gradients than Greek ones, and this suggests good levelling techniques by surveyors, who probably used the *libra*. The difficulty is that water flows fast and shallow on a steep gradient, and on meeting a gentler decline slows down and backs up, and may possibly overflow (p. 185). L. provides a fascinating examination of how the ancient surveyors overcame the problems of the aqueduct at Nîmes, with its extremely shallow gradient. There is also an excellent discussion of the building of Roman roads (pp. 217–45). The best-known feature of the roads is their straightness, and the intriguing question is how long, straight alignments were laid out. Surveying writers have little to say about road building, so most of the evidence comes from the roads themselves. The surveyors mainly used the *groma* and there were three stages: reconnoitre the land between the endpoints, mark out a straight line or an alternative between the endpoints, and work out the route in detail on the ground. L. considers the various possibilities for establishing long-distance alignment and his preferred solution is extrapolation from one fixed point based on the geometry of similar triangles (p. 232). He also notes that we should not suppose that all long alignments were laid out in the same way. For example, the Fosse Way was not a single road but a succession of short roads built to connect military installations. This sensible discussion is a salutary warning against elaborate theories for the layout of Roman roads. An epilogue to this section briefly considers parallels in other civilizations to Greek and Roman surveying instruments, and assesses the degree of continuity in surveying practice through the Sasanids in Persia, Byzantium, and Islam, after the fall of the Roman Empire in the West.

Part Three sets out translations of extracts from the relevant ancient sources, including Greek, Latin, Hebrew, Syriac, and Arabic texts. These are clearly expressed and usefully complement the discussion in the preceding sections.

The Queen's University of Belfast BRIAN CAMPBELL

AQUEDUCTS

D. R. Blackman, A. T. Hodge (edd.): *Frontinus' Legacy: Essays on Frontinus'* De Aquis Urbis Romae. Pp. xi + 170, ills. Ann Arbor: The University of Michigan Press, 2001. Paper, £12.50. ISBN: 0-472-06793-1 (0-473-09793-8 hbk).

For some decades, the study of ancient water supply has attracted a lot of scholarly attention from various disciplines. This book aims to be an interdisciplinary study of Frontinus' work, and intends to address the questions that lie between the lines of his text. The editors—one (Hodge) trained in classics, the other (Blackman) in mechanical engineering—have been engaged in this field before. Together they have written the major part of the book under discussion.

What do the editors mean by 'Frontinus' legacy'? Frontinus, *curator aquarum* in Rome in A.D. 97, has written the only treatise on water supply that is left to us from antiquity. For this reason, his *de aquis urbis Romae* is referred to in almost every study on Roman water supply. A clear answer to the question about the meaning of the book title is given in Chapter 12, 'Epilogue', p. 153, where Frontinus' true legacy is specified as 'Roman engineering and society'.

In the introductory chapter the reader is informed that the main issues raised in the book are techniques, capital, and labour. In addition, the gross parameters of the

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https://doi.org/10.1093/cr/52.2.344 Published online by Cambridge University Press

aqueducts of Rome as described by Frontinus are listed, and some remarks are made about ambiguities in Frontinus' technical terminology. After this chapter, the book consists of three parts, each subdivided into chapters addressing a number of loosely connected subjects.

The first part, 'Engineering Theory', is about the geometry of the *calices* (short pipes of standard diameter used to meter water delivery) and the *quinaria* (Frontinus' unit of measurement for water delivery). Roman number arithmetic, the uses of the abacus, Frontinus' number notation, and the measurement system for *calix* sizes are touched on. The authors dwell upon the well-known complaint that Frontinus was unable to measure water in flow, and his overall lack of skills in the field of hydraulics.

The second part of the book enters into 'Engineering Practice'. The rôle of professionals in the process of decision-making, the technical skills they may have had, and the practical solutions they have chosen for technical problems are discussed in Chapter 4. In the next chapter, Norman A. F. Smith goes into Roman levelling. He elaborates on surveying instruments for aqueduct planning. Those instruments have not survived. A few depictions on tombstones of the *libella* and the well-known, oft-quoted descriptions of Vitruvius and Hero of the *chorobates*, the *dioptra*, and the *libra aquaria* are all there is. Whether and how they were used to establish a level, or a series of levels to define a correct gradient, is a matter of speculation. The authors of this chapter are aware of that. They stress that evidently Roman engineers and builders could level accurately and consistently. A comparison with the way in which an aqueduct to London was levelled in the seventeenth century leads to the conclusion that in the intervening centuries the techniques did not change at all. Chapter 6 deals with estimates of manpower and costs required for the building of aqueducts. Since classical authors recorded quantitative data only occasionally, the estimates are based on assumptions about the time required for quarrying, transport, masonry, and the costs of access rights, material, wages, and administration. The authors hint at deployment of soldiers and the use of imperial quarries. In the next chapter, Ph. Leveau deals with a related subject, the financing of aqueducts all over the Roman Empire. His conclusion is clear: there are many forms of financing, as with public works in general. After that, he makes an estimate of the cost of a Roman aqueduct per kilometre, based on data of the aqua Marcia and the aquae Claudia and Anio Novus given by Frontinus [*sic*]. In Chapter 8, comments are made on water theft, aqueduct failure, and calcareous deposits, all requiring maintenance. It is followed by an excursus on calx by K. Grewe and D. R. Blackman in Chapter 9: the chemical process resulting in calx, growth and removal of calcareous deposits, and the use of the calx from the Cologne aqueduct as building material. In the last chapter of this part, attention is given to urban distribution. Frontinus' figures and accounting remain puzzling. The authors suggest that the system is dynamic, so that Frontinus' figures must be considered as a snapshot in time.

The last part, 'When in Rome . . .', contains a chapter on Frontinus and his treatise, in which well-known subjects like Frontinus' career, technical skills, and reliability, as well as his aim in writing, are reviewed. In the final chapter, the epilogue, the authors admit that 'The whole field of aqueduct construction, operation, financing, and so forth, is so wide and impinges on so many other aspects of classical society that they could not be adequately covered by either of the present authors'. I feel that an introduction is a more appropriate place for such a remark.

The conclusion must be that quite a broad concept of the field was chosen, and was found not to be really manageable. In addition, the literature consulted is mainly in English; recent research in other languages is hardly referred to. As a consequence,

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'some of the questions' the authors formulate at the end 'may already have been answered' (p. 153).

This confession sounds somewhat naïve, and is unusual for authors who profess to edit a scientific treatise. To put it mildly, the editors are extremely modest in their scientific ambitions.

Katholieke Universiteit Nijmegen GERDA DE KLEIJN

ROMAN WATERWORKS

G. De Kleijn: *The Water Supply of Ancient Rome: City Area, Water, and Population*. Pp. v + 353, maps, ills. Amsterdam: J. C. Gieben, 2001. Cased, Hfl. 150. ISBN: 90-5063-268-8.

In recent years aqueduct studies have seen a veritable renaissance. Though led by the Germans, under the banner of the *Frontinus Gesellschaft*, other groups have also made their mark, notably one centred on the Katholieke Universiteit Nijmegen, where a number of young scholars, led until his recent tragic and shocking death by Prof. Jos. De Waele, have concentrated on Pompeii. One such is the author under review.

Perhaps the book might have been better entitled something like 'Aspects of . . .', for though there is indeed a general treatment of the water supply of Rome, that is not its main thrust. Rather, as De Kleijn puts it, 'It is the objective of this study to investigate whether data borrowed from our knowledge of the urban water supply in Antiquity are any help in answering questions about the size of Rome's population, as well as the extent and social fabric of its built-up area'. In pursuit of this aim the author shows both strengths and weaknesses.

The weaknesses are partly dictated by the paucity of archaeological evidence for internal arrangements within the city, duly recognized by the author. At Rome in particular it is very fragmentary, as compared with the great arcades across the Campagna, and to fill the gap one has often to extrapolate from sites such as Pompeii; here one could have perhaps expected more material from the author's personal experience excavating there.

But the chief weaknesses are twofold. First, stemming from the gap in archaeological evidence, is a great, perhaps excessive, reliance on literary sources. Accordingly, much of the book reads like a repeat or even a re-hash of Vitruvius and Frontinus, and this material is usually repeated uncritically, even when demonstrably wrong. Thus (p. 41) we are told that an inverted siphon 'needed a device to reduce air pressure'. This is an accurate translation of Vitruvius 8.6.6, who prescribes 'collivaria' (whatever they may be) 'per quae vis spiritus relaxetur'. *Vis spiritus* is certainly air pressure. The trouble is that, no matter what Vitruvius says, there was no air in a siphon while running, only water. This has often been noted by hydraulic engineers, most recently by Deane Blackman (*JRA* 13, 411). Indeed, the whole section on siphons (pp. 41–2) is very confused and often contradictory, without explanation, of modern accepted views and terms. Thus a *venter* is not, as stated, a siphon, but only, where provided, the viaduct forming the bottom part of one; a *geniculus* is the bend where the siphon runs from the valley hillside on to the level viaduct, not, apparently, a horizontal bend to make the conduit contour around a valley; and the Yzeron (i.e. Beaunant) siphon at Lyon had nine, not twelve (p. 39 n. 117) lead pipes.

In a way, none of this is vital, since there were few if any siphons at Rome, but it

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