8. 'Greater than the Pyramids': the Water Supply of Ancient Rome

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Since antiquity the water supply of ancient Rome has attracted much admiration and amazement. Dionysius of Halicarnassus, writing in the 1st century BC, said "In my opinion indeed, the three most significant works of Rome, in which the greatness of her empire is best seen, are the aqueducts, the paved roads, and the construction of sewers" (3.67.5; in particular, he is referring to the Cloaca Maxima at this point). The Roman geographer Strabo wrote that "Romans had the best foresight in those matters which the Greeks made but little account of, such as the construction of roads and aqueducts, and of sewers that wash away the filth of the city to the Tiber" (5.3.8). He goes on to say that "water is brought into the city through aqueducts in such quantities that veritable rivers flow through the city and the sewers". Perhaps the best-known acclamation of the aqueducts of Rome was made by Frontinus: "With such an array of indispensable structures carrying so many waters, compare, if you will, the Pyramids or the useless, though famous, works of the Greeks!" (*On Aqueducts* 16). Rome's greatness was being measured by these vast examples of hydraulic expertise which have left their not insignificant mark on the Roman countryside even today. Obviously at its most basic level water is a necessity of life, but as the city of Rome, and other cities in the Empire, grew, water became essential not only as a means to stay alive but also as an important cultural symbol. The construction of aqueducts and fountains were a matter of civic pride, often being provided by both the authorities and private individuals.[1]

Our main, and indeed only specific source on Roman water supply is Sextus Julius Frontinus who was appointed *curator aquarum* (Water Commissioner) at Rome by Nerva. Vitruvius also discussed aspects of Roman hydraulic technology, but the passages are not always very clear nor are they specific to Rome (*On Architecture* 8). Frontinus was a distinguished military commander who had been governor of Britain from AD 74–77 (or 78), and had been given the post of proconsul of Asia by Domitian in 85/86, but had no experience in hydraulic engineering. He was appointed *curator aquarum* in AD 97. The importance of this post was immense. Obviously it bestowed a good deal of prestige on the holder, but more importantly upon this office depended the health and sanitation of the city (see below). Frontinus' published work *De aquis urbis Romae* (*On the Aqueducts of Rome*, henceforth *On Aqueducts*) was the result of his tenure of the post. He had already written works dealing with military matters and land surveying, the latter perhaps being one of a number of reasons for his appointment.[2] He was faced with a highly technical field that any engineer would have told him needed a lifetime to master. Frontinus makes clear his own view of his published work; it was intended as a personal handbook and one which would hopefully be of use to his successors (*On* Aqueducts 2.3).[3] As well as descriptions of the individual aqueduct lines, their sources, delivery points and capacity he gives invaluable information on the uses and misuses of water in the city; it is clear that he felt these to be important issues to address. However, a major drawback is that because the work concentrates on the city of Rome it is not a source applicable to the rest of the empire. Nor is it a good source for some of the standard features of Roman aqueducts elsewhere.[4] He gives little space to the day-to-day maintenance of the aqueducts and does not discuss at all the construction of aqueducts and the accompanying work of surveyors. But then that was not his purpose. He was put in office to overhaul a system which had been badly affected by corruption and neglect; in that respect he has left us with a great legacy. His work survives in a corrupt text which provides conflicting figures on the amount of water entering Rome and the distribution of the individual lines; but despite these problems, Frontinus remains a formidable source which must form the basis of any study of Rome's water supply.[5]

In more recent times our knowledge of the Roman aqueduct system owes much to the work of Esther van Deman, published as *The Building of the Roman Aqueducts* in 1934, and the companion work by Thomas Ashby, *The Aqueducts of Ancient Rome*, published posthumously in 1935. Since their work was carried out, Rome has changed dramatically and the monuments have suffered accordingly, but Ashby's work in particular still remains the standard work nearly 70 years after its original publication.[6] Work continues to be carried out on the structures themselves, but now scholars are beginning to ask different questions of the material. Why were aqueducts introduced into the city in the first place? Where did they deliver their water and how? What different needs did they meet and how did these change over time? The answers give a broader context for the structures, an insight into the advantages of a piped water supply for the general population, and a greater understanding of urbanization in the Roman world. In this chapter a range of concerns will be explored. Firstly, the technology, distribution and circumstances of the construction of the aqueducts which supplied Rome; secondly, the administration of this water supply and the application of Frontinus in modern studies; and thirdly, the broader significance of the ancient water supply to Rome in more modern times.

THE OFFICE OF *CURATOR AQUARUM*

The functioning of the aqueducts and the provision of a water supply was as important a factor in the city's government and the well-being of the population as 'bread and circuses'. The office of *curator aquarum*, to which Frontinus was appointed, was established under Augustus, with a remit to maintain the water supply of Rome and a body of imperial slaves to carry out the necessary tasks.[7] In the Republic the provision of aqueducts and the maintenance of Rome's water supply was one of the duties of the censors; the Aqua Appia in 312 BC and the Aqua Tepula in 125 BC were both the work of the censors.[8] The Aqua Anio Novus (272 BC) was supplied by the *duumviri aquae perducendae* (Livy 9.29; Frontinus, *On Aqueducts* 5–8). For the Aqua Marcia (144 BC) a praetor was put in charge commissioned by the senate and the project was financed by a specific grant from the Senate.[9] The Aqua Appia was probably financed by tribute and the Tepula probably from general revenue. Thus although maintaining an adequate water supply to the city was one of the censors' duties, the details of funding could vary. Further, the censors were only in office for 18 months every five years, so many of the day-to-day matters (for example the right to take water) were dealt with by the aediles.[10] The maintenance work was contracted out and it was the responsibility of the censors and aediles to ensure the work was carried out properly (Frontinus, *On Aqueducts* 96).[11]

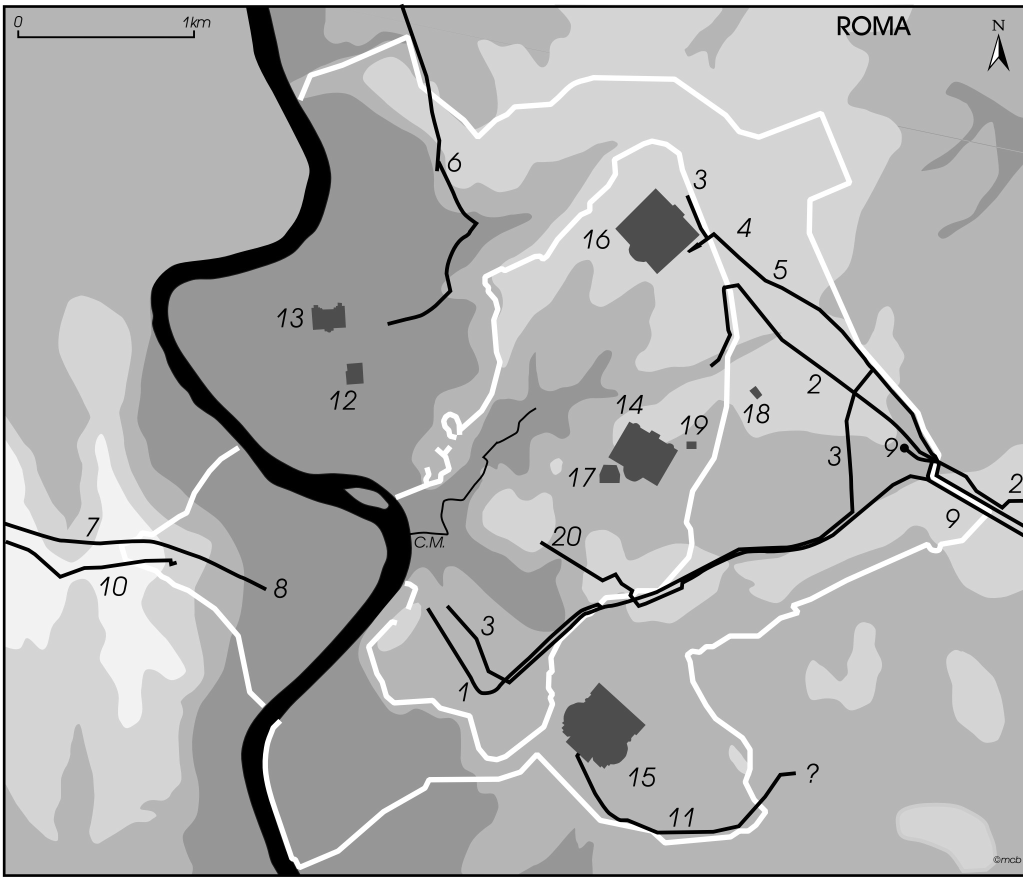

Fig. 8.1: Map of aqueducts. 1 Aqua Appia, 2 Aqua Anio Vetus, 3 Aqua Marcia, 4 Aqua Tepula, 5 Aqua Iulia, 6 Aqua Virgo, 7 Aqua Alsietina, 8 Naumachia Augusti, 9 Aqua Claudia & Anio Novus, 10 Aqua Traiana, 11 Aqua Antoniniana, 12 Stagnum and Baths of Agrippa, 13 Baths of Nero and Severus Alexander, 14 Baths of Trajan, 15 Baths of Caracalla, 16 Baths of Diocletian, 17 Baths of Titus, 18 Nymphaeum 'Trofei di Mario', 19 Sette sale, 20 Arcus Caelimontani. C.M. Cloaca Maxima.

In 33 BC as aedile Agrippa had not only built the Aqua Iulia but also repaired the existing aqueducts and maintained them with his own gang of slaves (240 men strong); these he bequeathed to Augustus who made them public property.[12] From these Augustus established the *cura aquarum*. This was a commission of three men of senatorial rank with a president, and it was provided with a staff which included architects and surveyors, clerks and the public slaves.[13] Under Claudius the post of *procurator aquarum* came into existence (Frontinus, *On Aqueducts* 105) which had executive control of the water supply and was concerned with it permanently; the *curatores* were often serving as part of their senatorial careers and all but one in the 1st century AD was of consular rank when he took up office. The post of *procurator* was held by imperial freedmen until the time of Trajan when the first equestrian *procurator* is encountered.[14] At first the appointment of *curator* was for life, an unusual phenomenon in Roman administration; it may be that the post was more honorary in nature, at least at this time. From the time of Nero, the *curator aquarum* was in office for an average of two years. For a large part of the 2nd century AD no *curatores aquarum* are known to us, but under Septimius Severus and Caracalla a new title is recorded, *curator aquarum et Minuciae*. [15]

It has been suggested that in the later 2nd century AD the headquarters for the *statio aquarum* was fixed at the Porticus Minucia, sharing its location with the *statio annonae*, and from the 4th century epigraphic evidence suggests it was at the Lacus Iuternae in the Forum Romanum.[16]

Being in charge of the water commission involved tasks in three main areas. The *curator aquarum*'s primary concern was to guarantee the water supply to the city and therefore he commanded a workforce of 700 slaves. He had control over private water lines and acted as judge in cases concerning aqueducts and water supply (Frontinus, *On Aqueducts* 17, 103, 104, 105, 109, 129). One of Frontinus' main concerns was to cut down on fraud.[17]

IN THE BEGINNING

Frontinus begins the main part of his treatise with the words: "For 441 years after the city was founded, the Romans were content with water supplies drawn from wells, springs or the river Tiber" (*On Aqueducts* 4.1). The site of Rome was well-provided with springs and streams, for example the Lacus Iuternae and the Lacus Curtius in the Forum Romanum. Springs, water deities and nymphs were closely linked with the foundation and growth of the city.[18] Such water sources retained their importance even after the construction of the aqueducts, and the well-watered site of the city was still discussed in glowing terms in the 1st century BC by Cicero (*On the Republic* II.3.5;5.10;6.1) amongst others.[19] The Tiber is not a particularly attractive prospect as a water source, but it was a logical one for early Rome. However, its waters also provided the easiest method of refuse disposal, either directly or indirectly via the sewers. This might involve anything from human waste to the odd dead body or two,[20] and it was a fact of which the inhabitants of Rome were reminded every time the river flooded. The Tiber was both threat and benefit to the citizens of Rome. It was a major transport route, particularly for the food brought not only from other parts of Italy but also from elsewhere in the Mediterranean and on which, by the imperial period, the city had become so heavily dependent. The regular flooding of the river was a constant threat to this food supply. There are constant references in Livy, Tacitus and Dio to flooding; in 193 BC the lower part of the city was flooded causing a number of buildings to collapse (Livy 35.9.2). The following year two bridges were washed away by the swollen river (Livy 35.21.5). In 23 BC the Pons Sublicius was destroyed for the second time in 40 years and for three days the city was navigable more easily by boat than by foot (Dio 53.33).[21]

The causes of such devastating inundations were partly natural and partly man-made. The Tiber, relatively fast-flowing in antiquity, rises in the Apennines and the water travels fast across a relatively wide flood plain before it reaches the rather narrower gorge formed by the hills at Rome coming close to the river banks. The site of Rome, of course, was originally very marshy and the valleys were only made habitable after a massive drainage and landfill scheme in the later 7th century.[22] Added to this was the rubbish which accumulated on the banks of the rivers, particularly in the port areas, and which restricted flow. Julius Caesar planned to alter the channel of the river in order, so Cicero claims, to double the size of the Campus Martius;[23] what effect this would have had is anyone's guess. Augustus dredged and cleared the river bed early on in his reign to facilitate flow and make the river less likely to flood (Suetonius, *Augustus* 30.1), but the floods continued.[24] We have very little evidence of who was responsible during the Republic for the care of the river and river banks, and although the importance of the river could not be overstated it may have been on a relatively *ad hoc* basis. In the early 1st century AD the *cura riparum et alvei Tiberis*, the commission for the Tiber, was created, comprising originally five senators who were charged with the supervision of the river and its banks.[25] However, from the time of Vespasian the commission appears to have been in the hands of one man of consular rank, and it continued its work into the 4th century when it became part of and answerable to the Urban Praefecture.[26] Under Trajan the care of sewers (*cura cloacarum urbis*) was made over to the *curator riparum et alvei Tiberis*, clearly demonstrating the authorities' awareness of the importance of co-ordinating these two closely connected concerns.[27]

The areas which suffered most in these floods were the low-lying areas such as the Campus Martius and the Emporium area, the latter of great importance for Rome's food supply. Even the heart of the city, the Forum Romanum, however, could also be affected; in AD 217 people in the Forum were swept away by the force of the waters (Dio 79.25). Hadrian raised the ground level of the northern Campus Martius, effectively creating a raised bank which would presumably have acted as a flood barrier.[28] The floods continued and it was not until the late 19th century and the canalisation of the river channel that such regular and devastating floods ceased.[29]

THE AQUEDUCTS

Long and impressive arcaded structures marching across the countryside in order to supply water to a city are often thought of as a characteristic of Roman urban design, though it would be true to say that not all Roman towns had an aqueduct.[30] It would also be true to say that not all aqueducts were high-level prominent structures; earlier Greek parallels for Roman aqueducts bringing water from outside were nearly all underground pipelines.[31] This is not because the Greeks lacked the technology; the Hellenistic aqueducts of Pergamum are clear witness to the fact that the Greek engineers were both familiar with, and skilled in, hydraulic technology.[32] It was more to do with the unstable and insecure times at which such pipelines were built. Aqueducts were vulnerable to enemy attack and very visible arcades could easily be destroyed or the water poisoned; hence such eye-catching arcades, so symbolic of Rome throughout the Empire, were projects of peace-time. The danger was shown very clearly during the 537 siege of Rome when the besieging Goths not only cut the aqueduct water supply to the city but also very nearly managed to enter the city along the channel of the Aqua Virgo (Procopius, *Gothic War* 1.1913, 18; 2.9.1–11). It has been commented on how early the Romans felt confident enough to build supply lines bringing water into the city of Rome.[33] These aqueducts became a necessity in order to supply baths, fountains, pools and basins which became so characteristic of the city and a symbol of its wealth. This is well illustrated by a passage relating to Agrippa's activities in 33 BC from Pliny the Elder (*Natural History* 121). In addition to renovating existing aqueducts and building the Aqua Iulia, he built 500 ornamental fountains, 300 of which were decorated with marble and bronze statues, as well as 700 basins and pools for public use. Such an abundance of water was impossible without a constant running water supply. By the early 3rd century AD Rome had 11 major aqueducts supplying her with water (Figs 8.1 and 8.2), nine of these are mentioned and described by Frontinus. In the Regionary

Name	Date	Length (m)	Source	Altitude of Source (m)	Level on entry into Rome	Average slope (m per km)	Length on arches (km)	Distribution within city
Appia	312 BC	16444.60	springs	30	20	0.6	0.1	II, VIII, IX, XI, XII, XIII, XIV
Anio Vetus	272–269 BC	63704.50	R Anio	280	48	3.6	–	I, III, IV, V, VI, VII, VIII, IX, XII, XIV
Marcia	144–140 BC	91424.10	springs	318	58.63	2.7	10	I, III, IV, V, VI, VII, VIII, IX, X, XIV
Tepula	125 BC	17745.40	springs	151	60.63	5.0	9	IV, V, VI, VII
Iulia	33 BC	22853.60	springs	350	63.73	12.4	10	II, III, V, VI, VIII, X, XII
Virgo	19 BC	20696.60	springs	24	20	0.2	1.2	VII, IX, XIV
Alsietina	2 BC	32847.80	Lake Alsietinus	209	71	6.0	0.5	XIV
Claudia	AD 38–52	68750.50	springs	320	67.40	3.8	14	ALL
Anio Novus	AD 38–52	86964.00	R Anio	400	70.40	3.8	11	ALL
Traiana	AD109	57700.00	springs	300	71.16	3.8	–	ALL
Alexandrina	AD 226	22,000.00	springs	65	43	1.0	2.4	IX

Fig. 8.2: Rome's aqueducts: statistics and features.

