells, already constructed by the local population? What, for that

\textsuperscript{106} Olley (2008), p. 6. See also, Wikander (2000), I.3. For a modern example of wells’ limited rates of water extraction hampering military logistics, see Preston (1921): during WWI in Syria, Preston’s mounted infantry unit did not have sufficient time to water all of its mounts at wells.

\textsuperscript{107} Caesar, \textit{B.Civ.}, 3.49.

\textsuperscript{108} Brush (1980), p. 15.

\textsuperscript{109} On water divining, Vitruvius, \textit{De Arch.}, 8.1; Cassiodorus, \textit{Letters}, 3.53.

\textsuperscript{110} Pompey: Plutarch, \textit{Pomp.}, 32.2 Aemilius Paulus: Livy, 44.33; Plutarch, \textit{Paul.}, 14.1.
matter, of other pre-constructed water architecture, such as cisterns and aqueducts? Surely a Roman general would consider these already extant water sources when planning his campaign.

The answer to this question is a resounding “maybe.” There is some ancient literary evidence suggesting the legions’ use of pre-dug wells; the Garamantes of North Africa certainly felt it necessary to conceal or collapse well shafts as the Romans advanced on their desert homeland.\textsuperscript{111} Comparanda and common sense certainly suggest that the Romans would use local wells when they were available.\textsuperscript{112} Yet while relying on preexisting wells freed the legionaries from the labor of digging, other issues with wells would have persisted. Except at artisanal wells (where underground pressure forces water above ground), time and labor were still required to lift water from the water table to the surface; by modern estimates a human using a rope and pulley system can extract only 10-15 L of water per minute from a 10 m well.\textsuperscript{113} At this rate, a well could certainly provision a small squad, but extracting the water requirement of a full legion would be laborious indeed, and extracting the water requirement of that legion’s mounts and pack-animals would be nearly impossible. Large clusters of wells, such as might be found in the desert at oasis centers, could perhaps suffice: a field of 20 wells can meet the water requirements of a legion in about 3 hours at minimum.\textsuperscript{114} Yet most desert communities were quite small and had no need for so many wells. In addition, as was the case with finding suitable locations to dig wells, finding pre-built wells would require either a detailed knowledge of local geography or

\textsuperscript{111}Pliny, \textit{NH}, 5.5.35; Appian, \textit{B.Civ.}, 2.7.44 may also refer to Roman use of local wells.

\textsuperscript{112}Maurice (1930), p. 221. On the British campaign at Gaza-Beersheba during World War I, “the future success of the operation hung upon finding the wells of Beersheba intact, as fortunately they were.”

\textsuperscript{113}Olley (2008), p. 6. Wells in the ancient world were typically 3-25 m deep: Wikander (1999), 1.3.

\textsuperscript{114}Assuming 20 wells producing water at 15 L/minute, along with our lower estimate of a legion’s water requirement at 51,500 L/day.
skilled and trustworthy guides (and we know of several cases in which local guides proved less than reliable).\footnote{Cassius Dio, 37.3; Strabo, 16.4.24.} Finally, pre-built wells were quite easy for an enemy to disrupt, whether by poison, pollution, or outright destruction (as in the case of the Garamantes above). As a result, a general who trusted his water supply to the availability of pre-dug wells courted disaster.

Cisterns and aqueducts (along with other methods of channeling and storing water for irrigation or human consumption) provide a thornier problem. Legionaries waging urban warfare certainly might make use of the monumental water features so typical in Roman cities; Caesar’s men drew water from the aqueducts, cisterns, and fountains of Alexandria during their combat there against Ganymede.\footnote{Caesar, \textit{B.Alex.}, 5.} However, urban water systems were subject to tampering, as Caesar’s troops learned when Ganymede diverted seawater into the network of Alexandrian conduits.\footnote{Caesar, \textit{B.Alex.}, 6.} Moreover, large scale water systems were unavailable outside of major cities, and so could not generally supply Roman troops in the field.

Cisterns, however, existed even in small settlements, particularly in desert environments where water was particularly precious.\footnote{Barker (1996), v.1, p. 10; Evenari (1982), ch. 9-10; Mattingly (1994), pp. 148, 157; Wikkander (1999), I.2.} Roman armies could potentially make use of the water from village cisterns while on campaign, although there is no mention in ancient literature of them doing so. At capacity, even the cisterns for tiny settlements could meet the legion’s needs; rainfall in the desert is generally unpredictable and torrential, and locals built large reservoirs and extensive catchment systems to stockpile water against future droughts. Ancient cisterns along the desert coast of Syrtica (the large gulf in the center of the modern Libyan coast) typically had
capacities between 40,000 and 200,000 liters. In the Tripolitanian desert fringe just to the west, several noteworthy cisterns have measured capacities of 90,000-165,000 L. Even in the comparatively well-watered hills of central Tunisia, where massive cisterns were less necessary, capacities ranged from 10,000-100,000 L.

