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Funding irrigation. Between individual and collective investments

Marguerite Ronin

Irrigation remains an underestimated and therefore insufficiently studied aspect of Roman agriculture.¹ If technical aspects, however, tend to be increasingly well understood, the economic and financial conditions of irrigation practices do not seem to have been much considered yet, even though they constitute a critical feature of an estate's management. Amongst the different choices a landholder had to make, investments in hydraulic infrastructure were guided by the particular needs of cultivation and breeding, which varied according to the environmental context. The costs involved had some direct consequences upon the economy of the farm holding.

This paper will try to contribute to a better knowledge of the funding of irrigation, either modest or extensive. The topic indeed matters because at its very core lie the modalities of management of a natural and sometimes limited resource. The question asked is therefore related to the way the different actors of the farming world controlled the water resource. What economic means could they use to get access to a water supply and to exploit it? Unfortunately, the sources do not allow us to assess the costs of the irrigation facilities themselves.² That is why attention will be turned towards the nature of the investments required, financial, human, and material, related to the institutional context, the natural environment, and the scale of the irrigation networks.

Because water is a collective resource, it seems relevant to question whether the investments were made individually or were collectively incurred. Owing to the nature of the evidence studied—inscriptions, archaeological data, and

¹ See Horden and Purcell 2000: 244 and Willi and Beltrán Lloris 2012 for a detailed bibliography about the topic in Roman Spain.

² The few prices we know are mostly related to urban aqueducts (Duncan-Jones 1982).

fragments from the *Digest* of Justinian—the geographical scope of this study is confined to central Italy, with some glances at the provinces of Africa and Spain.

IRRIGATION INFRASTRUCTURE: A WORTHY INVESTMENT FROM THE SECOND CENTURY BC ONWARDS

Before investigating more closely the nature of the investments made for irrigation infrastructures, it is necessary to keep in mind that watering the crops was a real concern for growers. From the second century BC onwards, the demand of rapidly growing urban markets within the Roman Empire expanded. In that context, irrigation allowed greater productivity, and hence possibly more profit.³ This evolution has been noticed in the market gardening business, which is particularly well documented for the Roman hinterland, but other fields of activity were also involved. The progress made in animal husbandry from the second century BC onwards is, for instance, closely linked to the development of irrigated meadows, and we have good indications that the African production of olive oil benefited greatly from irrigation systems and from flood-based agriculture.⁴

The agricultural productivity of Roman towns' hinterland and suburban areas is widely acknowledged, particularly in the case of Rome itself, where the production of quality goods was stimulated by the large urban market.⁵ Surveys in the vicinity of Rome have shown, in some areas, a high concentration of farms or villas. During the two first centuries AD, the extent of plots ranges from an average of 10–15 to 20 hectares around Fidenae, in the Tiber Valley, and from 25 to 30–35 between the Anio and the Via Nomentana.⁶ The limited size of the estates is generally used as an argument to consider that the region was orientated towards highly productive intensive farming. Added to the fact that the agricultural region in the close vicinity of Rome displays few traces of cereal cultivation, it has been assumed that it was largely devoted to the growing of fresh products, such as vegetables or flowers, a business

³ Although the difficulty of selling the surplus in some cases has been rightly pointed out (Kron 2012: 156–7).

⁴ Kron 2012; Hitchner 1995.

⁵ For a survey of literary evidence from Cato the Elder to Cassiodorus, see Thomas and Wilson 1994: 156–9.

⁶ Quilici Gigli 1994: 140. The author compares these dimensions to the possible 75 to 125 hectare estates in the Ager Veientanus or Casanus, but rejects the assumption of an average property size of 1 to 2.5 hectares as made by Andrea Carandini in the close southern suburbs of Rome (Carandini 1985: 69). For a validation of such a density over the first two and a half centuries of the Principate in the areas closest to the urban centre, see Witcher 2008.

considered as lucrative by Cato, from the outset of the second century BC.⁷ Market gardening is indeed a characteristic feature of the suburban landscapes: small-scale, intensively cultivated and irrigated plots, devoted to the cultivation of fresh products.⁸ Although it is well attested by written sources, it was for long thought to have left almost no traces in the landscape and was therefore considered undetectable by archaeological studies.⁹ However, the consideration that the gardening activity necessitated intensive irrigation, and that drainage and irrigation processes were clearly combined in the same technology of land improvement, provides good opportunities to trace it and estimate its importance.¹⁰ Remains of hydraulic equipment, such as large cisterns apparently devoted to irrigation, are indeed evident in the Roman hinterland and show a clear clustering along the Tiber, along which transport was cheapest.¹¹ Similarly, some drainage *cuniculi* observed in central Italy have been linked with operations of collecting water in order to increase the availability of water resources for villas downstream, for instance north and east of Rome, in Marcellina near Tivoli or in Civita Castellana near Viterbo, but also further south in Sperlonga.¹²

Probably further from the urban area, but still obviously focused on the urban market, meadows were devoted to cattle breeding, an activity which benefited from improvements of fodder crops. A survey of Columella's *De Re Rustica* shows a distinct concern for this topic, although irrigated pastures had already been mentioned by Cato two centuries earlier, even if with considerably fewer details.¹³ For growing lucerne (or alfalfa), renowned as a very nutritious forage, Columella advised to divide the terrain in small portions, of about 3 × 15 metres, allowing the setting of irrigation ditches between the plots.¹⁴ In those conditions, lucerne could be harvested 'four and sometimes six times' a year, which together with its excellent nutritious qualities made it a

⁷ On the absence of millstones noticed in field surveys, see Quilici Gigli 1994: 141. See also Thomas and Wilson 1994: 158–62; Wilson 2008: 758–9. Out of nine sorts of cultivations, Cato declares that irrigated *horti* came second: Cato, *De Agri Cultura* 1. See also Columella, *De Re Rustica* 2.2.6; 10.23–6; 10.40–9. See in particular Morley 1996: 83–95.

⁸ For indications of such cultivations in other Roman towns, see for instance Monteil et al. 2005: 33–5; Monteil 1999: 465–7.

⁹ Carandini 1985: 71; Morley 1996: 102 (both references cited by Wilson 2008). For written sources about irrigation around Rome, see for instance *CIL* 6.1261; *CIL* 14.3676; Frontinus, *De Aquis* 9.4–5; Cicero, *De Lege Agraria* 2.

¹⁰ Wilson 2008: 734, 760. For a comparison between different crops and their need for water, see Kron 2012: 170; and more details about central Italy in Thomas and Wilson 1994: 158–64.

¹¹ Wilson 2008: 746; Quilici Gigli 2008.

¹² Quilici Gigli 1997: 203–4. For examples of ditches from the 4th–3rd century BC to the Augustan era in Vallerano, south of Rome, see also Bedini 1997.

¹³ The care of meadows is specifically detailed in Columella, *De Re Rustica* Book 2, and also in Book 6 about the care for cattle. Cato gives his preference to water meadows over dry meadows in order to supply hay (Cato, *De Agri Cultura* 8.1). See also Varro, *De Re Rustica* 1.37.5.

¹⁴ Columella, *De Re Rustica* 2.10.26.

very profitable object of cultivation. Columella's detailed attention to pasture management and to fodder cultivation is obviously due to the fact that the techniques had reached a high degree of sophistication by his time. This can be explained by the spread of Carthaginian and Greek intensive-farming techniques, including convertible husbandry (i.e. the alternation of arable cultivation and artificial pasture on the same piece of land), in central Italy from the second century BC onwards.¹⁵ Indeed, archaeozoological and archaeobotanical data give clear evidence for a real improvement in the quality of forage and a major increase in the size of the cattle from that period until late antiquity.¹⁶

Whereas the irrigation of pasture is well attested by the Roman agronomists, it is not easy to associate it precisely with any region.¹⁷ Scattered epigraphic and legal documents however provide evidence that it was used in ancient Italy. To the north of Rome, east of Viterbo, masonry dams with associated channels and diversion *cuniculi* have been related to an inscription recording works on meadows (*prata*), carried out by C. Egnatius during the second century BC.¹⁸ The jurists were also involved in protecting the practice at least from the first century BC, as we know from a fragment of Justinian's *Digest*. Ulpian reports the opinion of Ofilius, a friend of Cicero and Julius Caesar, in a dispute where an arable field (*arvum*) had been changed into a pasture (*pratium*).¹⁹ This conversion led to a modification of the watering conditions: when used as arable land, the plot was irrigated only seasonally (*certo tempo anni*), when turned into a meadow, it was irrigated continuously (*adsidua*). But, although this change had harmful effects on the neighbour's plot, Ofilius refused him any judicial recourse and therefore favoured the breeder irrigating his land.

Watered meadows are also attested in another fragment dating back to the middle third of the first century AD, which arguably gives an indication that the practice was extended to a semi-arid region. Taking his case from Minicius, Julian mentions damage incurred by a farmer when his neighbour seized all the available water, which caused the meadows and trees to run dry.²⁰ Julian's African origin cannot be used to help us determine in which region the practice of irrigated meadows could be applied. The irrigation of trees, however, can be related to semi-arid regions, such as Africa or Spain, since their growth would particularly benefit from extra watering in these regions.²¹ Wadi agriculture, applied in the Tripolitanian pre-desert, south of the ancient cities of Leptis Magna, Sabratha, and Oea, took advantage of wadi-flood episodes. Cisterns and wells have been recognized by survey operations, but

¹⁵ Kron 2000; 2004b; 2012: 158 sqq.

¹⁶ Kron 2004a: 124 sqq.; MacKinnon 2015.

¹⁷ For modern to contemporary times, artificially irrigated meadows are particularly well attested and studied in England and in Alpine areas (Brown 2005; Riedener et al. 2015).

¹⁸ *CIL* 11.7505. Quilici Gigli 1989.

¹⁹ *Digesta* 39.3.3 §2 (Ulpian 53 *Ad Edictum*).

²⁰ *Digesta* 8.5.18 (Julian 6 *Ex Minicio*).

