Chapter 10: The role of water in industrial processes

10.1 Introduction

Water was integral to many industrial processes in the ancient world. This chapter will look at the processes of milling, tanning, dyeing, fulling and fish breeding, for which the archaeological evidence is best. It will assess what the water was used for during the process and how the water was supplied. Precursors to machines and technology used in these processes have already been discussed in Chapter 2.

10.2 Watermills and water-powered installations (Gazetteer 17)

Studies of watermills and water-powered installations have suffered in the past from the traditional view of technological stagnation in the ancient world. This view stemmed largely from Finley's declaration that there was little technical innovation or economic progress in the ancient world.[1] A retarded use of water-power was felt to be a consequence of slave labour and lack of interest in investment in new technologies. Therefore, the rise of water-power was deemed to be a progression of the early medieval period.

The idea that mills were not in widespread use during the Roman period, as well as the absence of references to mills in the literary sources, meant that few scholars dedicated time to their study. This situation began to be rectified by Wikander whose on-going work on ancient watermills since the late 1970s/1980s has opened up the field to study.[2] As well as indicating the archaeological evidence for watermills, he also pointed out that the appearance of documentary genres, such as monastic charters and hagiographies, accounts for the apparent increase in written evidence in the early medieval period. More recently Lewis has illustrated the potential of Roman technology and water-power, its role in industrial advancement and the diversity of its applications from milling grain to crushing ore.[3]

There are two main types of watermill that are distinguished by the orientation of the wheel: vertical or horizontal.[4] The vertical wheel requires a right-angle gear and turns a horizontal wheel shaft on the other end of which is a vertical cogwheel [Fig. 10.1]. This

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[1] Finley 1965. See Wilson 2002b for a detailed review of the history of ancient technology studies.
[2] Wikander 1979; Wikander 1981; Wikander 1984; Wikander 1985; Wikander 1990.
[3] Lewis 1997.
[4] For detailed descriptions of these wheels see, for example, Wikander 2000b, 373-378.

cogwheel drives a horizontal cogwheel and the millstones above. Variants of the vertical wheel include the undershot wheel, which is partially immersed in the water and driven by running water, the overshot wheel, which is powered by water conducted through a chute above the wheel and the breastshot wheel, which is powered by water hitting the back of the wheel. The horizontal wheel does not require a gearing system and is driven by water conducted either by a steep chute onto oblique paddles on the wheel or from a nozzle at the base of an *arubah* penstock (which functions like a tube delivering water to the water wheel), or exceptionally, as a turbine [Figs 10.2-10.3].

Twenty-five watermill sites and water-powered installations have been recorded in the Near East as potentially dating to our period (Gazetteer 17). The majority of mills from the East seem to be of the horizontal type with an *arubah* penstock [Fig. 10.3]. The *arubah* penstock is usually a 6-10 m high stone tower that contains a column of water. This column of water is let out through a narrow orifice at the bottom of the tower, so the wheel is driven by a jet of water under pressure.[5] This is a particularly efficient design where stream flow rates are limited, as in large parts of this region, because the power developed is proportional to the head of pressure in the drop-tower, which makes efficient use of smaller volumes of water.[6]

Schiøler has argued that a mill on the Crocodilion River on the western dam of the Caesarea Low Level aqueduct was of a turbine type, where the wheel is completely immersed in water, which falls upon it as a rotating column down a vertical shaft, such as found at Chemtou and Testour in North Africa [Figs 10.4-6].[7] Doubt has been cast, however, over the identification of this mill as a turbine and it is more likely that the mill could have been a horizontal type turned by a jet of water.[8] The problem with its identification as a turbine is partly due to the state of the evidence. As is shown in figs 10.4 and 10.6, the majority of the reconstruction of the lower part of the mill structure has no solid evidence because of the extensive Turkish remodelling to the mill shafts, possibly as undershot vertical mills. In addition, it would seem that the inflow channel entered the

[5] Wikander 2000b, 376.
[6] Wilson 1995b, 503.
[7] Artzy and Schiøler 1984-6; Schiøler 1989. On Chemtou see: Wilson 1995b.
[8] McQuitty 1995, 746 n. 3.

circular shaft radially rather than tangentially, as at Chemtou.[9] A tangential channel is necessary to cause the water to swirl, which means that the wheel would be submerged in a rotating column of water and therefore would rotate efficiently on a vertical axis. The radiocarbon dating of the mortar of this mill to AD 345-380 is also problematical. In this case it cannot be guaranteed that the sample was not contaminated by water-borne geological carbonates, which can skew the result to an earlier date (see Introduction and Table 10.1).