Based on these figures, we might certainly suspect that cisterns could provision adequate water supplies to sizeable Roman armies, particularly in villages with several cisterns. Yet several caveats are in order. First, depending on their design, drawing water from cisterns may have required time and labor comparable to extracting water from wells. Unlike the banks of a river or a spring-fed pool, only a few men could physically access a cistern at any one time, and the cramped confines of a typical village cistern hardly lent themselves to the efficient filling of canteens. In addition, cisterns were frequently the only water source for desert settlements, where water collected from a single torrential rainstorm might need to provide for the local inhabitants and their livestock for an entire year. If a Roman army of hundreds or thousands drew water from cisterns meant for dozens, they could fatally deplete the community’s water stores. In hostile territory beyond the empire’s borders, a commander might see this as an added benefit, warfare by dehydration. Within the bounds of Roman rule or among friendly neighbors, a conscientious or diplomatic commander might weigh the logistical availability of cistern water against the strategic consequences of embittering and endangering local

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123 Similarly, Roman generals plundered the food supplies of hostile populations not only to meet the needs of their soldiers, but to compel the starving enemy to give battle or surrender. Roth (1999), ch. 3.
populations. Finally, a general who put his faith in cisterns risked disaster if those cisterns were depleted by unexpected drought; when planning a campaign, a commander could never count on any particular cistern being full enough to provision sufficient water for his thirsty troops.

In summary, the list of water sources available to Roman armies was rather bleak. Rivers and springs were certainly the best sources available to ancient commanders. Where these were abundant, adequate water supplies would have been generally easy to secure, and the geographic availability of water would not severely limit the possibilities of Roman warfare. Where rivers and springs were scarce, as they were in the deserts along Rome’s southern and eastern borders, commanders had no other good options. Even in areas where the water table lay within the reach of ancient technology, forces on the march could not dig wells quickly enough to meet their needs. Pre-existing wells and cisterns would suffice for small squads, but a host of problems made them a risky proposition for even a single legion. As a result, Roman armies must have been severely limited by their reliance on rivers and springs; unable to carry water and only tentatively able to exploit water already tapped by human construction, the Romans could campaign flexibly and comfortably only in areas where water was well provisioned by nature.
5. Tripolitania, Water Logistics, and Strategic Limitations

To this point, this thesis has demonstrated the theoretical limits which water logistics imposed on ancient Roman legions. The daunting water requirements of large armies combined with the shortfalls of ancient technology indicate that Roman armies in arid regions would have been severely curtailed in where they could go and what they could accomplish. It remains to apply the theoretical model of Roman military water logistics outlined above to a specific landscape, exploring how Roman commanders might have been constrained by the hydro-geography of an actual desert. For this purpose, Tripolitania (Map 1) will serve as a suitable case study.\(^\text{124}\)

Although Tripolitania was administered as part of Africa Proconsularis until the reforms of Diocletian, it comprised a distinct geographic entity. To the east, the rugged Gebel hills divided Tripolitania from Africa proper; most travel between the region and the urbanized heartland of the former Carthaginian empire was forced to pass through the narrow coastal plain south of Tacape. The same highlands hampered traffic to the south, where hundreds of kilometers of wastes stood between Roman Tripolitania and the densely populated Garamantian oases. And to the east, the vast expanse of the Syritic gulf separated Tripolitania from the major coastal cities of Cyrenaica. Our area of GIS inquiry roughly corresponds with these geographic lines of demarcation, running roughly from Tacape (10°E) to the center of the Syrtic Gulf (17°E), and from the Mediterranean coast to the southernmost Garamantian oases (25°N).

\(^{124}\)BAtlas (2000), 35.
Though this southern boundary pushes well past the inland limits of Roman control, it allows us to examine the logistical problems of imperial campaigns into hostile territory, which played a crucial deterrent role in the security of the “Roman” coast.

Rome’s most important military objective in this area was to defend the major towns on the Tripolitanian coast, most notably Sabratha, Oea, and Lepcis Magna (the τρεις πόλεις from which the region takes its name). Originally Punic settlements, after the conquest of Tripolitania in the 1st century BCE these cities rapidly became the focal points of imperial presence and interest. Politically connected, economically important, and thoroughly Romanized, they were natural priorities for the imperial army. Properly defending the coastal cities required the army to expand both its territorial and hegemonic control inland. Tribes near the coast fell under direct Roman control, and were annexed into the province of Africa Proconsularis. Further into the desert, punitive raids and diplomatic missions checked any native threat to the valuable urban areas to the north.125