²¹ Kron 2012: 159; 166.

some must probably be related to pastoralism.²² Walls erected on the banks and along the slopes of wadis have, however, for a large part been linked to their irrigation of cultivated areas. A large quantity of olive presses has been discovered in a region remote from modern oil production areas.²³ Further-more, palynology has revealed a variety of cereals associated with foddergrasses and shrubs, which points to a system of rotation, meant to improve the productivity of the soil.²⁴ Archaeological research has, nevertheless, shown that the practice could be used in central Italy too. The works on the Metro-politana C line have thus allowed to discover the remains of a suburban estate, situated between the Caelian Hill and the Lateran, south-east of Rome, provided with a sizeable reservoir of 69 × 34 metres.²⁵ Supplied by a water-course hypothesized to be the Aqua Crabra, this large pool is also related to a water-lifting wheel. Irrigation was obviously decisive in this estate where vegetables, but also fruit trees, were grown during the first century AD. Amongst them, peach-trees, very recently introduced in Rome, must have been especially fashionable and lucrative, justifying the investment in the hydraulic facilities.²⁶ The region of the High Steppe around Cillium Kasserine, in Africa Pro- consularis, still bears numerous signs of the abundant production of olive oil, along with stock-raising, cereals, and maybe vines. Oil, in particular, was produced in very large quantities, probably destined for export.²⁷ This production was apparently the result of large-scale investment and suggests the intervention of people wealthy enough to finance the trees, farms, and presses.²⁸ If olive trees are markedly resistant to dry conditions, it is nevertheless possible to enhance the quality and productivity of the fruit by irrigation, especially in semi-arid environments.²⁹ Different kinds of hydraulic infrastructure directly related to olive orchards have indeed been observed around Cillium, and mostly date from the end of the first century AD onwards.³⁰ The wealth of the Flavii of Cillium is well-known thanks to the funerary poem inscribed on the second-century mausoleum erected by T. Flavius Secundus in memory of his father.³¹ To judge by their example, investment in agriculture was obviously profitable.³² More specifically, irrigation seems to have added to the profit (as reported in the text on the Flavii's mausoleum) and irrigation infrastructures must thus be considered to have been a profitable investment in northern Africa.

²² Barker et al. 1996: 170.

²³ Barker et al. 1996: 167–8.

²⁴ Barker et al. 1996: 265; 273.

²⁵ Rea 2011; Barbera 2015: 4–5; fig. 13a–20b.

²⁶ Peaches were probably introduced from Persia and/or Greece during the first half of the first century AD and rapidly became very popular (Sadori et al. 2009).

²⁷ Mattingly 1988: 45–7.

²⁸ Mattingly 1988: 51.

²⁹ Patumi et al. 2002: 33–4; Terral et al. 2009: 22.

³⁰ Hitchner 1995: 146–9; 154–5.

³¹ *CIL* 8.211–16.

³² Even so, it has been argued that the family was maybe not as wealthy as it seems, in spite of its clear social advancement (Lassère 1993: 226–7).

A growing need for water was indisputably linked with the development of intensive farming, of convertible husbandry, and of the extensive cultivation of olive trees. Irrigation infrastructure, having been introduced into central Italy during the second century BC, was thus a worthwhile investment.³³

INVESTMENT FOR INDIVIDUAL WATER SUPPLIES

Individual access to water and irrigation operations was achieved thanks to various hydraulic devices from the most simple and affordable trenches to more elaborate and accordingly more costly solutions. North of Rome, along the Tiber Valley, several large cisterns have been observed.³⁴ Associated with rural sites (usually villas from the imperial period), their capacity ranges from an estimate of 200 m³ to 700 m³. Some are only semi-interred, some are completely free-standing. They consist of neatly built masonry structures of *opus signinum* and *reticulatum*, with tufa quoins, and are sometimes vaulted.³⁵ Supplied by small-scale rural conduits, they could also be associated with a network of ditches.³⁶ Constructing such cisterns undoubtedly constituted a material investment. The volume of the walls (without even considering the vaults) may be estimated between about 105 m³ for the smallest ones and 240 m³ for the largest ones.³⁷ While it is not possible here to investigate the construction techniques with any precision, we may assume that the materials came from the site or from the vicinity. Bricks and tiles, which are necessary for the mortar, are very common in the Tiber Valley, even on small rural sites,³⁸ as is limestone.³⁹ Nevertheless, it still represented a significant amount of man-days to build them. Depending on the size of the facing elements of the *opus reticulatum* and the amount of mortar, it would have represented a minimum of 74 man-days of work for the smallest ones, going up to 167 for the largest ones to be erected, not taking into account the supplementary work constituted by the vaults.⁴⁰ Although it has been pointed out that, due to its standardization, the *opus reticulatum* required less skilled workers, depending on the complexity of the conception itself, the intervention of a professional mason might sometimes have been required.⁴¹ The expenditure was obviously justified by the need for a large quantity of water. This was probably drawn from an aqueduct for a limited time and then stored to be used when the

³³ See also the conclusions in Wilson 2002: 6.

³⁴ Wilson 2008.

³⁵ Wilson 2008: 735–9.

³⁶ For instance, Quilici and Quilici Gigli 1980: 206, site 35.

³⁷ These calculations and the following are based on the figures from DeLaine 2001.

³⁸ Wilson 2006b: 228.

³⁹ Heiken, Funicello, and De Rita 2007: 8.

⁴⁰ These estimates seem plausible although they are probably in many cases an underestimate.

⁴¹ Crawford and Coarelli 1977: 16–18; Wilson 2006b: 227; Dessales 2011.

supply was not available anymore because it was directed to another plot.⁴² Fragments of the *Digest* from the end of the first and the end of the second century a^o give evidence for such a system where the sharing was based either on the season or on the time of the day.⁴³ The high profits expected from agriculture in the area were clearly the reason that encouraged land-holders to equip their estates with a cistern.

In Tripolitania, another type of water storage device was implemented: water retention walls, evidenced by the *UNESCO Libyan Valleys Survey*. If some wall systems were intended to mark estate boundaries and others were linked to stock enclosure, a great number were associated with flood-based agriculture.⁴⁴ Strongly built in order to resist violent flood episodes, and orientated obliquely to the slope, they were intended to trap surface run-off. Water was then either directed into cisterns or infiltrated directly into the soil. Due to the difficulties of the terrain, to the extent of those networks, and to the materials required (some stones probably even having been quarried), the authors of the survey consider that the investment was enormous. As a knowledge-based activity, it was probably carried out by members of the local communities. It therefore did not necessarily require a considerable financial input, but a very substantial material and human investment. In Tripolitania, as in the Tiber Valley, high profits were expected from agriculture, principally for exporting olive oil.

Although they all insisted upon the need of water, Roman agronomists did not detail the technical aspects of water-channelling. Only Columella explained how to design drainage ditches and canals. From his description, one pictures a very simple technology, of covered canals or open ditches, depending on the nature of the soil. Open ones were directly cut into the earth and not necessarily channelled, provided that the ground was compacted enough. If covered, ditches had to be dug three feet deep and half-filled with small stones, gravel, or even branches. A few stones had to be laid at each side of the ditch, in order to rivet its banks.⁴⁵ Most of the private irrigation works recorded in the *Digest*, mainly by authors from the second and third centuries a^o, tally with the ditching operations described by Columella in the middle of the first century.⁴⁶ The simplest work consisted in digging irrigation ditches (called *rivi*), which could be covered or not.⁴⁷ To prevent important loss of water by infiltration, jurists also allowed the possibility of strengthening the

⁴² Wilson 2008: 739.

⁴³ *Digesta* 43.20.6 (Neratius 3 *Membranae*); *Digesta* 39.3.17.pr. (Paulus 15 *Ad Plautium*).

⁴⁴ Barker et al. 1996: 217.

⁴⁵ Columella, *De Re Rustica* 2.2.9–11.

⁴⁶ See, for instance, *Digesta* 43.21.3.pr. (Ulpian 70 *Ad Edictum*) and Möller 2010: 27, n. 57, about the juridical conditions of use and change of use of ditches described in this text.

⁴⁷ *Digesta* 43.13.1 §4 (Ulpian 68 *Ad Edictum*).

channels with stones and mortar or even of piping it in *fistulae*.⁴⁸ Wood could also be used for sluices or weirs (*septa*).⁴⁹ Such works are difficult to trace on the field, and more difficult to date. However, archaeology sometimes uncovers examples. Alongside more elaborated underground *cuniculi*, enclosed terracotta pipe networks have been unearthed around Rome.⁵⁰ This system probably made surveying of the course of the aqueduct simpler: the gradient did not have to be measured too precisely since the water could have run under some pressure.⁵¹ It seems, at first sight, that such irrigation infrastructure was quite elementary and required no particular engineering skills. The only human investment consisted therefore in the workforce: if this was not available within the estate itself, it was most probably possible to mutualize the efforts within the neighbourhood.⁵² The materials (small stones, gravel, and branches) were also doubtless close at hand, although some studies have shown that a few elements came from a certain distance, which probably implied a small occasional financial investment.⁵³ Despite this preliminary picture, it must be stressed that neither the legal texts, the agronomists, nor, in most cases, the archaeological sources provide details about the total length of the conduits, which was probably the most decisive variable due to the relief and the nature or the terrain.

Our first source of information on the organization and cost of such engineering works is Cicero, and especially the first paragraphs of a letter he wrote to his brother in September 54.⁵⁴ Acting on behalf of Quintus, he paid 101,000 HS for the *fundus Fufidianus* in Arpinum. As noted by Cicero, the principal interest of the property obviously lay in the large quantities of water it was provided with, and which could be employed for the irrigation of 50 *iugera* of meadows or for the ornament of the villa. Further on, the author questions the decision of his brother to keep his *fundus Bobilianus* instead of selling it.⁵⁵ This estate was well irrigated too, and Cicero argues that his

⁴⁸ *Digesta* 39.3.11.pr. (Paulus 49 *Ad Edictum*); *Digesta* 43.21.3.1 (Ulpian 70 *Ad Edictum*); *Digesta* 43.20.3 §5 (Pomponius 34 *Ad Sabinum*). On the durability of the jurisprudential rules through the evolution of vocabulary between this last text and others, Möller 2010: 82.