The water supply to the mills varied according to topography and local water resources. The Tiberias aqueduct fed six sets of mills along its course; the Kerak mill was located at the offtake point of the basalt pipeline branch to Kerak.[10] The Abu al-Fawares qanat supplied water to two milling installations at Palmyra.[11] The waterwheel at Wadi Faynan, was powered by water from an aqueduct-fed reservoir via a stone-covered leat (15.8 m long, 0.45 m wide and 0.4 m deep) [Fig. 10.7].[12] A penstock (0.2 m in diameter and c. 1.5 m long) fed by the leat opened up into a lower chamber (1.5 m wide and 2.4 m deep) that probably housed the waterwheel. It is highly likely that this mill dates to the Roman-period copper-mining activity, for which the site is famous. Water from a dam reservoir fed at least four vertical-wheeled mills at the south end of the low-level dam at Caesarea via a series of channels, sluice gates and cuttings.[13] Local oral history claims that the Homs dam also fed mills, but no archaeological evidence has been found of these. A large channel, the so-called 'fuller's canal' known from a 1st-century AD inscription, fed the possible mills at Antioch (see below).[14]

With the exception of the mills dated by literary evidence (see below) and the mill at Wadi Faynan, some of the other mills in the region potentially may be later than our period. In general, the dating of most of the mills included in this study is tentative as it has not been confirmed by fieldwork (see Table 10.1). A case in point is the mill complex at

[9] Wilson 1995b, 501, 506.
[10] Saarisolo 1927, 52, 69 fn. 1, 79f; Winogradov 2002, 299.
[11] Crouch 1975, 162.
[12] Barker *et al.* 1999, 277, 280.
[13] Oleson 1983.
[14] Lewis 1997, 99.

Lejjun, which was thought for several years to date to the Roman period, but excavation subsequently revealed that it dates only to the 19th-century AD Ottoman use of the area.[15]

Table 10.1: Nature and reliability of dating evidence for mills in the East.

Site	Proposed date	Dating evidence	Reliability of date
Amida	AD 359	Ammianus Marcellinus 18.8.11	High
Antioch [#506]	4th century AD	Libanius *Orat.* 4.29	High
Antioch [#517]	AD 73-74	Inscription	High
Caesarea (turbine)	AD 345-80	Radiocarbon dating	Low
Caesarea (vertical)	4th century AD	On analogy with channels feeding Low Level aqueduct	Medium
Diyateh	Roman or late Roman	Local oral history	Low
Jerash	5th-8th century	Architectural stratigraphy	High
Tiberias	Late Roman to early Islamic	Association with aqueduct; pottery sherds from plaster	High
Wadi Faynan	Roman	Associated with Roman copper mining settlement	High

In most cases the power from the water wheel in these installations was used to run grain mills, but there are two, possibly three, notable exceptions from Wadi Faynan, Jerash and Antioch. The water leaving the mill at the copper mining site at Wadi Faynan was not used for irrigation in the surrounding field systems. It is possible that the reason the water was not re-used was that it had been contaminated during an ore-crushing process.[16] If the mill at Wadi Faynan was used for ore-crushing this would be the first known example of water-power used for this process in the East. Other examples are known from elsewhere in the Empire from gold and silver mines in the Iberian Peninsula and Wales.[17]

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[15] McQuitty 1995, 746.
[16] Barker *et al*. 1999, 277.
[17] Lewis 1997, 106-110; Wilson 2002b, 21-23.