The physical geography of Tripolitania tested the Roman military’s capacity to complete its defensive mission. As Map 2 demonstrates, Tripolitania is an arid place; even the comparatively rainy stretch of coast between Oea (modern Tripoli) and Lepcis Magna (near modern Homs) receives on average only 300 mm of annual precipitation. The terrain turns to pre-desert on fringes of the Sahara at most 100 km to the south, where the 200 mm isohyet marks the boundary beyond which cereals cannot be produced on any scale without intensive irrigation.126 To be sure, sparse rainfall did not directly impact the water logistics of Roman armies. Troops would rely on collected rainwater only in exceptional situations, and a general

125 Barker (1996); Mattingly (1994).

126 For comparison, 200 mm of rainfall is roughly equivalent to the average precipitation of Phoenix, Arizona.
could never plan for such an occurrence.\textsuperscript{127} However, scarce and erratic rainfall was largely responsible for the lack of any perennial Tripolitanian watercourses; the wadi valleys carved through the region’s landscape fill with water only after sudden downpours. As a result, Roman commanders in Tripolitania did not have access to one of their two preferred water sources. Unable to rely on rivers or streams to meet their water needs, they were limited to the few oases and springs scattered throughout the parched landscape.

Moreover, the military dynamics of the Tripolitanian frontier required the Romans to engage in a particularly mobile form of campaigning, one that was particularly limited by the scarcity of local water sources. At least until the reign of Septimius Severus, Tripolitania possessed only a very small Roman garrison and few permanent defensive fortifications.\textsuperscript{128} Even after Severus strengthened the frontier south of his hometown of Lepcis, Roman military strength in Tripolitania never reached the levels achieved in Britain, Germany, or Syria. Imperial security on such a sparsely manned and fortified frontier depended to a great degree on the ability of Roman units to move flexibly over long distances in order to meet foreign and domestic threats. As we will see, reconstructing the hydro-geography of Tripolitania suggests that water logistics greatly hampered such rapid-response campaigns, and hindered the Roman’s ability to wield military force within the region.

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To what extent can we accurately map the water sources that would have been available to Roman troops in Tripolitania? Such a task is obviously a difficult one, and two

\textsuperscript{127} Such exceptional occurrences instances may be nothing more than literary tropes meant to demonstrate a commander’s luck or divine favor. See Herod’s good fortune at Masada (Josephus, \textit{BJ}, 1.286-287), Marcus Aurelius’ “rain miracle” against the Quadi (Coarelli (2008), pp. 51, 140-142; Cassius Dio, 71.10), and Alexander’s divine protection on his desert march to Siwah (Engels (1978), p. 52).

\textsuperscript{128} Barker (1996), pp. 112-116, 324-325; Mattingly (1994), ch. 4, 5.
methodological questions immediately arise. First, can we assume that the amount of water available in Roman Tripolitania was comparable to the amount of water available today? Some scholars have certainly suggested that the climate of the ancient Mediterranean was significantly more humid than the modern climate: Claudio Vita-Finzi’s work in the 1960s on geomorphology remains foundational to this argument.\textsuperscript{129} However, extensive data collected as part of the UNESCO Libyan Valley Survey (ULVS) strongly reject it.\textsuperscript{130} On these grounds, we may safely say that fresh water sources were not more widely available in the Roman period than they are today, and that modern GIS data should provide us with roughly the correct number of oases, springs, and other water sites.

A second question: would ancient water sources necessarily be in the same locations as water sources today? This question is difficult to answer decisively, but we may be tentatively confident that our GIS data roughly corresponds in location with water sources that would have been available to the ancient Romans. This is particularly true for Tripolitania, where fresh water sources are limited to springs and oases due to the lack of perennial rivers or streams. Rivers may change course over centuries as erosion and sedimentation alter the landscape. The locations of oases and springs, on the other hand, are based on the configuration of geological strata below the earth’s surface, occurring at places where aquifers approach or reach ground level.\textsuperscript{131} As a result, the locations of these water sources should change only on a geological timescale; 2,000 years will not have significantly altered their positions. This conclusion is supported by the frequent correlation between modern oases and springs and attested ancient

\textsuperscript{129}Vita-Finzi (1969).
\textsuperscript{130}Barker (1996), ch. 3.
\textsuperscript{131}Waller (1994).
settlements. To this day, the sites of Roman Tripolitania’s three great cities are watered by coastal springs and the ruins of Garamantian settlements still stand on their ancient oases.