⁴⁹ *Digesta* 43.21.1 §4 (Ulpian 70 *Ad Edictum*).

⁵⁰ For examples of underground *cuniculi*, see Quilici and Quilici Gigli 1986, sites 81 and 157.

⁵¹ Wilson 2008: 753–4.

⁵² Cato advised readers to maintain good neighbourly relations in order to exchange favours (*Cato De Agri Cultura* 4).

⁵³ Bedini 1997: 165–6 for an example of a network dated from the third to the first century BC; Ghisleni et al. 2011: 132.

⁵⁴ Cicero, *ad Quintum Fratrem* 3.1.1–2. I follow here the translation and suggestions of David Shackleton Bailey (Loeb Classical Library 462, Harvard, 2002). The French translation by Leopold-Albert Constans, regularly reprinted by the CUF since 1936 (most recently Les Belles Lettres, Paris, 2002), may lead to some inconsistencies.

⁵⁵ Here, Constans (see the previous footnote) proposes to read again *fundum Fufidianum* where most other editors suggest something close to *Bobilianum*. This small difference is not without consequences: if it were the same estate Cicero is referring to all through Paragraph 2,

brother should merely have secured the access to the water thanks to a servitude, and sell it, thus indicating that the water was the only worthwhile thing on this land. It is, however, strange that his main argument is that he thought the estate could have been sold at the same price with or without the water.

After mentioning his brother's properties, Cicero goes on to refer to the cost of a private aqueduct between two of them. Although some other solutions have been proposed, it seems very probable that the water was conducted from the *Bobilianum*.⁵⁶ Where it was conducted is not clear, but we know that the source and the destination were 2.2 kilometres (3,000 paces) apart. This length apparently necessitated the intervention of a professional contractor with his team of workers, for an estimated 22,500 HS.⁵⁷ Additionally, the work probably required some engineering, since another contractor was asked to join Cicero, perhaps to provide a second opinion or to bid for the contract, and this one was specialized in tunnels. Did this aqueduct represent an important investment? In his letter, Cicero repeatedly tries to induce his brother to use the water drawn from his different pieces of land for ornamental purposes, but his friend Caesius, who accompanies him, points out the profit it may bring to an agrobusiness. Although we do not know what was finally decided, it is possible that the work was part of an irrigation system. Now, if we hypothesize that Quintus' properties, located in the same area, were comparable in size, we can suppose that the profit expected was close to that of the 50 *iugera* of meadows of the *Fufidianum*. An annual profit of 6 per cent for such a piece of cultivated land gives a result of 7,500 HS a year.⁵⁸ The 22,500 HS of the aqueduct could therefore have been recovered within three years. Other expenses, such as staff costs, were also naturally incurred, but it must be stressed that investments in agricultural business were calculated on the long run,⁵⁹ and that aristocrats could rely on the profits of their other estates to cover the costs in new ones. Finally, it must be stressed that the amount probably did not represent an important expense overall for the brothers. Cicero states further on in the letter that Quintus' *vilicus* Nicephorus had agreed to build a little construction in his villa for a cost of 16,000 HS.⁶⁰ Although it is not said what the construction was intended for, the fact that

the whole buying and selling operation would have been completed in order to secure access to a perennial (and probably abundant) source of water. This would, however, have been a lot of work with some risk of not being able to sell the property at a good price.

⁵⁶ Elizabeth Rawson has proposed that the equipment was to draw water from the *Fufidianum* to the *Manilianum*, another of Quintus' properties, which she identifies with the *Arcanum*. See Rawson 1976: 98.

⁵⁷ This price was exactly 3 HS a foot for a length of 3 paces (=7.5 feet).

⁵⁸ On this percentage, see Columella, *De Re Rustica* 3.3.8–10.

⁵⁹ Columella, *De Re Rustica* 3.3 on investments and profits in vineyards.

⁶⁰ Cicero, *Ad Quintum Fratrem* 3.1.2.5.

Cicero calls it *aedificatiuncula*, the only known occurrence of this word, certainly implies that he did not consider that the price was a large sum. We may therefore assume that the price of 22,500 HS for an aqueduct conveying a perennial and abundant supply of water was not an expense about which they would worry very much.

An inscription of the second century provides evidence for the construction of a larger private hydraulic work, associated with a single estate.⁶¹ Near Viterbo, in Etruria, the senator and former consul Mummius Niger Valerius Vegetus bought a water source. To conduct the water to his villa along his almost nine-kilometre-long private aqueduct, the Aqua Vegetiana, he also purchased eleven stretches of land and obtained a *senatus consultum* to be allowed to build his aqueduct alongside a public road. The inscription mentions a width of about three metres for the masonry work and of about 1.80 metres for the pipes themselves. The region, being fertile, was intensively farmed: stock breeding, fruit trees or wine, vegetables, and cereals.⁶² Considering the extent of the investment, it has nevertheless been suggested that the whole operation was not intended to provide water for irrigation but for the embellishment of the senator's villa, and that he also intended to sell a part of the water to his neighbours.⁶³

Hydraulic works needing the intervention of a hydraulic engineer are also acknowledged by several jurists from the Severan era. Two fragments in particular lead us to believe that constructions involving a bridged conduit were not rare. It appears that rights of conducting water and rights of passage could clash, and Paulus denied the possibility of building or digging an aqueduct where someone already had a right of way. Almost at the same period, on the contrary, Pomponius decided that it was allowed to build a bridge conducting water over another aqueduct.⁶⁴ In the case of Cicero or of Valerius Vegetus, the main part of the workforce was likely to be available within their large *familia rustica* and materials could have been found on the estate or in the near vicinity.⁶⁵ The layout, however, still required the skills of professional engineers. It necessarily implied a financial investment, the amount of which depended on the length of the construction, as Cicero pointed out. By contrast, the very simple water-channelling techniques mentioned by Columella, and sometimes observed by archaeologists, made them a very affordable investment, as long as the estate was provided with enough

⁶¹ *CIL* 11.3003 = *ILS* 5771 = *AE* 2002, 471.

⁶² Broise and Jolivet 1997: 1327–50; Andreau et al. 2002: 22.

⁶³ Bruun 2018.

⁶⁴ *Digesta* 39.3.11.pr. (Paulus 49 *Ad Edictum*); *Digesta* 43.20.3 §6 (Pomponius 34 *Ad Sabinum*). For other examples of such hydraulic constructions, see also *Digesta* 43.20.3 §5 (Pomponius 34 *Ad Sabinum*) and *Digesta* 43.21.1 §11 (Ulpian 70 *Ad Edictum*).

⁶⁵ Villas could indeed exploit resources from the ground such as stones and clay (Marzano 2015: 189–95). On the difficulty of determining whose task it was, the proprietor's or the contractor's, to choose and provide the materials, see Dessales 2011: 49.

water. The cost of irrigation systems, including the length of the channelling, was indeed directly linked to the availability of a water supply.

Access to water must therefore be considered as a part of the overall investment for those who needed to reach remote supplies.⁶⁶ In some cases, as with flood-based agriculture, irrigators just had to wait for the water to periodically come to their fields. In other cases, it was necessary to lift or to conduct water. Although water-lifting devices are difficult to trace in archaeology because they were mostly composed of perishable materials, they are well attested in papyri.⁶⁷ A simple technology, like the shaduf, was widespread in the empire, but it does not allow the exploitation of large quantities of water or the irrigation of large areas.⁶⁸ Archives of estates from the mid-third-century Fayum show that the maintenance of more sophisticated devices like water-wheels was the object of very careful provisions, which obviously reflect the significant investment they represented.⁶⁹ The recurrent mentions of such repairs in the Arsinoite nome show that artificial irrigation was used extensively.⁷⁰

Additionally, landholders did not hesitate to conduct water over a long distance, as the building of the Aqua Vegetiana illustrates. Along its course, it was possible for a canal to cross other estates, as the legal texts repeatedly indicate: Paulus thought that it was possible to ask the holder of the intervening land to traverse his plot, while Africanus mentioned that it was legitimate to cut across several properties to convey the water.⁷¹ Furthermore, legal texts clearly demonstrate that access to water through a right of servitude, even if it did not lead to actual ownership of the source, had a financial value and could be sold.⁷² The vocabulary used by the jurists from Quintus Mucius (2nd–1st century BC) to Paulus (2nd–3rd century AD) leaves no doubt on the subject: a water servitude could be sold (*vendere*) and bought (*emere*).⁷³ A private deed, recorded by Paulus, emphasizes the fact that a landholder accepted that he would share water from his fountain with his neighbour (maybe his brother) for free (*tibi do donoque*).⁷⁴ As an easement was, by rule, attached to the land and not to the individual who acquired the right, it clearly gave an economic value to the plot concerned.⁷⁵

⁶⁶ See the revenues generated by the fees paid to access water in the city of Ptolemais Euergetis in 113 AD: Habermann 2000: 132–7.

⁶⁷ Malouta and Wilson 2013.

⁶⁸ Pliny, *Historia Naturalis* 19.20.60.

⁶⁹ For instance, P. Flor. 16 and P. Rein. 52.

⁷⁰ Rathbone 1991: 223–4.

⁷¹ *Digesta* 39.3.17 §4 (Paulus 15 *ad Plautium*); *Digesta* 8.3.33 §1 (Africanus 9 *Quaestiones*).

⁷² In a chapter directly inspired from the Roman servitudes, the French Civil Code states that compensation may be negotiated between both parties (*Code Civil*, article 682).

⁷³ *Digesta* 8.3.14 (Pomponius 32 *Ad Quintum Mucium*); *Digesta* 19.1.3 §2 (Paulus 6 *Ad Sabinum*). See Bruun 2015: 136–41 in particular.

⁷⁴ *Digesta* 8.3.37 (Paulus 3 *Responsa*).

⁷⁵ Justinian *Institutiones* 2.3.3; *Digesta* 8.3.20 §2 (Pomponius 33 *Ad Sabinum*). On the economic value of the servitude rights, see Johnston 1999: 70; on the possibility of selling a servitude right and its implications regarding contract law, see Möller 2010: 318–21.