Catalogues of the early 4th century, 19 aqueducts are listed feeding 1352 public fountains, 15 *nymphaea*, 11 imperial *thermae*, 856 public baths and 254 reservoirs.[34]

Aqua Appia. By the latter part of the 4th century BC Rome's wells and springs were no longer sufficient providers of water, or perhaps of good drinking water; Rome's population was on the increase and it was felt necessary to supplement supply with water brought in from outside the city. The first of Rome's aqueducts, the Aqua Appia, was built in 312 BC by the censor Appius Claudius Caecus.[35] This aqueduct, fed by springs near Albano to the south, was technologically very simple. It ran underground for 11,190 paces (16.5 km), entering the city in the area of the Spes Vetus near the Porta Maggiore and is reported to have been carried on arcades for a distance of 60 paces (100 m) of its course within the city. It terminated at the place called the Salinae near the Porta Trigemina in the southern Forum Boarium (Frontinus, *On Aqueducts* 5–6). There is some disagreement among scholars over the exact course taken within the city, though most agree that the arcade (the term used by Frontinus is '*substructio*') was located in the valley between the Caelian and the Aventine very close to the Porta Capena.[36] There is no evidence for an elaborate terminus, but it was at a height of only 15m above sea level, meaning that its original distribution would have been much restricted. It probably supplied the Forum Boarium itself, the foot of the north-western part of the Aventine as well as the Campus Martius. These areas were developing fast at this time and presumably made worthwhile the extraordinary measures by Appius Claudius to bring water in from a source only 10 to 15 m higher than the delivery point (Fig. 8.2).[37] We know that a century later there were high rise residential blocks in the Forum Boarium area (Livy 24.47.15) and this seems to have been the main target area.

By Frontinus' day the Appia had been repaired three times: in 144 BC by Q Marcius Rex, 33 BC by Agrippa and 11–4 BC by Augustus. It supplied seven of the fourteen Augustan regions,[38] made possible by a number of secondary lines, including a conduit which was carried over the Pons Aemilia to Transtiberim.[39] One of the most important of these secondary lines was a branch added by Augustus to augment the supply of the original water line (Frontinus, *On Aqueducts* 5.7). This was known as the Appia Augusta and had a separate source, but it is doubtful that it had a separate line into the city.

Over the next 400 years the amount of water brought to Rome was to increase by a factor of 15. It has been demonstrated that the construction of new aqueducts in the last 250 years BC can be tied in to periods of population growth in the city; such periods are prefaced by major episodes of military campaigning and a lull in building in the city.[40] However, although the suggested sequence of war, population growth, aqueduct (and other) building activity does fit the general scheme, the sequence of war, which brings in booty (i.e. finance), leading to building activity which leads to population growth, equally fits the evidence (and is certainly the case with the Aqua Anio Vetus). From the time of Agrippa and Augustus, the emphasis was on providing a better and more abundant supply of water with a wider distribution, but the construction of a large imperial bath building became a prime factor. [41]

Aqua Anio Vetus. The construction of Rome's second aqueduct was an altogether more ambitious enterprise. This was the Anio Vetus, built in 272 BC by the censors M'. Curius Dentatus and L. Papirius Carbo, and funded with the spoils taken from Pyrrhus.[42] As its name implies the intake for the aqueduct was from the Aniene River (the ancient Anio) above Tivoli. Like the Appia most of the channel ran underground, but it was almost 4 times the latter's length with a meandering course to maintain a steady gradient; by Frontinus' time it was 64 km long, but it had been shortened by the addition of bridges and arcades (Fig. 8.2).[43] According to Frontinus (*On Aqueducts* 21.3), it came into the city underground at the Spes Vetus and distributed its water just inside the Servian Wall at the Porta Esquilina. Remains of a *castellum* as well as traces of the *specus* (channel) were found in the 1970s which seem to corroborate Frontinus' account.[44] Its original distribution is rather more difficult to ascertain, though as its delivery point was fairly low (48 m above sea level) it was probably restricted to those areas easily within reach by gravity flow of the Porta Esquilina. However, it gives good evidence for the expansion of the city and this time towards the higher ground to the east.[45] Its distribution by the end of the 1st century AD had been much extended, presumably through the addition of later branch lines, and it supplied water to 10 regions.[46] Despite this broad distribution, the quality of its water was rather poor; river water anyway could be heavily laden with sediment and the Aniene was particularly muddy after storms. From the late 1st century AD at least its supply was as far as possible restricted to the irrigation of gardens and "the meaner services of the city".[47]

Aqua Marcia. The first half of the 2nd century BC was a busy time overseas for Rome, culminating in the sack and destruction of Corinth and Carthage in 146 BC. Now Rome was not just mistress of the Mediterranean; as capital her population had been growing since the Second Punic War and with the successes over Carthage and Macedonia it swelled rapidly.

Building was also on the increase and there is literary evidence that a new aqueduct had been planned in 179 BC by the censors for that year;[48] the project was blocked when Licinius Crassus refused a right of way across his land. Livy mentions the planned construction of arches, a significant feature on two counts, given that Rome's first two aqueducts were underground lines, at least outside the city. Firstly this implies the introduction of a relatively high line, representing a much more ambitious project. Secondly, it was also a physical display of Rome's new-found status and accompanying confidence after the Second Punic War. In 144 BC work finally started on the construction of a new aqueduct by the praetor Q. Marcius Rex, thus named the Aqua Marcia.[49] It was the first of Rome's high-level aqueducts and an astonishing engineering achievement which cost more than 180,000,000 sesterces (a figure which Platner and Ashby in 1929 reckoned to be in the region of $1,800,000); most scholars agree that the enterprise was most probably funded by booty from Corinth and Carthage.[50] The aqueduct, renowned for the clarity and quality of its water,[51] was fed by springs high up in the Aniene valley and its channel was 61710½ paces (91 km) long (Frontinus, *On Aqueducts* 7.6), making it the longest of all Rome's aqueducts (Fig. 8.2). The ancient installations at the source of the Marcia were destroyed when the modern line of the Acqua Marcia Pia was constructed in the 1870s, but some of the ancient remains were documented by Lanciani and Ashby.[52] Initially the route of the Marcia followed more or less that of the Anio Vetus. Near Romavecchia, the channel emerged from underground to be carried on arcades the remaining *c.* 10 km into the city (Fig. 8.3).[53] The most impressive trace of the Aqua Marcia, which very well demonstrates the constant repair, renovation and maintenance required by these supply lines, is the Ponte Lupo.[54] This carried the channel (*specus*) across the Valle dei Morti south-east of Tivoli. This is a massive structure 110–115 m long, with a maximum height of over 29 m. Van Deman neatly summarised the nature of this construction: "This colossal structure, an epitome in stone and concrete of the history of Roman construction for almost nine centuries, is composed of two lofty arches of early cut stone over the stream with heavy abutments of Augustan concrete on both banks, enclosed but a few years later in walls of concrete of the same general type which in their turn were reinforced by massive walls at least three times in as many centuries, with extensive later repairs".[55] Essentially the remodelling of the bridge reflects the major repair programmes of Agrippa and Augustus. The bridge was originally built of tufa blocks quarried from the banks of the valley; the two tall central arches are constructed of the original neatly squared blocks. A century later Agrippa replaced much of the original bridge using concrete for the first time in an aqueduct arcade.[56] However, only a few years later this structure required shoring up and Augustus increased the thickness. Much of this was similarly replaced by Titus in concrete faced with *opus reticulatum*, and more buttressing was added by Hadrian. In AD 212 a massive retaining wall, 8–15 m thick, was constructed under Caracalla. At the end of the 3rd century another such wall was built on the opposite side, 6 m thick and built up to the height of the channel. It was probably designed as a counter-weight to Caracalla's wall.[57] Another bridge, also built as part of the original line in 144 BC and similarly renovated and encased by later repairs, can be seen at Ponte S. Piero which carried the Marcia across the Valle della Mola.[58]

At Romavecchia, where the Marcia emerged from underground, stretches of the arcade can still be seen with the channels of the later Aqua Tepula and Aqua Iulia above, and the 1585 channel of the still functioning Acqua Felice which runs on the north side (Fig. 8.3).[59] The Marcia came into Rome at the Spes Vetus (Fig. 8.4) and it terminated at the highest point on the Viminal Hill within the Servian Wall near the Porta Viminalis (near the later Baths of Diocletian), though the exact location is unknown.[60] A branch, the Rivus

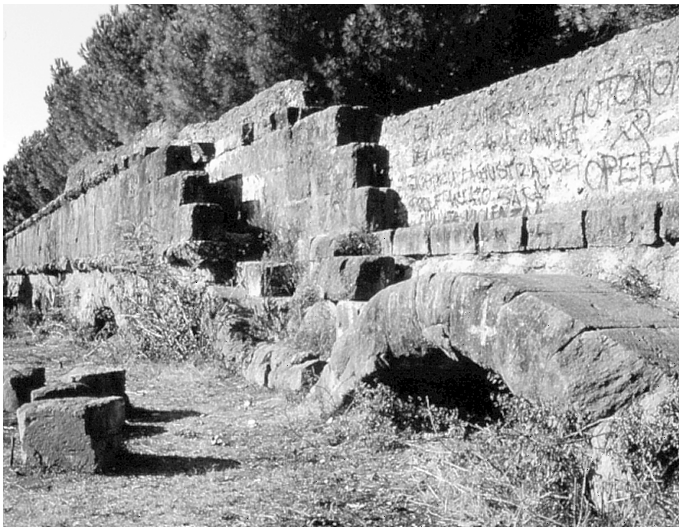

Fig. 8.3: The channel and arcade of the Aqua Marcia at Romavecchia. The channel of the Aqua Tepula partially survives on top (Photo: author).

Herculaneus, left the main line near the Porta Tiburtina and crossed the Caelian to the Aventine.[61] In the early 3rd century Caracalla brought a branch from the Marcia, the Aqua Antoniniana, to supply his baths, and the Baths of Diocletian may also have been supplied from its terminal reservoir by a channel. A large reservoir, 91m by 16 m, known as the Botte di Termini and destroyed in 1876, was built by Diocletian as part of the construction programme.[62]

The Marcia served the northern parts of Rome especially the Quirinal and Viminal (Frontinus, *On Aqueducts* 19.3–5); visible and in place until 1992 near Termini was a small circular distribution point built of tufa and travertine. The exact function of this is unknown though it did have two lead pipes issuing from the north sides.[63] Perhaps most importantly, waters from the Marcia reached the Capitoline Hill, probably by siphon.[64] By Frontinus' time the Marcia had a very wide distribution and supplied the Palatine, the first of Rome's aqueducts to do so; the higher delivery point of the supply probably made this possible, using a siphon. The Aqua Marcia greatly improved the supply to the city centre and southern Campus Martius. [65]

With the building of the next two aqueducts we can see a development of the arcade system which is without parallel elsewhere in the Roman world. As the needs of the city increased, these extra requirements were met by tapping new springs. Additional supplies were not fed into the existing system, but completely new channels were constructed. In their upper courses aqueducts followed the hillsides, but once they emerged out onto the Roman Campagna they required expensive masonry arcades. To reduce materials, effort and cost a new channel was simply carried on top of an existing one, piggy-back fashion. In Agrippa's rebuilding work in 33 BC the Marcia acquired the Tepula and the Iulia to form a triple-decker, though the Tepula may have used the arcades of the Marcia from the beginning (see below).

Aqua Tepula. The Aqua Tepula is the most problematic of all the republican aqueducts. It was constructed in 125 BC but because it was radically altered by Agrippa, most of the information given by Frontinus refers to its 1st century AD state; equally there is very little archaeological evidence for its original form.[66] In addition the original purpose of the aqueduct is difficult to ascertain. Its construction only 20 years or so after that of the Marcia must indicate a fairly

Fig. 8.4: A pier of the Aqua Marcia preserved in the later Aurelianic Wall. The smaller channels of the Tepula and Iulia are visible above the stone channel of the Marcia (Photo: author).

rapid growth in the city's population, as well as the fact that it also apparently supplied the Capitoline, probably to supplement the rather limited supply of the Marcia.[67]

The springs that fed the Tepula were located on the northern slopes of the Alban Hills at the foot of Monte Cimino;[68] the water was warm (60°F) giving the aqueduct its name. As a result the water was probably not suitable for drinking and the aqueduct may well have been introduced originally for industrial uses to free up the Marcia for drinking. Given that the Tepula supplied the Capitoline, it would have had to have come into the city at a high level. It has been suggested, therefore, that in order to cut down on the expense of building more arcades (which had been built for the Marcia only 20 years before), the arcades of the Aqua Marcia were used even at this early stage; Agrippa's rebuilding work, however, makes it very difficult to elucidate the exact situation.[69]

Aqua Iulia. The Aqua Tepula was completely reworked in 33 BC when Agrippa was aedile in conjunction with his construction of the Aqua Iulia (Frontinus, *On Aqueducts* 9). The 1st century BC had been riven with political strife and civil war and by the 30s BC Rome's water system was in desperate need of attention. Agrippa repaired the Appia, Anio Vetus and Marcia whose channels were in a very bad state (Frontinus, *On Aqueducts* 9.3). It was also at this time that he laid the foundations of the administrative system for Rome's water supply, *the cura aquarum* which was established in 11 BC (see above).[70]

The source of the Aqua Iulia was a set of abundant springs near modern Grottaferrata and Agrippa added the waters of the Tepula, the combined waters running for 6 km to a settling tank near Capanelle.[71] From here the two lines were separated and carried into Rome on the arcade of the Marcia. Both these additional channels were much narrower than the original cut-stone channel of the Marcia. Further, they were not placed centrally over the bottom channel. One side wall was directly above the side wall of the Marcia below, while the other rested upon the Marcia's cover slabs. When the Marcia was built it had not been anticipated that it would have to bear such extra weight and these slabs often cracked. The Tepula's channel had to be narrower because the aqueduct had a smaller discharge, but the height had to be the same to permit access for maintenance. If it had been as wide as the Marcia, with the smaller volume of water, the flow would have been reduced and the risk of silting up of the channel increased.[72]

The Iulia was the third highest of all the lines (Frontinus, *On Aqueducts* 18.4) and had a capacity almost double that of the Tepula. Its terminus was near that of the Marcia near the

Porta Viminalis[73] and it had a wide distribution via a number of secondary *intra urbem* branches by the time of Frontinus (*On Aqueducts* 83.2) (Figs 8.2 and 8.5). The Iulia was very important in Agrippa's general reworking of Rome's water supply and it made a significant contribution to the total volume of water coming into Rome at the time. The Iulia supplied a large proportion of its waters to public areas, in contrast to the Tepula the water of which was destined more for private users. Certainly by mixing the waters of the two lines, Agrippa much improved the earlier aqueduct, increasing its capacity and lowering the temperature of the water. Further, the Iulia had a specific function, that of supplying water for the Augustan building programme.[74]

Aqua Virgo. In 19 BC Agrippa added the Aqua Virgo to Rome's water system, the purpose and distribution of which was quite different from the Tepula and Iulia (Frontinus, *On Aqueducts* 10; Dio 54.117).[75] This aqueduct is noteworthy on a number of counts; it is the only ancient aqueduct which has continuously functioned since antiquity; it was the only one to enter Rome from the north; and it was the first aqueduct line to be built to supply a specific complex of buildings in a specific area (the Baths of Agrippa, the Stagnum and the Euripus on the Campus Martius).[76] Further, apart from the Alsietina and the Appia, this was also one of the lowest aqueducts in terms of elevation (20 m above sea level) (Frontinus, *On Aqueducts* 18) (Fig. 8.2). For an aqueduct to be most effective and reach most of any city it needed to enter the city at or close to the highest point, a reality of which Frontinus was certainly aware (*On Aqueducts* 18). However, the purpose of this line, to supply a very low-lying area, negated this need to some extent.[77] Pliny the Elder particularly comments on the special suitability of its water for the purposes of bathing in comparison to the Marcia which was ideal for drinking water (*Natural History* 31.42). The springs which supplied the Virgo were 10.5 km from Rome. According to Frontinus (*On Aqueducts* 10) the aqueduct received its name as a result of a young girl showing Agrippa's engineers the hidden source which supplied good quality, clear, cool water in abundance. Pliny the Elder (*Natural History* 31.42) gives another explanation: "The springs are close to the stream of Hercules, but because the waters of the Virgo run away from this, it was so named". The water channel was underground for most of its course until it emerged in the area of the modern Piazza di Spagna. The channel was then carried on a low arcade to the area of the Saepta Iulia whence the water was distributed.[78] The complex supplied by the aqueduct was large indeed. The Stagnum, essentially an artificial lake, was extensive enough for boating; swimming is only mentioned by the sources in connection with the Euripus.[79]

The distribution of water from the Virgo complemented that of the Aqua Iulia, supplying water to three regions.[80] It was clearly planned to meet the specific requirements of districts only marginally supplied by earlier aqueducts, as well as to supply Agrippa's new set of buildings (Fig. 8.5). At this time the Campus Martius was undergoing major monumentalization and until this time had been badly served by Rome's water supply lines.[81] The Transtiberim was supplied by a branch of the Virgo carried across the Pons Agrippae, and it has been suggested that this was the reason for the bridge's construction.[82] By Frontinus' time the Transtiberim region was supplied by the Appia, the Anio Vetus and the Marcia, the pipes being carried across the Tiber on bridges.[83] However, the distribution from the Virgo via the Pons Agrippae started further upstream and therefore could have had a much wider delivery into the northern region of Transtiberim.[84]

Aqueduct	Castella	Delivery extra urbem Caes. nom.	Delivery extra urbem priv.	Total delivery intra urbem	nomine Caesaris intra urbem	privati intra urbem	usibus publicis intra urbem	opera publica (Total 95)	lacus (Total 591)
Appia	20	5		699	151	194	354	123 (14)	226 (92)
Anio Vetus	35	169	404	1508.5	64.5	490	552	196 (19)	218 (94)
Marcia	51	261.5		1472	116	543	491	61 (15)	113 (256)
Tepula	14	58	56	331	34	237	50	7 (3)	32 (13)
Iulia	17	85	121	597	18	196	383	181 (11?)	65 (28)
Virgo	18	200		2304	509	338	1457	1380 (16)	51 (25)
Alsietina		254	138						
Claudia & Anio Novus	92	728	439	3498	816	1567	1115	374 (18)	585 (226)

Fig. 8.5: Capacities and distribution of Rome's aqueducts according to Frontinus.