There are several difficulties with this interpretation. No parallels for horizontally-wheeled *arubah* penstock mills driving machinery in a reciprocating linear fashion are known elsewhere in the Mediterranean region.[18] This may be for two related reasons. Firstly, one would need to use a right-angled gearing mechanism attached to the wheel spindle to convert the direction of rotation from vertical to horizontal in order to drive the trip-hammer. Secondly, the speed of rotation in an *arubah* penstock mill is high, but the power developed may be too low; the need for a gearing mechanism would not improve this situation. Finally, there may not be sufficient room within the mill house itself to accommodate a trip hammer.

The existence of sawmills in late antiquity for a long time was based around a passage from Ausonius in AD 367 that clearly describes sawmills on the Moselle River.[19] A passage from Gregory of Nyssa (referring to Cappadocia) may also allude to water-powered sawmills in the 4th century AD.[20] The installation at Jerash now proves archaeologically the existence of such mills in the late Roman period. This sawmill, which was inserted into the pre-existing Temple of Artemis complex, must date between the 5th-century abandonment of the Temple of Artemis and the great earthquake of AD 749 [Figs 10.8-10]; a Justinianic date is likely as that was a period of great prosperity at Jerash.[21] A 7th-century sawmill may also have been identified at Ephesos, in association with ten overshot watermills, which points to a large-scale operation.[22] The Jerash mill was used to saw up column drums for use as veneer. Therefore, not only is this mill another example of industrial complexes encroaching on public space in late Roman Jerash, but also it was actively involved in the spoliation and destruction of the Classical architecture of the city.

A small cistern, acting as a header tank, in the courtyard of the Temple of Artemis fed the mill, which was located 4 m below in a subterranean chamber.[23] The outlet channel was not explored, but probably exited the building and joined the main street sewer; it is not

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[18] Significantly later examples are known from China, where horizontal water-wheels were used to drive reciprocating machinery for metallurgical furnaces in the 14th c. AD, and for square-pallet chain pumps via right-angled gearing in the 17th c. AD.: Needham 1962-1971.
[19] Ausonius *Moselle* 359-364. On some of the arguments on this topic see: White 1962; Rosumek 1982; Simms 1983; Simms 1985; Wikander 1989; Seigne 2002.
[20] Gregory of Nyssa *In Ecclesiastem* III, 656A; Wikander 1989, 190.
[21] Seigne 2002, 212.
[22] Vetters 1984, 225; Wikander 1989, 190.
[23] The following description is based on Seigne 2002, 206-212.

surprising that the water was not re-used as it would have been contaminated by stone dust. Carved rectangular sockets for shaft bearings were found in the wheel race, one of which showed signs of circular wear traces. These patterns point to an overshot waterwheel of at least 1 m diameter mounted on a short horizontal shaft with a vertical wheel at each end of the shaft. The most important finds for the identification of this mill's function were two column drums one with four slots and one with a pair of saw slots separated by four preparatory cutting lines; in each set the slots penetrated to the same depth. These partly-cut column drums suggest that there must have been four saw blades working simultaneously on each side of the wheel.

The saw blades are likely to have used abrasive material and water rather than teeth, to have been 2.2 m long minimum and set in a rigid frame for tension. The saws would have cut vertically down through the stone with blades moving back and forth horizontally to take advantage of their weight. A system with cranks or with eccentric and connecting rods would have been necessary to ensure the transformation of a continuous circular motion (from the mill-wheel) into a longitudinal reciprocating motion (for cutting the stones with the saw). It is likely that each of the wooden wheels on the wheel shaft would have carried an eccentric pin that was linked to the end of the saw frame via long connecting rods. The sophistication of this installation suggests that this was not a prototype, thus making it probable that other, earlier examples did exist and adding weight to the idea that the mills described by Ausonius in AD 367 were indeed sawmills. Archaeologically, however, this is probably the earliest attested example so far of this kind of technology.[24]

Lewis has argued persuasively that the 1st-century AD 'fullers' canal' at Antioch, known only from epigraphy, must have driven fulling mills [Fig. 10.11].[25] Fulling mills and stocks can be used as part of the beating process of fulling. Traditionally this beating process was done by hand, but at some point it became mechanized; a trip-hammer, cam and (normally) a waterwheel were harnessed together to create fulling stocks and fulling mills.[26] The use of a fulling mill means that less manpower would have been needed and potentially more fulling performed. This is often felt to be a medieval progression, but

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[24] The 7th-century Ephesos example might be earlier than the sawmill at Jerash.
[25] Lewis 1997, 96-99.
[26] Lewis 1997, 92.