Storage obviously represented a human and even financial investment because of the construction of masonry cisterns. Water-lifting devices ranged from very basic investments with low output to more elaborate pieces of equipment. For conducting water, the costs depended on whether it was necessary to hire a professional engineer, on the length of the channels, and on the materials required. In all cases, access to water represented a strong concern for irrigators. Scarcity or distance could have been the reason why landholders decided to share supplies or equipment thanks to a collective investment.

Archaeological evidence for shared private hydraulic infrastructure is rare, although some instances are known in Italy and Gaul.⁷⁶ This scarcity is, however, probably due to a lack of information, since legal texts from the first to the third century *ad* repeatedly indicate that the practice was usual. Through the right of servitude, private individuals could be granted by a neighbour the right to share a water supply, but also the devices required for its distribution (*lacus*) and the conveyance (*fistula, rivus*).⁷⁷ To avoid conflicts, it was also possible to agree on a schedule between the different beneficiaries.⁷⁸ It is, however, not completely clear, to judge from the texts, if the practice of sharing a water servitude was intended for the benefit of the dominant estate, which enjoyed the right of conducting water, or for that of the subservient one, from which the water was led away. Ulpian explains that granting a right to several people diminishes in a proportionate quantity the amount of available water. For that reason, he advises that the validity of a servitude right be submitted not only to the consent of the water source's owner but also to that of the other beneficiaries.⁷⁹ The Severan jurist points out that it could be in the best interests of a proprietor to distribute his water widely, in exchange for certain compensation, in kind or in money, but that it would be to the disadvantage of the dominant estates. In fact, the sharing of the supply itself, through a right of servitude, is not really profitable since each beneficiary had to negotiate his right separately, and most probably had to pay separately.⁸⁰ By contrast, it was probably advantageous to share the infrastructure, as it reduced the cost of construction and maintenance.⁸¹ Although obviously modest in the case of small canals, the saving could have been more important for masonry buildings, private distribution *lacus*, or substantial water-lifting devices.

⁷⁶ Leveau 2006: 106–7; Wilson 2008: 749; Messineo 2005: 2.

⁷⁷ *Digesta* 43.21.3 §3 (Ulpian 70 *Ad Edictum*); *Digesta* 43.20.3 §5 (Pomponius 34 *Ad Sabinum*).

⁷⁸ *Digesta* 8.3.2 §1 (Neratius 4 *Regulae*).

⁷⁹ *Digesta* 39.3.8 (Ulpian 53 *Ad Edictum*).

⁸⁰ *Digesta* 8.6.16 (Proculus 1 *Epistulae*); *Digesta* 8.1.17 (Pomponius, *Regulae*). For a discussion about the independence of servitude rights, see Bannon 2009: 49.

⁸¹ *Digesta* 43.21.3 §3 (Ulpian 70 *Ad Edictum*); *Digesta* 43.20.3 §5 (Pomponius 34 *Ad Sabinum*).

Concessions from the public water network to private individuals are a well-known fact, evidenced through literature and epigraphy, in Rome as well as in provincial towns.⁸² In some cases, neighbours could even form an association in order to share water from the same *castellum*.⁸³ Although they are not frequently recorded, it is also possible to report a few examples of diversions of the supply towards villas and large estates. The *Anio Vetus* had, for instance, a special branch to water the gardens and farmland of Tibur.⁸⁴ The water of the *Aqua Crabra* was used to irrigate the numerous villas of the *ager Tusculanus*.⁸⁵ An inscription found on the Aventine depicts the irrigation scheme of several estates belonging to freedmen of Caesar and Augustus around Rome.⁸⁶ The drawing clearly shows reservoirs, which Stefania Quilici-Gigli believes to be a good model for large *lacus*, collecting water from drainage canals and to which distribution networks are connected. She has discovered such cisterns in the suburban area of Teanum, north of Naples, and in the Roman suburbs along the Tiber.⁸⁷ An inscription from the region of Amiternum registers several rural properties benefiting from a diversion of a local aqueduct.⁸⁸ Other archaeological examples may be found around Arles, in Gallia Narbonensis, or Cillium, in Africa Proconsularis.⁸⁹

Referring to a *senatus consultum* from 11 BC, Frontinus recalls that when an association of private individuals had been granted a common water supply, they had to build their own *castellum* in order to distribute water to each of the *socii*.⁹⁰ The benefit for the neighbours was obviously to reduce the construction costs. Indeed, the distribution devices designed for private functions observed in Italy are generally small and simple, but examples of more elaborate masonry equipment are also attested and would be more appropriate for the collective housing Frontinus seems to refer to.⁹¹ In certain cases, archaeology also shows that the same conduit from the common *castellum* could be shared by a row of houses, each supplied by a secondary canal.⁹² Common reservoirs and channels were thus probably funded by neighbours acting in association. Such associations are better documented in towns, but there is no reason why a similar system could not occur in rural areas and for

⁸² See amongst other examples Vitruvius, *De Architectura* 8.6.2; Frontinus, *De Aquis* 106.1 and 108 (*SC De aquaeductibus*); Frontinus, *De Aquis* 129.44–7 (*Lex Quinctia*); *Codex Theodosianus* 14.15.4; *Codex Theodosianus* 15.2.8; *CIL* 2–5, 267 = 1643 = *CILA* 3–1, 3; *CIL* 8, 51.

⁸³ Frontinus, *De Aquis* 106 and 109.4–5.

⁸⁴ Frontinus, *De Aquis* 6.6. See Evans 1993.

⁸⁵ Cicero, *De Lege Agraria* 3.9.7; Cicero, *Ad Familiares* 16.18.3.1.

⁸⁶ On *CIL* 6.1261, copied out in the seventeenth century and now lost, see Rodríguez Almeida 2002: 22–3.

⁸⁷ Quilici Gigli 1997: 208–12.

⁸⁸ *ILS* 5792 = *CIL* 1².1853. For discussion, see Buonocore 1994; Rodríguez Almeida 2000.

⁸⁹ Gazenbeek 2000: 227–8; Hitchner 1995: 155.

⁹⁰ Frontinus, *De Aquis* 106.

⁹¹ For discussion, see Dubouloz 2011: 345–6; Dessales 2013: 245–6. For different types of domestic distribution reservoir, see Dessales 2013: 211–16.

⁹² Dessales 2013: 246.

agricultural purposes. As the role of urban aqueducts for irrigation has been reconsidered in recent years, such schemes could arguably have applied to the networks recorded on the inscriptions of Amiternum and of the Aventine, as well as on a very similar document from Tivoli.⁹³

The construction of public aqueducts, like other monumental building projects, could be undertaken by the emperor, by local communities, or by private citizens.⁹⁴ Although it is well known that the emperor had the potential to contribute to municipal hydraulic equipment by tax rebates or by the provision of raw material or even of hard cash, imperial benefactions are seldom reported in inscriptions in Africa and Spain.⁹⁵ Meanwhile, the intervention of the legions in construction projects are mostly related to military camps or peace-keeping operations.⁹⁶ The completion of such works by municipalities, although attested, is however quite rarely commemorated.⁹⁷ If we take the examples from northern Africa and the Iberian Peninsula, we can see that the epigraphic documentation records gifts made by individual benefactors (*evergetai*) to their *patria* with some frequency, but this category is probably overrepresented due to the tendency of private citizens caring for their reputations to display their generosity as visibly as possible.⁹⁸ Finally, another well-represented category of financing public aqueducts is constituted by the combination of private and municipal funds.⁹⁹

As far as local construction projects are concerned, it must be stressed that local elites were constantly called upon to finance public works, either as benefactors acting voluntarily or through the payment of the *summa honoraria* and *pollicitatio*, which have arguably been considered the main sources of municipal income, at least in the western provinces.¹⁰⁰ If members of the

⁹³ *CIL* 14.3676 = *AE* 2002, 180 = *Inscrit* 4.239. For a discussion of the role of urban aqueducts in rural supply, see for instance Wilson 1999; Gazenbeek 2000; Leveau 2010; 2013.

⁹⁴ On the fact that there is no particular difference between aqueducts and other buildings in this regard, see Leveau 2001: 85; Duncan-Jones 1982: 75–8; 124–5.

⁹⁵ With the mention of the *indulgentia principis*: Verecunda (*CIL* 8.4205), Castellum Tidditanorum (*ILAlg*, 2–1, 3596 = *AE* 1946, 61). For examples in the Eastern Provinces, see Mitchell 1987: 344 sqq.

⁹⁶ Examples in Lambaesis (*CIL* 8.2572 and *CIL* 8.2658), in Gheria-el-Gharbia (*AE*, 1973, 573), in *Aquae Flavianae* (*CIL* 8.17727). On the difficulty of interpreting the mentions of construction projects undertaken by the legions on behalf of the emperor, see Le Roux 2009.

⁹⁷ In Saldæ (*CIL* 8.2728 = 18.122), Thugga (*CIL* 8.1480 = 26.534). See also in Thignica for a restoration at public expense (*CIL* 8.1412 = 15.204).

⁹⁸ Examples in Ebusus (*CIL* 2.3663), possibly in Dianium (*CIL* 2.3586), Ilugo (*CIL* 2.3240), Igabrum (*CIL* 2–5, 316), by testament in Mellaria (*CIL* 2.798), in Capsa Iustiniana (*CIL* 8.120), Leptis Magna (*CIL* 8.11), Sabratha (*AE* 1925, 103).

⁹⁹ Probably in Bisica (*CIL* 8.23.888), in Abbir Maius (*AE* 1993, 1738), in Thugga (*CIL* 8.1480), in Haïdra (*AE* 1988, 1119). Maybe in Castulo (*CIL* 2.3280) and Mellaria (*CIL* 2.798).