With these methodological concerns put to rest, what data sources can we use to map springs and oases? Map 3 employs four data sets to display the most likely water sources in Tripolitania and the surrounding regions. It includes all Libyan and Tunisian springs and oases listed in the GeoNames database, a massive Swiss GIS data aggregation project.\textsuperscript{132} All oasis and well sites from the \textit{Barrington Atlas of the Greek and Roman World} have been digitally traced and included, as have oasis sites from Mattingly’s definitive monograph on Roman Tripolitania.\textsuperscript{133} A fourth data set is compiled from the list of Tripolitanian oases and springs recorded in the 1920 \textit{Handbook of Libya}, an exceptionally detailed geographic survey produced by the British Naval Intelligence Service.\textsuperscript{134}

We may be reasonably certain, though not entirely positive, that this map includes all major oasis and spring sites in Tripolitania, the most likely sites at which a large concentration of Roman troops could count on finding water. In fact, this map may even overestimate the number of possible watering sites for Roman armies. Though oases are often associated with springs, ground water does not breach the surface at all such sites. Even where water does come to the surface, it may be of poor quality or insufficient quantity.\textsuperscript{135} To be sure, such deficient oases still have a greater ability to meet military water needs than the deserts that surround them. Oases’

\begin{footnotesize}
\begin{enumerate}
\item \textsuperscript{132} GeoNames (2014).
\item \textsuperscript{133} \textit{BAtlas} (2000), 35-37; Mattingly (1994), Fig. 1:2, 2:5.
\item \textsuperscript{134} Geographical Section (1920). Sadly, only those sites from the \textit{Handbook} which could be located on Google Maps or OpenStreetMap are included (not always an easy task given the changes in toponyms over a century and the inevitable vagaries of Arabic-English transliteration). In the interests of efficiency, I chose not to include the numerous oases the Handbook recorded in the vicinity of ancient Garama, as these were well mapped by both Mattingly (1994) and the \textit{Barrington Atlas}.
\item \textsuperscript{135} Geographical Section (1920), pp. 144, 160.
\end{enumerate}
\end{footnotesize}
inhabitants may well have sunk numerous wells into the shallow water table beneath their feet, perhaps even enough wells to meet the needs of sizeable Roman armies. Nevertheless, we should not assume that every point on Map 3 could successfully water a Roman army; sites included on this map which offer insufficient water should more than compensate for any potential watering sites that have been omitted.

What of the lower order water sources discussed above, such as cisterns and wells already constructed by local populations? Such sources could certainly have supplied small contingents of Roman troops, and in ideal circumstances might even have met the water needs of entire armies. Needless to say, these sites are practically impossible to plot with total accuracy. Even in areas covered by extensive survey archaeology, it would be unreasonable to expect the discovery of more than a fraction of ancient wells and cisterns; in most of Roman Tripolitania, we lack even the limited data sets that landscape archaeologists can provide. That said, we can attempt to indicate where ancient cisterns and wells were likely to appear by employing recent advances in satellite imaging. For this purpose, Maps 4, 5, and 6 illustrate a fifth and final data set: the first displays maximum green vegetation fraction (MGVF) data for Tripolitania and its environs. Developed by researchers at the University of Arizona, MGVF mapping divides the Earth’s land surface into 1 km squares, and indicates the maximum percentage of each square covered by green vegetation in the average year (based on satellite imagery from 2001-2012). Grid squares with higher MGVF values will have more readily available water, whether through groundwater sources or human irrigation. Map 5 is an altered display of the same data, indicating sites at which Roman troops have some chance of procuring water; grid squares with

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136 British geographers certainly found this to be the case in oasis sites such as Mizda or Kasr Beni Ulid. Geographical Section (1920), pp. 151-153, 158-160. On the potential limits to the Romans use of pre-dug wells, see above, pp. 33-35.

137 Broxton (2014).
MGVF of 15% or higher are indicated in green, squares with lower MGVFs appear in white. Map 6 is simply a digital trace of Map 5, converting the “flat” image of the original dataset into more easily manipulable GIS shape files.

We cannot claim that the water sources indicated by this MGVF data necessarily existed in the ancient world. This is particularly true since many areas on this map which now support agriculture do so only thanks to human irrigation schemes. Indeed, we must omit entirely the cross-hatched area in Map 6, a stretch of land made “green” only by the suburban outgrowth of modern Tripoli and Muammar Gaddafi’s completion in the early 1990s of the “Great Man-Made River,” a colossal aqueduct bringing water from aquifers deep beneath the Sahara to the coastal capital. We cannot assume that every relatively well-watered site on Map 6 was inhabited in antiquity, just as we cannot assume that the potential farmstead at such a site would have wells or cisterns on the scale necessary to provision a Roman army. What we can claim is that the sites with high MGVF values indicated on Map 6 are more likely to have provided adequate water in antiquity than the comparatively barren regions surrounding them.