Aqua Alsietina. Agrippa's provision and repair of the Tepula, Iulia and Virgo reflect supplies for particular needs, although they also provided water more generally. The last Augustan aqueduct was the most specialised of all. This was the Aqua Alsietina, built by Augustus to supply his *naumachia* on the west bank of the Tiber, the only aqueduct to deliver water to a point outside the city limits.[85] The source for this aqueduct was the Lacus Alsietinus, the modern Lago Martignano to the north of Rome. Most of the 33 km course was underground and it came into the urban area near the later Porta Aurelia, after which it was carried on an arcade before again going underground to Trastevere.[86] The aqueduct arrived at the city at a high elevation (71 m above sea level) and as such would have had a wide distribution throughout the Transtiberim region.[87] The *naumachia* was at a much lower level (*c*. 16 m above sea level), and in order to achieve this much lower elevation over such a short distance, the water was probably used to irrigate gardens on the hillslopes; it has also been suggested that it was used to power mills on the slopes of the Janiculum (see below).[88]

The *naumachia* basin itself was inaugurated with a magnificent show of naval warfare in 2 BC in connection with the dedication of the Temple of Mars Ultor. It was located in the area bounded by S. Cosimato, S. Francesco a Ripa and the Janiculum 1800 Roman feet by 1200 Roman feet.[89] The water of the Alsietina was considered unwholesome in the extreme and Frontinus (*On Aqueducts* 11.2) says it was not used for public needs but was fit only for industrial uses and for watering gardens. However, although the population of Transtiberim was usually by this time supplied by water from the Marcia and the Virgo which was piped across from the east bank, when these were cut during bridge maintenance, the people had no choice but to use the Alsietina's doubtful supplies.[90] Frontinus in fact gives very little detail of the Alsietina.[91] It is true to say that the line would have declined in importance after the introduction of the Aqua Traiana in the early 2nd century AD, possibly even going out of use. Philip the Arab is recorded as having constructed a *naumachia* in the Transtiberim region to celebrate the millennium of Rome in AD 247, but it could easily have been supplied by the Aqua Traiana – if this notice has any truth at all.[92]

Aqua Claudia and Aqua Anio Novus. In the early 1st century AD water was becoming increasingly important for display and decorative purposes, so much so that within 50 years Agrippa's aqueducts were no longer sufficient. In AD 38 Caligula started the construction of probably the two greatest aqueducts in terms of volume of water carried into Rome – the Aqua Claudia and the Aqua Anio Novus.[93] The project was completed by Claudius in 52; in Frontinus' description the two lines are seen as a single project although they have very different sources.[94] The Claudia was fed by springs in the Aniene valley further upstream from those serving the Marcia and considered in quality second only to the Marcia.[95] It also emerged from underground at Capanelle to cross the Campagna near Romavecchia on a lofty arcade for a distance of 10 km to the city (Fig. 8.6).[96] At Spes Vetus it was carried across the Via Labicana and Via Praenestina on the Claudian monumental arch now known as the Porta Maggiore (Fig. 8.7).[97] The Anio Novus, as the Anio Vetus before it, was fed by the Aniene river itself and was initially troubled by the infiltration of mud despite special settling tanks at the point of intake (Frontinus, *On Aqueducts* 15.1–2; 90; 93.4). The intake was remodelled by Trajan to deal with the sediment problem and indeed the quality was improved immeasurably. The source was moved upstream to one of the lakes formed when Nero had dammed the Aniene for a pleasure lake at his villa at Subiaco.[98] Near Capanelle the channel passed through a settling tank (see below) and for the approach to Rome across the Campagna was carried piggy-back by that of the Claudia;[99] the consequences of carrying two channels on one arcade not designed for the purpose can be clearly seen. The arcade and *specus* of the Claudia were constructed of neatly cut blocks of *peperino* tufa; the channel of the Anio Novus was of concrete, clearly indicating that this arrangement had not been part of the original plan.[100] The tendency was for the arches to settle or even crack from the extra weight causing leaks in the conduits above. Various later repairs and reinforcements were designed to correct the problem. Under Hadrian bracing arches were built between the piers, and support was inserted where necessary in the form of arches of brick as a liner to the stone arcades. This was not wholly successful because the liner often settled more than the arch it was supposed to support, leaving gaps between the two. [101]

The Aqua Claudia and Aqua Anio Novus were, with the Aqua Traiana, the highest of Rome's aqueducts in terms of urban elevation, and their waters were mixed within the city before distribution, much to the disapproval of Frontinus (*On Aqueducts* 72.6; 91.1–4; see below) (Fig. 8.2). The terminal *castellum* was located near the 'Temple of Minerva Medica' and was recorded in a famous engraving of Piranesi; it was unfortunately destroyed in a fire in 1880 (Fig. 8.8).[102] Despite some of its waters being mixed with the Anio Novus, a branch left the Claudia before this occurred and the water from this supply line was distributed under the name of Claudia. This is the Arcus Caelimontani. This branch diverted from the main conduit just south of the Porta Maggiore. It maintained a high elevation for 2 km across the ridge of the Caelian to terminate behind the platform of the Temple of the Deified Claudius at the area known as 'Aqueductium' on the *Forma Urbis* (Fig 8.9). Nero was responsible for this line, hence Frontinus referring to it as Arcus Neroniani (Fig 8.10). The purpose of this line is one which has been questioned in recent times.[103] Most scholars have assumed that Nero built the branch line to supply his Domus Aurea and its extensive water systems, in particular the lake in the valley of the Colosseum and the *nymphaeum* on the north-west slopes of the Caelian (actually the unfinished Temple of the Deified Claudius). After Nero's death and the dismantling of much of these systems, the line continued to be useful, delivering good quality water to the centre of the city. However, the lake could have been just as easily formed by damming the stream which flows between the Caelian and the Esquiline

Fig. 8.6: The arcade of the Aqua Claudia at Romavecchia. The partially preserved channel of the Anio Novus runs above that of the Claudia (Photo: author).

(whose presence is still in evidence in the lowest levels beneath S Clemente nearby); an aqueduct could have topped it up but it was not absolutely necessary.[104] Indeed, given that Roman aqueducts could not be turned off,[105] if this branch line supplied the lake as well there must have been various and substantial installations to allow the water to drain away without causing flooding. The aqueduct might therefore have been constructed as part of the general welfare programme instituted by Nero after the Great Fire in 64.[106] It is interesting to note that nowhere does Frontinus say that Nero built this branch to supply the Domus Aurea. However, clearly its high elevation meant it could supply good quality water to a wide area, and it perhaps replaced in some areas the water supplied by the Marcia which could then be delivered more selectively.[107] Under Domitian this branch was extended to the Palatine; much of that standing today is a Severan rebuild.[108] Certainly the combined Claudia and Anio Novus supplied all regions of Rome and had a considerable capacity (Frontinus, *On Aqueducts* 20.5; 76.3) (Figs 8.2 and 8.5). From the Caelian, the Aventine and Transtiberim region could be easily supplied and it is significant that no new water supply-line was felt necessary for 60 years.[109]

Aqua Traiana. The Aqua Traiana, the last of the great aqueducts to supply the city, was constructed in AD 109.[110] Built after the time that Frontinus was writing, we know very little about it, a fact which underscores the value of the water commissioner's writings. The Aqua Traiana brought high quality water from springs above the Lacus Sabatinus (Lake Bracchiano) to the north of Rome. The channel has been traced at various locations along its course to the Janiculum, including its association with mills which were reported by Lanciani in 1886 and which are depicted on the *Forma Urbis*.[111] A large *castellum* or receiving tank was found on the Via Aurelia just inside the city wall.[112] With its point of entry high above the Transtiberim region, the water of the Aqua Traiana vastly improved the lot of the inhabitants of the west bank who had increased considerably in numbers during the 1st century AD. Particularly if supplies from across the river were cut, this may have been its primary purpose (Fig. 8.2).[113] However, its elevation meant that it could deliver water to all 14 regions (as the Claudia and Anio Novus) , and for the first time water was piped to the east bank from the west.[114] The Aqua Traiana also supplied water to the new Baths of Trajan on the Esquiline Hill, although the details of how this was achieved are lacking. What is clear is that it was not the main supplier. The Sette Sale, the huge cistern to the north-east of the baths and built

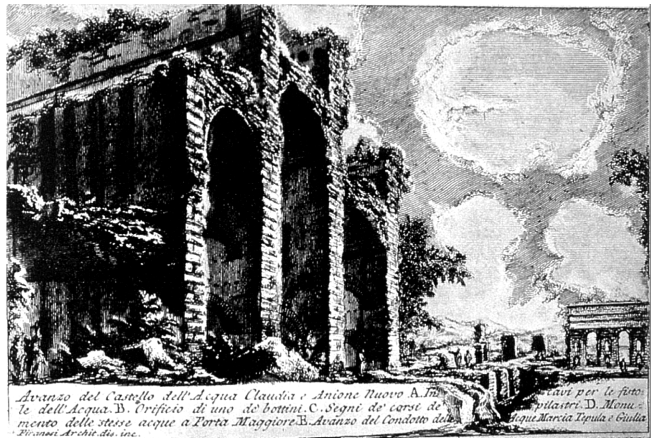

*Fig. 8.8: Piranesi's engraving of the reservoir (*castellum*) of the Aqua Claudia and Aqua Anio Novus (destroyed in 1880).*

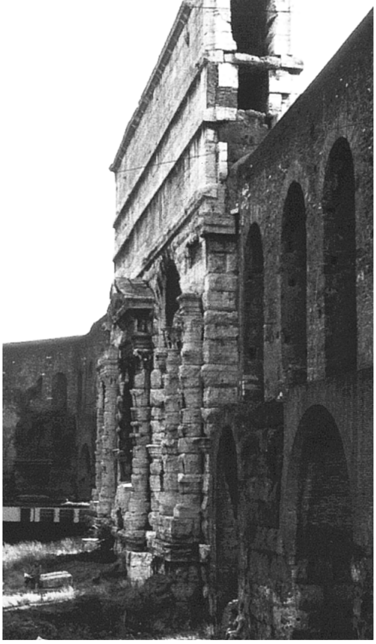

Fig. 8.7: The Claudian Porta Maggiore which carried the channels of the Aqua Claudia and Aqua Anio Novus across the Via Praenestina and the Via Labicana (Photo: author).

contemporaneously with them, was not supplied by the Aqua Traiana, but by one of the aqueducts entering the city at Spes Vetus, possibly the Aqua Claudia (see below).[115]

Aqua Alexandrina. The Aqua Traiana was the last of the great aqueduct lines of imperial Rome. One further aqueduct was built, the Aqua Alexandrina, constructed by Severus Alexander in the early 3rd century.[116] Most scholars assume, on the basis of the *Historia Augusta*, that it was brought in specifically to supply his rebuilding of the Baths of Nero in the Campus Martius, but there are several problems with this assumption. The passage in the SHA (*Severus Alexander* 25) mentions the construction of the aqueduct in the same sentence but does not specifically state that it was built to supply the refurbished baths; many modern commentators seem to ignore the fact that the earlier Baths of Nero had to have been supplied with water. This, coupled with a major lack of knowledge of the course of the Aqua Alexandrina within the city, makes the situation far less certain than is often made out.[117] The source of the Alexandrina was at springs in a marshy area south of the 14th milestone of the Via Praenestina; in certain locations it was carried on arcades with the most impressive surviving section at Viale Palmiro in Centocelle.[118] It entered the city at ground level in the vicinity of Spes Vetus, but little is known of its course after that; a structure close to the Saepta has been identified as the terminal *castellum*.[119] In 1585–7 the waters of the Alexandrina were regathered by Sixtus V as the Acqua Felice (see below).

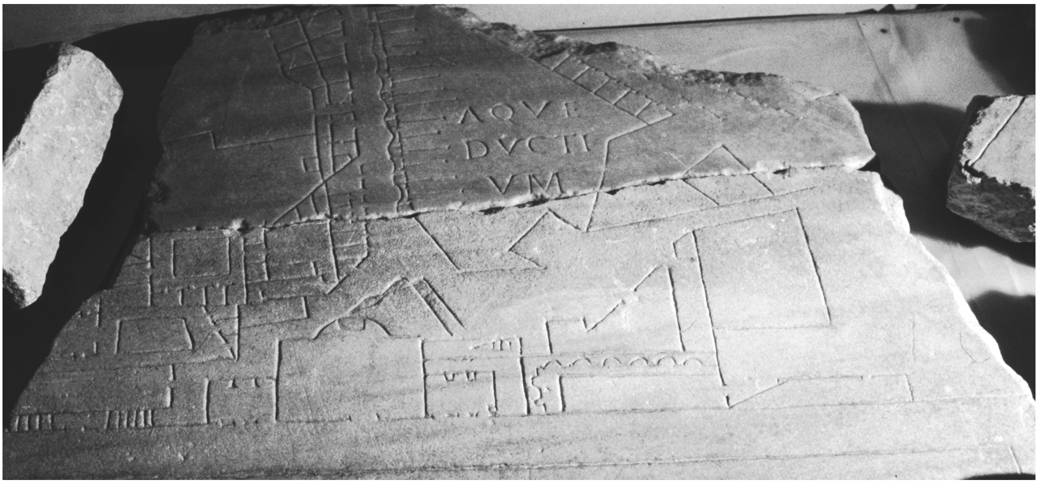

Fig. 8.9: The area to the south-east of the temple of Claudius depicted on the FUR and labelled 'Aqueductum' (Photo: author).

QUALITY, TANKS AND MAINTENANCE

Frontinus goes into some detail in *On Aqueducts* about the quality of the water provided by these supply lines and the problems involved in keeping supplies uncontaminated. The Marcia was universally lauded as the best; it was clear, cool and pure.[120] Indeed, Nero outraged public opinion by bathing in the springs which supplied the aqueduct (Tacitus, *Annals* 14.22). The Alsietina, on the other hand, was universally despised.[121] There were therefore good reasons for keeping the channels separate. However, there were provisions along a number of the aqueduct lines for the diversion of water from one channel to another to facilitate maintenance and to reduce flow.[122] The level of the water in the channels varied with rainfall and since the sources were in a variety of areas, the rate of flow was complicated by both seasonal and regional peaks. This variation has also been noted in the study of the aqueducts supplying Lyon.[123] Whilst diversion made practical sense in theory, it was not always intelligently carried out; good water could be wasted or contaminated by bad. Frontinus (*On Aqueducts* 67, 90–2) says that the Anio Vetus which ran at a lower level than the others kept its pollution to itself, though by the end of the 1st century AD it did draw some of its water from the Marcia. Not so the Anio Novus. Being the highest of all the aqueducts and also very abundant, it was used to make up any shortage in the others.[124] Frontinus laments the fact that the waters of the Claudia, which were also plentiful, were mixed with those of the Anio Novus when the two channels entered the city.[125] With obvious anger he says "even the Marcia, so charming in its brilliancy and coldness, is found serving baths, fullers, and even purposes too vile to mention" (Frontinus, *On Aqueducts* 91).

This switching of water from one channel to another was facilitated by the channels being placed one on top of the other. The problem was that the better quality water ran in the bottom channel – the Marcia and the Claudia; any maintenance work required in the upper channels would almost certainly mean diversion of the inferior water into the far better quality supply. This can also happen in more complicated arrangements. At Grotto Sconce there is a settling tank on the Anio Novus.[126] Two channels run out from it, one carrying the Anio Novus, the second running out to supply the Claudia and the Marcia via cross-link channels. These last

Fig. 8.10: Piranesi's engraving of the Arcus Neroniani or Arcus Caelimontani which carried a branch of the Claudia onto the Caelian.

two aqueducts ran at a lower level – and both carried water of much higher quality. The Anio Novus was notoriously sandy and the reservoir would have served as a settling tank to rid it of as much of the impurities as possible before being mixed with the purer waters of the Claudia and Marcia. At S. Cosimato, the channel of the Claudia crossed over that of the Marcia; a vertical shaft, 1.2 by 1.08 metres, at the crossing point allowed water, controlled by a sluice-gate, from the Claudia to drop through the floor into the Marcia.[127]

Such settling tanks along the route of an aqueduct were important so that the water could arrive in the city rid of the worst of its impurities, though not all aqueducts may have had them.[128] The importance of these settling tanks can probably be best demonstrated by the example on the course of the Anio Novus discovered in 1884 at the Villa Bertone, Capanelle.[129] The tank comprised two chambers, 6 by 6.70 m and 12 by 6.70 m and both were completely full of small, completely round, pea-sized pebbles. These seem to have travelled from Subiaco in the Sabine Hills, a distance of some 70 km, along the bed of the Anio Novus. What is amazing here is that not only were the tanks full when discovered but the Villa Bertone itself seems to have been built on an artificial platform made up of the debris from numerous cleaning operations of the settling tank. With the material surrounding the tank, which also included sand, the owner of the villa was able to plaster six or seven buildings on his farm, without appearing to diminish the deposit, and to gravel about a kilometre of avenues.[130] In fact one of the improvements under Trajan was to realign the intake for this aqueduct so that water was taken from the middle of three large dammed pleasure lakes created by Nero which could thereafter act as giant settling tanks.[131] This great mass of sand and pebbles at the Villa Bertone merely represents the final residue that still managed to escape this screening process. A major, and never-ending, task for the maintenance teams was not only the removal of this kind of debris, but also of lime incrustation (*sinter*) from the inside of the conduit; a build-up of lime could severely restrict the flow of water.[132]

GRADIENT AND SPEED OF FLOW

Nine of Rome's eleven major aqueducts drew their water from sources in the Sabine Hills and their course then followed the valley of the Aniene to Tivoli; the water ran in large, covered conduits, either rock-cut or closed by slabs. All were gravity-flow aqueducts and the speed of flow was determined by the gradient of the channel which must not be too shallow or too great (the water might 'burst its banks' or lie still and become stagnant).[133] At Tivoli the aqueducts were confronted by an escarpment which abruptly dropped 180 m; the river itself negotiates this in the celebrated Tivoli cascade. The aqueducts avoid this by swinging to the south-west and maintaining the same gradient, taking a route which slopes down the face of the escarpment.[134] For Vitruvius (*On Architecture* 8.6.1) the minimum slope was ½ foot per 100 feet or 5 m per km (0.5%); for Pliny (*Natural History* 31.57) it is ¼ inch per 100 feet or 20 cm per km (0.02%). Archaeological evidence suggests that Pliny's figure is more accurate, though it is rather shallow. For the principal aqueducts of Rome, an average gradient of 3m per km (0.3%) is common (Fig. 8.2). The difference in slope along an aqueduct line is mainly the result of topographical factors but the quality of the water (for example if it is laden with silt) could also be a consideration.[135] On the Anio Novus gradients varied quite considerably (the highest estimated velocity was 4.08 m per second and in some tunnels the gradients were very steep indeed).[136] Hodge suggests that the usual speed of water in a channel was about 1–1.5 m per second (average speed 3.5–5.5 km per hour),[137] which means that it might take up to 24 hours for water to travel from source to city in the longest aqueducts (obviously this would be considerably less for shorter lines).