¹⁰⁰ Briand-Ponsart 1999: 217. Although it has been argued that the payment of the *summa honoraria* was only occasional and not an automatic requirement in some regions of the empire (see Zuiderhoek 2009: 44, for the province of Asia), it seems that in Africa, it was compulsory for

local aristocracy, who exploited agricultural lands, could naturally resort to their own water works when they needed to irrigate their plots, properties situated near the urban aqueduct could also have benefited from a diversion of the water supply. As we know, this was largely the case around Rome where landowners diverted urban water supplies for profitable agricultural purposes.¹⁰¹ This option would have been even more advantageous given the possibility of obtaining the water for free.¹⁰² Did the properties represented on various inscriptions along the course of public aqueducts belong to those who played a significant role in financing it? To answer this question, it would be necessary to know more about the constraints ruling the layout of the aqueduct.¹⁰³ This would unfortunately require an investigation well beyond the scope of this chapter. It is, however, useful to recall that the municipal *lex* of the colony of Urso gives evidence that the rights of rural properties had to be considered by the local assembly when they determined the route of an aqueduct. Decurions and *duumviri* had indeed to decide which estates the aqueduct could go through.¹⁰⁴ Besides technical requirements, some political negotiations probably took place between members of the assembly. It is well known that euergetism could be ruinous and that some aristocrats were very cautious not to squander their resources. Benefiting from the public network could thus have been an opportunity for them to reduce the costs of their private constructions and the amount of their investments.¹⁰⁵

Although not easily perceptible, shared investment in small-scale irrigation activity did exist. Whether human, material, or financial, it remained modest, however. Private water supplies were obviously not the object of large collective investments, at least not through servitude rights. The equipment and devices for shared systems were, on the contrary, more likely to be collectively funded, even in cases where the expense appears moderate. If concessions from the public network had to be subscribed individually, public infrastructure could however be shared. It probably helped to reduce the costs of irrigation, but depending on the amount of water needed, and probably the region, it was apparently not always sufficient, as the example of large irrigation facilities will show.

holding office or being a member of the local senate (Duncan-Jones 1962: 65–9; Jacques 1975). It is nevertheless possible that the situation of the African provinces was exceptional due to the wealth of the municipal elites.

¹⁰¹ Pliny, *Historia Naturalis* 31.42. Regarding this text, Philippe Leveau emphasizes that ‘in theory, the great landowners could hope to derive a profit from contributing, by gift or otherwise, to the construction of an aqueduct’ (Leveau 2001: 86).

¹⁰² Frontinus, *De Aquis* 80, 107–109; *CIL* 10.4760 = *ILS* 6296; *CIL* 12.5413.

¹⁰³ Leveau and Paillet 1976: 149 sqq.; 165 sqq.; Paillet 2007.

¹⁰⁴ *Lex. Col. Gen.*, 99.37; 100.1–8. See also Leveau 2015: 341.

¹⁰⁵ An idea that fits well with the assumed greed of Roman landowners (Purcell 1995: 162).

MODES OF COOPERATIVE INVESTMENT IN LARGE-SCALE IRRIGATION FACILITIES

Irrigation communities are rural associations gathered to share a common water resource thanks to collective hydraulic equipment.¹⁰⁶ Our knowledge of this sort of organization in Italy, Africa, and Spain is scarce, although two texts offer compelling glimpses of their functioning: the Lamasba decree from Numidia, dated to the reign of Elagabalus (218–22), and the Bronze of Agón (or *Lex Rivi Hiberiensis*) from Spain.¹⁰⁷ Both inscriptions illustrate the complexity and variety of that particular type of water management. The channel of Agón was probably an open diversion canal, situated on the right bank of the river Ebro—at least between 117 and 138.¹⁰⁸ In Lamasba, it has been proposed that the irrigation facility was a *qanat* (or *foggara*) or even a ‘hybrid between true foggaras and classic Roman aqueducts’.¹⁰⁹ The Lamasba decree records the water allocation of eighty-five plots. However, as we possess only fragments, the total property has been assessed at least at 170 plots and c.325 hectares.¹¹⁰ Our understanding of the financial capacity and of the general economic pattern of those communities is limited, due to a lack of evidence. The texts nevertheless clearly show that they were autonomously ruled by common interest.¹¹¹ Their existence and perpetuation depended on largewatering infrastructures. The question is, then, to evaluate what sort of investment was necessary to implement and maintain them.

Theoretically, the large rivers of the Roman Empire were public because they were considered a common good.¹¹² Their water could consequently be freely shared between those who held lands along the bank, proportionally to their possessions.¹¹³ In the case of the Agón community, the supply of water was therefore presumably free of charge, since it came from the Ebro. The implementation of the infrastructure, however, remained to be funded. As in any extensive irrigation scheme, not only was a workforce required, but also some qualified technicians, able to draw up a plan and calculate the gradient of the conduit, even if the level of competence varied according to the technology employed and the size of the facility. The community, in Agón

¹⁰⁶ For a global overview, see Maganzani 2010. Detailed examples in Richardson 1983; Troussset 1986; Cotton and Yardeni 1997: 212–16; see also Beltrán Lloris 2006b: 267–9, about the *Compagani Rivi Larensis*.

¹⁰⁷ *CIL* 8.4440; *AE* 1993, 1043 = *HEp* 5 (1995), 911 = *AE* 2006, 676 (Shaw 1982; Beltrán Lloris 2006a). Large irrigation facilities, i.e. very large canals, are much better known in Egypt: with the designations of different types of canals, according to their size, Schnebel 1925: 30–4.

¹⁰⁸ Beltrán Lloris 2006a for the *editio princeps*, an English translation by Michael Crawford, and an extensive commentary on the text.

¹⁰⁹ Fentress 1979: 168 sqq.; Wilson 2009: 33; 36.

¹¹⁰ Shaw 1982: 76, Table 3.

¹¹¹ Beltrán Lloris 2014a.

¹¹² Möller 2016: 13–14.

¹¹³ *Digesta* 1.8.2 §1 (Marcianus 3 *Institutiones*); *Digesta* 8.3.17 (Papyrus Iustus 1 *Constitutiones*) records a rescript made by the emperors Marcus Aurelius and Lucius Verus.

and elsewhere, might have had to hire people, which requires financial capital, or it might, on the contrary, have been able to recruit the workforce from its members, thus making use of its own human capital.¹¹⁴

Nevertheless, various reasons render an imperial intervention in the digging of the Ebro Canal, on the colonial territory of Caesaraugusta, as plausible as a community investment. Firstly, the *Lex* had been enacted under the direct authority of a representative of the emperor, the governor, or his legate.¹¹⁵ In the second place, the army possibly played a role in the implementation of other hydraulic networks observable within the territory of the colony. Indeed, the immense dams of Almonacid de la Cuba and of Muel were seemingly funded by the emperor when the colony was founded in 15 BC for Augustus' veterans.¹¹⁶ At least a part of the irrigated plots, situated on the territory of a colony where the centuriation stretched over 35 km along the Ebro River, appears to have been the property of veterans, and then that of their heirs.¹¹⁷ The implementation of an irrigation system played a significant role during the land division.¹¹⁸ A connection seems therefore possible between the establishment of water networks around the colony of Caesaraugusta and that of the centuriation.¹¹⁹ However, if the first edition of the text suggested a very large canal of about 20 km, exploited by a community composed of proprietors of *pagi* belonging to two different cities (the colony of Caesaraugusta and the municipium of Cascantum) a new reading of the title of the inscription leads to a different conclusion, namely that only one pagus was involved in the *Lex*.¹²⁰ In this case, we would have to think of a much smaller community, not as autonomous as was thought before. But it would also compel us to consider the irrigation in the Ebro Valley, as it is organized by the *Lex*, a much more commonplace phenomenon. Instead of a large community of irrigators, organized independently from the colonial and municipal powers, the picture would be that of numerous smaller communities, organized by *pagi*, within the boundaries of civic institutions. That is, however, not necessarily contradictory with an imperial intervention, or at least supervision.

Lamasba, unlike Caesaraugusta, was a *municipium* where nothing leads us to believe that the army played a role in the establishment of the network, and

¹¹⁴ Five centuries earlier, P. Lille 1 offers a particularly interesting basis for comparison and shows how gigantic these kinds of work possibly were. On the third-century-BC estate of Apollonios, in Philadelphia, a project of canals and dams representing the excavation of 84 km in total was reckoned to cost 1 talent and 3,834 drachmas, i.e. the work of 500 workers for three and a half months. Schnebel 1925: 48–9; Burnet 2003: 102–3 n. 46.

¹¹⁵ Beltrán Lloris 2014b: 61–2.

¹¹⁶ Beltrán Lloris 2014a: 130–1.

¹¹⁷ Beltrán Lloris 2006a: 188; Esparraguera et al. 1994: 199–200.

¹¹⁸ *Lex Colonia Genitiva* 104.10–19; Siculus Flaccus, *De Conditionibus Agrorum* 2.35; 43–4 (Guillaumin 2010: 47 and 49).

¹¹⁹ Willi and Beltrán Lloris 2012: 28.

¹²⁰ Tarpin 2014; followed by Einheuser 2017: 36–40. Previous suggestions in the same direction were already made by Castillo García 2008; 2009.

where the conflict that arose between the irrigators was apparently settled locally by a group of arbitrators linked to the *ordo*.¹²¹ Fairly modest plots were acquired by private agriculturalists, within a system controlled by the local aristocracy, which undoubtedly had an interest in the whole operation.¹²² The Roman state probably confined its involvement to providing an institutional and legal framework 'to protect property and water rights and to resolve conflicts'.¹²³ The qanat-based technology, used in the Aurès Mountains and the Sahara, and probably used in Lamasba, did not necessarily present many technical difficulties even though, depending very much on the length of the tunnel, it must have required a certain practical knowledge. Even if it was not actually introduced by the Romans, army engineers undoubtedly had mastered most of its technical features by the time the Lamasba decree was issued.¹²⁴ Around military settlements like Lambaesis (where, of course, veterans could also have settled), only about 30 km away, it is thus conceivable that military land surveyors could have helped the local communities with their networks.¹²⁵ The letters reproduced by the surveyor Nonius Datus on his *stela*, however, clearly indicate that, about half a century before and in the same region, the military authorities did not readily allow their engineers to contribute to civilian projects, and Pliny possibly refers to a lack of engineers for civilian public works in his letters from Bithynia.¹²⁶ Irrigation communities could then hire some qanat technicians, able to locate a water table and to determine the course of the underground canal. Examples of travelling specialists of the sort are known in Persia and Oman.¹²⁷ Papyri also attest that itinerant river-worker teams, specialized in the irrigation systems of the Nile, were hired by independent farming communities. They earned a daily wage or were paid on a piece rate, received food, and were treated with great respect.¹²⁸ Finally, some members of the irrigation communities of the region could have been expert enough to implement the equipment themselves, provided that the water table was not too deep. As for the workforce itself, it was probably available within the community, although, given that tunnelling was a hard and dangerous task, ethnographic examples of qanat digging from North Africa show that it was often assigned, as much as possible, to a servile workforce.¹²⁹

¹²¹ The status of *municipium* had been granted around the end of the first century AD, and the city never became a colony to our knowledge (*CIL* 8.18.501).