MGVF data combines with the four datasets described above to produce a “master map” of potential water sources for the Roman military in Tripolitania (Map 7). Though it is certainly possible that some water sources are omitted from this map, in all likelihood it overestimates the frequency of water sources in Tripolitania. Not every site marked on this map would necessarily provide Roman troops with adequate water, though all might have; this holds particularly true for

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138 The 15% divide is admittedly a somewhat arbitrary distinction on my part. That said, this divide produces a map that generally fits our other sources on Tripolitanian geography; for instance, somewhat greener areas are indicated in the Soffègin and Zem Zem wadi basins where the ULVS surveys suggest that they should be (Barker, 1996).

the water sources tentatively derived from MGVF data.\textsuperscript{140} We may also reasonably doubt that a Roman commander could locate all the water sources on this map, particularly isolated oases deep in the desert.

This overestimation of water availability in Roman Tripolitania is no accident. First, it is my hope and belief that water sources included on this map which do not provide adequate water more than compensate for any locations which would offer adequate drinking water but do not appear here. Second, it is the central contention of this paper that water supplies limited the possibilities of Roman military action in the field. This argument is strengthened if it succeeds in spite of the intentional overestimation of water availability. If Roman forces would have been constrained even on this overly generous map of local water supplies, they would have been all the more restricted in the more arid landscape of Tripolitania as it (in all probability) actually existed.

Based on the “master map,” where in Tripolitania could Roman troops actually wage war? This, fortunately, is a relatively simple calculation. Walter Scheidel and the ORBIS Project claim that a Roman army can travel 30 km in a day.\textsuperscript{141} This is a high estimate even on well-built Roman roads; it would probably be unattainable over the rocky wastes of the Tripolitanian highlands. Nevertheless, in the interests of overestimation, let us suppose that a Roman force can cover 30 km in a day. As we argued above, Roman forces did not carry large quantities of water with them, and refilled their water skins at least once per day except under extraordinary circumstances. Therefore, Roman troops could, under general conditions, access

\footnote{\textsuperscript{140} These sites from our fifth data set are indicated by hollow circles for precisely this reason, noting that it was less likely for Roman troops to find adequate water at these sites than at sites drawn from the first four datasets.}

\footnote{\textsuperscript{141} Scheidel, (2014).}
any point within 15 km of a water source.\textsuperscript{142} This radius of accessibility is indicated on Map 8: any shaded area is within a day’s march of a water source.\textsuperscript{143} In addition, if the 15 km circles surrounding two water sources overlap, a Roman army could travel between those sites without taking the exceptional step of transporting multiple days’ worth of water.

This map immediately and decisively demonstrates the extent to which water logistics limited Roman action in Tripolitania. Sizeable swaths of territory both within and beyond the Roman frontier (ultimately established along the Gebel hills) were generally inaccessible to imperial armies. From the empire’s perspective, the Gefara plain lying between the oases of the coast and the Gebel hills on the desert fringe must have been particularly troubling (Map 9).\textsuperscript{144} To be sure, no large-scale military threat could originate from such barren wastes; the Gefara was mostly uninhabited in antiquity (as it remains today), and the same dearth of water sources that kept out Roman troops would also have excluded sizeable enemy forces.\textsuperscript{145} Nevertheless, the existence of this inaccessible “pocket” within Roman territory could have hampered effective policing of the region. Comparative evidence from across the Roman empire suggests that landscapes harsh enough to exclude the Roman military often served as places of refuge for

\textsuperscript{142}It should be noted that this 15 km radius does not allow said Roman force to accomplish anything of significance. It would spend half a standard “work-day” marching out from its water source and another half-day marching back in (or to another water source), leaving precious little time to conduct military operations.

\textsuperscript{143}As with Map 7, sites derived from MGVF data are marked differently than sites from the first four datasets. Areas accessible only from such sites are shaded in a lighter color, indicating that they are less likely to be accessible to Roman soldiers, and particularly to large concentrations of troops.

\textsuperscript{144}The barren aridity of the Gefara is supported by Google Earth satellite imagery and by Mattingly (1994), p. 6.

\textsuperscript{145}On the lack of major settlements, \textit{BAtlas} (2000), 35.
bandits and fugitives. The highlands of Trachonitis in Syria preserved brigands from the wrath of Herod and Rome; El-Leja, the modern name for this rugged plateau, means “refuge” in Arabic. The mountains of Iberia protected the Cantabri of Spain from the Republic for two centuries, to the point where Marcus Agrippa, after his victory over the tribe in 19 BCE, forced them “to move from their settlements in the mountains down into the more controllable valleys.” Deserts could play a similar role as refuges for guerillas and insurgents; it is for this reason that Lucullus in Plutarch’s account refused to immediately attack Mithridates, knowing that his wily foe, faced with a superior Roman army, would vanish into the “vast and trackless desert behind him.” Although the barren Gefara just off the Tripolitanian coast may never have played host to a refugee as singularly menacing as Mithridates, it may well have offered a hideout and base of operations to the low-level criminals, fugitive slaves, and political dissidents of Roman Tripolitania.