Lewis believes this inscription points to an earlier use of waterpower in fulling. Although one needs a good water supply for fulling, the estimated 300,000 m^3 of water at a velocity of almost a metre per second supplied by the Antioch channel would be far in excess of what was needed for regular fulleries, especially when compared to the aqueduct at Pompeii that supplied significantly less (2,500 m^3), yet fed 14 fulleries as well as the public fountains. It seems possible then that the channel was used to provide waterpower as well as supply water. As the river could turn *norias* at this location, the channel could turn other undershot water wheels. The channel's size and the amount of power it could generate means that potentially it could have run 42 pairs of stocks. This makes it possible that there was fulling on an industrial scale at Antioch as early as the 1st century AD. Although there are no certain examples of fullers' mills until the 11th century AD, this is a tempting, but circumstantial, argument.[27] Antioch (and Syria in general) was still renowned for exporting textiles in the 4th century AD.[28]

10.3 Tanning, dyeing and fulling (Gazetteer 18)

Two installations were associated with dyeing textiles: Beirut [#466] and Jerash [#504].[29] A further four may have been fulleries: Antioch, Beirut [#453], Jerash [#503] and Scythopolis.[30] Ten sites have installations that are of uncertain function, but are most probably connected with tanning, dyeing or fulling: Dor, Caesarea (2), Gaza, Sarafand, Tel Yizre'el, Khirbet Summaqa, Khirbet Ni'ana, Auara, Zeugma (2) and Ain Feshka. All of these installations are characterised by a series of vats, sometimes connected by channels that occasionally were controlled by a complex system of sluice gates.

Textiles were dyed by macerating plants or shellfish in a solution of water that was often heated.[31] The purple dye was extracted from the hypobronchial gland of the *Murex* sea snail.[32] Pliny records that this was undertaken by heating a mixture of shellfish and salt in water with air piped from a furnace.[33] While the colour develops a garlic smell is

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[27] Wikander 2000b, 406.
[28] Liebeschuetz 1972, 79.
[29] Ovadieh 1969, 197; Raban 1995, 298-301; Curvers and Stuart 1996, 229; Uscatescu and Martin-Bueno 1997, 78.
[30] Foerster and Tsafrir 1992, 7; Perring *et al.* 1996, 195-6; Perring 1997-1998, 22.
[31] Wilson 2000b, 144.
[32] Herzog 1987, 22; Wilson 2000b, 144.
[33] Pliny *NH* IX 38, 133-5.

exuded, so it is no surprise to hear Strabo complaining of the bad smell at Tyre from its dye factories.[34] Tyre was famed in antiquity for its dyeworks, which came under imperial control under Diocletian.[35] By the late 4th century AD restrictions imposed by the Emperors Valentinian, Theodosius and Arcadius had made commercial production and dyeing of both wool and silk in mollusc purple a capital offence; all such activity had to be carried out in Imperial dyeworks.[36] Circular rock-cut vats, some in clusters that were connected by narrow rock-cut channels, and piles of *murex* shells were observed at Tyre in the 19th century.[37]

The Roman installation at Beirut [#466] comprised a basin that was associated with a large quantity of *Murex* shells.[38] This seems to have been small-scale local textile production, which reflects the earlier, Roman date of the installation.