¹²² For a municipality involved in irrigation issues, see the example of the *Tabula Contrebiensis* (*CIL* 12.2951) in Birks, Rodger, and Richardson 1984: 47–8.

¹²³ Wilson 2012: 2–3.

¹²⁴ Wilson 2006a, esp. p. 213 for strong arguments against the hypothesis that the qanat-based technology was introduced by Romans from elsewhere in the empire.

¹²⁵ A few veterans are mentioned amongst the irrigators of Lamasba, such as Flavius Fortis or Iunius Felix.

¹²⁶ *CIL* 8.2728; Pliny, *Epistulae* 10.39–40.

¹²⁷ Birks and Letts 1976.

¹²⁸ Rathbone 1991: 166, 226.

¹²⁹ Grandguillaume 1973: 439, 448; Wilson 2006a: 210.

If the irrigators chose to employ itinerant hydraulic specialists, the wages ought to have been paid by the whole community. This therefore implies the creation and the management of a common fund. This system is well attested elsewhere, for instance in the *Tabula Contrebiensis* and even in the *Lex Rivi Hiberiensis*, although there is no clear indication in this case what the money was intended for.¹³⁰ The possibility that the works were carried out by some members of the community is also confirmed by other documents. It indeed appears that the detailed rules described in the inscriptions were necessary not only to avoid conflicts, but sometimes for an efficient organization of collective tasks as well. Irrigation networks require regular operations of cleaning, repair, redigging of canals, and strengthening of the dykes and dams. The *Lex Rivi Hiberiensis* provides a detailed account of the members' obligations on that aspect.¹³¹ Any breach of these compulsory assignments led to the payment of a fine to the common fund.¹³² In Egypt, corvée labours on the irrigation networks constituted a very strong obligation for anyone in the farming communities. The instructions given by a *strategos* from the nome of Oxyrhynchus in a papyrus 278 defined clear and severe penalties towards anyone neglecting these duties.¹³³

There are several reasons why rural or urban communities might have made use of the human capital at their disposal. The most obvious explanation is that compulsory labour allowed very convenient savings where financial capital might have been scarce. That could have been the case in Lamasba, and a free workforce was indeed an invaluable asset. One may nevertheless make another assumption, more germane to the distinctive features of irrigation communities: the corvées were a suitable means of controlling the workforce in a field of activity where timing was of great concern.¹³⁴ This indeed is what Danielle Bonneau observes in Egypt, where the flooding of the Nile was carefully observed.¹³⁵ Timing very much mattered in irrigation communities too, both for issues of water-sharing and also for maintenance operations, which were precisely achieved by corvée labour. In the midst of the Ebro community, the one-month period of the dry season when the water supply had to be shut down was determined by a vote of the irrigators' assembly, which indicates how important this decision was. The cleaning of the canal had to be carried out during that particular month and it was indubitably an

¹³⁰ *Tabula Contrebiensis* l. 13–14; *Lex Rivi Hiberiensis* §1b and §11a.

¹³¹ *Lex Rivi Hiberiensis* §1a, §2b, §3a, §3b.

¹³² *Lex Rivi Hiberiensis* §1b.

¹³³ P. Oxy. 12, 1409. For other examples on the topic of compulsory labour within a community, see Feissel 1985; Tarpin 2009: 133.

¹³⁴ Interestingly, P. Lille 1 states that the costs for the works on irrigation canals depended on the time of the year when they were undertaken. From winter to the harvest period, the costs increase by almost 40%, which is obviously due to the low availability of the workforce, when everyone is engaged in the fields (as also clearly shown by PSI 502).

¹³⁵ Bonneau 1993: 307; see also the comments of Horden and Purcell 2000: 254.

urgent task, for which the authorities might have wanted to have tight control of the workforce.¹³⁶

CONCLUSION

The costs of irrigation in single estates varied according to the technical constraints (length and construction of the conduit, necessity of storing water), but the efforts and investments also reflected the profits expected. That was probably the case for the cisterns observed along the Tiber Valley, not far from Rome: cultivating fresh produce in the area was a very profitable business, which explains the presence of such equipment. A key element concerning investments related to irrigation, in any situation, is however the access to water. In that respect, Roman law played an essential role through servitude rights. The numerous fragments of the *Digest* from the second century BC to the second century AD about water in rural contexts show how accessing the resource was important for landholders. Mere rights of use, even shared, even without the actual property ownership, had an economic value. As a water servitude was attached to the land itself, it certainly represented a useful investment to enhance the value of an estate. The role played by urban aqueducts in this regard is still poorly known and documents like the inscriptions of Amiternum, of Tivoli, or of the Aventine still raise many questions about the links between public aqueducts, rural or peri-urban estates, and irrigation. In the provinces, the members of the municipal aristocracy, proprietors of large estates on their city's territory, took decisions and participated in the funding of the hydraulic projects. Their economic interests presumably had an influence in the matter. Further investigations into concessions and diversions towards rural estates, as well as into legal and political constraints put on the course of the aqueducts, would help to understand it better.

One of the aspects that have been considered, collective investment, is uninformative as far as individual landholders are concerned. The texts related to the rights of servitudes show that such costs were individually incurred, especially because water servitudes were almost certainly negotiated personally. In irrigation communities, on the other hand, one can observe substantial human, material, and perhaps financial collective investments. It is significant that the documentation for such organizations comes from Africa and Spain, two dry regions where irrigation would be crucial to ensure sufficient production, or even any production at all in the case of pre-desert landscapes.¹³⁷

¹³⁶ The same concern applies to management of oases: Bédoucha-Albergoni 1976: 47–8.

¹³⁷ See also Cotton and Yardeni 1997: 203–23 for an example in the Judean desert.

As in oases, the environmental conditions, the scarcity of water or its irregular availability, led agricultural communities to cooperate in order to access the water resources and build the necessary infrastructure. A collective system was in those cases necessary and involved a collective investment, whether in material, human participation, or financial capital.¹³⁸

REFERENCES

- Andreau, J., Broise, H., Catalli, F., Galeotti, L., and Jolivet, V. (2002). *Musarna 1. Les trésors monétaires*. Rome.
- Bannon, C. J. (2009). *Gardens and Neighbors: Private Water Rights in Roman Italy*. Ann Arbor, MI.
- Barbera, M. (2015). 'Roma Caput Mundi dell'acqua: acquedotti e novità archeologiche', in J. Papadopoulos and E. Proietti (eds), *Simposio bilaterale di Archeologia Italia Israele (Expo Milano 2015, Padiglione Israele), 7–8 Ottobre 2015*. Rome, 1–24.
- Barker, G., Gilbertson, D., Jones, B., and Mattingly, D. J., eds (1996). *Farming the Desert: The UNESCO Libyan Valleys Archaeological Survey. Volume One, Synthesis*. Paris & London.
- Bedini, A. (1997). 'Modi di insediamento e bonifica agraria nel suburbio di Roma', in S. Quilici Gigli (ed.), *Uomo acqua e paesaggio: atti dell'Incontro di studio sul tema*. Rome, 165–84.
- Bédoucha-Albergoni, G. (1976). 'Système hydraulique et société dans une oasis tunisienne', *Études Rural*. 62: 39–72.
- Beltrán Lloris, F. (2006a). 'An irrigation decree from Roman Spain: the Lex Rivi Hiberiensis', *JRS* 96: 147–97.
- Beltrán Lloris, F. (2006b). 'Rural communities and civic participation in Hispania during the principate', in J. Remesal Rodríguez, F. Marco Simon, and F. Pina Polo (eds), *Repúblicas y ciudadanos: modelos de participación cívica en el mundo antiguo*. Barcelona, 257–72.
- Beltrán Lloris, F. (2014a). 'Irrigation infrastructures in the Roman West: Typology, financing, management', in A. Kolb (ed.), *Infrastruktur als Herrschaftsorganisation im Imperium Romanum. Herrschaftsstrukturen und Herrschaftspraxis III: Akten der Tagung in Zürich 19–20 Okt 2012*. Berlin, 121–36.
- Beltrán Lloris, F. (2014b). 'I pagi e l'organizzazione dell'irrigazione in Caesar Augusta', in L. Maganzani and C. Buzzachi (eds), *Lex Rivi Hiberiensis. Diritto e tecnica in una comunità di irrigazione della Spagna romana. Giornate di studio in ricordo di Giorgio Luraschi, 2–3 juillet 2012*. Naples, 55–73.
- Birks, J. S. and Letts, S. E. (1976). 'The 'Awamr: Specialist well and falaj-diggers in Northern Interior Oman', *Journal of Oman Studies* 2: 93–100.