Thanks to its lack of water sources, the Gefara plain also severely hindered the ability of Roman armies to move within Tripolitania in response to threats. To be sure, it was relatively easy for Roman forces to move east and west through the province by one of two routes. Water was readily available inland along the fringe of the Gebel hills; troops could “hop” from one source to the next within a day’s march, with small but troublesome arid gaps appearing only in the east and west of the region. Ultimately, this line of hills formed the core of the Roman

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146 Bear in mind that while the desert plain of Tripolitania did not have sufficient water to provision a sizeable contingent of Roman troops, it may have yielded enough water to meet the needs of small bands of bandits and fugitives, particularly if such individuals knew the local terrain well.


military frontier by the Severan period, in large part because it offered adequate water to the empire’s armies.\textsuperscript{150} Armies could also move laterally along the Mediterranean coast, though large forces might well have struggled to cross the dry gap between Oea and Lepcis.\textsuperscript{151} In fact, the difficulty of water logistics in this arid stretch might explain the delayed arrival of Roman auxiliaries to Lepcis in 69 CE, during the war between Lepcis and Oea; the Oeans, aided by mercenary tribesmen from the desert, were able to besiege Lepcis and lay waste to its countryside before Roman forces were able to relieve the beleaguered city.\textsuperscript{152}

Despite the potential challenges of the dry coast west of Lepcis Magna, lateral movement between the eastern and western ends of Roman Tripolitania was relatively unhindered by a dearth of water supplies. However, the barren Gefara severely hindered vertical movement within the region; Roman troops could not easily move north and south between the relatively well-watered coast and the Gebel. Based on the availability of water supplies, armies could cross between the two bands only at their eastern and western ends, where they come together near Tacape and Lepcis. At no point in between is a north-south transit of the Gefara possible without taking exceptional measures to provision water.

This geographic restriction of movement posed a serious threat to Roman security in the region. In the event that an enemy struck out of the desert at Severus’ Gebel fortifications, troops from the coast could not rapidly move inland to respond. And in the event of disturbances along the coast, such as the Oea-Lepcis war in 69, troops stationed along the Gebel could not

\textsuperscript{150}Mattingly (1994), p. 83. See also ch. 3, note 35.

\textsuperscript{151}The actual aridity of this reason is questionable, particularly since MGVF data cannot be included here due to the immense impact of the Great Man-Made River (see above, p. 43-44). There was certainly settlement in the area in the Roman period: \textit{BAtlas} (2000), 35 F2 & G2.

\textsuperscript{152}Tacitus, \textit{Hist.}, 4.50; Mattingly (1994), p. 71.
easily redeploy north.\textsuperscript{153} This immobility was particularly dangerous given the limited numbers of troops along the Tripolitanian frontier. The entire province of Africa Proconsularis was garrisoned by only a single legion, and until the reorganization of the frontier by Septimius Severus no sizeable contingent of that force was stationed in Tripolitania itself.\textsuperscript{154} Though the few legionaries in Tripolitania were no doubt supplemented by auxiliaries, the fact remains that their numbers were woefully inadequate for a frontier some 700 km long. The ability of the Romans to protect and monitor this boundary depended on the tactical flexibility of their forces, on the ability of scattered contingents to shift and unite in response to threats. By preventing vertical movement between the coast and the Gebel, the barren Gefara physically divided the already undermanned Roman forces and badly compromised regional security.

The presence of the Gefara within the borders of Roman Tripolitania was obviously a complicating factor in the region’s defense, both as a refuge for small bands of non-traditional combatants and as an obstacle to Roman response to larger-scale military threats. Yet all in all the Gefara was a rather small desert within an otherwise well-watered area. Even in the driest, western sector of the plain, a Roman force would be only two days march (roughly 60 km) from the nearest water supply. Though north-south crossings could not be made without carrying water, such crossings would be relatively brief and relatively achievable (particularly for small forces which would require fewer additional pack animals). Perhaps most importantly, crossings of this desert would have been relatively safe, since a Roman commander could fully trust in the availability of adequate water on the desert’s far side. To the south of the Gebel hills, none of

\textsuperscript{153}To be sure, it is uncertain that there were Roman troops in the Gebel at such an early date.

\textsuperscript{154}Le Bohec (1989); Mann (1974). Contra Mattingly (1989, 1994) who argues that small \textit{vexillationes} from the Legio III Augusta were installed along the Tripolitanian border. Even if his view is accepted, my point still stands: the number of legionaries in Tripolitania before Severus would have been hundreds at the most.
these factors held true. The Gefara desert was inconvenient and troublesome for Roman forces securing Tripolitania. The rugged plateau of the Hamada al-Hamra, dryer and immensely larger, presented a much more severe threat to provincial security.