The so-called *officina tinctoria* in *tabernae* 10-12 and *exedrae* 2-3 of the *macellum* at Jerash [#504] was a larger undertaking and dated to the 6th-early 7th centuries AD [Figs 10.12-13].[39] This installation had a furnace, which is the only known example from the eastern empire. Of the six vats (dimensions unknown), four were rectangular and plaster-lined and had amphorae at the bottom, which were probably used to bring water from a small cistern in *taberna* 10; these were probably used to immerse the cloths. Two of the vats were semi-circular and made from re-used architectural fragments; these vats were not deep enough apparently to hold much liquid and may have been used for the spreading out of dyed cloths for enhancement with fuller's earth or dried dyes as described by Pliny.[40] Two water tanks were also found that were connected via pipes to the central fountain in the *macellum*. The dyeworks thus involved the renewed use of the water system in this area as well as adaptations to the urban scenery for industrial purposes, e.g. the earlier Roman pavement was broken in order to install the water tanks. An alternative use for this installation may have been fulling, perhaps in combination with dyeing.

Fulling, which cleans clothes and prepares textiles for dyeing, involves the removal of animal fats and grease by the trampling of the cloth in tubs that contain an alkaline

[34] Herzog 1987, 19-20; Karmon and Spanier 1987, 149. Strabo *Geography* XVI.2.23.575.
[35] *Ibid.*
[36] Bridgeman 1987, 160.
[37] Wilde 1840, 378-380; Appendix M, 629-644.
[38] Curvers and Stuart 1996, 229. The report does not specify whether the *Murex* shells were crushed.
[39] Uscatescu and Martin-Bueno 1997, 77-8.
[40] Pliny *NH* IX 35, 198.

solution of water and fuller's earth, dilute urine or other alkaline substance. The archaeological remains of these installations usually consist of small tubs for trampling the cloth and large vats for rinsing them afterwards [Fig. 10.14].[41] The late Roman complex from the hippodrome area in Jerash was described as comprising three vats and four plastered jars sunk partially below floor level opposite the vats.[42] Sadly, no plans or photographs of this area have been published. This description is similar to the fulleries at Ostia [Fig. 10.14]. No detailed information is available about the late Roman fulleries from Beirut and Scythopolis, but both were supplied by piped water. The water supply to the fulleries at Antioch has already been discussed (section 10.2 above). It seems significant that three of the known examples of this type of installation did not have to rely on wells or cisterns, but were deemed worthy of their own specific supply of water. It is possible then that these installations may be compared with the large-scale ventures found at Rome, Ostia and Pompeii.

The ten other sites in the Near East of unclear function consisted of complexes of basins or vats with channels, some of which had sluices (see Gazetteer 15 for details). The two installations from Zeugma were found in caves on the bank of the Euphrates and seem to have been fed by water percolating through the cave walls as calcite formations were found on the walls of a rock-cut niche above a basin.[43] A system of channels of varying dimensions criss-crossed the floor of the caves; all of them angled down to the mouth of the caves and the Euphrates and some of them had an ashy charcoal-rich fill [Fig. 10.15]. These caves are reminiscent of similar installations in caves at Cyrene in North Africa; these installations are also of unclear function, but the provision of small basins and large vats suggests that they were used for fulling [Fig. 10.16].[44]

A complex of a vat, basins, pits and channels at Ain Feshka is commonly thought to be associated with tanning or vellum preparation because of the site's proximity to Qumran where such activities could not be carried out due to religious strictures. Also Ain Feshka had a permanent and abundant supply of water [Fig. 10.17].[45] The low phosphate content

[41] Wilson 2000d, 143.
[42] Glueck 1934, 6.
[43] Abadie-Reynal and Ergec 1997, 355.
[44] Thanks to Prof. Andrew Wilson for showing me these caves on a trip to Cyrene in 2001.
[45] For example: Harding 1967, 200. This is also the interpretation of the original excavator: De Vaux 1959; De Vaux 1960.

and lack of organic traces (hair, plant remains and diatomaceous bodies) in residues from this complex show, however, that animal skins were not processed there.[46] Tests for tannins were also inconclusive and flax-retting is also unlikely as there were no plant remains.[47] It is possible that these may have been fishponds as the water was not static, but no recesses or jars were found (see below section 10.4).

10.4 Fishponds (*vivaria*) (Gazetteer 19)

Nine possible fishpond sites have been recorded across the Near East. Jars set into the walls, probably the cells described by Columella as essential in a fish-breeding pond, are diagnostic for fishponds. Such jars, set horizontally into the walls, were found at Khirbet Sabiya (300 jars), Caesarea [#490: 60 jars], Caesarea [#496: 16 Gaza amphorae] and Sataf [Figs 10.18-19].[48] A similar arrangement was found in the south-eastern reservoir at Andarin, but instead of jars or amphorae rectangular recesses were found at the base of the reservoir walls, possibly numbering 200 [Fig. 10.20].[49] The installations at Khirbet Sabiya and Caesarea [#496] both had pits of unknown function in the middle of their floors.[50] If these installations were indeed *vivaria*, it is possible that they were used by the nobility as attested by Varro.[51]

In general these installations were rectangular or square and varied from 3 m to 13.6 m long, from 2 m to 5.44 m wide and from 0.4 m to 3 m deep. The example from Andarin was exceptionally large measuring 61 m long x 61 m wide x 3 m deep;[52] this is probably because it also acted as a reservoir for irrigation supplies (see Chapter 5.3). As it was fed by freshwater it is possible that catfish were bred there. Catfish were the only freshwater fish bred in fishponds cited in ancient sources, such as Apicius and Pliny;[53] in addition, catfish bones have been identified in the assemblage retrieved from the Andarin bathhouse.[54]

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[46] Poole and Reed 1961, 122.
[47] *Ibid*.
[48] Ayalon 1979, 175-177, 179; Gibson 1991, 41; Stieglitz 1998, 63-5; Mango 2002, 325. Columella *De Re Rustica* 8.1.3, 17.1-6.
[49] Mango 2002.
[50] Ayalon 1979, 176; Stieglitz 1998, 63.
[51] Varro *Res Rusticae* 3.3.5-10; 3.17.2-9.
[52] Mango 2002.
[53] André 1981, 109-113.
[54] Mango 2002.

With the exceptions of Khirbet Sabiya, Andarin and Sataf, all of these sites were coastal. The examples from Dor seem to have been fed by seawater.[55] A pipeline branch (Channel E) from the Caesarea High Level aqueduct channel A fed the reservoir for the *piscina* at Tel Tanninim [#496]; the pipeline ran up a ramp attached to the southern wall of the reservoir.[56] The reservoir at Andarin was fed by qanat water, which was subsequently channelled out into the fields for irrigation.[57] This multi-functional use of the qanat water is unsurprising given Andarin's inland, pre-desert position. Spring water from a spring flow tunnel at Ein Bikura, Sataf fed a pool with two rows of ceramic jars in its sides with mouths towards the pool.[58] In all of these cases the nature of the water supply means that a constant supply of circulating water was ensured.[59] The water could also be reused for other activities, for example, irrigation at Andarin and in a possible bathhouse at Tel Tanninim. The installation at Khirbet Sabiya, however, had no channelled or piped water supply and could only have been fed by wells identified in the vicinity of the site.[60] This would suggest that the water was not changed frequently on this inland site, which may be related to the type of fish contained within the pond. Palladius advocates putting eels and river fish, for example, into cisterns in order to create a current.[61]

The paired rock-cut tanks from Dor [#481-483] and Beirut [#578] had no such recesses or jars. It is possible that these pools were therefore not used for fish breeding, which may also explain why these tanks were found in pairs unlike the other installations. It has been suggested that the Beirut tanks, which were lined with *opus signinum*, might have been holding tanks for holding the catch after the return of the fishing vessels. This is because the vats were in close proximity to a cove to which they were linked by a flight of steps.[62] A similar function is also possible for the Dor installations since they too were situated very close to the coastline.

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[55] Raban 1995, 343.
[56] Stieglitz 1998, 57-8.
[57] Mango 2002.
[58] Gibson 1991, 41.
[59] Columella states that fishponds required circulating water: *De Re Rustica* 8.1.3, 17.1-6.
[60] Ayalon 1979, 179.
[61] Palladius *Opus agriculturae*, 1.17.2. This does seem to be at odds with Columella's advice, but may offer a possible explanation for the curious situation at Khirbet Sabiya.
[62] Thorpe 1998-99, 36-38.

Alternatively, it is possible that these were vats for the production of *salsamenta* where the flesh of the fish was cut up and salted. While there is evidence that fish were salted in the eastern Mediterranean, archaeological evidence has been lacking so far, prompting the idea that maybe the process was done in *pithoi* or *dolia*.[63] Salting vats in the western Mediterranean (in particular Spain, Portugal and Morocco) were remarkably similar and almost universal in construction, though they varied in size and depth.[64] While the rectangular or square tanks in the western Mediterranean were usually built of brick or rubble, rock-cut examples are known from Portugal (Punta de l'Arenal and Praia de Angeiras). These Portuguese examples were not joined together as was usual elsewhere, which is similar to the possible salting vats (except Dor #483) from the East. The western examples were faced with *opus signinum*, as at Beirut. Large, round holes are sometimes found in the ground near the vats, which may have been for holding *dolia*; no examples of these have been recorded at Beirut or Dor. In addition, the western vats were usually arranged in rows along the inner walls of a room or building. No evidence for buildings was found at Dor and Beirut, but this may be due to large-scale truncation in the vicinity. Finally, in the west, the processing installations usually had a fresh-water supply from wells, cisterns or occasionally an aqueduct; again this has not been recorded in the East. So, the pairs of vats at Beirut and Dor illustrate some, but not all, of these common traits. It is possible, but not definite, that these installations may be, then, the first fish-salting sites identified from the eastern Mediterranean.

10.5 Conclusions

The evidence presented here, albeit limited, has shown that a wide variety of industries were taking place in the East, particularly involving fabrics and fish. It is clear from this that there is scope for more work on the remains of industrial installations in the East. The East stands out from other areas of the Empire in its high use of *arubah* penstocks for water-powered grain mills. This is largely due to the climate and limited water supplies of the region, which means that an *arubah* penstock that functions efficiently on low flow rates is ideally suited.

[63] Wilson forthcoming, b; Curtis 1991, 112-8, 129-147.

[64] The following description of archaeological evidence for salting vats is based on Trakadas 2005, 69-72.

The special uses of waterpower at Jerash and Antioch point to an awareness of how to maximise productivity. The connection of the dyeworks at Jerash and the fulleries at Beirut and Scythopolis to the municipal water supply also indicate that these industries were recognisably important and presumably profitable enough to merit the expense of connection. Furthermore, it is likely that if a constant water supply was needed, these installations must have been highly productive. With the exception of the Antioch fulling mill, these installations date to the late Roman period, which may point to a general upturn in industrial processing, or maybe it moved into the cities in this period.

In Beirut alterations in the mid 4th century saw one shop become a fullery. Further ovens, sunken storage vats and mortar floors were inserted into shops in the area during the mid 5th to 6th centuries. This supports the latter argument (and possibly the former as well). Late Roman Jerash possessed not only two of the larger and more sophisticated installations, but also saw substantial changes in the area and buildings surrounding these installations in order for them to function effectively, for example the dyeworks intruded on a previously public space (the *macellum*). Furthermore, the sawmill in the Temple of Artemis complex was involved in the spoliation of the city's Classical monumental architecture. This evidence seems to point to a change in emphasis in the use of public space in the city during its later history. Monumental space appears to have been used more frequently for utilitarian purposes, a trend that also seems to have occurred at Apamea (see Chapter 7.6.1). Further archaeological investigation on the site, as well as on other sites across the East, with this as a focus would certainly be worthwhile and would contribute to two important on-going debates: the extent of the productive role of the city and the nature of decline or change in the late Roman East.[65]

[65] For current views on these topics see, for example, papers in: Mattingly and Salmon 2000; Lavan and Bowden 2001.