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- Birks, P., Rodger, A., and Richardson, J. S. (1984). 'Further aspects of the Tabula Contrebiensis', *JRS* 74: 45–73.
- Bonneau, D. (1993). *Le régime administratif de l'eau du Nil dans l'Égypte grecque, romaine et byzantine*. Leiden.
- Briand-Ponsart, C. (1999). 'Summa honoraria et ressources des cités d'Afrique', in *Il capitolo delle entrate nelle finanze municipali in occidente ed in oriente. Actes de la Xe Rencontre franco-italienne sur l'épigraphie du monde romain, Rome, 27–29 mai 1996*. Rome, 217–34.
- Broise, H. and Jolivet, V. (1997). 'Une colonie étrusque en territoire tarquinien', *CRAI* 141.4: 1327–50.
- Brown, G. (2005). 'Irrigation of water meadows in England', in J. Klápště (ed.), *Water Management in Medieval Rural Economy. Rurality V, 27 septembre–2 octobre 2003, Lyon—Villard-Sallet*. Prague, 84–92.
- Bruun, C. (2015). 'Water use and productivity in Roman agriculture: Selling, sharing, servitudes', in P. Erdkamp, K. Verboven, and A. Zuiderhoek (eds), *Ownership and Exploitation of Land and Natural Resources in the Roman World* (Oxford Studies on the Roman Economy). Oxford, 132–49.
- Bruun, C. (2018). 'Servitudes et autres dispositions pour la distribution de l'eau en Italie et en Afrique du nord', in V. Brouquier-Reddé and F. Hurlet (eds), *L'eau dans les villes de l'Afrique du Nord et leur territoire. Actes du colloque de Bordeaux, décembre 2012* (Coll. Mémoires). Bordeaux, 35–42.
- Buonocore, M. (1994). 'Fra topografia ed epigrafia. L'acquedotto di Amiternum (L'Aquila)', *Journal of Ancient Topography* 4: 185–94.
- Burnet, R. (2003). *L'Égypte ancienne à travers les papyrus*. Paris.
- Carandini, A. (1985). 'Orti e frutteti intorno a Roma', in R. Bussi and V. Vandelli (eds), *Misurare la terra: centuriazione e coloni nel mondo romano. Città, agricoltura, commercio: materiali da Roma e dal suburbio*. Modena, 66–74.
- Castillo García, C. (2008). 'La tabula riui Hiberiensis: carácter del documento', *Espacio Tiempo y Forma. Serie II, Historia Antigua* 0.21: 255–7.
- Castillo García, C. (2009). 'Documentos de regadío en el valle del Ebro: ¿figuraba la vascona Cascantum en el Bronce de Agón?', in J. Andreu Pintado (ed.), *Los vascones de las fuentes antiguas: en torno a una etnia de la Antigüedad peninsular*. Barcelona, 415–21.
- Cotton, H. M. and Yardeni, A., eds (1997). *Aramaic, Hebrew and Greek Documentary Texts from Nahal Hever and Other Sites* (Discoveries in the Judaean Desert, 27). Oxford.
- Crawford, M. H. and Coarelli, F. (1977). 'Public Building in Rome between the Second Punic War and Sulla', *PBSR* 45: 1–23.
- DeLaine, J. (2001). 'Bricks and mortar. Exploring the economics of building techniques at Rome and Ostia', in D. J. Mattingly and J. Salmon (eds), *Economies Beyond Agriculture in the Classical World*. London, 230–68.
- Dessales, H. (2011). 'Les savoir-faire des maçons romains, entre connaissance technique et disponibilité des matériaux. Le cas pompéien', in N. Monteix and N. Tran (eds), *Les savoirs professionnels des gens de métier: études sur le monde du travail dans les sociétés urbaines de l'empire romain* (Collection du Centre Jean Bérard, 37, Archéologie de l'artisanat antique, 5). Naples, 41–63.

- Dessales, H. (2013). *Le partage de l'eau: fontaines et distribution hydraulique dans l'habitat urbain de l'Italie romaine* (BEFAR, 351). Rome.
- Dubouloz, J. (2011). *La propriété immobilière à Rome et en Italie, Ier–Ve siècles: organisation et transmission des praedia urbana* (BEFAR, 343). Rome.
- Duncan-Jones, R. (1962). 'Costs, outlays and Summae Honorariae from Roman Africa', *PBSR* 30: 47–115.
- Duncan-Jones, R. (1982). *The Economy of the Roman Empire: Quantitative Studies*, 2nd edition. Cambridge.
- Einheuser, V. (2017). *Studien zur lex rivi Hiberiensis: zur Rechtsdurchsetzung innerhalb einer Bewässerungsgemeinschaft im 2. Jh. n. Chr.* Wiesbaden.
- Esparraguera, J. M. G., Gil, E. A., Garriga, A. L., and Martínez, J. M. P. (1994). 'El estudio de los catastros rurales: una interpretación estatigráfica del paisaje', *Zephyrus. Revista científica internacional de Prehistoria y Arqueología* 47: 189–217.
- Evans, H. B. (1993). 'In Tiburtium usum: Special arrangements in the Roman Water system (Frontinus, Aq. 6.5)', *AJA* 97.3: 447–55.
- Feissel, D. (1985). 'Deux listes de quartiers d'Antioche astreints au creusement d'un canal (73–74 après J.-C.)', *Syria* 62.1: 77–103.
- Fentress, E. W. B. (1979). *Numidia and the Roman Army: Social, Military and Economic Aspects of the Frontier Zone*. Oxford.
- Gazenbeek, M. (2000). 'Interaction entre aqueduc et habitat rural. Deux cas d'étude en France méditerranéenne: Nîmes et Arles', in G. C. M. Jansen (ed.), *Cura Aquarum in Sicilia. Proceedings of the Tenth International Congress on the History of Water Management and Hydraulic Engineering in the Mediterranean Region, Syracuse, May 16–22, 1998*. Leiden, 225–30.
- Ghisleni, M., Vaccaro, E., Bowes, K., Arnoldus, A., MacKinnon, M., and Marani, F. (2011). 'Excavating the Roman peasant I: Excavations at Pievina', *PBSR* 79: 95–145.
- Grandguillaume, G. (1973). 'Régime économique et structure du pouvoir: le système des foggara du Touat', *Revue Occident Musulman Méditerranée* 13–14: 437–57.
- Guillaumin, J.-Y. (2010). *Les arpenteurs romains. Tome II, Hygin, Siculus Flaccus*. Paris.
- Habermann, W. (2000). *Zur Wasserversorgung einer Metropole im kaiserzeitlichen Ägypten: Neuedition von P. Lond. III 1177: Text, Übersetzung, Kommentar (Vestigia; Bd. 53)*. Munich.
- Heiken, G., Funicello, R., and De Rita, D. (2007). *The Seven Hills of Rome: A Geological Tour of the Eternal City*. Princeton, NJ.
- Hitchner, R. B. (1995). 'Irrigation, terraces, dams and aqueducts in the Region of Cillium (Mod. Kasserine). The role of water works in the development of a Roman-African town and its countryside', in P. Trousset (ed.), *L'Afrique du Nord antique et médiévale. 1, Productions et exportations africaines, actualités archéologiques*. Paris, 143–58.
- Horden, P. and Purcell, N. (2000). *The Corrupting Sea: A Study of Mediterranean History*. Oxford.
- Jacques, F. (1975). 'Ampliatio et mora: évergètes récalcitrants d'Afrique romaine', *Antiquités Africaines* 9: 159–80.
- Johnston, D. (1999). *Roman Law in Context*. New York.
- Kron, G. (2000). 'Roman ley-farming', *JRA* 13: 277–87.

- Kron, G. (2004a). 'Roman livestock farming in Southern Italy. The case against environmental determinism', in M. Clavel-Lévêque and E. Hermon (eds), *Espaces intégrés et ressources naturelles dans l'empire romain. Actes du colloque de l'Université de Laval, Québec (5–8 mars 2003)*. Besançon, 119–34.
- Kron, G. (2004b). 'A deposit of carbonized hay from Oplontis and Roman fodder quality', *Mouseion* 3.4: 275–331.
- Kron, G. (2012). 'Food production', in W. Scheidel (ed.), *The Cambridge Companion to the Roman Economy*. Cambridge, 156–74.
- Lassère, J.-M., ed. (1993). *Les Flavii de Cillium: étude architecturale, épigraphique, historique et littéraire du mausolée de Kasserine: CIL VIII, 211–216* (Collection de l'École française de Rome, 169). Rome.
- Le Roux, P. (2009). 'Armées et operae: un état des lieux', *CCG* 20.1: 143–55.
- Leveau, P. (2001). 'Aqueduct buildings: Financing and costs', in D. R. Blackman and A. T. Hodge (eds), *Frontinus' Legacy: Essays on Frontinus' De aquis urbis Romae*. Ann Arbor, MI, 85–101.
- Leveau, P. (2006). 'Les aqueducs d'Aquae Sextiae et la gestion de l'eau sur le territoire de la cité', in M. Provost and N. Nin (eds), *Carte archéologique de la Gaule. 13,4. Aix-en-Provence, Pays d'Aix, Val de Durance*. Paris, 93–109.
- Leveau, P. (2010). 'Les aqueducs romains, le territoire et la "gouvernance" de l'eau', in L. Lagóstena Barrios, J. Cañizar Palacios, and L. Pons Pujol (eds), *Aquam Perdv-cendam Cvravit: captación, uso y administración del agua en las ciudades de la Béticay el Occidente romano*. Cadiz, 1–20.
- Leveau, P. (2013). 'Évolutions climatique et construction d'ouvrages hydraulique en Afrique romaine', in F. Baratte, E. Rocca, and C. Robin (eds), *Les barrages dans l'Antiquité tardive*. Paris, 125–38.
- Leveau, P. (2015). 'Conclusions. Les aqueducs de Gaule et de la péninsule Ibérique: ingénierie hydraulique, archéologie de la construction et environnement', in L. Borau and A. Borlenghi (eds), *Aquae ductus. Actualité de la recherche en Franceet en Espagne. Actes du colloque international de Toulouse, 15–16 février 2013*. Bordeaux, 333–43.
- Leveau, P. and Paillet, J.-L. (1976). *L'alimentation en eau de Caesarea de Maurétanie et l'aqueduc de Cherchell*. Paris.
- MacKinnon, M. (2015). 'Changes in animal husbandry as a consequence of developing social and economic patterns from the Roman Mediterranean context', in P. Erdkamp, K. Verboven, and A. Zuiderhoek (eds), *Ownership and Exploitation of Land and Natural Resources in the Roman World* (Oxford Studies on the Roman Economy). Oxford, 249–73.
- Maganzani, L. (2010). 'Le règlement des riparia de communautés d'irrigation dans le monde romain', in E. Hermon (ed.), *Riparia dans l'Empire romain: pour la définition du concept. Actes des journées d'étude de Québec, 29–31 octobre 2009* (BAR International Series, 2066). Oxford, 225–32.
- Malouta, M. and Wilson, A. (2013). 'Mechanical irrigation: Water-lifting devices in the archaeological evidence and in the Egyptian papyri', in A. K. Bowman and A. Wilson (eds), *The Roman Agricultural Economy: Organization, Investment, and Production*. Oxford, 273–306.