The principal threat of the Hamada al-Hamra came not from the plateau itself, but from the Saharan tribes it protected to the south. For the first century of Roman rule in Tripolitania, the sizeable tribal confederation known as the Garamantes presented the greatest threat to the region.\textsuperscript{155} Striking on horseback from their desert oases, the Garamantes fought on Tripolitanian soil during the Gaetulian War (3 BCE-6 CE), the revolt of Tacfarinas (17-24 CE), and the Lepcis-Oea war (69 CE).\textsuperscript{156} Though these are the only conflicts recorded in the literary record, low-level raiding by Garamantes and other desert dwellers probably persisted throughout the 1\textsuperscript{st} centuries BCE and CE. For their part, the Romans launched punitive expeditions against the Garamantes in 19 BCE under Cornelius Balbus, as well as in response to Garamantian involvement in the Gaetulian and Lepcis-Oea wars. Such deterrent strikes were a key weapon in Rome’s imperial arsenal; striking across the frontiers, legions would devastate “barbarian” homelands, forcing tribes to come to terms and accept Roman hegemony. Though these borderlands were not generally annexed into the empire, they were left pacified, pliable, and thoroughly impressed with Roman wrath. In short, by making war across the frontiers, Roman armies won peace on the frontiers.\textsuperscript{157}

Map 10 suggests just how difficult this strategy was to execute on the Tripolitanian frontier. There were certainly ways through the broad desert separating Romans and


\textsuperscript{156} Mattingly (1994), ch. 3, 4.

\textsuperscript{157} Luttwak (1976), ch. 1.
Every year, transhumant herders would follow these tracks on their way to and from pastures near the coast; lightly armed and fast-moving Garamantian raiders presumably used the same paths to strike Roman territory. Yet water supplies along these routes were generally inadequate for a Roman force of any considerable size.\(^{159}\)

According to our data, only four potential paths lead south through the desert. The westernmost path is clearly unsuitable for a Roman expedition. Troops would first have to travel from the Gebel crescent to Cidamus, an oasis site ultimately garrisoned by Septimius Severus; this transit alone requires a Roman army to undertake two waterless marches of about 100 km (3.5 days) each, assuming troops passed through the band of oases centered on Chawan. Based on our data, further progress south was impossible for our army: over 450 km (15 days) separates Cidamus from the nearest water site to the south.\(^{160}\)

To the east, a second route, only slightly more practicable, runs southeast from the oasis at Derg. Again, troops from the north would have to undertake protracted desert marches even to reach Derg. According to Mattingly, the next water source is a well 110 km (3.5 days) due southeast, though a more sensible route might have cut south through the springs of Ayn’ al-Barbi before turning east towards the well (an itinerary which requires two desert crossings of approximately 50 and 70 km but adds 20 km in total distance). In all likelihood, a Roman army could not march beyond this point. 230 km (7.5 days) of desert lie between this well and the

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\(^{158}\) The routes in Map 10 follow Mattingly (1994), Figure 2.5.

\(^{159}\) Campaigns against the Garamantes would have required large numbers of soldiers. Charles Daniels (1989) estimates that the confederation comprised at least 10,000 people.

\(^{160}\) In the *Encyclopédie Berbère*, Pol Trousset claims that Cornelius Balbus took this route to Garama. *Enc.Berb. s.v.* Fezzan, 18.2802-2803.
next water source; by our model, transporting water over such a distance was well beyond the Romans’ logistical capacity.\textsuperscript{161}

Route three would have been technically possible for Roman armies to travel, though the journey would not be an easy one. Travel as far south as Gheriat el-Garbia need not have required any particular hardships, provided that the MGVF-derived water-sources on either side of Mizda were actually present and sufficient for the army’s needs. The Romans would make their first desert transit at this point, marching about 100 km (3.5 days) between Gheriat el-Garbia and Schwerif. The legion would then march roughly 160 km (5.5 days) south by southwest to the spring at Thamad al-Uhaymir.\textsuperscript{162} After moving southeast along a band of springs and wells, the army would turn south, crossing a last stretch of desert 80 km (2.5 days) wide before finally striking upon the northernmost oases of the Garamantian homeland. Though the only achievable option so far, this path would severely tax the Roman logistical apparatus. Large numbers of pack animals would be required, and a 5.5 day waterless march was nearly beyond the bounds of possibility. Any delay, any diversion, any wrong turn across the wastes would spell catastrophe.