DISTRIBUTION *INTRA* AND *EXTRA URBEM* (FIG. 8.5)

According to Frontinus (*On Aqueducts* 78–86) just over a quarter of water delivered by Rome's aqueducts never reached Rome, but was drawn off outside the city (*extra urbem*); this was a considerable amount considering that Frontinus probably reckoned the area up to the 7th milestone as *intra urbem*.[138] Private consumers who owned estates along an aqueduct could arrange to draw off water at certain times; payment for water rights helped pay for maintenance costs.[139] Land irrigated unlawfully, that is by drawing water off illegally, was a problem mentioned by Frontinus and one which continued into late antiquity.[140] There are a number of instances of private lines taken off main aqueducts. An imperial example is provided by the Commodan period (180–192) branch off the Aqua Claudia which supplied the earlier Villa of the Quintilii on the Via Appia.[141] Private examples include the estate of Manlius Vopiscus at Tivoli which was supplied with water by a branch off the Aqua Marcia, and the mid-2nd century AD large villa of Sette Bassi at Casale Romavecchia which was served by a branch from the Anio Novus.[142] The Hadrianic villa at La Vignacce was very close to the line of the Marcia from which water was taken into a very large cistern, so designed that water could only be drawn off if the *specus* of the Marcia was running at two-thirds full.[143] In his discussion of the Aqua Iulia (*On Aqueducts* 9) Frontinus mentions the Aqua Crabra, a small aqueduct which supplied all the villas in the area of Tusculum. Apparently the supply for this aqueduct had received the attentions of some of the watermen who had used it for illegal distributions. Frontinus put a stop to the practice and restored the supply to the area of Tusculum. The Anio Vetus supplied through a branch *in Tiburtium usum* (for the use of Tibur (Tivoli), and presumably the surrounding district); the poorer quality water from the Anio Vetus was recommended only to be used for irrigating gardens. The Alsietina was employed almost exclusively for irrigation outside Rome.[144]

Most of Rome's aqueducts entered the city from the east; only the Alsietina and the Traiana came in on the west bank. The Transtiberim region was well-served with springs and until the late Republic this was sufficient for its small population. However, in the imperial period the population of Regio XIV greatly increased, necessitating other measures.[145] Six pipelines are known to have been taken across the Tiber, five of which can be deduced from Frontinus; the earliest are the Appia, Anio Vetus and Marcia (Frontinus, *On Aqueducts* 79.2; 80.2; 81.2).[146] The Aqua Virgo was taken across by Agrippa; the Aqua Claudia was extended by Nero (Frontinus *On Aqueducts* 20). After Frontinus' time the Aqua Traiana was taken across in the other direction and supplied the Baths of Trajan.[147] One of the most complex aspects of Roman water supply was how water was distributed within towns, a feature further complicated by how little it has been studied.[148] Another problem is the almost complete lack of survival *in situ* of the lead pipes used to convey the water. Closed pipe-lines were not the only way of conveying water within the city; free-flow channels were also used, for example the Arcus Neroniani of the Claudia/Anio Novus and the Rivus Herculaneus of the Aqua Marcia.[149]

FRONTINUS' FIGURES AND THE CAPACITY OF ROME'S WATER SUPPLY (Figs 8.5 and 8.11)

Reference has already been made to Frontinus' figures for the volume of water delivered by each of the aqueducts, but the problem is that scholars cannot agree on how much water this actually constituted.[150] "Students of Frontinus correct him at their own peril"[151] is advice which is not always followed. Frontinus' description of measurement and capacity uses three basic concepts: *modus* (quantity), *conceptio* (supply available), *erogatio* (amount delivered); he gives his figures in the form of *quinariae*. According to Frontinus (*On Aqueducts* 24–30) there were two main methods of measuring the size of a water-pipe which were relevant to Rome. The first, possibly introduced by Agrippa and certainly mentioned by Vitruvius (*On Architecture* 8.6.4), was based on the width of the sheet of lead from which the pipe was made. The *quinaria* was the smallest lead pipe in use; its name derives from the fact that the lead sheet from which it was made was 5 *digiti* in width (a *digitus* is approximately 1.85 cm); the diameter of the pipe was 2.3125 cm.[152] The second method, apparently in use since Augustus (Frontinus, *On Aqueducts* 99), still used the *quinaria* as the basic unit, indicating a diameter of 5 *quadrantes*. The method was only used for pipes with a diameter up to 20 *quadrantes*; after this the pipe was named according to the area of the pipe measured in *digiti*. The *quinaria* is therefore used as the basic unit of measurement and reflects the diameter of the pipe; it does not reflect the volume or time, but merely a cross-section.[153] This is really at the heart of the problem. How can a simple pipe and its linear diameter dimension be used to measure volume of water? Frontinus is using the *quinaria* pipe as a measurement of volume, that is the amount of water passing through pipe under a fixed given head. On the factor of rate of flow, Frontinus has not been sympathetically treated by modern commentators; one goes so far to say that the Romans must have been aware of something so obvious, and Frontinus got it wrong because he was a civil servant and not an engineer.[154] The Romans could, and did, measure volume (for example of wine and olive oil); they could also measure time. But it was the two together, velocity, for which there was no convenient method, although the concept and effect were known.[155] Further, the rate of flow in an aqueduct is influenced by a number of factors, for example the local conditions of the channel itself, and by the situation both upstream and downstream of it. One could therefore have varying depths of water flowing in a channel along its course, as well as varying rates of flow, as has been well demonstrated in recent studies.[156] As a result of this, we now face a situation where we have widely differing estimates of how much water the Roman aqueducts carried – from

322,000 m^3 per day to 1,010,000 m^3 per day.[157] These modern estimates are based on the *capacity* of the aqueducts estimated from Frontinus' measurements taken at source (given here in Fig. 8.11 with a sample of modern estimates; Grimal's figures include modern estimates for the Traiana and Alexandrina). Any estimates on a *per capita* basis are based on these figures of capacity and rarely on the actual amount delivered. Frontinus' figures for the actual amount of water delivered by each aqueduct, and therefore available for use by Rome's population, are set out in Fig. 8.5; these rarely figure in modern calculation of Rome's water supply.[158] Further, modern estimates do not take into account that the amount of water available to the upper classes, who could afford their own private connection and private bath suites, was many times greater than the amount reaching (and being used by) the ordinary person who had to rely on the nearest fountain. Blackman's very meticulous set of figures suggests that we should be looking at the lower end of these estimates, but the margin of error is still too great for these figures to have any real meaning.[159] One particular problem with Frontinus' figures (*On Aqueducts* 2, 4–5, 80–81, 90–2, 101–2, 125, 135) is that they reflect the situation in his own time rather than the original capacities of the aqueducts; repairs would presumably have improved their capacity and efficiency. A further problem is that his figures are sometimes misquoted, adjusted or rounded up by modern scholars. The aqueducts of his day had a capacity of 24,413 *quinariae*; he gives the figure of 14,018 *quinariae* for the amount delivered (Frontinus, *On Aqueducts* 87.3; 64.4). These two figures are most often used for modern calculations, overlooking the fact that the amount delivered includes 4063 *quinariae* drawn off *outside* the city.[160] Moreover, Frontinus wrongly assumed that the quantity of water in open-flow channels could be reckoned in the same way as for closed pipes in an urban distribution system.[161] The lack of any exact figure (and lack of consistency in expression of that figure) for the water delivery to the city of Rome therefore makes it difficult to try to calculate how much water was available on a *per capita* basis (added to which estimates of the population of Rome also vary widely!)[162] Given the above discussion, one has to ask whether *any* of these calculations has any value. However, Frontinus' figures do afford an extremely valuable body of evidence for where, when and why water was needed, and the relative quantities delivered to different consumers.

Part of Frontinus' duties as curator of Rome's aqueducts was to correct any discrepancies in the records as well as address the problem of abuse of the system by both private individuals and the employees of the water office. He refers on a number of occasions to where the imperial records do not tally with his own measurements (*On Aqueducts* 64–76). And he lays the blame fairly and squarely on the "dishonesty of the water men, whom we have detected diverting water from the public conduits for private use" and also "a large number of landed proprietors, past whose fields the aqueducts run, who tap the conduits; whence it comes that the public water-courses are actually brought to a standstill by private citizens, just to water their gardens".

That is not to say that it was not possible to legally tap into the system outside the city. Frontinus states that of the total delivery of 14,018 *quinariae* of Rome's aqueducts, only 9,955 were divided *intra urbem* (71%).[163] Of the 4063 *quinariae* delivered outside Rome just under half (1718 *quinariae* or 42.3%) was subject to the disposition of the Emperor, the rest went to private individuals (2345 *quinariae*) (Fig. 8.5).[164] One final point to bear in mind is that Rome had a high water table and never had to entirely depend on aqueducts for its water. There is now little way of knowing how significant a role wells and cisterns might have played in the lives of the city's population.

CASTELLA

However much water actually came into Rome, a settling tank was normally positioned at the end of an aqueduct's run when it entered the city, although in some cities elsewhere in the Roman world aqueducts delivered water into very large cisterns.[165] This slowed the flow sufficiently to allow any material carried in suspension to drift to the bottom. The water was then piped off to different parts of the city. Arrangements within the structure varied although a common principle was to have at least two chambers. Pliny the Elder (*Natural History* 36.173) recommends two chambers for a *castellum divisiorum*, but in the terminal *castellum* for the Aqua Virgo, recorded in the 17th century at the foot of the Pincian, the water circulated through 4 chambers in turn, allowing impurities to settle by gravity.[166] The water flowed into one of the upper chambers but had to pass through the two lower chambers before leaving via a channel in the second upper chamber, having deposited debris and impurities in the lower chambers; one of these lower chambers had an opening low on one side running directly into the sewers. With chambers arranged on different levels the water would become less and less contaminated; certainly the Virgo ranked after the Marcia and Claudia for purity (Pliny, *Natural History* 31.42). Presumably grills or some such mechanism could have been fitted; there is no evidence on any of the Rome aqueducts, where of course the volume of water to be treated is enormous, that the water was filtered in some way. The water was then carried to secondary *castella* sometimes on arcades, sometimes underground.[167]

The various terminal *castella* were obviously in different locations but all were fairly high to facilitate distribution within the city. For example, the Claudia and Anio Novus discharged into a *castellum* near the Minerva Medica, which is recorded in an engraving of Piranesi. It was destroyed in 1880, but it was an imposing structure 21.5 by 14.2 m and consisting of 5 rectangular cisterns with semi-circular niches on the façade (fig. 8.8).[168] From here the waters were distributed through a shared network of secondary *castella* from which pipes supplied individual customers (Fig. 8.5).

Rome in the time of Frontinus had 247 *castella*, with the Claudia and Anio Novus combined waters supplying 92, the Marcia 51 and the Anio Vetus 35 (Fig. 8.5).[169] Vitruvius' prescription for a *castellum* requires three chambers, all supplied by an aqueduct and so arranged that when the two outer chambers overflow, the water goes into the middle one (Vitruvius, *On Architecture* 8.1–2). From the middle one, pipes go off to serve the public fountains; the other two serve the baths and private homes. The priorities are clearly established. But what is clear from Vitruvius' account is that it does not recognise the priority of public fountains usually inferred by modern commentators in that his design makes no effort to ensure that they are served first; in time of dearth all three go short. If we look at the *castellum* at Pompeii we here see in plan the three divisions as outlined by Vitruvius, but the difference from his prescription is that the three outlets are at different heights with the lowest supplying the public fountains and therefore the last to dry up. For Rome we know very little about this side of the water supply despite having Frontinus' account. He does talk of fountains with two water jets, each supplied by a different aqueduct so that if one was out of commission the provision of water was not interrupted, so there were contingency plans. The pipelines from the *castellum* might be lead or terracotta pipes; the *castellum* marks the end of the open channel and the beginning of the low pressure pipe system of urban distribution [170]

Name	Total capacity at intake (*quinariae*)	m³ (Grimal)	m³ (Forbes)	m³ (Aicher)
Appia	1825	73000	75737	75000
Anio Vetus	4398	175920	182517	180000
Marcia	4690	187600	194365	190000
Tepula	445	17800		17800
Iulia	1206	48240	50043	48000
Virgo	2504	100160	103916	100000
Alsietina	392	15680	16228	16000
Claudia	4607	184280	191190	185000
Anio Novus	4738	189520	196627	190000
Traiana		113920		
Alexandrina		21160		
Total	24805	1127220	1010623	1001800

Fig. 8.11: Comparative figures of aqueduct capacities.

CONSUMERS, PIPES AND FOUNTAINS

Frontinus specified three clearly separate groups of water consumers within the city.[171] The first, which included selected public baths, was accorded special privileges by the emperor (*c*. 17% of the water). The second group consisted of public users such as military and official establishments, theatres, fountains and baths (*c*. 44%). The third was private users, houses and industries (*c*. 38%).[172] Basic fountains would have been near enough on every street corner and are marked as circles on the *Forma Urbis Romae*; but decorative fountains were not introduced into Rome until the 1st century BC.[173] Frontinus (*On Aqueducts* 78.3) lists a total of 591 open water basins (*lacus*) within the city. We know of one from an inscription, the *fons cuniculi*; presumably the wall from which the feed pipe emerged was carved with the figure of a rabbit. Similar types of fountain head can still be seen at Pompeii. A number of other fountains are listed in the Regionary Catalogues, but of a total of 1212 (or 1352) fountains known to have existed in ancient Rome, only a few can be identified now.[174] One which is known and excavated is the Lacus Servilius in the Forum Romanum which was fed by the Aqua Marcia and drained into the Cloaca Maxima. The Lacus Iuternae was also situated in the Forum and was fed by springs.[175] Ovid (*Fasti* 1.708) clearly indicated the position of the fountain but it was not known until 1900 with Boni's excavations of the Forum Romanum.[176] One exceptional fountain, perhaps more properly called a *nymphaeum*, still stands in what is now the Piazza Vittorio Emanuele. This is a brick-faced concrete structure, popularly known as the Sedia del Diavolo or Trofei di Mario, which has been dated to the 3rd century AD (Fig. 8.12). Traditionally described as the terminus of the Aqua Iulia, this is now very much in doubt.[177] This comprised a number of chambers on several levels; the upper storey consists of a large apsidal niche flanked by open arches. Below this water poured from niches into a broad channel and from there it flowed to the lower storey, largely taken up by a large basin. Five main outlets are still visible – one on the 2nd storey, three in the first and one on each side. This building is an excellent illustration of the importance of large water-providing installations with a combined display function. The parallels are numerous around the Mediterranean and indeed this may be the only surviving example in Rome of a type of fountain called '*munera*' by Frontinus (*On Aqueducts* 79–86).[178] Such terminal display fountains have traditionally been provided since the post-Roman period for each aqueduct serving as a public memorial to the whole hydraulic achievement of the aqueduct; but as an ancient Roman practice this may not have been usual.[179] Probably the most famous large fountain in Rome was the Meta Sudans, destroyed in 1936 (Fig. 8.13). This stood south-west of the Colosseum and in its final form was built in the Flavian period. It consisted of an elongated cone with bowed sides, 7 m in diameter at the base and possibly three times as high. The original basin was over 13m in diameter and was surrounded by an open drain that caught the overflow. The aqueduct which supplied it is unknown.[180]

Given all the problems in calculating how much water was coming into Rome, is it possible to work out in very rough terms how much water was available to each person? From figures given by Frontinus (*On Aqueducts* 78.3), there were 591 *lacus* served by the aqueducts in his day. Estimates vary from 67 litres per person per day to over 1,000 litres per person per day.[181] But what does this mean? Do the figures only reflect domestic use? What about industrial use and the baths? How certain can we be of the discharge from each *lacus*? Comparisons with modern consumption, although they are dramatic, have limited value. All that seems clear is that, drawing the analogy of Pompeii, anywhere in the city a consumer would not find himself far away from a public fountain.[182]

According to Frontinus, water was conveyed to private customers' houses, usually from a secondary *castellum*, or sometimes from a conduit, by means of a *calix*.[183] Private consumers paid a tax or subscription to draw water from the public supply line. The *calix* was a bronze nozzle or tube at least 12 digits (21.6 cm) long and of standardized size which was fitted onto the lead pipe (Frontinus, *On Aqueducts* 36, 105, 112, 113, 129).[184] It was mounted into the side of the *castellum* or conduit and governed the amount of water the user could receive. The *calix* was effectively a water meter, and through it the customer would receive water day and night. The *calices* came in regular sizes to match the different gauges of pipe in use, and since they controlled the distribution and consumption of the water, it is not surprising that Frontinus spends about a third of his *On Aqueducts* (39 chapters out of 130) setting out the niceties of this arrangement.[185] In theory the *calix* was stamped with its nominal size, and a pipe connected to it was repeatedly marked for the first 50 feet of its length to certify that it too was the correct size.[186]

In practice, however, the opportunities for cheating and abusing the system were boundless; if Frontinus is anything to go by the Rome City Waterworks staff were expert in all of them! The *calix* might carry the wrong stamp, or not be stamped at all, or it might be of a larger size than that authorised if the gang carrying out the work had been well-bribed.[187] As a result, says Frontinus, "We have found irrigated fields, shops, garrets even, and last of all brothels fitted up with fixtures through which a constant supply of flowing water might be assured" (*On Aqueducts* 76).

Within the city, water was conveyed by both lead pipes and free-flow channels both above and below ground; a good above-ground example is the Arcus Neroniani (see above). There is a major problem in that evidence for these major free-flow channels survives in a patchy manner. Lead was the usual material, at least in Rome, for water pipes.[188] This has raised a number of interesting questions amongst modern scholars concerning the risk of lead poisoning with the assertion that this may have contributed to the decline of the Roman aristocracy.[189] Certainly Vitruvius (*On Architecture* 8.6.11) was aware of the poisonous nature of lead and it is perhaps surprising therefore that lead was used for piping. Lead is a plentiful by-product in the refinement of silver and the ancient world was not short of the material;

utilising it to make water pipes was a logical and practical solution to this glut.[190] But the water, of course, was flowing through and was not stationary within the pipe line. Therefore the amount of time it is actually in contact with the lead is minimal. Further, many pipes, including aqueduct channels themselves, in hard water areas develop a coating of lime scale. This insulating effect of the deposit inside lead pipes is well-known to modern water engineers.[191] Rome's aqueducts are notorious for heavy lime incrustation, and it did not escape the notice of Frontinus either.[192] It is only if water was left standing in a lead or lead-lined basin that there might be a problem – and only if this was to be drunk. The Roman aqueduct system was designed on the principle of continuous flow and off-take with no peak or slack hours. Thus, lead-poisoning is not really an issue in this situation.[193]

AQUEDUCTS AND BATHS

By the imperial period the largest single users of water within the city were the baths, and according to Frontinus (*On Aqueducts* 94, 107, 108) supplying water to them was of major concern for the aqueduct administration. Bathing for the Romans was in the full sense of the word, an institution, going far beyond considerations of hygiene.[194] Public baths became popular in Rome in the 3rd and 2nd centuries BC; Frontinus (*On Aqueducts* 65–68) says that water consumption had doubled by the later 2nd century, presumably partly for this reason. An aqueduct was not essential for the functioning of smaller bath buildings but for the larger baths and the *thermae* in Rome it was critical; the final abandonment and disuse of the *thermae* and many smaller baths of Rome only came in 537 when the aqueducts were cut by the Goths (Procopius, *Gothic War* 5.19.13).[195] In the Republic all water entering the city in aqueducts was designated for specific public uses (Frontinus, *On Aqueducts*, 94); baths are not individually mentioned but lumped in with fullers' shops as consumers which were granted the use of run-off water from public troughs, although not without having to pay. This seems to indicate that at this time the baths were private enterprises as opposed to public services; indeed there is no evidence for the authorities in the Republic providing public baths for the city.[196] By the 4th century AD there were 11 *thermae* and 856 *balnea*, according the the Regionary Catalogues.[197]

The great volume of water used in a Roman bath did not only serve strictly bathing needs, but also fed large and small fountains; Seneca (*Letters* 86.7) describes the fashionable baths of his day and comments on the amount of water flowing from fountains.[198] Frontinus does not mention baths explicitly in his discussion of consumers; under 'public use' he includes public basins (*lacus*), camps (*castra*) and ornamental fountains (*munera*), but there is no mention of baths (*On Aqueducts* 79–86). A big unknown is whether privately owned public access baths would come under 'public use' or 'private citizens'.[199] The water was brought to the baths either by a main line from the *castellum* or by a branch of an aqueduct. A major reservoir was necessary for the collection and distribution of the water to various parts of the building. The Aqua Virgo was the first of Rome's aqueducts to be built specifically to supply a bath building, the Baths of Agrippa, which, until they were bequeathed to the Roman people on Agrippa's death in 12 BC, were privately owned and funded. The Virgo also supplied the Stagnum Agrippae and the Euripus Canal, which with the Baths were set within sumptuous gardens on the Campus Martius.[200] The Aqua Virgo may also have supplied the Baths of Nero built in 62, also on the Campus Martius.[201]

The Baths of Trajan on the Oppian Hill were dedicated in 109; they were supplied mainly from the reservoir known as the Sette Sale, fed by one of the aqueducts coming into Rome at

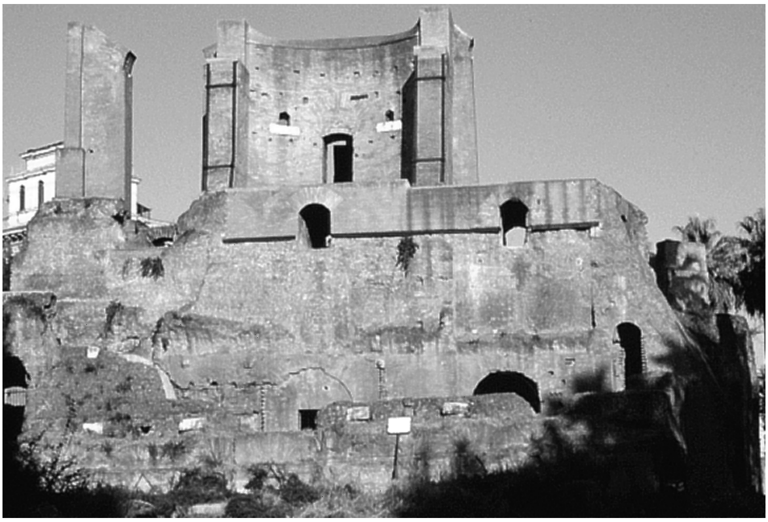

Fig. 8.12: The nymphaeum *known as La Sedia del Diavolo or Trofei di Mario (early 3rd century AD) in Piazza Vittorio Emanuele (Photo: author).*

Spes Vetus, perhaps the Claudia/Anio Novus. The Traiana did supply water to the baths themselves, although not to the Sette Sale.[202] The Sette Sale was contemporary with the baths and comprised nine interconnecting chambers with overall dimensions of nearly 30 m by 40 m; the vaulted chambers are 8m high, and the capacity is approximately 15,000 m^3. Predictably one of the most impressive of these reservoirs is that serving the Baths of Caracalla, fed by the Aqua Antoniniana.[203] The reservoir is situated on the west side of the outer terrace. It was double-storeyed and had 18 chambers with an estimated capacity of 30–40,000 m^3, roughly 30 times the quantity required to fill the great *natatio*.[204] The Aqua Marcia also served the great reservoir of the Baths of Diocletian on the Quirinal via another branch; this was later known as the *Botte di Termini* and was demolished in 1876 during the construction of the railway station. It was a trapezoidal structure, measuring approximately 16 by 91 m, situated just outside the south-east side of the baths precinct. [205]

AQUEDUCTS AND MILLS

Feeding the population of Rome was a constant battle against shortages and famine (see Mattingly and Aldrete in this volume), the accompanying problems becoming more acute as the empire started to disintegrate. A large mill complex on the slopes of the Janiculum operated from the later 3rd to the 5th century AD; excavation in the 1990s has clarified the form and chronology of these structures. The complex can be dated on pottery finds to some time after the early 3rd century AD and was powered by water from the Aqua Traiana (the channel of the aqueduct actually flows through the building), not the Alsietina as has sometimes been thought. The mills went out of use sometime in the late 4th/early 5th century, but were back in action in the 7th, 8th and 9th centuries (see below). [206]A small water-mill was located in a subterranean room of the Baths of Caracalla, powered by outflow water from the baths, though the exact chronology is unclear.[207] After the mills could no longer be used because the aqueducts had been cut, Belisarius came up with an ingenious solution to the provision of much needed grain

Fig. 8.13: View from the Colosseum of the foundations of the Meta Sudans, the large and elaborate fountain built by Domitian and destroyed in 1936 (Photo: author).

for the beleaguered city. He built floating mills on the Tiber itself at the Pons Aurelius with the mill mechanisms attached to a line of boats across the river (Procopius, *Gothic War* 5.19–27). The Goths tried to destroy them by throwing debris into the river further upstream. Belisarius acted swiftly and suspended a chain across the river on which the debris caught and was then brought safely to the river bank. All mills ceased to function in the middle of the 6th century. Pope Honorius I in the 7th century repaired the Aqua Traiana in conjunction with the construction of a mill outside the walls at S. Pancrazio, and smaller mills were built across the slopes of the Janiculum.[208] Floating mills were installed on the Tiber for the second time from the 10th century and there were still such structures in the 19th century.[209]

DIRTY WATERS

There is very little literary evidence on the form and administration of sewers and latrines (*foricae* or *latrinae*) in the Roman world; Vitruvius is noticeably, but discreetly, silent. The practice of incorporating latrines into bath structures, apart from the obvious advantages to the bathers, had very practical technical advantages of sharing drainage facilities and using discharge water for flushing.[210] However, latrines in baths would not have been sufficient and there were certainly other public latrines around the city.[211] In the Regionary Catalogues 144 public latrines are recorded in the city,[212] though only a few are known from archaeological evidence. One of Hadrianic date can still be seen above shops in the Forum Iulium and another is situated in the Largo Argentina/Portico of Pompey area (Fig. 8.14). A presumably public latrine was discovered in 1963 in the Via Garibaldi in Trastevere. Its painted decoration (giving a date of the 2nd to 3rd century AD) and black and white mosaic floors were very rich, giving an air of opulence which was presumably not always the case in such structures.[213] The value of the figure in the Regionary Catalogues is severely limited by a number of factors. Firstly, the seating capacity is not known for each facility, nor is it certain what proportion of the population used public latrines. It is usually assumed that many private dwellings in Rome, particularly the high rise dwellings, did not have latrines; they were not furnished with a running water supply, which, though not absolutely necessary to flush a

Fig. 8.14: Latrine in the south-east corner of the Portico of Pompey, now visible in the north-west corner of the Largo di Torre Argentina excavations (Photo: author).

Fig. 8.15: The Cloaca Maxima emptying into the Tiber (Photo: author)

latrine, was obviously a distinct advantage.[214] However, given that we have so little evidence surviving it seems rather inadvisable to make any definitive statements on this subject.[215]

In the modern world there is an obvious connection between latrines and sewers; in the Roman world other arrangements are also found. The law codes distinguish between public sewers maintained by the state, and private sewers the upkeep of which was the responsibility of individual property owners. The latter had the right to connect a private to a public sewer without having to receive permission from the authorities.[216] On the other hand, there was no *legal* obligation for a home-owner to connect his dwelling to a public street sewer, and archaeological evidence from Rome, Ostia and Pompeii indicates that very few dwellings were directly connected to street drains. Latrines feeding into internal cesspits seem to have been more normally in use. At Pompeii the combination of kitchen and latrine has been noted with some alarm about health risks, but there is the practical advantage that cooks could conveniently dispose of kitchen waste.[217]

The expense of installing drains would seem at first sight to have been well worth the consequent improvement in hygiene within a property, but why was this not more commonly done? There are probably several explanations. For one, Roman drains lacked traps to prevent gases such as hydrogen sulphide and methane escaping from the sewers and thereby causing not only an odour nuisance but also the danger of explosions – a consequence known from Victorian toilets in London![218] The ideal was that Roman *cloacae* were self-cleansing but it is clear that some had to be cleaned manually (*Digest* 43.23.2). There were two other potentially disagreeable consequences of being connected to the main drain system. In Rome, in low-lying areas, sewers could back up when the level of the Tiber rose (and this could be quite a considerable rise). Thus sewage and waste water which normally fed into the Tiber would be forced back up the network and into any houses connected to it. Vermin and other animals could enter a house via these connections – a spectacular and fanciful case being one referred to by Aelian (*HA* 13.6) whereby a rather enterprising octopus swam up a house drain each night from the sea to eat pickled fish stored in the house of an Iberian merchant!

However, there was one factor which may have outweighed all others: human waste was a valuable commodity as a fertilizer.[219] The contents of a domestic cesspit could therefore be sold on. Having your latrine connected to the public sewers could mean that you were literally throwing money down the drain.

The Romans have frequently been charged with wasting a large amount of the water which they brought into the city. This accusation stems from the fact that in principle in the Roman aqueduct system the water could not be turned off, as we can in modern water supply networks, it could only be diverted.[220] As we have seen, water *could* be stored in cisterns, but the major problem for modern scholars is that the water ran day and night, particularly from the fountains, even though demand must have been drastically reduced during the hours of darkness. Arguably, the Romans considered constant water flow as a particular sign of richness and a high standard of living.[221] The fact that Frontinus makes no reference to taps and similar devices should not be taken as supporting evidence; archaeology has brought to light a range of such devices – though they should be thought of as more like stopcocks than as the taps we might have in the bathroom or kitchen. These allowed for the *diversion* of water to either a place of storage or to where it *was* needed.[222]

Indeed Frontinus clearly states "There must necessarily be some overflow from the reservoirs, this being proper not only for the health of our city, but also for use in the flushing of the sewers" (*On Aqueducts* 111). If the literary sources are to be believed, even allowing for gross exaggeration, it is very clear that such an overflow was vital not only to the cleansing of the drains but also of the streets themselves. Juvenal (*Satires* 3.296–305) outlines the way in which a man dices with death as he walks along a street, especially at night: "It is a long way up to the roof tops, and a falling tile can brain you – not to mention all those cracked or leaky pots that people toss out of windows. So hope and make your miserable prayer, that the women are content to empty out their basin" (that is not drop the pot as well). This is the 'gardez l'eau' practice of the Roman world.[223] If you did not have a cesspit in which to rid yourself of waste, the street was the next best place.

Thus overflow from the fountains would flush such detritus down into the drains. The most famous Roman drain is the Cloaca Maxima, the original construction of which is attributed to Tarquinius Priscus.[224] This was an open ditch to help drain the marshy land particularly in the Forum Romanum area and the Subura, debouching into the Tiber near the Pons Aemilius/Ponte Rotto (Juvenal *Satires* 5.104–6; Fig. 8.15). Although it was meant to carry off surplus water it was inevitable from its early days that it also carried sewage. In the later Republic the Cloaca Maxima was enclosed in a subterranean channel which is still in use today. As the crow flies the distance between start and outflow is over 900 m, but its course meanders as a result of it being artificially diverted where buildings made this necessary. Thus its actual length is approximately 1600 m. Its size is noteworthy; in places it is 4.2m high and 3.2m wide, and Roman writers agree that it was large enough for a wagon load of hay to pass through. Agrippa is reported to have sailed in a boat through the underground world of Rome's drainage system on a tour of inspection.[225]

THE AQUEDUCTS AND WATER SUPPLY AFTER ANTIQUITY

Rome's aqueducts continued to function into the 6th century AD when Vigitis is recorded to have cut them and Belisarius to have deliberately blocked them to prevent their use as a means of infiltrating the city.[226] Many claim that after these events Rome lacked the resources, and perhaps the demand, to maintain an artificial water supply, but there is both archaeological and documentary evidence for the subsequent repair of at least some of the aqueduct lines, as well as of the Tiber

Fig. 8.16: La Fontana di Trevi, completed in 1762 and supplied by the Acqua Vergine which reuses the Roman Aqua Virgo (Photo: author).

embankments.[227] Belisarius may have restored them after the siege, although the main evidence is in the form of surviving masonry which is notoriously difficult to date accurately.[228] Within 60 years of the Gothic siege the aqueducts were running again, according to a letter of Gregory the Great dated 602 (*Letters* 12.6), but who and what they supplied seems to have changed. There is no evidence for the great public baths having continued in use after this time; the chief consumers in the early Middle Ages were the city's mills and the church (baptisteries and baths for the clergy and the poor). For drinking water the city relied on wells.[229] By the late 8th century the papacy had taken charge of the city's aqueducts, though the church had carried out earlier repairs on several branch lines.[230] Property documents from as late as the 11th century mention functioning aqueducts both inside and outside the city, but such references slowly disappear after the 12th century.[231] Rome's population became concentrated in the low-lying bend of the Tiber, an area which came to be known as the *abitato* and the river itself increased in importance.[232] The supply of domestic water played a very minor role in papal aqueduct repairs. Those aqueducts which were repaired did not for the most part reach this densely populated area; Trastevere was supplied by the Aqua Traiana but all sources point to the prime importance of the mills and the S. Pietro in Vaticano complex . Wells were the most likely replacement for domestic water supply. Although there does not seem to be evidence of Christian patronage of aqueducts to supply ordinary drinking water, there is clear evidence of such patronage of wells.[233] Christian hydraulic patronage in the form of the provision of fountains in church atria was of importance at this time; clearly this was for washing hands. The Pine Cone fountain, set up in the 5th century in the middle of the atrium of S. Pietro, survived until the demolition of the Constantinian church; the pine cone sculpture is now the centrepiece of the Cortile della Pigne in the Vatican. It was almost certainly supplied by the Aqua Traiana and the fountain functioned into the early Middle Ages, making it, it has been suggested, the only public fountain to do so in western Christendom.[234] Pope Symmachus (498–514) set up a public lavatory in St Peter's Square which was possibly flushed by water from the fountain (*Liber Pontificalis* 1.262).

The papal Lateran palace enjoyed an elaborate water supply for its bath-house. It is first mentioned in 667 in the *Liber Pontificalis* (1.343) when Constans II is recorded to have bathed there. It was supplied by the Aqua Claudia which was repaired under Hadrian I (772–95; *Liber Pontificalis* 1.502–3). Leo III added a porphyry fountain in one of the palace dining rooms (795–816; *Liber Pontificalis* 2.11). Sumptuous rebuilding took place under

Gregory IV (827–44) when the bath house was described as being much in need of repair (*Liber Pontificalis* 2.81).[235]

The mills on the Janiculum are first recorded in an inscription, probably of 5th century date, and vividly described by Procopius in the 6th century:

> "... across the Tiber there is a great hill where, for a long time, all the mills of the city have been built, as a great deal of water is brought by an aqueduct to the crest of the hill and rushes down the slope with great force" (Procopius, *Gothic War* 1.19.8).

They continued to function intermittently, fed by the Aqua Traiana, and there were a number of papal repairs: under Honorius I (625–38), Hadrian I and Gregory IV.[236] The papal interest in these mills was understandable; they were vital for the provision of the city's bread. The last mention of the Aqua Traiana is under Nicholas I (827–44) when repairs were carried out; it presumably fell out of use soon after this along with most of the other aqueducts.[237] It is not referred to again until the later 15th century when it was first repaired by Innocent VIII (1484–96) and then by Paul V in 1611. It still supplies the fountains in Trastevere and the Vatican as the Acqua Paola with a great and imposing terminal fountain, a *mostra*, the Fontana Paola.[238]

Major repair work was carried out on the Aqua Virgo into the 14th century, but by as early as the 8th century much of the arcades had fallen, so that a relatively short stretch was left running as far as modern Piazza di Trevi. A modest fountain was established at the foot of the Quirinal Hill and by the 10th century a small suburb had developed around it complete with several churches serving a neighbourhood of one-storeyed dwellings with gardens; Rome was changing and the Aqua Virgo gave way to the Acqua Vergine (Fig. 8.16).[239] It is not until Sixtus V (1585–90) that new aqueducts were constructed, the first being the Acqua Felice, regathering the springs of the Aqua Alexandrina, with an imposing *mostra,* the Fountain of Moses. Predictably, these post classical *mostre* were much influenced by the great Trofei di Mario *castellum*.[240]

The supply of water to ancient Rome was not something planned as an overall scheme but grew and developed with the city and as the population's needs and demands changed. The fact that three of the eleven great aqueducts of the ancient city in effect (with major modifications) still function today (Aqua Virgo as the Acqua Vergine Antica, the Aqua Alexandrina as the Acqua Felice, and the Aqua Traiana as the Acqua Paola) is testament to the skill and planning of the ancient hydraulic engineers. As Pliny the Elder (*Natural History* 36.123) declared:

> " But if anyone will note the abundance of water skilfully brought into the city, for public uses, for baths, for public basins, for houses, runnels, suburban gardens and villas; if he will note the high aqueducts required for maintaining the proper elevation; the mountains which had to be pierced; the levelled valleys; he will admit that there has never been anything more marvellous in the whole world".

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Smith read and commented on a draft of the chapter and rescued me from many errors and illogical arguments; any that remain and the opinions expressed are mine alone.

NOTES

1 A practice taken on with zealous vigour in the provinces and especially in Asia Minor; a particularly telling example is the aqueduct at Ephseus built between AD 4 and 14 and supervised with a colleague by Sextilius Pollio, who paid for the very visible part of the aqueduct where the channel was carried across the main road from Ephesus to Magnesia and the Maeander further south (*IGR* 4.242). For other examples in Asia Minor see COULTON 1987, 81. For *nymphaea* in Greece: WALKER 1987. See PURCELL 1996 for a general discussion of the management of water by the Romans as a symbol of power.

2 BRUUN 1991, 10–19; HODGE 1992, 16–7; RODGERS 1996, 395–8. For a discussion of Vitruvius and aqueducts: HODGE 1992, 13–16; LEWIS 1999.

3 ASHBY 1935, 26–7; BRUUN 1991, 11–13; LLOYD 1979, 408. HODGE 1992, 17, feels that it was clearly intended to demonstrate that he really had mastered the intricate technicalities of Rome's water supply**.** For a full discussion of the aims and purpose of Frontinus' *On Aqueducts*, see GRIMAL 1961, xv–xvi, who sees it clearly as a piece of political writing despite its format as a technical treatise.

4 For example the siphon, HODGE 1982: LEWIS 1999, 162–67 for Vitruvius and the siphon.

5 See REYNOLDS 1986, 166–70, for the manuscript tradition. LANCIANI 1881, a magisterial commentary of Frontinus, is still important; the subject of Roman water supply generally has been recently well-served by (amongst others) BRUUN 1991; HODGE 1992; EVANS 1994; AICHER 1995, all usefully discussed with supporting bibliography by WILSON 1996.

6 DEMAN 1934; ASHBY 1935. This was published in Italian 10 years ago (ASHBY 1991). AICHER 1995, essentially a guide to the remains at the end of the 20th century, provides a very valuable companion to Ashby.

7 Frontinus, *On Aqueducts* 1; BRUUN 1991; RODGERS 1996, 398–400.

8 CORNELL 1995, 373–377 and 385. Livy (39.44) records that Cato in 184 BC, when he was censor, repaired channels and reservoirs.

9 Q. Marcius Rex, responsible for the Marcia, was the only urban praetor recorded as the builder of an aqueduct. Further, the Marcia is the only Republican water supply line built following a *senatus consultum*. For the tradition that this line goes back to Ancus Marcius, Pliny, *Natural History* 31.41.

10 ROBINSON 1992, 96.

11 For the problems which had to be dealt with as a result of this system, see the activities of Marcus Caelius Rufus (Cicero, *Ad familiares* 8.6.4; Frontinus, *On Aqueducts* 76).

12 Frontinus, *On Aqueducts* 98–99; BRUUN 1991, 148–52; 190–94.

13 There were apparently two gangs of slaves – about 240 state-owned slaves descended from those bequeathed by Agrippa and another of about 460 created by Claudius which remained imperial property (Frontinus, *On Aqueducts* 116). BRUUN 1991, 190–99.

14 BRUUN 1987; ROBINSON 1992, 100–101. Under Claudius there were three *curatores aquarum* in office (*CIL* 6.1248). See BRUUN 1991, 150, 174–89, 207–9 and 218–20 for *procuratores*. For the title *curator aquarum et Minuciae*: *CIL* 5.7783.

15 Frontinus (*On Aqueducts* 102) lists the *curatores aquarum* from the 1st century AD, making 17 in all including Frontinus himself. There were long periods of time when the office does not appear to have been filled: BRUUN 1991, 179; RODGERS 1996, 398–9.

16 ROBINSON 1992, 101; *Lexicon* IV, *s.v.* 'Statio Aquarum', 346–49. For the location at the Porticus Minucia *CIL* 5.7783; 6.1532;14.3902; for location in the Forum Romanum *ILS* 8943, 9050. BRUUN 1989; 1991, 195–6 doubts the existence of any special headquarters for the water administration and suggests that we should think about it in a more abstract and general sense. The term is not used by Frontinus, but it is attested epigraphically: *CIL* 6.8489, 36781; 14.7338.

17 Frontinus, *On Aqueducts* 69, 72, 75–77 on fraud and abuse. On private and public users see Frontinus, *On Aqueducts* 79–86. For a general discussion see BRUUN 1991, 183–87; ROBINSON 1992, 99–10.

18 Frontinus, *On Aqueducts* 4. *Lexicon* I, *s.v.* 'Lacus Iuternae', 168–70; *s.v.* 'Lacus Curtius', 166–7.

19 RAMAGE 1983, 62–4; WENTWORTH RINNE 1996, 145–6; PURCELL 1996.

20 Cicero (*For Sestius* 77) gives a lurid picture of urban violence in 57 BC; the Tiber was filled with bodies and the sewers stuffed with more. See also Tacitus, *Annals* 6.19 in AD 33 after Sejanus' downfall.

21 RAMAGE 1983, 72–4. Other instances: 13 BC (Dio 54.25), when Balbus was unable to enter his theatre except by boat; AD 5 (Dio 55.22), when a bridge (unspecified) was destroyed and the city was navigable for seven days; AD 12 (Dio 56.27), when the Circus was flooded and the Ludi Martiales had to be held in the Forum Augustum.

For a list of the floods known from antiquity see LE GALL 1953, 29–30. For the Tiber generally, see LE GALL 1953; D'ONOFRIO 1970.

22 AMMERMAN 1990; HOLLOWAY 1994, 86–7; SMITH 1996, 101–2. This drainage was partially achieved through the construction of the Cloaca Maxima.

23 Cicero, *Letters to Atticus* 13.33a; FAVRO 1996, 73–5; the plain of the Campus Martius, despite the flooding problems, was the obvious place and direction for expansion.

24 Dio 55.22; 56.27.4. For the *cura riparum* and Augustan activity *CIL* 6.31541;31542. *CIL* 14.85 records Claudius building canals in AD 46 in conjunction with the construction of the harbour at Portus, stating hopefully that they would "free the city from floods".

25 Tacitus, *Annals* 1.76 and 79, and Dio 57.14.7–8 both credit Tiberius for its creation. ROBINSON 1992, 86–88. *CIL* 1.766a; *CIL* 6.31451.1 – censors and consuls delimiting banks.

26 The post was held by Pliny the Younger before his departure for Bithynia *ILS* 2927. For the 4th century, see *Notitia Dignitatum, Occ.* IV.6.

27 ROBINSON 1992, 88.

28 BOATWRIGHT 1987, 40–42.

29 D'ONOFRIO 1970.

30 For example there is no evidence for aqueducts at Ampurias, Tiddis or London (HODGE 1992, 61) where wells, cisterns and springs were the main sources of water.

31 CROUCH 1993.

32 The bibliography on the Pergamum aqueduct is quite extensive and conveniently collected together in HODGE 1992, 368.

33 COULTON 1987, 73. However, the early lines may not have been that much of a risk. By the end of the 4th century BC the Latins had been pacified and there was limited external threat to Roman territory. Added to which most of the length of these early lines was underground.

34 NORDH 1949, 100.15–101.10 (11 *thermae*); 101.11–102.11 (19 aqueducts); 104.11 (15 *nymphaea*); 105.6 (856 *balneae*); 105.7 (1352 *lacus*); 105.9 (254 *pistrina*). These are the figures listed in the concluding section, but the individual figures given by region produce the following, slightly different, figures: 942 public baths (*balneae*), 1204 public fountains, 257 reservoirs; the figures for *nymphaea* and *thermae* are the same. See also Zachariah of Mitylene, *The Syriac Chronicle* 10.16. The situation is further complicated by the indiscriminate, combined use by modern scholars of Frontinus' figures (which are similarly flawed) and those from the later sources.

35 For the urban population of Rome in the Republic see BRUNT 1971, 376–388. Aqua Appia: Frontinus, *On Aqueducts* 5, 22 & 65; *Lexicon* I, *s.v.* 'Aqua Appia', 61–2; DEMAN 1934, 23–28, 368, 365; ASHBY 1935, 49–54; RICHARDSON 1992, 15–16; MUCCI 1986a; EVANS 1991, 22–25; 1994, 65–74; AICHER 1995, 34–5.

36 PARKER (1876, 8–9, Pl. XVIII) claimed to have seen this structure and recorded it in 1867. See also LANCIANI 1881, 249–50; DEMAN 1934, 26–27; ASHBY 1935, 52–53; PACE 1983, 120.

37 This reflects a drop over the entire course of not more than 0.5–0.6% – the absolute minimum prescribed by Vitruvius (*On Architecture* 8.6.1). See HODGE 1992, 178–184 for a discussion of aqueduct gradients. It is interesting to note that Appius Claudius also interfered with cult activity in the Forum Boarium by transforming the Ara Maxima from a private concern into a publicly administered cult (Livy 9.29.9–11; COARELLI 1988, 80–2; CORNELL 1995, 385).

38 144 BC: Frontinus, *On Aqueducts* 7.3. Agrippa: Frontinus, *On Aqueducts* 9.9; Pliny, *Natural History* 36.121. Augustus: Frontinus, *On Aqueducts* 5.6–8; *Res Gestae* 20.2; *CIL* 6.1244. Regions supplied (Frontinus, *On Aqueducts* 79.2): Caelius (II), Forum Romanum (VIII), Circus Flaminius (IX), Circus Maximus (XI), Piscina Publica (XII), Aventinus (XIII), Transtiberim (XIV).

39 EVANS 1982, 409; 1991, 24–5; 1994, 107. TAYLOR 1995, 78–9, however, disagrees pointing out that this would be overloading this one bridge; there were other bridges which could have been used.

40 HODGE 1992, 274.

41 For example the Aqua Virgo and the Baths of Agrippa on the Campus Martius. The large imperial *thermae*, requiring constantly running water, were huge consumers of water.

42 Frontinus, *On Aqueducts* 6.2; *Lexicon* I, *s.v.*. 'Anio Vetus', 44–45; ASHBY 1935, 54–87; RICHARDSON 1992, 11; EVANS 1994, 75–82; AICHER 1995, 35–36. The work was unfinished at the end of the censors' term of office; the two men were elected *duumviri aquae ducendae* two years later to finish the project.

43 For the course see RONCAIOLI LAMBERTI 1986. For the improvements and additions ASHBY 1935, 54–87. For new *cippi* marking the course see MARI 1991. BLACKMAN 1979 estimates the length at 81 km, but has a discussion of the various lengths arrived at by different scholars.

44 SANTA MARIA SCRINARI 1979, 61–2; AICHER 1995, 36.

45 EVANS 1994, 77. See also BRUNT 1971, 384 for a reflection of the city's population growth in the increased water supply.

46 Distribution (Frontinus, *On Aqueducts* 80.2): Porta Capena (I), Isis and Serapis (III), Templum Pacis (IV), Esquiliae (V), Alta Semita (VI), Via Lata (VII), Forum Romanum (VIII), Circus Flaminius (IX), Piscina Publica

(XII) and the Transtiberim (XIV). For the aqueduct crossing to the Transtiberim region and a discussion of which bridge was used: TAYLOR 1995. Frontinus (*On Aqueducts* 21) mentions a branch called the Octavianus, which from its name probably dates from the Agrippan or Augustan overhaul of the system; its purpose seems to have been to serve the growing residential area outside the Servian Wall to the south-east (EVANS 1994, 78–9).

47 Frontinus, *On Aqueducts* 92. Unlike the later Anio Novus, the Anio Vetus was never given a major overhaul to address this problem. For repairs on the Anio Vetus: 144 BC: Frontinus, *On Aqueducts*, 7; Pliny, *Natural History* 36.121. Agrippa: Frontinus, *On Aqueducts* 9; Dio 49.43.

48 Livy 40.51.7. Population increase: BRUNT 1971; NOY 2000. For increases in building activity see COARELLI 1977.

49 Aqua Marcia: Frontinus, *On Aqueducts* 7; Pliny, *Natural History* 36.121; Martial 6.42.18; *Lexicon* I, *s.v.*. 'Aqua Marcia', 67–69; ASHBY 1935, 88–159; MORGAN 1978; RICHARDSON 1992, 17–18; EVANS 1994, 83–93; AICHER 1995, 36–7; VOLPE 1996. MORGAN 1978, 25–6 points out that the circumstances surrounding the actual construction of this aqueduct line are unclear, partly as a result of problems with Frontinus' text.

50 Frontinus, *On Aqueducts* 7.4; PLATNER and ASHBY 1929, 24–7. FRANK 1933, 226–7 estimates the cost at $9 million. FORBES 1964, 180, gives the figure of £3.5 million. See also BLACKMAN 1979; ROBINSON 1980, 49.

51 Pliny, *Natural History* 31.41; Propertius 3.2.14; Vitruvius, *On Architecture* 8.31. Nero swam in the source, much to people's disgust (Tacitus, *Annals* 14.22).

52 ASHBY 1935, 95–8 and references.

53 Frontinus, *On Aqueducts* 7.8 says that 7,463 paces (10 km) were carried on arcades. For *cippi* along the course of the Marcia see MARI 1991.

54 ASHBY 1935, 117–21; AICHER 1995, 116–122.

55 DEMAN 1934, 95.

56 AICHER 1995, 118.

57 AICHER 1995, 121–2.

58 AICHER 1995, 126–28. These various repairs to the Marcia were recorded at the Porta Tiburtina (*CIL* 6.1244 (Augustus 4 BC))and on *cippi* (*CIL* 6.1250, 1251 and 31750c; 1246 (Titus AD 79); 1245 (Caracalla AD 212)).

59 AICHER 1995, 99–101.

60 EVANS 1994, 85. Frontinus refers to the immediate area of the Porta Maggiore as *ad Spem Veterem* because of its proximity to an old temple of Hope (for example *On Aqueducts* 5, 19, 20).

61 See EVANS 1994, 87–9 for the problems relating to this branch; AICHER 1995, 37.

62 *Lexicon* I, 68; ASHBY 1935, 151. It was almost certainly the Marcia-Tepula-Iulia line which supplied the later Castra Praetoria. For the Aqua Antoniniana: *CIL* 6.29843; AICHER 1995, 74–5. This branch was brought from the Marcia near the 3rd milestone on the Via Latina and crossed the Via Appia on the Arch of Drusus (*Lexicon* I, *s.v.* 'Arcus Drusi (Via Appia)', 93; AICHER 1995, 75–6).

63 For the course of the Aqua Marcia within the city DEMAN 1934, 116–22; ASHBY 1935, 146–49; CATTALINI 1986a, 49–50; EVANS 1994, 85; VOLPE 1996, 64–81.

64 Nothing remains of this branch which probably delivered a very small supply: EVANS 1994, 86. MORGAN 1978 48–51 discusses opposition at the time to the provision of water to the Capitoline. On the course of this section of the Marcia between the Quirinal and the Capitoline see TORTORICI 1993. For the use of siphons in Roman aqueducts see HODGE 1982. More properly this is the inverted siphon which made it possible to supply water to locations at a higher level than the supply-line itself.

65 Siphon: BRUUN 1991, 134. For the Marcia being carried across the river on bridges: TAYLOR 1995, 78–82.

66 Frontinus, *On Aqueducts* 8; 67–9; *Lexicon* I, *s.v.*. 'Aqua Tepula', 70; ASHBY 1935, 160–1; RICHARDSON 1992, 18; EVANS 1982, 403–406; CATTALINI 1986c; EVANS 1994, 95–98; AICHER 1995, 38.

67 Frontinus, *On Aqueducts* 8; EVANS 1982, 404. Competition in building between Roman elite families may also have played a part, rather than this aqueduct actually being required (*pers.comm*. Christopher Smith).

68 CATTALINI 1986c, 60. Frontinus (*On Aqueducts* 68) says that the water came from rivulets (*venae*) from these springs.

69 EVANS 1994, 95–8; cf AICHER 1995, 38; 92–5 (Romavecchia). For the course of the Marcia-Tepula-Iulia see ASHBY 1935, 128–58; EVANS 1982, 404.

70 *Cura Aquarum*: Frontinus, *On Aqueducts* 99.1–5; SHIPLEY 1933, 24–26; BRUUN 1991, 148–49. For a discussion of Agrippa's work in general, SHIPLEY 1933; LLOYD 1979; EVANS 1982.

71 *Lexicon* I, *s.v.* 'Aqua Iulia', 66–67; EVANS 1982, 406–408; RICHARDSON 1982, 17. For the course of the Iulia see ASHBY 1935, 128–58 (Marcia-Tepula-Iulia),161–66; CATTALINI 1986d; EVANS 1994, 99–103; AICHER 1995, 38–9, 92–5. For *cippi* dating to Augustus: *CIL* 6.31563a, b, c.

72 ASHBY 1935, 130–2; HODGE 1992, 168–70.

73 ASHBY 1935, 149–50; EVANS 1994, 100.

74 For the general distribution of the Iulia see ASHBY 1935, 149–58; EVANS 1994, 102–103. Although there is no direct physical evidence, the building complexes almost certainly supplied were the Forum of Caesar, the

Forum of Augustus and the Augustan buildings in the Forum Romanum. Presumably these supply lines would also have been useful during the construction of these areas.

75 *Lexicon* I, *s.v.* 'Aqua Virgo', 72–3; ASHBY 1935, 167–83; LLOYD 1979; EVANS 1982, 408–409; RICHARDSON 1992, 19; QUILICI 1986; EVANS 1994, 105–109; AICHER 1995, 39–41. Pliny, *Natural History* 36.121 erroneously gives the date as 33 BC.

76 In Frontinus' day this was the third largest of the aqueducts (*On Aqueducts* 83). Feeder channels along the course of the aqueduct might help to explain why it could still deliver water in the Middle Ages (AICHER 1995, 40; COATES-STEPHENS 1998). For the papal and modern reworkings of the Aqua Virgo see TOLOMEO 1986; CAMBEDDI 1986; PINTO 1986. For the Agrippan building programme: SHIPLEY 1933; EVANS 1982, 409–411.

77 For the height of entry into a city see HODGE 1992, 104. The fact that the Virgo also delivered a substantial amount *extra urbem* (to suburban areas) may have had some influence (QUILICI 1986, 65–6).

78 LLOYD 1979, 193–5; AICHER 1995, 40. The aqueduct was carried across the Via Lata on the Arch of Claudius (*Lexicon* I, *s.v.*. 'Arcus Claudii', 85–6) which commemorated Claudius' 'conquest' of Britain: *CIL* 6.920, 31203.

79 The Stagnum may have been fed by run-off water from the baths (LLOYD 1979, 195). Tacitus, *Annals* 15.37 describes an extravagent and notorious banquet held at the Stagnum during Nero's reign. For swimming in the Euripus: Ovid, *Tristia* 3.12.22; Martial, *Epigrams* 11.47.5–6. Seneca in his youth would start the year off with a plunge in its cold waters (*Letters* 83.5)!

80 Frontinus, *On Aqueducts* 84.2: Via Lata (VII), Circus Flaminius (IX) and Transtiberim (XIV).

81 The Appia, Anio Vetus and Marcia did partially serve these areas but in a limited way (Frontinus, *On Aqueducts* 79–81; EVANS 1994, 106–7).

82 SHIPLEY 1933, 66–68; COARELLI 1977, 842–43; LLOYD 1979, 195–201; EVANS 1994, 107.

83 EVANS 1982, 409; 1991, 24; 1994, 71, 77 identifies the Pons Aemilia as the one bridge used. However, TAYLOR 1995 disagrees feeling that this is overload and that other bridges were available.

84 LLOYD 1979, 201; BRUUN 1991, 117 and n.5; TAYLOR 1995, 82–90.

85 The Alsietina is sometimes also called the Aqua Augusta. Frontinus, *On Architecture* 11.1; Res *Gestae* 23.1; *Lexicon* I, *s.v.* 'Aqua Alsietina', 61; RICHARDSON 1992, 15; LIBERATI SILVERIO 1986, 72–73; EVANS 1994, 111–113; AICHER 1995, 41; TAYLOR 1997. For the Aqua Alsietina and the *naumachia* of Augustus see TAYLOR 1997.

86 AICHER 1995, 41; TAYLOR 1997, 482–3, for a section of tunnel uncovered near S. Cosimato in Trastevere.

87 EVANS 1994, 112. LANCIANI 1897, 58; AICHER 1995, 165 give the elevation as 16.60 m and 17 m respectively, the level of the *naumachia* and final destination of the supply line.

88 EVANS 1994, 112. It also probably supplied a fish hatchery discovered near the modern Stazione di Trastevere (DEMAN 1934, 184–5; LIBERATI SILVERIO 1986, 75), though the Aqua Traiana may have provided its water (ASHBY 1935, 307).

89 *Lexicon* III, *s.v.* 'Naumachia Augusti', 337–8; RICARDSON 1992, 265; TAYLOR 1997; COLEMAN 1993, 50–55. According to Dio (62.20; 66.25) the *stagnum* was used by both Nero and Titus; see Coleman in this volume.

90 For discussions of which bridges were used see EVANS 1982; 1991;1994; and for a more correct assessment of the archaeological evidence, see TAYLOR 1995. The construction of the Aqua Claudia and Aqua Anio Novus and the Aqua Traiana served to redress this situation.

91 TAYLOR 1997, 468–73.

92 *Lexicon* III, *s.v.* 'Naumachiae Philipporum', 338; QUILICI 1989, 79; Aurelius Victor, *Caes.* 28; LIBERATI SILVERIO 1986, 73. For the course and distribution of the Alsietina: TAYLOR 1997, 483–4.

93 *Lexicon* I, *s.v.* 'Aqua Claudia', 63–5; *s.v.* 'Anio Novus', 42–4; RICHARDSON 1982, 11, 16; EVANS 1994, 115–128; AICHER 1995, 42–44. BRUNT 1971, 385 points out that the construction of these two aqueducts need not indicate an increase in population; Claudius was substantially raising standards.

94 Frontinus, *On Aqueducts* 13.1–2; BLACKMAN 1978.

95 Frontinus, *On Aqueducts* 13.4. Even in the 3rd century the high quality of the water of the Aqua Claudia was well-known; the emperor Severus Alexander would drink a pint of cold Aqua Claudia before taking food (SHA, *Severus Alexander* 30.44).

96 ASHBY 1935, 224–6; AICHER 1995, 42, 97–98.

97 *CIL* 6. 1256 records the construction and completion of both the Claudia and the Aqua Anio Novus.

98 SMITH 1970; AICHER 1995, 162–164. For the source of both the Anio Vetus and the Anio Novus see RONCOAIOLI LAMBERTI 1987.

99 DEMAN 1934, 237–50; ASHBY 1935, 224–42; MUCCI 1986b, 84–86; AICHER 1995, 97–8.

100 Frontinus, *On Aqueducts* 124 draws attention to the problems of maintenance and repair that this situation called for.

101 The buttressing to the piers are original to the structure. *CIL* 6.1257 and 1258 on the Porta Maggiore record repairs to the Claudia under Vespasian and Titus, which they claim was due to the inadequate functioning of the Claudia. No mention is made of the Anio Novus which would also have been affected by this work and EVANS

(1994, 116–117) suggests that these inscriptions reflect Flavian propaganda and perhaps minor repairs and work to the line. See also VODRET 1987.

102 ASHBY 1935, 243–44 ; MUCCI 1986b. The mixing of water carried by different supply lines of course had already occurred with Agrippa's combining of the waters of the Tepula and the Iulia.

103 Frontinus, *On Aqueducts* 20.3–4; *Lexicon* I, *s.v.* 'Aqueductium', 73–4; EVANS 1983; 1994, 118. For the course of this branch: DEMAN 1934, 266–70; ASHBY 1935, 244–49; MUCCI 1986c, 95–99. For the Aqueductium on the *Forma Urbis*: CARETTONI 1960, 63, pl. 16. Remains of the terminal *castellum* are still visible in the garden of the Passionist Fathers. For discussion of the purpose of this line: EVANS 1983; 1994, 119; ELSNER 1994.

104 PLATNER and ASHBY 1929, 361; EVANS 1983, 395–7; RICHARDSON 1992, 268.

105 HODGE 1992, 3. Roman aqueducts worked on the principle of constant supply and off-take 24 hours a day; they could not be turned off in the way we today can turn water on and off in our homes. The water could only be diverted to another location or destination.

106 ELSNER 1994. EVANS 1994, 120 suggests that this branch was part of the original Claudian plan and that Nero was upgrading and improving an already existing system; Frontinus, *On Aqueducts* 76.5–7 says that *castella* were adopted for the Arcus Caelimontani which had supplied water from the Marcia and Iulia to the Caelian and the Aventine.

107 EVANS 1994, 120. For Nero's concern to provide adequate water supplies for public needs, see Tacitus, *Annals* 15.43. The silence in the sources in this regard is even more striking, given that abuse of natural resources for private gain was a fairly strong and standard charge against Nero.

108 *CIL* 6.1259 (AD 201).

109 For a discussion on the supply across the river, see TAYLOR 1995, 91.

110 *Lexicon* I, *s.v.* 'Aqua Traiana', 70–2; CIL 6.1260; ASHBY 1935, 299–307; RICHARDSON 1992, 18–19; VIRGILI 1986, 118–9; EVANS 1991, 25–6; 1994, 129–33; AICHER 1995, 44, 76–9.

111 On the mills: LANCIANI 1893–1901, 127; WIKANDER 1979, 13–36; *Lexicon* V, *s.v.* 'Molinae', 277. These apparently produced much of Rome's flour in late antiquity and the early medieval period (see below).

112 EVANS 1994, 130 and n. 8; *Lexicon* I, *s.v.* 'Aqua Traiana', 71. TAYLOR 1995, 97, 102 thinks that although this might have been the terminus of the aqueduct and therefore the main distribution tank, after some of the water had been distributed to Transtiberim, the bulk of the water was taken to the east bank; the construction of the baths alone, however, did not justify the large amount of water taken across to the east bank.

113 The supply of the Naumachia Traiani is often cited as the main reason for the construction of the Aqua Traiana (TAYLOR 1995, n. 73; *Lexicon* III, *s.v.* 'Naumachia Traiani', 338–9).

114 BRUUN 1991, 135, states there is no trace of an arcaded river crossing. However, TAYLOR 1995, 98 suggests that the crossing was via a specially constructed aqueduct bridge just downstream from the Aventine. LANCIANI 1893–1901, Pl. 34, shows ancient piers in the river which Taylor suggests are the remains of a hitherto unidentified aqueduct bridge for the Aqua Traiana. If this is so, it is the only example of an exclusive aqueduct bridge in the city.

115 Epigraphic evidence (BLOCH 1944; EVANS 1994, 131) confirms the connection between the Aqua Traiana and the Baths of Trajan. For a recent detailed discussion of the river crossing and supply to the baths see TAYLOR 1995, 91–102. See also CONNOLLY and DODGE 1998, 240–1. For the Sette Sale: FINE LICHT 1990.

116 ASHBY 1935, 308–15; CARUSO 1986, 308–15; CARUSO and GIUSBERTI 1993; EVANS 1994, 132–3; AICHER 1995, 45, 74–5; *Lexicon* I, *s.v.* 'Aqua Alexandrina', 60–61; *Lexicon* V, *s.v.* 'Thermae Neronianae/Alexandrinae', 60.

117 According to COATES-STEPHENS 1998, 176 n.29 the Baths of Nero were supplied by the Aqua Virgo; FAGAN 1999, 73 says the complex was supplied by the Claudia/Anio Novus.

118 AICHER 1995, 104–112.

119 *Lexicon* V, *s.v.* 'Thermae Neronianae/Alexandrinae', 60. COATES-STEPHENS 1998, 176–77 suggests that the Alexandrina and the Antoniniana were in fact the same aqueduct, referred to in later sources as the Aqua Iovia.

120 Frontinus, *On Aqueducts* 7; Pliny, *Natural History* 31.41; Propertius 3.2.14; Tibullus 3.6.58; Vitruvius, *On Architecture* 8.3.1; Plutarch, *Coriolanus* 1.

121 Frontinus, *On Aqueducts* 11.1; EVANS 1994, 112–13.

122 For flow, velocity and gradient in general HODGE 1992, 215–45.

123 HODGE 1992, 169, 226–7; BLACKMAN 1979, 55–7.

124 BLACKMAN 1979, 55.

125 EVANS 1994, 117.

126 ASHBY 1935, 278; HODGE 1992, 120–1; AICHER 1995, 136–39; EVANS 1994, 117.

127 ASHBY 1935, 101–2; HODGE 1992, 120–1.

128 HODGE 1992, 274. The Appia, Virgo and Alsietina had no settling tanks and the water arrived unfiltered; Frontinus (*On Aqueducts* 1,11 and 22) did not consider the Alsietina worth cleaning up.

129 ASHBY 1935, 226; HODGE 1992, 124–5.

130 ASHBY 1935, 226–7.

131 SMITH 1970; AICHER 1995, 43. SMITH 1991, 124 claims it was the biggest of all Roman dams; it was overcome by floods in 1305.

132 This work was further complicated by the need to divert the flow of water to allow access into the channel (LEVEAU 1991, 152–3). See ASHBY 1935, 272 and Plate XIX for major lime incrustation of the channel of the Anio Novus.

133 For a discussion of gradient and velocity see BLACKMAN 1979; SMITH 1991, 120–23; HODGE 1992, 216–221. For a discussion of Vitruvius and aqueduct gradients see LEWIS 1999, 152–56. It was important for aqueduct channels to be covered to prevent evaporation, debris from falling in and blocking the channel or fouling the water, and the growth of algae as a result of the effect of sunlight on the water.

134 HODGE 1992, 218.

135 FRENCH 1985, 285; an average velocity of 2–3 ft per second (0.61–0.91 m per second) is enough to prevent sedimentation when there is a low silt load.

136 ASHBY 1935, 271, 287.

137 HODGE 1992, 94, 220–1. Average speeds in modern aqueducts are not normally above 1.2–1.3 m per second.

138 Frontinus, *On Aqueducts* 19; BRUUN 1991, 116–8, 148; for deliveries *extra urbem* generally: WILSON 1999.

139 Frontinus, *On Aqueducts* 18; 9.5; *CIL* 6.1261, 31566; 14.3676. For the use of aqueduct water for irrigation, see HORDEN and PURCELL 2000, 247–9.

140 Frontinus, *On Aqueducts* 97; WIKANDER 1991, 144–5. This was a problem even in the Republic; Plutarch, *Cato* 19 says that the censor in 184 BC cut off the pipes which were being used by private individuals to rob the aqueducts of water for their own houses and gardens. This might have caused a diminished flow in the Appia and Anio Vetus, necessitating the planning of a new line and the eventual construction of the Aqua Marcia (MORGAN 1978, 28–9).

141 WILSON 1999, 316–7. Villa of the Quintilii: ASHBY 1935, 223–4; AICHER 1995, 103–4.

142 Manlius Vopiscus: Statius, *Silvae* 1.3.66–7; this included a siphon beneath the river Anio itself (HODGE 1982, 157). Sette Bassi: ASHBY 1935, 228 (who dates it to the late 3rd or early 4th century AD); AICHER 1995, 103.

143 ASHBY 1935, 133–4; SARTORIO 1986; AICHER 1995, 93–5; WILSON 1999, 316. See also THOMAS and WILSON 1994.

144 Frontinus, *On Aqueducts* 11; 92; EVANS 1993; TAYLOR 1997, 488–92.

145 For population in this region HERMANSEN 1978, 160–2.

146 TAYLOR 1995 for aqueduct river crossings, which as he points out, is a much neglected area of the subject. EVANS 1982, 409, thinks that these 3 lines were all initially carried on the Pons Aemilius, but TAYLOR 1995, 78 points out that the evidence in Frontinus makes this unlikely; neither the Anio Vetus nor the Marcia supplied Regio XI, an the eastern end of the Pons Aemilius (*On Aqueducts* 80.2; 81.2).

147 BLOCH 1944; EVANS 1994, 131.

148 HODGE 1992, 275–303. The subject is always going to be hindered as much as helped by the survival of Frontinus. See also HODGE 1996.

149 BRUUN 1991, 118–25.

150 FORBES 1964; BLACKMAN 1978; 1979; HODGE 1984; 1992, 298–300; RODGERS 1986; BRUUN 1991, 51–55. Added to which, as FAGAN 1999, 71 has pointed out, some scholars (eg YEGÜL 1992, 393–4) give more credence to modern interpretations of Frontinus' figures as opposed to Frontinus' original figures. See SMITH 1991, 120–1; BRUUN 1991; 1997, 126–30; EVANS 1994, 140–44 for a much more measured discussion of this subject.

151 TAYLOR 1997, 468.

152 BRUUN 1991, 51–5; HODGE 1992, 296–7 (on pipes in general 308–15); LANDELS 1978, 42–57.

153 We, of course, tend to think in terms of quantity = units per period of time. A standard of 0.48 l/sec (based on a minimum head of 12 cm) is now more or less universally accepted by scholars as a minimum value for the *quinaria* (DIFENIZIO 1916). As RODGERS 1986, 355, points out, we have no *evidence* for any standard except for capacity; we, therefore, are basing much of these calculations on ignorance. See generally on this subject RODGERS 1986, 353–4; SMITH 1991, 120–1; HODGE 1992, 299. BRUUN 1991 has an Appendix aptly titled 'The impossibility of reaching the exact value for the Roman *quinaria* measurement'.

154 HODGE 1984, 205–6. See TAYLOR 1997, 468–71 for a more recent, and very useful, discussion.

155 HODGE 1984; RODGERS 1986, 354.

156 BLACKMAN 1978, 71.

157 GRIMAL 1961: 1,127,220 m^3 per day; PACE 1983: 1,010,000 m^3 per day; GARBRECHT 1982, 33: 525,000–635,000 m^3 per day; BLACKMAN 1978: 560,000–620,000 m^3 per day for the four largest aqueducts (Anio Vetus, Marcia, Claudia, Anio Novus); it does not help the situation that these estimates are often difficult to compare as they are expressed in different ways (SCOBIE 1986, 423; HODGE 1989, 130; BRUUN 1991, 98–104; 1997, 137–41). FAGAN 1999, 74, following FORBES 1964, 174, gives the following water consumption figures for 1936 – Rome 150 gallons per head per day; London 35.5 gallons per head per day; Munich 55 gallons; New York 120 gallons, and compares this with an estimated 198 gallons per head per day for Rome in 50 BC. On the other hand YEGÜL 1992, 393 says that the 9 aqueducts of Frontinus supplied nearly 1 million m^3, an estimated 300 gallons per person per day. BRUUN 1991, 103–4 suggests the figure of 67 litres per person per

day, much lower than other estimates, for example ADAM 1994, 268: 1,100 litres per person/day. Whilst such figures help to gain an appreciation of the overall scale, they can only be guesstimates.

158 The approach used by EVANS 1994, expressing Frontinus' figures as percentages, seems to be a far more valuable, accurate and honest use of the water commissioner's data.

159 BLACKMAN 1978. See HODGE 1992, 304–7 for Pompeii. SMITH 1991, 120–2 provides a very pragmatic approach.

160 RODGERS 1996. The 10,000 *quinariae* discrepancy between the amount which could be supplied and the amount actually delivered is explained by Frontinus as being the result of fraud (*On Aqueducts* 74.2). HERSCHEL 1913, 203, points out that Frontinus' data is at times too general and vague to give us a clear idea of how he reconciled these different figures.

161 RODGERS 1986, 360.

162 A further example is given by HODGE 1989, 130, who provides a set of calculations the results of which suggest that 1st century AD Rome's water supply was twice that of New York in 1986. This completely ignores the fact that water use has changed and in modern New York is completely different. On population estimates for Rome, see most recently Noy 2000, 15–22. See FAGAN 1999, 71 for a very sensible discussion of this whole problem.

163 Frontinus, *On Aqueducts* 78.3, though as EVANS 1994, 139 points out, when the individual deliveries in 79–86 are added up a higher figure, 10,409½, is achieved.

164 EVANS 1994, 140.

165 Cisterns: HODGE 1992, 58–60, 79, 89 (274–294 for urban distribution).

166 This structure is probably Hadrianic (DEMAN 1935, 173) and was certainly added after Frontinus who says that the Virgo had no settling tanks along its course (*On Aqueducts* 1.11. See ASHBY 1935, 174; ADAM 1994, 571; AICHER 1995, Fig. 6).

167 This whole process would be somewhat negated when two supply lines of differing qualities are mixed before they came into the city. Filtering: the water could flow across a bed of sand or pass through some porous cleansing agent. There is evidence for this process surviving from Ampurias in Spain and Cirta (Constantine) in Algeria; in the latter case a filter, constructed on sandbags, was fitted across the aqueduct channel (BERTHIER 1955–56; see also HODGE 1992, 275–6). For secondary *castella*, see HODGE 1992, 280.

168 ASHBY 1935, 242: AICHER 1995, 55. The *castellum* of the Marcia was on top of the Porta Capena (ASHBY 1935, 155). Juvenal, *Satires* 3.11 refers to the Porta Capua as 'dripping' (*madida*), reflecting one of the constant problems of maintenance.

169 Frontinus, *On Aqueducts*, 79–86; EVANS 1994, 139–41.

170 HODGE 1994, 282–91.

171 Frontinus, *On Aqueducts* 78.3; EVANS 1994, 139–144. For a full study of the stamps on pipes (*fistulae*) and their importance in our understanding of Rome's urban water supply, see BRUUN 1991.

172 BRUUN 1991, 58; 101–4; YEGÜL 1992, 393–4; EVANS 1994, 140. FORBES 1964, 173, followed by HODGE 1992, 257–8; it should be noted that aqueduct water was put to a wide variety of uses in the city rather than being restricted to bathing or drinking.

173 HODGE 1994, 304–307; *Lexicon* II, *s.v.* 'Fons', 255; EVANS 1991, 25.

174 NORDH 1949, 104.11 (15 *nymphaea*); 105.7 (1352 *lacus*). The discrepancy in the figures is a problem with the Catalogues themselves.

175 *Lexicon* II, *s.v.* 'Fons', 255–61; III, *s.v.* 'Lacus Servilius', 172–3; 'Lacus Iuternae', 168–70; RICHARDSON 1992, 162–3. Pompeii is very much the model which modern scholars follow. See also MORTON 1966, 46–52.

176 NASH 1961–2 vol. 2, 18–20. The direct connection with a sewer increased the potential for contamination.

177 *Lexicon* IV, *s.v.* 'nymphaeum Alexandri', 351–3; RICHARDSON 1992, 270–1. The topography and general urban layout was much changed in the 18th century, presenting major problems of interpretation. TEDESCHI GRISANTI 1986a, 126 has excluded the Iulia from supplying this structure on the grounds that the channel is at a lower level than that actually supplying the *nymphaeum*. It was more likely supplied by the Claudia and Anio Novus. See also CATTALINI and TEDESCHI GRISANTI 1986; TEDESCHI GRISANTI 1987; AICHER 1993, 348–350; EVANS 1994, 127, 407.

178 AICHER 1993, 350–1. It is from this monument that Pope Sixtus V in 1590 removed the marble trophies which are now set on the balustrade of the Piazza del Campodoglio, hence its medieval name 'Trofei di Mario'; see TEDESCHI GRISANTI 1977; 1986a; AICHER 1995, 60–1.

179 TEDESCHI GRISANTI 1986b; AICHER 1993.

180 *Lexicon* III, *s.v.*. 'Meta Sudans', 247–9. Water was brought probably from the Esquiline in concrete-built channels, rather than lead pipes. For the results of recent excavations: PANELLA 1990; 1996. For a possible connection with the Domus Aurea: LEONE 1985. Gladiators are said to have been in the habit of drinking there after a fight in the Colosseum.

181 SCOBIE 1986, 423; HODGE 1989, 130.

182 HODGE 1992, 304–7, Fig. 213.

183 HERSCHEL 1913, 203–11; FORBES 1964, 170–3; BRUUN 1991, 41–44; HODGE 1992, 294–300. See TAYLOR 1997, 484–6 for a discussion of legal rights and aqueducts.

184 No bronze pieces have been found which correspond to the details given by Frontinus either in Rome or Ostia, and there are a number of places where no *calices* were used at all (BRUUN 1991, 41–44).

185 For different pipe sizes: Frontinus, *On Aqueducts* 39–45; LANDELS 1978, 42–44. GRIMAL 1961 lists some of the commonest *calix* sizes as listed by Frontinus with modern measurements. See also LANDELS 1978, 53–57.

186 BRUUN 1991, 41–44. Frontinus (*On Aqueducts* 113) admits that *calices* were not always applied. The archaeological evidence is difficult and contradictory. BRUUN 1991, 44 suggests that Frontinus' account of the *calix* is prescriptive not descriptive.

187 LANDELS 1978, 52. See Frontinus *On Aqueducts*, 112–115 on cheating; 105 on legal provisions for stamping *calices* and lead pipes connected to them.

188 LANDELS 1978, 42–5; BRUUN 1991 124–127; 304–309 (manufacture of Roman lead water pipes); HODGE 1992, 307–17.

189 HODGE 1981; BRUUN 1991, 127–30. If the daily intake of lead exceeds 0.6 mg, the body becomes saturated and can no longer eliminate the excess which gradually accumulates, poisoning the system.

190 Vitruvius, and other ancient writers, are in fact more concerned with the poisonous nature of white lead (*cerussa*): HODGE 1981, 486. See COULTON 1987, 76–80 for a discussion of why lead is not used everywhere in the empire for piping.

191 HODGE 1981, 488. Lead is soluble in water but if the water has been flowing over sedimentary rocks, as is the case with Roman period water supply lines, the calcium carbonate makes it less likely for the lead to dissolve.

192 ASHBY 1935, 271–2 and Pl. XIX; HODGE 1992, 72; 227–32.

193 HODGE 1981, 489–91 points out that this does not mean that the Romans were necessarily free from lead poisoning. NEEDLEMAN 1985 provides an exhaustive discussion on Roman infertility and concludes that it was caused by gonorrhea. There still remains the possibility, however, that this is just another literary *topos*.

194 For baths and bathing generally see YEGÜL 1992; NIELSEN 1993; FAGAN 1999, 85–103 on baths and the Romans' perception of their medical value; 107–117 on the construction of the imperial baths; 357–67 for non-imperial baths in Rome; DELAINE 1999.

195 The Stabian Baths at Pompeii illustrate how a bath building can be well supplied with water from cisterns and wells and how the supply system can change and adapt. When the aqueduct was built under Augustus a specific channel carried water from the *castellum aquae* to the baths: ESCHEBACH 1979; NIELSEN 1993, 23.

196 See BRUUN 1991, 72–6 for *fistula* evidence; FAGAN 1999, 105–6 and Appendix 2 for evidence for non-imperial baths in Rome in the imperial period. This was partly due to senatorial conservatism; cf the ban in the late Republic on the construction of permanent theatres which were seen by ancient commentators as incitements to indolence and dissent (Tacitus, *Annals* 14.20, FRÉZOULS 1983).

197 NORDH 1949, 100.15–101.10, 105.6; the *thermae* listed are Traianae, Titianae, Commodianae, Antoninianae, Syranae, Decianae, Agrippianae, Alexandrinae, Diocletianae, Constantinianae and Severianae . For ownership of public baths: BRUUN 1991; 1999; YEGÜL 1991, 43–46. For the imperial *thermae* in Rome, see YEGÜL 1991, 128–83. For the new excavations on the Baths of Titus, see CARUSO and CECCHERELLI 1987–88.

198 YEGÜL 1992, 395. See PURCELL 1996 for discussion of water as a symbol of wealth and luxury. MANDERSCHEID 1988 and 1991 explores within the context of the Baths of Caracalla the theme of abundant water display and is firm in the belief that at least the imperial *thermae* in Rome were supplied with fresh running water, making it unnecessary to change the water in the plunge pools on a daily basis.

199 FAGAN 1999, 72; BRUUN 1991, 73.

200 *Lexicon* V, *s.v.* 'Thermae Agrippae', 40–42; SHIPLEY 1933 says that 19,000 m^3 of water per day was delivered to the baths – over one third of the total flow of the Virgo.

201 *Lexicon* V, *s.v.* 'Thermae Neronianae/Alexandrinae', 60–62. There is some dispute about the supply of water to this complex under Nero and under Severus Alexander who restored the baths (SHA, *Severus Alexander* 24.5). Traditionally, the Aqua Alexandrina is described as the main supply line for the later rebuilding but there are major problems with this assumption (see above Aqua Alexandrina). FAGAN 1999, 73 suggests that the Baths of Nero were supplied by the Claudia and Anio Novus.

202 *Lexicon* V, *s.v.* 'Thermae Traiani', 67–9; ANDERSON 1985; CONNOLLY and DODGE 1998, 238–47. For the Sette Sale: FINE LICHT 1990. For epigraphic evidence for the connections between the aqueduct and the baths: BLOCH 1944; EVANS 1994, 131. Exactly how the baths were fed by the Traiana is unknown, though see recent work by TAYLOR 1995, 95–102, who suggests the line after crossing the river was taken around the southern slopes of the Aventine and through the valley between the Palatine and the Caelian. He also notes (99 and n. 83) that a number of baths, significant enough to be mentioned in the Regionary Catalogues, were built along this route, particularly in the area of the Aventine soon after the completion of the aqueduct; clearly this region benefited much from the large capacity and wide distribution of the Aqua Traiana.

203 *Lexicon* I, *s.v.* 'Aqua Marcia', 67–9; V, *s.v.* 'Thermae Antoninianae', 42–8; ASHBY 1935, 158; CONFORTO and IACOPI 1987; MANDERSCHEID 1988; 1991; GARBRECHT and MANDERSCHEID 1992; 1995; DELAINE 1997, 16–17 and bibliography.

204 YEGÜL 1992, 394. GARBRECHT and MANDERSCHEID 1992 give an estimated capacity of 11,500m^3, whilst *Lexicon* I, 68 gives 8 million litres, yet another indication of how scholars complicate the issue by using different methods to describe volume and quantity.

205 ASHBY 1935, 151; *Lexicon* V, *s.v.* 'Thermae Diocletiani', 53–8. For the reservoir see AURIGEMMA 1974, 3–10.

206 For a discussion of the Alsietina and the mills see WIKANDER 1979; BELL 1994, 73–89. For the new work being carried out by Andrew Wilson, and the new interpretations of the evidence: *Lexicon* V, *s.v.* 'Molinae', 277. For the mills in the early medieval period: WARD-PERKINS 1984, 143.

207 WIKANDER 1979, 28–9.

208 WIKANDER 1979, 34–5; *Lexicon* V, *s.v.* 'Molinae', 277. WARD-PERKINS 1984, 143–4, who also believes that the Traiana would never have been maintained purely to power the mills; the fact that water from the Traiana also supplied St Peter's was the all-important factor.

209 KRAUTHEIMER 1980, 241 and fig. 190. The mills were concentrated by the Tiber Island where the current is at its fastest.

210 SCOBIE 1986, 407–18, 427–30; HODGE 1992, 270–2; FAGAN 1999, 77–78.

211 SCOBIE 1986, 413 estimates 40–50,000 kg of human waste, produced by a population of about 1 million, would have gone into the Tiber per day through the Cloaca Maxima by the imperial period.

212 NORDH 1949, 105.11.

213 SCOBIE 1986, 413; ROBINSON 1992, 119–22. Forum Iulium: BLAKE 1973 18–19. Largo Argentina/Portico of Pompey BLAKE 1947, 135–6; for a reconstruction see CONNOLLY and DODGE 1998, 133. For the Via Garibaldi latrine: CHINI 1993; PORTELLA 2000, 258–61. The Domus Transitoria had a very large latrine, apparently able to accommodate 60 occupants at any one time and thought to have been for palace servants; it is now located benath the *triclinium* and peristyle of the Domus Flavia (NASH 1961–2, 375).

214 Obviously people did not run out in the middle of the night if they got caught short! Some *insulae* at Ostia had communal ground floor latrines, although PACKER 1971 frustratingly gives few details.

215 116 latrines or *necessariae* were incorporated into the Aurelianic Wall at the level of the rampart (when the wall was heightened in the 4th century), a position suggesting that they were for the wall garrison. There was no provision to remove the waste from where it fell at the base of the wall, making these areas particularly unpleasant! Only one of these latrines survives today, to the east of the Porta Salaria: RICHMOND 1930, 84–6; NASH 1961–2 vol 2, 288.

216 *Digest* 43.23 *de cloacis* 1.2–3; ROBINSON 1992, 118. On the *cloacae* of Rome generally see MOCCHEGIANI CARPANO 1984.

217 SCOBIE 1986, 409–11; JANSEN 1991, 155–8: nearly every house or apartment at Herculaneum and many at Pompeii, including those above ground floor, has a latrine. Very few at Pompeii were flushed by running water but fed into a cesspit. Similar arrangements for latrines with cesspits were also found at Cosa (BROWN 1980, 42).

218 SCOBIE 1986, 412 and accompanying bibliography.

219 ROBINSON 1992, 122–24. Columella 1.6.24; 11.3.12; Varro, *On Farming* 1.13.4. GOWERS 1995, 27 says there were few latrines and few cesspits, thereby falling into the trap of argument from the non-survival of evidence; ROBINSON 1992, 120 for wagons taking out the night soil. For the mechanics of this in a modern setting (in 19th century Hamburg), see EVANS 1990, 129–31, particularly on how horrible the situation could be with the contents of chamber-pots, as well as the pots themselves, in the street.

220 Frontinus, *On Aqueducts* 104; HODGE 1992, 3.

221 HODGE 1992, 1, 5, 32.

222 HODGE 1981, 489–91; 1992, 322–6. Roman taps can range from stopcocks to discharge taps. A number of Roman taps have been discovered, but they mainly fall into the stopcock category.

223 Although *Digest* 43.10.1 prohibits the throwing of excrement, corpses and animal skins onto the streets, clearly it did happen.

224 Overflow: Frontinus, *On* Aqueducts 111; ASHBY 1935, 46. BAUER 1989; *Lexicon* I, ' Cloaca Maxima', 288–290; Strabo 5.8; Pliny, *Natural History* 36.108. Pliny (*Natural History* 36.24) ascribes its construction to Tarquinius Priscus, whilst Livy (1.38.6 and 1.56.2) credits Tarquinius Superbus. For a fanciful discussion of the symbolism of the Cloaca in literature, see GOWERS 1995.

225 Pliny, *Natural History* 36.104–108; Dio 49.31. Cassiodorus (*Variae* 3.30.1–2) was still singing the praises of Rome's sewers in the 6th century (see Christie in this volume).

226 Procopius, *Gothic* Wars 5.19.1, 18; Lexicon V, *s.v.* 'Molinae', 277; COATES-STEPHENS 1998.

227 See generally WARD-PERKINS 1984, 250–55; COATES-STEPHENS 1998. The reason for this apparent lack is that the evidence just has not been looked for until recently (WARD-PERKINS 1984, 153). For a particularly grim picture at the time of Gregory the Great see LLEWELLYN 1971, 97.

228 DEMAN 1934, 20, 330, 334; ASHBY 1935, 99, 240, 310. WARD-PERKINS 1984, 130, is highly sceptical.

229 The cutting of the aqueducts by Vitigis was mainly felt by the Romans in the closing of the baths (Procopius, *Gothic War* 1.20.5). It is clear from *Liber Pontificalis* 1.291 that wells and springs provided sufficient drinking water. On the baths: KRAUTHEIMER 1980, 111; WARD-PERKINS 1984, 135–49 (eg baths attached to churches built

by Pope Symmachus at S. Paolo fuori le muri, S. Michele and S. Pancrazio); COATES-STEPHENS 1998, 171–6. For wells, see HUBERT 1990, 78–9.

230 *Liber Pontificalis* 62.5, 91.2; AICHER 1995, 28–9. The aqueducts were often referred to as *formae* in the medieval period. Pope Honorius I built a mill on the Janiculum supplied by the Traiana and Gregory II restored the water supply to the baths at S. Lorenzo fuori le muri, originally built by Pope Hilarus (461–8) (WARD-PERKINS 1984, 137). In the 770s Pope Hadrian I repaired the Claudia, the Virgo, the Traiana and the 'Iovia' (*Liber Pontificalis* 97.59, 61–2, 65). The Claudia had a wide distribution supplying private water mills, houses at the Porta Maggiore, on the Esquiline and along the course of the Arcus Neroniani towards the Palatine (WARD-PERKINS 1984, 254–5; COATES-STEPHENS 1998, 173–4). The 'Iovia' is a name which first appears in 7th century sources and is generally believed to correspond to the Antoniniana, the branch of the Marcia built by Caracalla to supply his baths. COATES-STEPENS 1998, 174–6 suggests that the Aqua Iovia might in fact refer to the Aqua Alexandrina and that this and the Antoniniana are in fact the same line; he also claims that it is wrong to think that the Alexandrina was built to supply the refurbished baths of Nero by Alexander Severus. WARD-PERKINS 1984, 255, argues that the medieval name Iovia refers to the whole of the Marcia, possibly acquiring it after radical repairs under Diocletian (see RICHARDSON 1992, 18).

231 HUBERT 1990, 76–8; COATES-STEPHENS 1998, 172–3.

232 KRAUTHEIMER 1980, *passim,* but especially 271–288. Rome was exceptional at this time in the abandonment of the hills for settlement on low-lying ground, presumably because of the security offered by the Aurelianic walls. As WARD-PERKINS 1984, 125 points out, the drainage of the land was a much more important factor, a function superbly carried out by the Cloaca Maxima.

233 WARD-PERKINS 1984, 144–5.

234 KRAUTHEIMER 1980, 251–2; WARD-PERKINS 1984, 141–3. See also MORTON 1966, 202–205 (for the Pine Cone fountain); 202–216 (for St Peter's and fountains generally).

235 KRAUTHEIMER 1980, 251–2; AICHER 1995, 29. It was the Neronian branch of the Claudia which supplied the palace, hence its mediavel name, the 'Forma Lateranensis'.

236 5th century inscription: *CIL* 6.1711. RICHARDSON 1982, 258–9; WARD-PERKINS 1984 143–44. They were also referred to in the 8th century *Einsiedeln Itinerary*.

237 WARD-PERKINS 1984, 253.

238 LANCIANI 1881, 166–8; MORTON 1966 164–201.

239 PINTO 1986, 21–27 and *passim*; LANCIANI 1880, 128–30; MORTON 1966, 73–116.

240 MORTON 1966, 117–63.

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