- Marzano, A. (2015). 'Variety of villa production. From agriculture to aquaculture', in P. Erdkamp, K. Verboven, and A. Zuiderhoek (eds), *Ownership and Exploitation of Land and Natural Resources in the Roman World* (Oxford Studies on the Roman Economy). Oxford, 187–206.
- Mattingly, D. J. (1988). 'Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman empire', *JRA* 1: 33–56.
- Messineo, G. (2005). 'Villa a Tor di Quinto e nelle Tenute di Grottarossa e Acquatraversa', in *Roman Villas around the Vrbs: Interaction with Landscape and Environment. Proceedings of a Conference at the Swedish Institute in Rome, September 17–18, 2004*. Rome, 1–5.
- Mitchell, S. (1987). 'Imperial building in the eastern Roman provinces', *Harvard Studies in Classical Philology* 91: 333–65.
- Möller, C. (2010). *Die Servituten: Entwicklungsgeschichte, Funktion und Struktur der grundstückvermittelten Privatrechtsverhältnisse im römischen Recht* (Quellen und Forschungen zum Recht und seiner Geschichte, 16). Göttingen.
- Möller, C. (2016). 'Elemente des Römischen Wasserrechts – Lex und Natura, Servitus und Vetustas', in I. Czeguhn, C. Möller, Y. Quesada Morillas, and J. A. Pérez Juan (eds), *Wasser – Wege – Wissen auf der iberischen Halbinsel: vom Römischen Imperium bis zur islamischen Herrschaft* (Berliner Schriften zur Rechtsgeschichte, 6). Baden-Baden, 9–28.
- Monteil, M. (1999). *Nîmes antique et sa proche campagne: étude de topographie urbaine et périurbaine (fin VIe s. av. J.-C.–VIe s. ap. J.-C.)*. Lattes.
- Monteil, M., Breuil, J.-Y., Bel, V., and Pomarède, H. (2005). 'Réflexions sur une ville etsa proche campagne dans l'Antiquité: le cas de Nîmes (Gard)', in A. Bouet and F. Verdin (eds), *Territoires et paysages de l'âge du fer au Moyen Âge. Mélanges offerts à Philippe Leveau*. Bordeaux, 19–44.
- Morley, N. (1996). *Metropolis and Hinterland: The City of Rome and the Italian Economy, 200 BC–a.d. 200*. Cambridge.
- Paillet, J.-L. (2007). 'Réflexions sur la construction du specus des aqueducs antiques', *Africa* 3: 21–36.
- Patumi, M., d'Andria, R., Marsilio, V., Fontanazza, G., Morelli, G., and Lanza, B. (2002). 'Olive and olive oil quality after intensive monocone olive (*Olea europaea* L., cv. Kalamata) growing in different irrigation regimes', *Food Chemistry* 77: 27–34.
- Purcell, N. (1995). 'The Roman villa and the landscape of production', in T. J. Cornell and K. Lomas (eds), *Urban Society in Roman Italy*. New York, 151–79.
- Quilici, L. and Quilici Gigli, S. (1980). *Latium Vetus, III: Crustumium*. Rome.
- Quilici, L. and Quilici Gigli, S. (1986). *Latium Vetus, V: Fidenae*. Rome.
- Quilici Gigli, S. (1989). 'Paesaggi storici dell'agro falisco: i prata di Corchiano', *OpRom* 17.9: 123–35.
- Quilici Gigli, S. (1994). 'The changing landscape in the Roman Campagna', in J. Carlsen, P. Ørsted, and J. E. Skydsgaard (eds), *Land Use in the Roman Empire* (Analecta Romana, suppl. 22). Rome, 134–44.
- Quilici Gigli, S. (1997). 'L'irregimentazione delle acque nella trasformazione del paesaggio agrario dell'Italia centro-tirrenica', in S. Quilici Gigli (ed.), *Uomo aquae paesaggio: atti dell'Incontro di studio sul tema*. Rome, 193–212.

- Quilici Gigli, S. (2008). 'The management of the water regime in agrarian contexts in central Italy', in E. Hermon (ed.), *Vers une gestion intégrée de l'eau dans l'empire romain: actes du colloque international, Université Laval, octobre 2006*. Rome, 217–42.
- Rathbone, D. (1991). *Economic Rationalism and Rural Society in Third-century a.d. Egypt: The Heroninos Archive and the Appianus Estate* (Cambridge Classical Studies). Cambridge.
- Rawson, E. (1976). 'The Ciceronian aristocracy and its properties', in M. I. Finley (ed.), *Studies in Roman Property by the Cambridge University Research Seminar in Ancient History*. Cambridge, 84–102.
- Rea, R. (2011). 'Metropolitana di Roma Linea C. Stazione San Giovanni. Dati sulla cintura ortiva intorno a Roma tra la fine del I sec. a. C. e il III secolo', *Bolletino di archeologia* 2: 21–42.
- Richardson, J. S. (1983). 'The Tabula Contrebiensis: Roman law in Spain in the early first century BC', *JRS* 73: 33–41.
- Riedener, E., Melliger, R. L., Rusterholz, H.-P., and Baur, B. (2015). 'Changes in landscape composition of differently irrigated hay meadows in an arid mountain region', *Applied Vegetation Science* 18.2: 242–51.
- Rodríguez Almeida, E. (2000). 'Breve nota sulla Lex di una furcatio aquaria', *MEFRA* 112.1: 231–6.
- Rodríguez Almeida, E. (2002). *Formae urbis antiquae: le mappe marmoree di Roma tra la Repubblica e Settimio Severo*. Rome.
- Sadori, L., Allevato, E., Bosi, G., Caneva, G., Castiglioni, E., Celant, A., Di Pasquale, G., Giardini, M., Mazzanti, M., Rinaldi, R., Rottoli, M., and Susanna, F. (2009). 'The introduction and diffusion of peach in ancient Italy', in J.-P. Morel and A. M. Mercuri (eds), *Plants and Culture: Seeds of the Cultural Heritage of Europe*. Bari, 45–61.
- Schnebel, M. (1925). *Die Landwirtschaft im hellenistischen Ägypten* (Münchener Beiträge zur Papyrusforschung und antiken Rechtsgeschichte, 7). Munich.
- Shaw, B. D. (1982). 'Lamasba: An ancient irrigation community', *Antiquités Africaines* 18: 61–103.
- Tarpin, M. (2009). 'Organisation politique et administrative des cités d'Europe occidentale sous l'Empire', in B. Cabouret, J.-P. Guilhembet, and Y. Roman (eds), *Rome et l'Occident* (Pallas, 80). Toulouse, 127–46.
- Tarpin, M. (2014). 'La Lex rivi Hiberiensis: une restitution graphique de l'incipit', *ZPE* 192: 265–72.
- Terral, J.-F., Durand, A., Newton, C., and Ivorra, S. (2009). 'Archéo-biologie de la domestication de l'olivier en Méditerranée occidentale: de la remise en cause d'une histoire dogmatique à la révélation de son irrigation médiévale', *Etudes Héraultaises* 233: 13–25.
- Thomas, R. and Wilson, A. (1994). 'Water supply for Roman farms in Latium and South Etruria', *PBSR* 62: 139–96.
- Trousset, P. (1986). 'Les oasis présahariens dans l'Antiquité: partage de l'eau et division du temps', *Antiquités Africaines* 22: 163–93.
- Willi, A. and Beltrán Lloris, F. (2012). 'El regadío en la Hispania romana. Estado de la cuestión', *Cuadernos de prehistoria y arqueología de la Universidad de Granada* 21: 9–56.

- Wilson, A. (1999). 'Deliveries extra urbem: Aqueducts and the countryside', *JRA* 12: 314–32.
- Wilson, A. (2002). 'Machines, power and the ancient economy', *JRS* 92: 1–32.
- Wilson, A. (2006a). 'The spread of Foggara-based irrigation in the ancient Sahara', in D. J. Mattingly, S. MacLaren, E. Savage, Y. al-Fasatwi, and K. Gadgood (eds), *The Libyan Desert: Natural Resources and Cultural Heritage*. London, 205–16.
- Wilson, A. (2006b). 'The economic impact of technological advances in the Roman construction industry', in E. Lo Cascio (ed.), *Innovazione tecnica e progresso economico nel mondo romano atti degli Incontri capresi di storia dell'economia antica (Capri, 13–16 aprile 2003)*. Bari, 225–36.
- Wilson, A. (2008). 'Villas, horticulture and irrigation infrastructure in the Tiber Valley', in F. Coarelli and H. Patterson (eds), Mercator Placidissimus. *The Tiber Valley in Antiquity: New Research in the Upper and Middle River Valley*. Rome, 731–68.
- Wilson, A. (2009). 'Foggaras in ancient North Africa or How to marry a Berber princess', in V. Bridoux (ed.), *Contrôle et distribution de l'eau dans le Maghreb antique et médiéval. Actes du colloque organisé par l'Institut national du patrimoine de Tunisie et l'École française de Rome, Tunis, 22–25 mars 2002*. Rome, 19–39.
- Wilson, A. (2012). 'Water, power and culture in the Roman and Byzantine worlds: an introduction', *Water History* 4.1: 1–9.
- Witcher, R. (2008). 'The Middle Tiber Valley in the Imperial period', in F. Coarelli and H. Patterson (eds), Mercator Placidissimus. *The Tiber Valley in Antiquity: New Research in the Upper and Middle River Valley*. Rome, 467–86.
- Zuiderhoek, A. (2009). *The Politics of Munificence in the Roman Empire: Citizens, Elites and Benefactors in Asia Minor*. Cambridge