Based on our data, the fourth, easternmost march of attack was by far the most practical. A Roman army would set out from Gholiaia, though reaching this oasis from the north requires an 80 km (2.5 days) transit of the waterless stretch of the wadi basin south of Wadi Zem Zem. The largest expanse of desert lies south of Gholiaia: it is 190 km (6.5 days) to the oasis at Hun, though the trip could be divided into two waterless segments of 100 km (3.5 days) if the green enclave on the northeast edge of the Hamada al-Hamra was extant in antiquity and provided

\textsuperscript{161}See above, pp. 12-27.

\textsuperscript{162}Based on our map of water-availability, Mattingly’s route appears to proceed too far south before turning east, passing a day’s march below two much-needed springs.
sufficient water for a Roman force. From Hun, the army would follow an almost continuous line of springs and wells south by southwest until their path joins with route three. The same 80 km (2.5 day) march would then have separated the Roman army from its Garamantian targets. Provided that the desert crossing from Gholiaia to Hun could have been divided into two segments with a water source in between, route four would have presented Roman forces with the least extreme waterless march. Yet as we have discussed above, even such relatively short desert transits taxed the Roman logistical apparatus.

To attack the Garamantes and deter their incessant raiding on the Tripolitania frontier, a Roman commander was limited to two routes. Neither was well watered. Both required significant investments in additional pack-animals as well as significant risks: if a desperately needed well ran dry several days from the nearest water source, disaster would ensue. If the Garamantes, as they were evidently wont to do, buried wells in the desert sands to keep them from Roman use, disaster would ensue. Therefore, as with all expeditions away from local sources of water, Roman commanders would enter this desert only rarely, and only under extreme circumstances.

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6. Conclusion

Given the hydro-geography of the desert south of Tripolitania, we should marvel that Roman armies ever reached the Garamantian homeland. Campaigns piercing the heart of the desert required the greatest exertion of Roman military logistics. As Mattingly puts it, “Rome’s achievement in adapting to desert warfare should not be underestimated.”

Yet we should also not forget that the sheer hostility of the desert landscape typically preserved the Garamantes from Roman reprisals. For all the trouble they caused the Roman empire, the Garamantes were never annexed, like the Musulames and Cinithi in what is now Tunisia. In a century of intermittent warfare, they were invaded only three times, and no permanent Roman garrison ever approached their borders. And although a Roman invasion in 70 CE finally put an end to large-scale Garamantian attacks on the coast, we may suspect that it succeeded in this only by offering elite tribesman substantial material incentives to maintain the peace; expensive Roman pottery and glassware appears in the Garamantian archaeological record around 70 CE, a sign that peace was bought as much as it was won. The Garamantes were able to threaten Tripolitania so brazenly


165 Mattingly (1994), p. 70. Like the Garamantes, both tribes were involved in Tacfarinas’ revolt in the early 1st Century CE (Tacfarinas himself was a member of the Musulames). As punishment, both were brought under direct Roman rule.

166 Mattingly (1994), p. 74. Contra Daniels (1970), who insists that Roman goods appear as a result of equal trade, not as gifts or bribes.
for so long because a campaign against them presented almost insurmountable logistical challenges.

We should not imagine that the challenges outlined here were unique to Roman Tripolitania. The empire confronted deserts all along its southern and eastern frontiers. Maps similar to the ones I have displayed here would, in all likelihood, show just how thoroughly the constraints of water logistics stymied Aelius Gallus’ expedition to Arabia Felix, or complicated centuries of Roman warfare against Parthians and Persians.  

Ultimately, investigating how Roman legions obtained adequate supplies of fresh water highlights the severity of the challenges which the empire faced. Although the Roman army was able to stretch the implacable limits of geography through exceptional logistical effort in moments of crisis, under normal circumstances biological requirements and technological shortcomings reasserted their grip on the Roman military. On the arid fringes of empire, the Roman army’s ability to move and fight was severely limited by its basic need for drinking water.

167 Strabo, 16.4.22-24.
MAPS

1. Roman Tripolitania
2. Average Rainfall
3. Tripolitanian Springs and Oases
4. Maximum Green Vegetation Fraction 1
5. Maximum Green Vegetation Fraction 2
6. Maximum Green Vegetation Fraction 3
7. Tripolitanian Water Sources
8. Areas Within One Day’s March of Water Sources
9. The Gefara Desert
10. Routes Against the Garamantes
Maps 4 and 5
Map 6

Maximum Green Vegetation Fraction (MGVF)

- ○: ≤15%
- □: ≥15%

Result of modern irrigation and development

Mediterranean Sea

Gabriel Moss, 2014
Map 10
BIBLIOGRAPHY


**Ancient Sources**

Unless otherwise noted, all quotations from ancient sources come from the Loeb Classical Library, an imprint of Harvard University Press. I have adjusted the Loeb translations as necessary.

**GIS**

In addition to the printed sources listed above, the GIS work in this thesis is based on the following digital data sources: