

WORKING WITH WATER IN MEDIEVAL EUROPE

TECHNOLOGY AND CHANGE IN HISTORY

VOLUME 3



WORKING WITH WATER IN MEDIEVAL EUROPE

Technology and Resource-Use

EDITED BY

PAOLO SQUATRITI



BRILL
LEIDEN · BOSTON · KÖLN
2000

This book is printed on acid-free paper.

Library of Congress Cataloging-in-Publication Data

Working with water in medieval Europe : technology and resource-use /
edited by Paolo Squatriti.

p. cm. — (Technology and change in history, 1385-920X ; v. 3)

Includes bibliographical references and index.

ISBN 9004106804 (cloth : alk. paper)

1. Hydraulic Engineering—Europe—History. 2. Middle Ages—
—History.

I. Squatriti, Paolo. 1963-

TC55.W67 2000

627/.094/0902—21

00-064182

CIP

Die Deutsche Bibliothek – CIP-Einheitsaufnahme

Working with water in medieval Europe : technology and
resource use / ed. by Paolo Squatriti. – Leiden ; Boston ; Köln : Brill,
2000

(Technology and change in history ; Vol. 3)

ISBN 90-04-10680-4

ISSN 1385-920X

ISBN 90 04 10680 4

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PRINTED IN THE NETHERLANDS

*The editor's share in this work is for R. S., "l'ingegnere," and
for D. M. S., the historian*

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INTRODUCTION

Paolo Squatriti

One of the primary inspirations behind the present volume was R. J. Forbes' multivolume collection of *Studies in Ancient Technology*, which Brill published in the 1950s and 1960s. In the preface to the first volume, which appeared in 1955, Forbes claimed his "series of small booklets, each containing a number of essays on ancient technology" were designed to "promote discussion and research." With this end in mind, Forbes cast his net widely over "ancient technology," and treated diverse subjects, from bitumen and its extraction to refining substitutes for sugar, from mining to refrigeration, from glass manufacture to metallurgy. Scattered throughout several of Forbes' *Studies*, especially the first two volumes, were serene, informed assessments of the water-related technologies used in pre-industrial societies, though, as even an abbreviated list of his topics shows, the University of Amsterdam's "Professor of Pure and Applied Sciences in Antiquity" delved into past technology in all its guises, and certainly did not limit himself to just aqueous techniques, in his investigation. For those interested in how people came to terms with the aqueous element in their environments in former times, *Studies in Ancient Technology* is still worthwhile reading.

Such reading can be a discouraging experience for any who hope to emulate Forbes, even in the (for him) narrow realm of technology related to water. Forbes was capable of describing and evaluating a huge array of machines and methods from the most disparate quarters and periods (despite the programmatic title, Forbes actually did treat the European Middle Ages); he did all this with apparently equal precision and ease. In the last decade of the second millennium, it is impossible for the solitary researcher to replicate the omniscience and breadth of knowledge which distinguish the *Studies*. In numerous ways, academics have become much more specialized since the 1950s, reacting to the vast accumulation of information made possible by decades of research and improved availability of data. To take a straightforward example, contemporary knowledge of Iberia's medieval irrigation culture, much of it deriving from the last

twenty-five years' revolutionary archaeological surveys, is on a scale and depth unimaginable in the 1950s (see chapter 7). Even in that decade, some researchers had begun to respond to the overwhelming wealth of information on past techniques. Indeed, how arduous was the Dutchman's feat of erudition is set in relief by another classic English-language survey of technological history published roughly at the same time as Forbes's, Charles Singer's (and E. J. Holmstead's, A. R. Hall's, and Trevor William's) multivolume *History of Technology*, which enrolled a small army of scholars, Forbes included, to treat its subject. Similarly, a somewhat more recent heroic attempt by a single scholar to describe the history of human technology, Bernard Gille's *Histoire des techniques* (1978) ended up, in volume 2, enlisting an additional three researchers to bring the project to completion.

While the current dazzling abundance of information from archives and archaeological digs and published works, and the resultant need to specialize, place Forbes-style analyses in the realm of dreams for most scholars, it is also true that it is now difficult to match the confidence, the crispness of vision, and certainty of judgment which distinguish the *Studies*. For if Forbes ranged broadly in geographical and chronological terms, he also maintained lofty levels of sureness and an almost Olympian authority in his writing. Postmodern skepticism and self-questioning now erode the definitive pronouncements of those engaged in the study of past techniques. Scholars are both more aware of the hypothetical nature of their reconstructions, and more sensitive to how knowledge, and thus the "applied" knowledge visible in technology, interacts with social, economic, and cultural circumstances, as well as with political power. For instance, Forbes' "progressive" conceptions of accumulating technical wisdom leading slowly from the Middle Ages to modern levels of sophistication were, quite clearly, shaped by the growing use of writing in, and hence availability of written evidence from, Europe after the end of the first millennium A.D. (chapters 2 and 6 in this work stress this). Archaeological research in the past three or four decades has led to less teleological models of technological history, and to a re-evaluation of the early medieval period, particularly in the Mediterranean region. And though a Forbesian catalogue of techniques and innovations is admirable enough, the technologies become more fully comprehensible when discussed as part of the social networks that employed them, the economic systems that made them viable, and the cultural norms that gave them meaning and acceptance.

The new circumstances confronting researchers into the history of technology, the embarrassment of riches in data and the novel ways of conceiving our relationship with the past, mean that a fresh (and humbled) rendition of what Forbes achieved in his study of machines and methods associated with water is worth attempting. The attempt must take into account these changed circumstances. Hence, for example, the collaborative effort visible in the pages which follow, where eleven specialists' competence is pooled to attain the kind of coverage the lone Forbes offered almost a half century ago. Hence, also, the authors' striving to describe machines and techniques, but also to explain how they fit in their social environments. Hence, finally, the less sanguine and celebratory tone adopted to describe how Europeans coped, or failed to cope, with recurrent problems of excess and dearth of water of the types they deemed desirable (this is detectable especially in chapters 2 and 4, but the concept of "technological lock-in" used in chapter 3 is another symptom of this orientation).

Working with Water in Medieval Europe brings together, between two bookcovers, accessible and up to date syntheses of work on the human adaptation to water resources. This synoptic and summarizing method resembles that of Forbes. Unlike Forbes, however, the authors who contributed chapters to this collection restricted their chronological scope to the Middle Ages, between roughly 500 and 1500, a period which happens to be their academic specialty, though many of the chapters consider continuities with the technical worlds of Antiquity, too (see chapters 1, 4, 5, 6, and 8; chapter 7 is unique in stressing Iberia's independence from the classical heritage). Also unlike Forbes, most of the authors restricted their scholarly sights to well-defined regions within Europe. Though neither Italy nor Germany (nor, really, Spain, the Netherlands, Ireland, England, or France) existed in the Middle Ages as anything more than vague linguistic or perhaps cultural zones, modern national boundaries provide a convenient set of limits to which modern scholars' knowledge often conforms. There are also sound ecological reasons for dealing separately with, say, Irish and Iberian hydraulic technologies. But a quick glance at the bibliography or index at the back of this book, where regional specializations dissolve, indicates that the "medieval *Europe*" of the title should be taken seriously. By presupposing that the European areas considered here shared a common technological culture and can be treated together, *Working with Water* encourages comparative, trans-European

analysis and invites “de-nationalization” of technological history; in this respect *Working with Water* reflects some of the most powerful political trends of the closing second millennium, when “Europeanness” has come to the fore in political and cultural discourse.

Thus, while early medieval Ireland seems to have been exceptionally prone to adopting and refining the ancient techniques of water milling, while Iberian irrigation systems appear unparalleled in their complexity, and while high medieval Holland appears to have developed land drainage methods to a unique extent, the rest of Europe was not cut off from these developments. In the area of urban water supply medieval Europeans displayed the coherence and uniformity of their technological culture especially well, deploying the same basic methods to guarantee acceptable abundance and purity from Hamburg to Granada. Fishing, too, was characterized by relatively homogeneous responses to cultural and environmental constraints, though eastern European watersheds produced some of the most meaningful technical novelties, exported with equally meaningful rapidity to the rest of Christendom, in the high and late medieval period (see chapter 8). A further common denominator, traceable in the “national” chapters, is the active involvement of ecclesiastical institutions, especially monasteries, but also bishoprics, in the adoption of machines and techniques to modify or take advantage of the way water behaved in a given locale. Medieval Europe, even subdivided as it is here, offers striking instances of technological unity. Seeing such techno-historical congruence, dating from the Middle Ages, may please those who approve of recent experiments in European unity. But holding a book like *Working with Water*, one of whose strong themes is the question of the connection between past technologies and the cultural horizons within which they fit, we should wonder also about how modern studies of past technologies and cultures function within their modern settings. In this instance, ironically, western Europe’s post-Maastricht yearnings may have tinted the spectacles through which we observe the medieval technologies for managing water, inducing us to perceive more harmonies than existed.

For just as Europe was united by its technological adaptations to water, it was also heterogeneous and fragmented, though not necessarily along national lines. Urban communities’ economic and cultural predisposition for hydraulic “improvements,” chronicled in several chapters of this book, is a demonstration of how specific

social groups (townsfolk, in this case) could become peculiarly receptive to technologies of water management, and foster innovation or sustain elevated levels of complexity in this field. Other special communities had their own special affinities for hydraulic techniques: the Cistercians' involvement in land-drainage and engineering water supplies for energy and hygiene in their abbeys is an example (chapter 5 emphasizes the willingness of the Cistercians to invest more heavily in hydraulic technologies than others groups did). Another example comes from the pronounced aristocratic interest in artificial fishponds in the high and late Middle Ages (chapters 2 and 8 discuss this). Similarly distinctive were the Muslim settlers of Iberia, many from North Africa, whose unique social organization and specific culture were important to their refined irrigation systems; their technologies stand out in the European landscape of around 1000 (see chapter 7).

If the unities outweigh the differences in medieval Europe's hydraulic technologies, to some extent such unity derives from the uniform characteristics of the element the technologies were designed to confront. Though water in the Vistula catchment basin may freeze rather more often than does water in the Biferno valley, and though streams may flow more regularly in Yorkshire than in Mallorca, the properties of water were the same everywhere in Europe. Water obeyed the lure of gravity, and, whether in slender lead pipes or rough, open ditches, it more willingly moved from where it was to other places than did stone, wood, or earth. Malleability and moveability conferred on water unique characteristics, making it the most changeable of elements, the most subject to people's manipulations, though the inhabitants of floodable areas knew water was not just a subject, but also a willful ruler. Therefore, regardless of whether people intended to drink it, power pumps with it, fish in it, or remove it altogether from their arable fields, water elicited technical responses that were closely related to each other. The distance between a grist-mill powered by water and a hydraulic pump to dry a mine shaft, or between an irrigation channel and the conduits to regulate water levels in fishponds, was not great. For this reason it seems logical to isolate those techniques medieval people used when working with water, and analyze them as a coherent subset of a broader technological horizon. This horizon is itself part, and an important part, of medieval Europe's diverse and yet coherent cultures.

Together with Julian Deahl, editor at Brill and enthusiastic patron of the project underlying this book, and with Marc Kiener and Pamela Rae Waxman, who translated into English chapters 4 and 5 respectively, I must thank all the authors whose learning and zeal for matters of technology and water made the assemblage of the book possible.

CHAPTER ONE

WATERPOWER IN MEDIEVAL IRELAND

Colin Rynne

Introduction: Ireland in Early Medieval Europe

The island of Ireland (figure 1.1) never became part of the Roman empire, although it was neither isolated from nor immune to Roman influences. Indeed, Ireland was the first region outside the *limites* of the Roman world to become Christianised, even though other trappings of Roman rule—towns, organised communications, currency and a literate bureaucracy—did not exist there. Thus, its precocity in the realm of water-powered technology in the early medieval period, relative to other areas of Europe, is best explained in terms of Ireland's dual nature as a world apart and one well connected to the outside. Indeed, the widespread use of watermills in early medieval Ireland is indicative of important developments such as a growing need to ensure regular supplies of grain for a rapidly increasing rural population, and its corollary, the expansion of tillage. Watermills are therefore a useful index of the increased importance of cereal crops, the necessity of being able to process larger harvests more efficiently and also, perhaps, of a more broad-based distributive network for milled cereals, all specifically Irish, indigenous developments of the early Middle Ages. Yet the diffusion of watermills is also *the* clearest indication of the close cultural and trading links between Ireland and Europe. The discovery of post-Roman pottery in Ireland is usually cited as evidence for close commercial links with Merovingian Gaul, and this conclusion cannot be disputed. However, this pottery was never manufactured in Ireland, nor does it survive beyond the seventh century. Horizontal- and vertical-wheeled watermills, instead, clearly implants of a late Roman building tradition, continued to be built throughout the medieval period. Watermills' technological importance for early medieval Irish society made them much more wide-ranging in their effects on the contemporary economy than the wine trade with Merovingian Gaul.

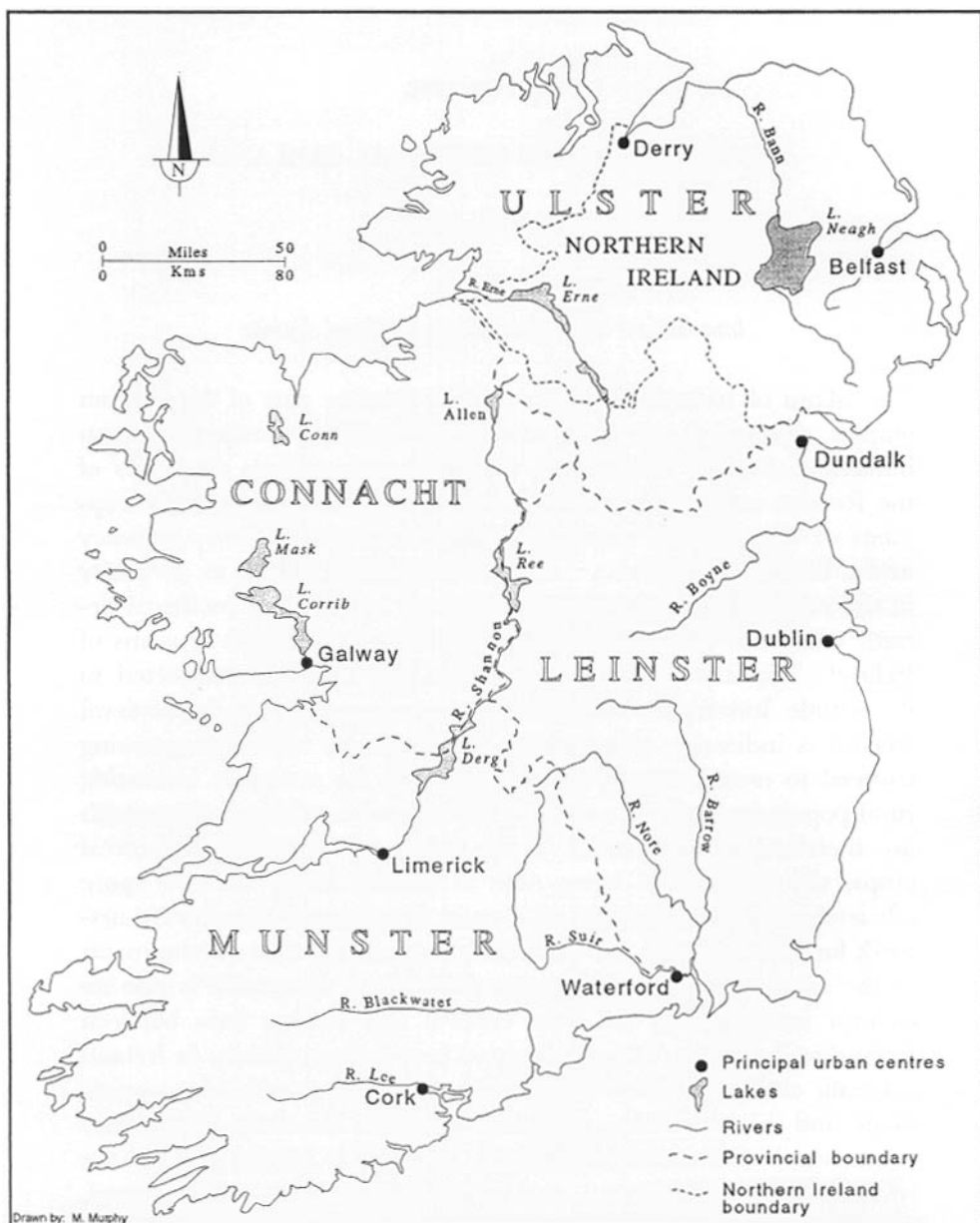


Figure 1.1. Ireland, main features.

In Ireland seldom has water been a scarce resource. The island's mild and rainy climate has encouraged dairying for almost two millennia. The temperate winters have enabled cattle to graze all year round without requiring investments in fodder crops, which were virtually unknown before the arrival of the Anglo-Normans in the twelfth century. Agricultural activity in Ireland did not require irrigation, and in fact the earliest indications of the widespread use of man-made water channels are associated with hydro-power. The first evidence for the use of large-scale water supply systems, for both domestic and industrial purposes, dates to advent of the Cistercians and the Augustinians in Ireland in the first half of the twelfth century (see page 43 below). The development of urban supply systems in Ireland is equally late. The medieval city of Dublin did not have a regular piped supply until 1245, whilst Cork was not provided with such a supply until the end of the thirteenth century.¹ With regards to water-related technologies, therefore, the importance of the Irish documentary and archaeological record derives from the insights it provides into the worldwide development of water-powered technology in the first millenium A.D. As will be seen below, the earliest archaeologically attested examples of certain varieties of watermill, which are documented throughout Asia and Europe, have been found in Ireland. Furthermore, the earliest vernacular terms for the principal components of the horizontal-wheeled mill, in any European language, are in Old Irish. Water-powered technology is thus the area in which Ireland's record is best and most relevant for comprehension of the history of human water management. This chapter reviews the documentary and archaeological evidence for the development of water-power in medieval Ireland in the light of recent archaeological discoveries and a comprehensive reappraisal of the documentary evidence.

*The Documentary Evidence for the Use of Water-Power
in Early Medieval Ireland*

(a) Early Irish Law Tracts: Before the introduction of Christianity to Ireland and the subsequent adoption of the Latin alphabet, native

¹ Walsh (1997), 22; O'Sullivan (1937), 43.

Irish law was transmitted orally. Most of this was written down in seventh (or even as early as the sixth) century A.D., while glossing (i.e., adding commentaries to the texts) began in the ninth century (by this latter period the substance of the texts appears to have become obscure to the jurists).² Five early Irish legal texts deal with different aspects of watermills (construction, ownership and water-rights, and terminology), some in interesting detail.

De Ceithri Slichtaib Athgabála ("on the the four sections of distraint") which lists "the eight parts of the mill" (treated below), is a very early tract on distraint (*athgabála*), and is included in the "first third" of the seventh/eighth-century legal compilation known as the *Senchas Már* ("The Great Tradition"). From Binchy's analysis of the main legal developments in the text, it is clear that these must have been completed, at the latest, by A.D. 600; this suggests that horizontal-wheeled mills were common enough in the sixth century A.D. to feature in cases of distraint.³ The *Senchas Már* also contains *Crith Gablach* ("branched purchase"), a law tract on status of about A.D. 700 which, amongst usages pertaining to mills in early Ireland, lists penalties for use of watermills without the owner's permission and for any damage caused while doing so. More significantly *Crith Gablach* specifies the degree of ownership in a mill (i.e. in full or in part) appropriate to the various ranks of society,⁴ which clearly indicates that the use of water-powered mills was widespread amongst the early medieval population of Ireland.

Coibnes Uisci Thairidne ("Kinship of conducted water"), a seventh-century law tract dealing with a specific aspect of the law of neighbourhood, is arguably the most comprehensive tract on the water rights of mills from anywhere in medieval Europe. This law tract, which forms part of the "middle third" of the *Senchas Már*, deals with legal matters relating to the construction of mill races and the ownership of mills and outlines a complex system of rotation governing their use based on the degree of ownership amongst kinship groups and individuals. According to *Coibnes Uisci Thairidne* no individual can prevent another from excavating a millrace across his land, provided suitable compensation is paid. The only lands exempt from this were those owned by the Church, the precincts of graveyards and of the

² Binchy (1966), 84–92, esp. 88; Kelly (1988), 231–32.

³ Binchy (1973), 22–71.

⁴ Binchy (1941), vol. 2, 96, 155, 238.

dún, or ringfort—the archetypal settlement site of the Irish early medieval rural landscape. Furthermore, the owner of the land across which the millrace is to be cut can also claim the right to use the mill within a seven day period of rotation. The strict sabbatarian prohibition of the use of mills on Sunday in *Cáin Domnaig* (discussed below), could be an indication of the pre-Christian origins of the system of rotation outlined in *Coibnes Uisci Thairidne*. For three generations after the construction of the millrace the ownership of the land which it traversed continued to be vested in the original owner. After this period, however, the original owner's rights were relinquished.⁵

In *Coibnes Uisci Thairidne* the millrace is listed amongst seven ditches or man-made cuttings which were exempt from the payment of compensation, or any form of liability, in the event of someone falling into them. But, above all, the importance of mills is underlined by a privilege they shared with the use of bridges, fishing weirs and fruit falling from a tree onto the land of another individual: only in these cases was access to a neighbour's property deemed appropriate. An analogous situation obtained in relation to the same cases in medieval Welsh law, where a mill, a weir and an orchard formed the *tri thlws cenedi* or "three ornaments of a kindred".⁶

Two further early legal texts also underline the importance of water-powered mills in early medieval Ireland. In *Bretha Étgid* or "judgements of inadvertence" (traditionally translated under the incorrect title of *Lebar Aicle* or "The Book of Aicill"),⁷ there is a list of the "exemptions of the mill", which involves those liable for damages in the event of injuries received by those operating it.⁸ The *Cáin Domnaig* or "Law of Sunday", one of the four main *cána*, or laws, is a late eighth- or early ninth-century law tract which deals with Sunday observance.⁹ In one section of the text the Church sought to outlaw "grinding in mill or quern" on the Sabbath by imposing fines, which were higher on Church-owned mills than on those controlled by the laity; clearly this was because the Church was expected to show an example in the area of Sunday observance. Thus from the *Cáin Domnaig* there is a clear indication that by the late eighth century

⁵ Binchy (1955), 52–84; Ó'Cróinín (1995), 96–7.

⁶ Glanville Jones (1983–1984), 135–46, esp. 137; Kelly (1988), 108–9; Ó'Cróinín (1995), 98.

⁷ Kelly (1988), 272.

⁸ Binchy (1978), 287; MacEoin (1982), 13–19.

⁹ O'Keefe (1905), 189–214, esp. 17; Hamlin (1982), 11.

Church-owned mills were sufficiently common to feature in contemporary legal texts. A further early Irish legal text adverts to the first indication of the existence of a specialised craft of millwrighting from anywhere in medieval Europe. *Uraicecht Becc* ("small primer") lists the honour price of a *saer muillin* ("millwright") at seven "sets", while elsewhere the *saer muillin* is accorded the lowest rank of nobility.

(b) Hagiography: The main source of ecclesiastical literature for the use of watermills in early medieval Ireland are the *Vitae* or saints' lives, though unfortunately very few of these are contemporary with the events they purport to describe. As Charles Thomas has pointed out, the essential importance of the early *Vitae*, as a tool for the archaeologist, is the range of incidental details that are related in the descriptions of the events in which the saints are said to have been involved.¹⁰ And, if the events described in the *Vitae* were written some time after the *floruit* of a particular saint (as in the two *Vitae* examined below), then the technological details so described can at least be ascribed to the time in which the hagiographer was writing. The two earliest *Vitae* of Irish saints date to the late seventh century A.D. and, significantly, one of these describes the construction of a watermill while the other would indicate that one was used to meet the daily needs of an early monastic community. The *Vita S. Brigidae*, written about St. Brigid of Kildare (d. A.D. 523) by Cogitosus, was until recently thought to have been written between A.D. 650–675 but the latest editor of the life suggests that a date of A.D. 680–90 seems more likely.¹¹ An episode in this *Vita* (chapter 32) describing the difficulty of workers in removing a large millstone from the hilltop where it had been dressed by masons has been much used by scholars. The stone was miraculously rolled down the side of the hilltop after the name of St. Brigid had been invoked, and in a further incident it is made clear that this stone was part of a mill undergoing construction; the *Vita* describes a subsequent fire in which the stone miraculously survived when the lower millstone was destroyed. In this instance, we are clearly dealing with posthumous miracles attributed to the saint by the hagiographer, who claims to have witnessed them himself; and this episode can be taken as an indication that watermills were in existence during the lifetime of Cogitosus.¹²

¹⁰ Thomas (1971), 206.

¹¹ Kenney (1929), 359–60; Thomas (1971), 206–7; MacEoin (1982), 13.

¹² Chap. 34; Thomas (1971), 211; MacEoin (1982), 13.

The *Vita S. Columbae* was compiled in the 690s by Adomnán, the ninth abbot of Iona, almost a century after the saint's death in c. A.D. 597, but it seems likely that the hagiographer was aided in recounting events by a solid oral tradition.¹³ Adomnán refers to a corn-drying kiln and to the grinding of grain, which presumably involved large quantities of cereals if a kilning facility was required. He does not, however, indicate the means by which the dried grain was milled. Nonetheless, from the late Roman period onwards, the appearance of the corn-drying kiln in western Europe is associated with the adoption of mechanised milling and in view of this it is hardly likely that rotary querns were used in conjunction with a kilning facility. There is also a curious reference to a "crux molari infixa lapidii," or a "cross fixed in a millstone", which at least one early commentator saw as an explicit reference to a water-powered millstone.¹⁴ This inference was by no means unreasonable, even though the cross involved is likely to have been wooden, as a rotary quernstone could not have provided a solid base. Very recently the curious use of the millstone at Iona, referred to by Adomnán, was actually recorded in Ireland at Clonmacnoise, county Offaly, where the base of the north cross (c. A.D. 800), during its removal, was found to be set in the bedstone of a horizontal-wheeled mill.¹⁵ Indeed, recent excavations beside a shallow stream on Iona called *Sruth a' Mhuilinn* ("the mill stream"), although far from conclusive in terms of the remains of any recognizable mill structure, would also suggest that a water-powered mill was used here during the early medieval period.¹⁶

As many of the lives of Irish saints (both in Irish and Latin) are considerably later than those referred to above, their contents cannot

¹³ Anderson A., Anderson M. (1961), 109–12; Adomnán of Iona (1995), 53–65.

¹⁴ Joyce (1903), vol. 2, 334; *Vita S. Columbae* 3.23 (see Adomnán of Iona (1995), 227, 373 n. 406).

¹⁵ Manning (1992), 8–9. The suggestion by Anderson, Anderson (1961) in their translation of the life of Columba, p. 115, and by Richard Sharpe in the most recent edition of the saint's life (in Adomnán of Iona [1995], 373 n. 406,) that the millstone involved was a rotary quernstone, can no longer be accepted. The existence of the grain drying kiln on Iona during Columba's time would also suggest that a water-powered mill was in existence on the island in the early medieval period. The discovery of a water-powered millstone dating from the later medieval period during excavations on the island, which appears to have been re-used as the base for a wooden cross, would suggest that the practice, noted by Adomnán and recorded at Clonmacnoise, survived into the later medieval period; see Barber (1981), 282–380, esp. 308 and plate 19a; Royal Commission (1982), 239.

¹⁶ O'Sullivan (1994), 491–508.

be taken as wholly representative of conditions in early Irish monasteries. They do, nonetheless, provide interesting information on the operation and usages of Irish early medieval watermills. In the Irish life of St. Berach, for example, we are provided with a glimpse of the conditions surrounding the operation of a privately owned mill, while the Irish life of St. Fechín of Fore describes how the saint set out a mill and miraculously led water from a distant lake to fill its artificial reservoir.¹⁷

(c) Annalistic Sources: The Irish annals are perhaps the poorest primary source for information on early Irish watermills, where generally mills are only referred to in passing. The *Annals of Ulster* for the year A.D. 651 describes the killing of Dúnochad and Conall, the sons of Blathmac, in the underhouse of a mill by Maelodran, but, while these deaths are also recorded in the *Annals of the Four Masters*, *Tigernach*, and *Inisfallen*, the events surrounding them are different, as indeed are the years under which they are listed.¹⁸ The incident at Maelodran, however, provides the earliest documentary evidence for the existence of vertical-wheeled mills in Ireland around the same period. A further event described in various annals, again under different dates, is the collapse of the great standing stone the *Lia Ailbe* in A.D. 994, from the remains of which Máel Sechnaill II is said to have had four millstones cut.¹⁹ For the most part, however, the annals provide few technological details of early Irish watermills and can thus only serve as confirmation of the existence of watermills in Ireland before the tenth century A.D.

(d) Early Irish Saga Literature: References to mills and millers are also relatively common in the Irish sagas, though all of the compilations are relatively late. Important texts in this regard are the eleventh century *Togail Bruidne Da Derga* ("The burning of Da Derga's Hostel") which may have been written down as early as the ninth century A.D. and *Fled Bricenn* ("Bricriu's Feast").²⁰ Of these, *Togail Bruidne Da Derga* provides confirmation for the milling terminology used in the sixth century tract, *De Ceithri Slichtaib Athgabála*, discussed below.

¹⁷ Plummer (1922), vol. 2, 25–26; Stokes, (1892), 344–47. A variant of this legend is also found in the Latin life of Fechín (see Plummer [1968], vol. 1, 81–82) and in the Irish life of St. Mochua we find that Fechín was assisted in these feats by Mochua (Stokes [1890], 283).

¹⁸ MacAirt, MacNiocaill (1983), vol. 2, 127–29; Mac Eoin (1983), 60–64; O'Donovan (1856), 263; Stokes (1895), 374–419; MacAirt (1977), 649.

¹⁹ Joyce (1903), vol. 2, 334; O'Corráin (1972), 51.

²⁰ Stokes (1901), 165–215; Knott (1936); Henderson (1899).

Old Irish Technical Terms for Water-Powered Mills

In the sixth/seventh-century law tract *De Ceithri Slichtaib Athgabála* (hereafter D.C.S.A.), we find the earliest vernacular terms for horizontal-wheeled mill components in any European language. D.C.S.A. lists what are termed the “eight parts of the mill” along with a number of everyday items upon which a stay of execution obtained in cases of distraint in early Irish law. The implication is of course that if the component parts of a horizontal-wheeled mill could feature in such cases by the turn of the seventh century A.D., then these mills must have been extremely common in early Irish society. This latter circumstance is fully confirmed by the Irish archaeological record, but the evidence is much more wide-ranging than one might reasonably expect. For not only had a specialized craft of millwrighting grown to prominence in early medieval Ireland, but there are also clear indications that in the same period regional millwrighting styles had already evolved. But now we must turn our attention to the Old Irish technical terms for these mills.

The horizontal waterwheel is an impulse turbine which utilises fluid energy in its kinetic form, where the potential energy of the water in the reservoir is converted into kinetic energy as it falls towards the waterwheel (figure 1.2). The flume or guiding apparatus developed a waterjet which was discharged against the waterwheel, the spoons or buckets of which yielded against its impinging force. Once actuated, the torque exerted on the waterwheel's drive-shaft was communicated directly to the upper millstone, whose lower face was articulated with an iron power take-off device tied to the upper end of the driveshaft. Adjustments to the distance between the upper and lower millstones to facilitate either shelling or grinding were made by lifting or lowering the tentering mechanism—a two-piece lever—the lower horizontal arm of which positioned the lower section of the wheel's footstep bearing. An upward movement of the vertical arm (lightening-tree) induced a corresponding movement of the horizontal arm (sole-tree), where the whole waterwheel assembly was actually lifted *upwards*. As this slotted into the lower face of the upper millstone, this also was pushed upwards. This latter operation was conducted to enable the shelling of cereal grains, but when the kernels were re-admitted to the stones for reduction to bran or flour, the tentering arms were lowered to narrow the gap between the stones. Grain feed to the millstones was probably

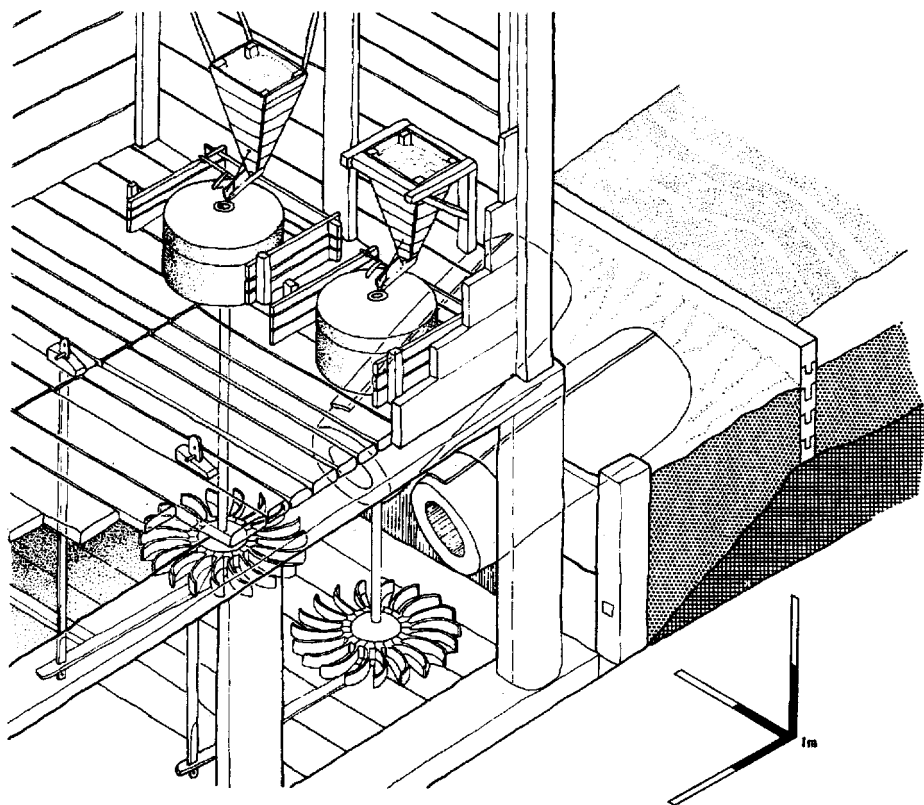


Figure 1.2. Reconstruction of twin-flume horizontal watermill at Littleisland, county Cork (c. A.D. 630).

automatic. Traditionally, a wooden hopper was used for this purpose, whose lower chute (the shoe) was allowed to come into contact with the rotating upper millstone, where the oscillation or joggling motion created by this contact ensured a steady trickle of grain from the hopper into the eye of the millstone (figure 1.2). Once the hopper was filled, therefore, and the mill set in motion, no further attention was necessary until the hopper needed re-filling. The ground debris passing through the millstones was discharged centrifugally at their periphery, around which a series of boards are likely to have been positioned to prevent draughts of air from scattering bran or flour around the grinding room floor.

(a) The Undercroft and Water Wheel Assembly: The Old Irish term for “undercroft”/“wheelhouse” is *fothach*. It contained both the

waterwheel assembly and the vertical and horizontal arms of the tentering mechanism. *Mol* is the term for the millshaft, whilst *cennrach* is the Old Irish term for the mill spindle/rynd bar assembly, which is listed in D.C.S.A. and is also used in *Togail Bruidne Da Derga* to describe part of the waterwheel assembly.²¹ The etymology of *cennrach*, as derived by MacEoin, suggests that this was something which was tied at the upper extremity of the axle-shaft, but this may not be taken as an explicit reference to the mill rynd.²² The power-take-off device at the top of the axle-shaft is likely to have been a two-piece construction, consisting of the mill-spindle (a vertical iron bar inserted into the driveshaft) and the rynd (figure 1.3). The rynd bar would not have been directly tied to the driveshaft (*mol*), thus *cennrach* (literally "head-tie") is likely to be a generic term for the complete power-take-off assembly. Curiously enough, there was no special term for "millwheel" although the vanes or paddles are termed *sciath* (plural *sciathaib*, literally "wings") in *Togail Bruidne Da Derga*, from which the Scottish Gaelic term *sgiathain* (mill vanes) may be derived.²³ In D.C.S.A. the terms *emtiud* and *milaire* are applied, respectively, to the pintle of the waterwheel's footstep bearing and the "pivot stone" supporting it and, while there has been some confusion about this, the glosses on each term, as MacEoin has demonstrated, leave us in no doubt as to their original function.²⁴ The term *oircel*, (literally a "trough") is used in D.C.S.A. to denote the mill flume (the water-delivery chute) or penstock, and is also found in *Fled Bricenn*, an Ulster cycle text written down in the twelfth century, but which describes an early medieval milieu.²⁵ The tentering mechanism of these mills, which is attested at two early sites, receives no mention in "the eight parts of the mill," even though this would clearly have been an important part of the machinery.

(b) The Grinding Machinery: In the earliest Irish texts the terms *lia* and *indeoin* designate, respectively, the upper and lower millstones. The term *cup*, as has been conclusively demonstrated by MacEoin, refers to a hopper or automatic grain feed device. Similarly, the term *comla*, which Curwen suggested was a reference to the eye of the

²¹ MacEoin (1982), 17; Knott (1936), 795.

²² MacEoin (1982), 17.

²³ Knott (1936), 794; Curwen (1944), 141.

²⁴ MacEoin (1982), 16-17.

²⁵ MacEoin (1982), 16; Henderson (1899), 66-67.

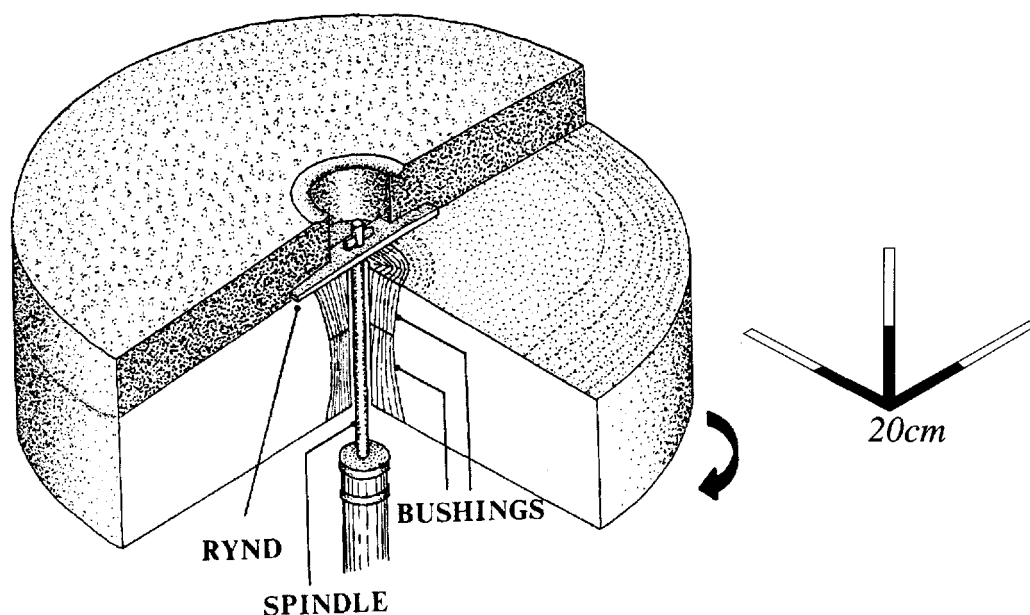


Figure 1.3. Millstone assembly in early medieval Irish horizontal-wheeled mill.

upper millstone, has been shown by Lucas to refer to the sluice gate; the same term, indeed, being used as late as 1934 for the sluice gate of a horizontal-wheeled mill in Conemara.²⁶

The Archaeological Evidence

The Irish corpus of mill sites from before the tenth century A.D. is the largest in the world. Despite the wealth of information this has placed at our disposal, this evidence continues to be plagued by the extreme variability of the conditions in which it is recovered. One of its major drawbacks, indeed, is that mill components by and large are rarely recovered under controlled conditions, and in consequence their interpretation is generally governed by comparison with the structural members of finds examined *in situ*. A second problem attendant upon early Irish watermills is the general absence of suitable comparanda outside Ireland, and while our knowledge of the tech-

²⁶ MacEoin (1982), 16; Curwen (1944), 140; Lucas (1953), 38.

nical development of the early Irish examples is greatly augmented by both regular discoveries and the science of dendrochronology, the rate of archaeological discovery in other European countries is inexplicably low. To date there are only a handful of excavated sites of early medieval date outside Ireland that can serve as chronological parallels for the early Irish developments—Tamworth, Staffordshire, Old Windsor, Berkshire, Ljørring and Omgård in Denmark and Earl's Bu, Orkney—which have produced remains on a scale comparable to those found in early medieval Ireland.²⁷ When we talk about the early technical development of the horizontal-wheeled mill, therefore, we are, owing to the frequency with which these mills occur in the Irish archaeological record, really talking about the Irish developments which must (for the present at least) serve as a datum for the interpretation of future discoveries outside Ireland.

Although the corpus of Irish sites is quite large, only a small proportion of these have been properly excavated. And, while many of these have been dated by dendrochronology, many only came to light in adverse conditions, where structural timbers were disturbed by mechanical excavators in the course of land reclamation schemes. The large number of sites that were discovered in the 1960s and 1970s is of course a result of the more "progressive" farming methods adopted in the last three decades or so and financed in the main by European Community grants, where large areas of what was formerly "marginal land" were brought into use. With few exceptions (e.g. Littleisland, county Cork, where a horizontal mill appears to have been superseded on the same site by a vertical-wheeled mill, as discussed below), all of the known early mill sites appear to have been single phase. Still, it is fair to say that we know very little about the water requirements for these mills, changes in which may have necessitated modified structural arrangements when, for example, a head or tail-race channel had to be adapted to suit long-term changes in water levels. A further example of this would be repairs to mill dams resulting from flash-floods, or additions to the latter to compensate for headage losses caused by the build up of silt, whilst erosion of the mill channels would also require regular maintenance.

²⁷ Rahtz, Meesom (1992); Wilson (1958), 183–221; Steensberg (1959), 130–135; Steensberg (1978), 345–356; Nielsen (1986), 177–210; Batey (1992), 303–4; Batey (1993), 20–28.

Some 28 Irish mill sites have been dated by dendrochronology, and most of these dates fall between the early seventh and early tenth centuries A.D. A further seven sites have been dated by C14, although up until quite recently the determinations produced for the Irish mills using this technique could at best provide the outline date of "early medieval".²⁸ At least three of the sites dated by dendrochronology were clearly vertical-wheeled mills. The sites dated by dendrochronology include the earliest-known tide mills, the earliest close association of vertical and horizontal-wheeled mills in post-Roman Europe and the earliest European twin-flume horizontal-wheeled mills.²⁹ There are also a large number of sites discovered during the nineteenth century which, on the basis of their morphology, are likely to be early medieval in date. Other important sites, such as Masha-naglass, county Cork, which were excavated in the 1950s are probably early medieval in date too.³⁰

(a) Mill siting and water supply (dams, millponds and millraces): On present evidence, fast flowing upland streams were the most common water source for watermills in early medieval Ireland. The suitability and ultimate utility of any supply of water would have been governed by a number of factors: its accessibility relative to the site chosen for the millworks, the degree of seasonality and the fall from the source to the proposed mill site. However, even the most copious waterflow could run at greatly reduced levels during crucial periods, particularly during the summer months. Indeed, the vast majority of the water-powered mill sites established in Ireland during the last century suffered from the seasonality of their watercourses. But whereas millwrights in more recent times could partially compensate for this by being able to calculate rates of flow available to them, relative to the power input and output of the waterwheel, their early medieval counterparts would have been almost wholly reliant on local observation of a watercourse or water supply over a long period of time. Nonetheless, early medieval millwrights must have possessed some basic survey skills to ensure a steady fall from the bed of the millpond, through the millrace or leat to the millworks themselves.³¹

²⁸ Baillie (1982), 180–92; Baillie (1995), 126–7; Otlet, Walker (1979), 358–383.

²⁹ Rynne (1992b), 22–24; Rynne, (1989), 21–31; Rynne (1992a), 54–68.

³⁰ Rynne (1990), 20–29.

³¹ In the later medieval Latin and Irish lives of St. Fechin of Fore, the saint miraculously draws water to a dry millpond, drowning the millwright who had fallen asleep in the area set out for the pond: Stokes (1892), 347–49. See also Plummer (1910), vol. 1, 81–82; Wikander (1985), 149–54.

The requisite survey knowledge for establishing relative levels for watercourses must indeed have been commonplace throughout medieval Europe. In many parts of Europe, from the Roman period onwards, agriculture was only possible through the construction of complex irrigation networks. The engineering structures associated with European, North African and South West Asian irrigation societies—artificial watercourses, dams and storage reservoirs requiring considerable survey skills—began to be widely used in Ireland with the advent of water-powered mills. Thus, it is by no means unreasonable to assume the survey skills necessary for their construction formed part of the craft of the early Irish millwright.

In D.C.S.A., the term *Topur* is used for the natural source of the mill's water supply and forms the first part of the "eight parts of the mill". While the proper meaning of *Topur* is "well," in the original manuscript this is glossed to explain that a well or spring need not be the only source of water impounded for the use of a mill. The term *tir linde* is used to denote the millpond, and its use instead of *lind* ("millpond") would suggest that *tir linde* (literally "the land of the pond") refers to the land flooded by it.³² A further term, *brígat na linne*, or "neck of the pond", also occurs, which clearly refers to the opening in the dam which allowed water into the headrace.

To date, there is only one excavated example of an early medieval mill dam in Ireland, from Mashanaglass, county Cork, although the remains of what appears to be a further example, associated with the remains of an early medieval monastic watermill, on High Island off the Galway coast, have recently been investigated (figure 1.4).³³ However, at least two further examples have been noted in association with Irish horizontal-wheeled mill sites at Milverton, county Dublin, and at an early ninth-century site at Crushyree, county Cork.³⁴ Yet although mill dams, ponds and channels would have been common features of the early medieval Irish landscape, as the law tract *Coibnes Uisci Thairidne* and the large corpus of mill sites which have thus far come to light clearly attest, very few Irish examples have been identified, let alone excavated. Nonetheless, the Old Irish terms *lind* or *tir linde* (literally "the land of the pond"), which is used in D.C.S.A., the late sixth/early seventh-century law tract

³² MacEoin (1982), 15.

³³ Rynne (1990), 25; Rynne, Rourke, White-Marshall (1996), 24–27.

³⁴ O'Donovan (1858–9), 252. Information on Crushyree Co. Cork was provided by Mr. Eamon Cotter, Department of Archaeology, University College Cork.



Figure 1.4. Early medieval monastic settlement on High Island off the coast of county Galway. (a) Main monastic enclosure. (b) Millpond. (c) Headrace channel. (d) Mill building. Photo by C. Brogan, courtesy of Department of Arts, Culture and Gaeltacht, Ireland.

on distraint, is the earliest-known non-Latin term for this feature in post-Roman Europe. Occurrences of related terms in other vernacular languages are somewhat later

In many instances, considerable effort was expended on the provision of a water supply for these mills. An ingenious system of feeder ponds and leats was constructed on High Island, off the Galway coast, to power a small horizontal-wheeled mill for the adjacent monastery.³⁵ A further island mill site on Littleisland in Cork Harbour, dating to c. A.D. 630, exploited tidal changes to power a large double horizontal-wheeled mill and a small vertical-wheeled mill. The structural arrangements of the Littleisland mills have no parallel in the existing corpus of early medieval mill sites in either Ireland or Europe as a whole.³⁶ Nonetheless, whether a relatively large milling complex such as Littleisland or more ordinary sites such as Cloontycarthy and Mashanaglass in county Cork were involved, all of the construction work would have required close supervision from the individual responsible for laying out the site.³⁷ In at least one later hagiography of St. Fechín of Fore, the work of the millwright is miraculously executed by the saint, whilst St. Moling is said to have dug his own millrace (*taidín*) as a penance.³⁸

Early documentary and archaeological evidence for the use of millponds outside Ireland is relatively rare. The earliest known dams for water power, dating from the Roman period, appear to have been diversion dams, built across small rivers or streams, where the function of the dam was to raise the level of a natural watercourse and divert it into a feeder or headrace channel for a mill. The overflow dam or weir for a the third-century A.D. Roman undershot, vertical watermill at Haltwhistle Burn Head on Hadrian's Wall, consisted of a barrage of granite blocks thrown across an adjacent stream.³⁹ In the immediate post-Roman period the construction of mill weirs is described in early hagiographical literature. Around the turn of sixth century A.D., Gregory of Tours described the construction of a mill dam for the monastery of Loches; "When he had driven poles

³⁵ Rynne, Rourke, White-Marshall (1996), 24–27.

³⁶ Rynne (1992b), 22–24; Rynne (1992c), 21–31.

³⁷ Fahy, (1956), 13–57; Rynne (1992b), 24–27.

³⁸ Plummer (1910), vol. 1, 82, 193–94; MacEoin (1982), 15.

³⁹ Simpson (1976).

across the river and brought together heaps of huge stones, he built a weir and collected water into the channel, by the force of which he made the wheel of the mill rotate at great speed".⁴⁰ The Salic laws of the late sixth century A.D. even prescribe a fine for the destruction of mill dams.⁴¹ At least one Saxon site, Wharram Percy, has produced evidence for a mill dam with evidence for internal revetting, a practice which is well-documented in later medieval accounts.⁴²

The formation of millponds, however, is less well documented in early medieval European sources. Millponds are referred to in the sixth century Visigothic law code and in c. A.D. 740 there is a reference to a *stagnum fluminis* at Tauberischafsheim in Germany.⁴³ The earliest known mention of the Old English compound *mylepul* ("millpond"), for example, appears in an Anglo-Saxon charter of A.D. 833.⁴⁴ There can be little doubt that by the later medieval period millponds were common features of the landscape. Their maintenance, along with related features such as millraces and sluices, often proved to be a heavy financial burden on both monastic and manorial estates.⁴⁵ Their frequency was such that early Irish jurists went to great lengths to provide a legal framework for the water rights pertaining to them, as is evidenced by the law tract *Coibnes Uisci Thairidne*.

The skills involved in laying out mill sites, manufacturing the mill plant and constructing the mill buildings themselves were vested in an elite body of craftsmen. The existence of a specialized craft of millwrighting in early medieval Ireland is, indeed, made explicit in the early Irish documentary sources. In the law tracts ample recognition is given to the *saer mulinn* or millwright, who is accorded the status of an *Aire Désa*, the lowest grade of nobility. In a story of the mythical *ard ri*, Cormac MacAirt, related by the poet Cuán ua Lothcáin (d. 1024), Cormac was said to have brought a millwright (*saer mulinn*) over from England to construct a watermill, to relieve

⁴⁰ *Vitae Patrum* 17.2; Rahtz, Bullough (1977), 15–39, at 20; Horn (1975), 229.

⁴¹ Koehne (1904), 34–5.

⁴² Young, Clarke, Barry (1983), 209; Rynne (1989b), 148ff.

⁴³ Wikander (1985), 152.

⁴⁴ Rahtz, Bullough (1977), 23.

⁴⁵ Chadwick (1911), 352–392; Faull, Moorhouse (1981); le Patourel (1956).

his mistress, Ciarnait, from the labour of the hand mill.⁴⁶ Indeed, according to *Uraicecht Becc* ("small primer"), millwrights were also accorded the same status as other master carpenters such as wood carvers, shipwrights and those capable of making an oratory (*durthech* or "oak house"). Furthermore in Triad 106 the construction of a watermill is included in "three payments" (*dulchinni*) in which assistance to a craftsman is apportioned a share, as the craftsman cannot complete the work by himself and is obliged to employ another worker (*gniae*).⁴⁷

The Early Irish Watermill

From the archaeological evidence it is clear that two varieties of horizontal-wheeled mill, which employed either single or double flumes, were in use during the early medieval period in Ireland. The vast majority operated with a single flume, or water-delivery chute, but there are at least six recorded examples of mills (which include the earliest known Irish horizontal-wheeled mill at Littleisland, county Cork), which employed two delivery chutes. The existence of multi-flume mills is also referred to in passing in *Fled Bricenn*. In *Fled Bricenn* the *muilend dec forcel*, or "mill of ten *oircel*" (Old Irish *oircel*, literally a trough, but used in the late sixth-century/early seventh-century legal text on distraint, D.C.S.A., to refer to the mill flume), while obviously an hyperbole "to convey an impression of enormous speed and power", clearly refers to the existence of mills utilising more than one delivery chute.⁴⁸ The vertical-wheeled mill in Ireland is at least as early as the two varieties of horizontal-wheeled mill, and so the work of the early Irish millwright can be said to have encompassed at least three basic mill types.⁴⁹

The Horizontal-Wheeled Watermill

The Mill Buildings

In the early Irish horizontal-wheeled mill, the undercroft, the lower section of the building housing the waterwheel assembly, is always

⁴⁶ Stokes (1890), 861; Gwynn (1903), 22–3.

⁴⁷ Kelly (1988), 61.

⁴⁸ Lucas (1953), 31.

⁴⁹ Rynne (1989a), 21–31.

rectangular in outline, with retaining walls of either planks, stone or both. On present evidence three main types may be distinguished: one (type a) where the sole plates or foundation beams defining the side walls of the undercroft are articulated to the flume support beams (e.g. Ballykilleen, county Offaly, A.D. 635); another (type b) where the side walls are of stone with the flume support abutting them at right-angles (e.g. Mashanaglass and Knockrour, county Cork); and a third type involving a combination of (a) and (b) with the foundations of the side walls built over the sole plates (e.g. Cloontycarthy, county Cork, A.D. 833; figure 1.5).

The early Irish horizontal-wheeled mill, as has been seen, was a split-level building, its lower level housing the waterwheel and the tentering arms, and its upper level (which presumably corresponded with ground level) housing the grinding machinery. However, unlike the arrangements made at many sites for waterjet delivery, the plans of many mill undercrofts, apart from the essential rectangular outline, appear to differ in many respects. Nonetheless, as far as the archaeological record is concerned, undercrofts with stone retaining walls are clearly less common than those with timber frameworks. In the end, this is more likely to reflect the availability of building materials than separate millwrighting traditions.

One of the most important considerations taken into account when leading water from the feeder stream or millpond towards the millworks was the provision of a suitable fall, to ensure that the passage of water between these two sections of the mill was facilitated by gravity. The difference in height between the level of the millpond and the outfall of the mill is called the "head;" and this determines the power input. In a working situation, water pressure is likely to have been built up in the head race channel immediately in front of the mill flume or penstock, a hollowed-out baulk of timber which was used to develop a jet of water. The difference in height between the level of the water impounded behind the penstock and the tail race channel is the "effective" or "operational head." The "effective head" may be defined as "the difference between the head at inlet to the machine and the head at outlet to it."⁵⁰ In early Irish horizontal-wheeled mills, these are represented by the rear end of the flume (or the upper edge of a cistern constructed behind it) and the bed of the tail race channel (figure 1.6).

⁵⁰ Massey (1979), 47.

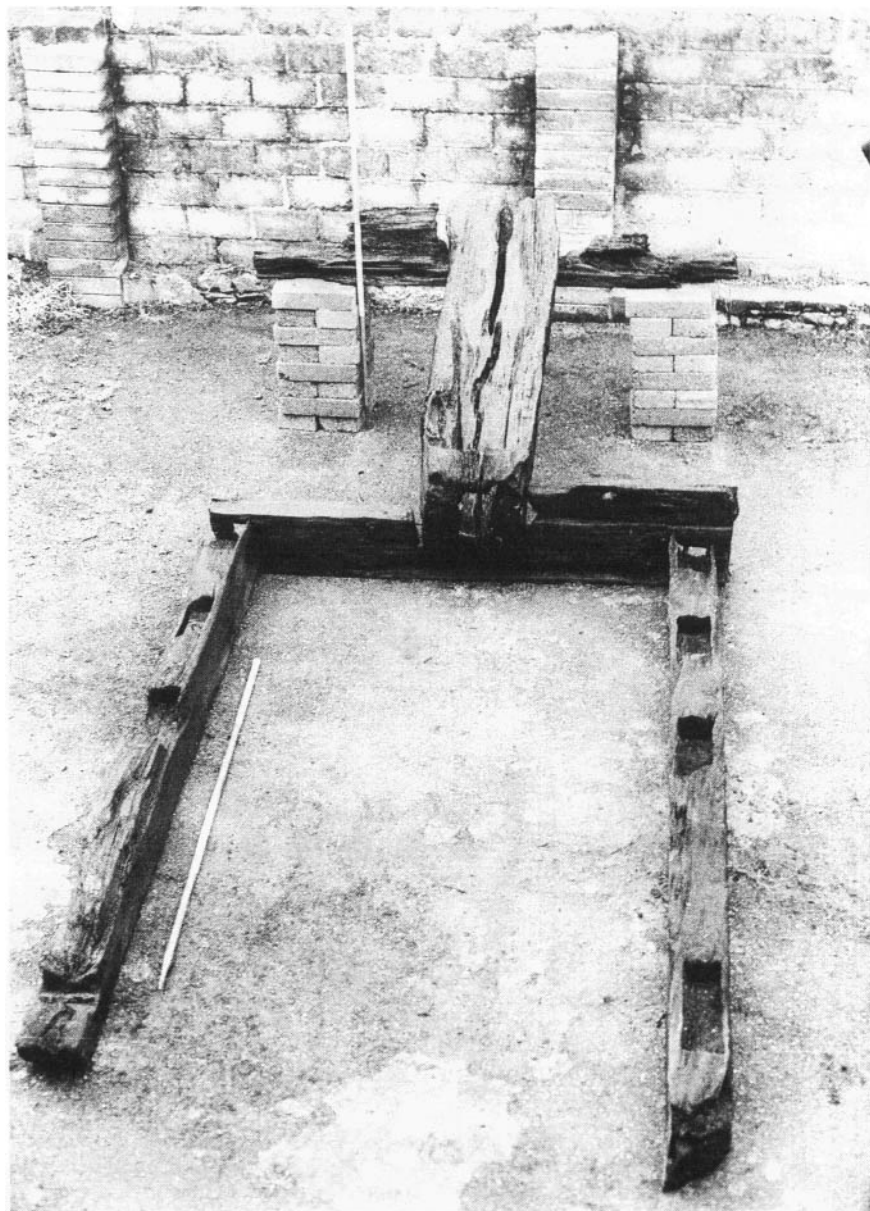


Figure 1.5. Mill timbers from Cloontycarthy, county Cork (A.D. 833), as reassembled at Department of Archaeology, University College Cork in 1981. Note the steep angle of the mill flume and the position of the beams supporting it.

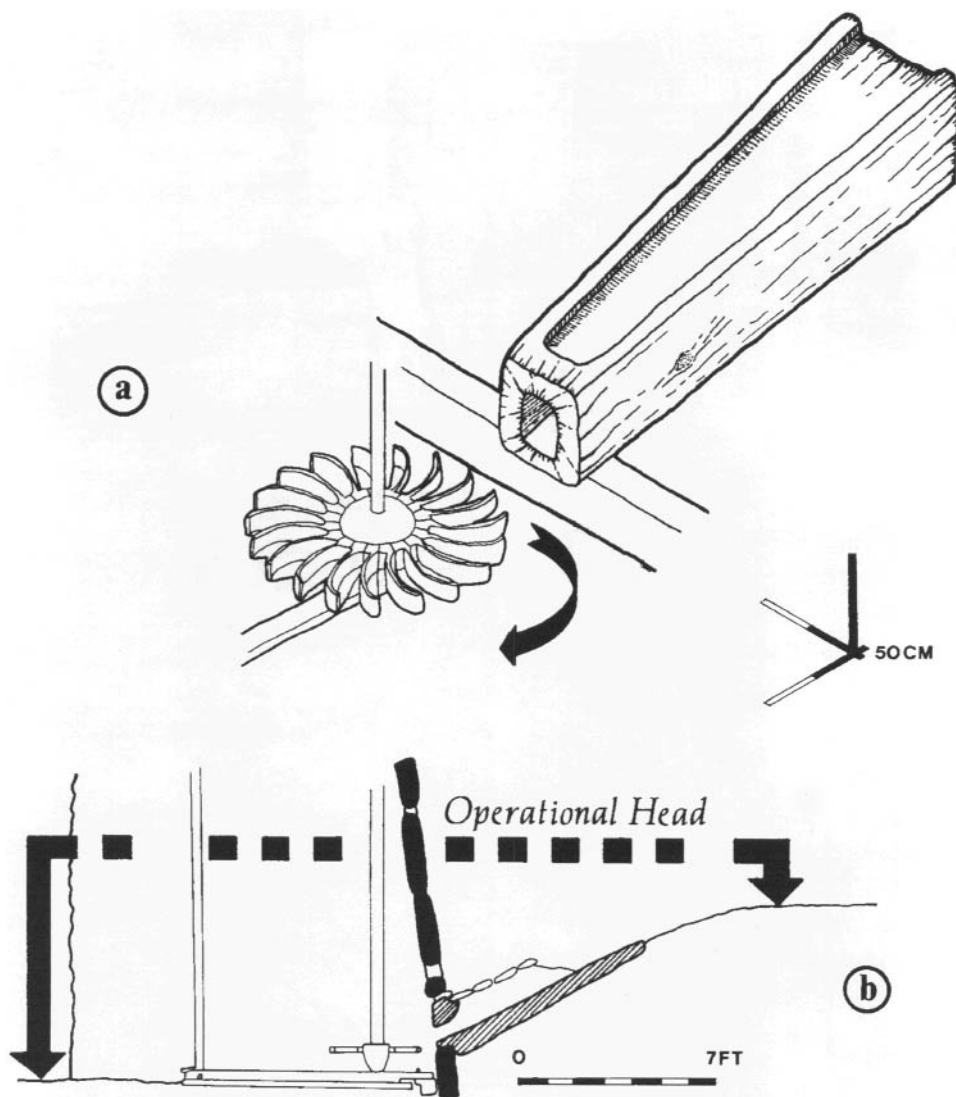


Figure 1.6. (a) Relationship of flume and waterwheel in early medieval Irish horizontal-wheeled watermill. (b) Operational head of early medieval Irish horizontal-wheeled watermill, based on Mashanaglass, county Cork, after Fahy (1956).

Three Irish sites—Mashanaglass, Cloontycarthy (A.D. 833, Figure 1.5) and Crushyree (early ninth century), in county Cork—present us with firm evidence of the practice of inclining the flume steeply in relation to the waterwheel. The prevalence of this practice at the vast majority of the other sites can be safely inferred from the custom of cutting a slanting face at the fore end of the flume and the provision of a lid for its upper face. As was demonstrated at Mashanaglass, Cloontycarthy, and Crushyree, along with an A.D. 732 county Derry site, Drumard,⁵¹ the fall from the rear end of the flume to the floor of the undercroft was maximised by setting the foundations of the mill building well below ground level, thus creating a building with two floors: the undercroft housing the waterwheel (below ground level), and the grinding room set at ground level. At the ninth century Cloontycarthy site a deep cut was made into the underlying rock for the mill's foundations, a practice which is also recorded at the eighth century Drumard site, though in most cases an excavation roughly corresponding to the dimensions of the undercroft would have sufficed. The sides of this cut (as was evidenced at Mashanaglass and Cloontycarthy) would then have been retained by stone walls or planking, which also provided support for the upper floor. In more recent horizontal-wheeled mills in Europe and elsewhere in which wooden flumes were employed, the flumes involved were generally not provided with lids, as the mill buildings are raised on stilts or dry-stone pillars. In early Irish mills, on the other hand, the leading of the flume into the excavated recess containing the undercroft normally required the area around the flume to be backfilled, whence the need for a lid.

From the foregoing it is clear that while incoming water was in some cases impounded in an artificial reservoir, connected by means of a feeder channel to the mill-works, there can be little doubt that although the feeder channel was contrived so as to fall towards the rear of the mill flume, incoming water was impounded behind the flume prior to entry through it. This enabled water pressure to be built up, which resulted in a more powerful waterjet striking against the waterwheel. The necessity of this practice inevitably raises the question of whether or not some kind of sluice-gate or flap valve was employed. The use of a stout wooden beam to support the rear

⁵¹ Baillie (1975), 25–32.

end of the flume associated with the ninth century Cloontycarthy mill (figure 1.7) would suggest that some sort of gate fixture was positioned behind it where, as in the contemporary Saxon watermill at Tamworth in Staffordshire, the base of the flume would have been raised above the bed of the head race channel. And, whereas the back of the Mashanaglass flume was positioned on the bed of the head race channel (which suggests that entry into the flume was direct), the use of rear support beams at Cloontycarthy and Tamworth clearly indicates that the head race channel immediately behind the respective flumes was deliberately widened to facilitate the build-up of water pressure. Other Irish mill sites have also produced evidence to this effect, which include a probable early medieval site at Bantry, county Cork discovered in 1844; and at a further undated site discovered in the 1920s at Knockrour, county Cork.⁵²

The obvious explanation for this practice, apart from the benefits accruing to the issuing jet, was that, owing to the light-weight construction of the waterwheel, a large degree of control had to be exercised over the incoming water. Apart from the use of sluice gates, as suggested above, at least two further modes of water-inlet control were used: by-pass channels (as at High Island, off the coast of county Galway), and possibly jet deflectors.

To conclude this section, we may summarize by saying that the operational head of early Irish horizontal-wheeled mills was governed by two factors, namely the excavation of a deep recess for the mill foundations (thus leading the flume at a steep angle from the top of the recess to the waterwheel positioned on the floor of the recess); and the raising of the water in the head race channel well above the rear opening of the flume, to increase water pressure and the efficacy of the waterjet.

Mill Flumes

Two basic types of early medieval Irish mill flume may be distinguished, both of which are one-piece constructions fashioned out of enormous oaken balks. All but two of the known examples are of rectangular cross-section with a slanting face at the fore end, good examples of which have been investigated at Mashanaglass, county Cork, Knocknagranshy, county Limerick (dated to the eighth/ninth

⁵² O'Conlon (1926), 96–101.

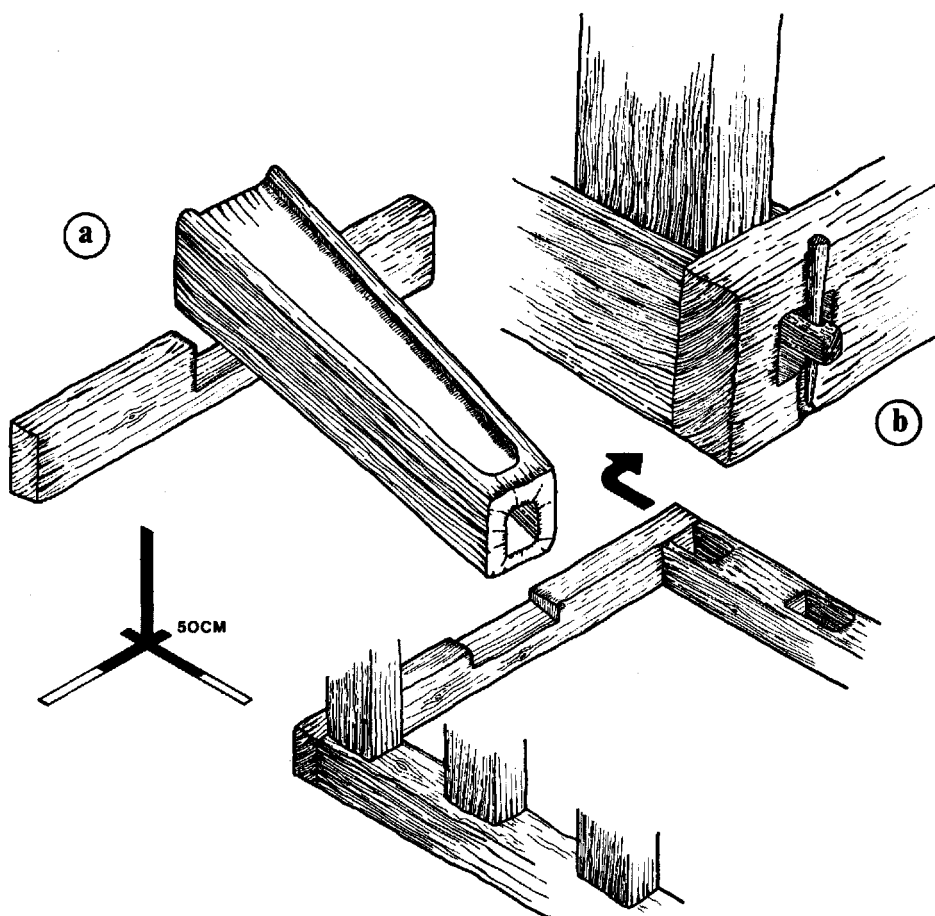


Figure 1.7. (a) Arrangement of flume support beams at Cloontycarthy, county Cork.
(b) Detail of joint fixing soleplate to flume support beam.

centuries A.D. by C 14); and Killphillibeen (c. A.D. 827) and Cloontycarthy (c. A.D. 833) in county Cork (figure 1.8). The second type have a circular cross section internally and are sub-oval externally with a vertical face at the fore end, and are further characterised by a narrow slot on the upper face which presumably accommodated a lid. The earliest examples of Irish mill flumes, flumes I and II from Littleisland, county Cork (A.D. 630) are of this type (figure 1.9).⁵³

⁵³ Fahy (1956), 26-7; Lucas (1969), 12-22.

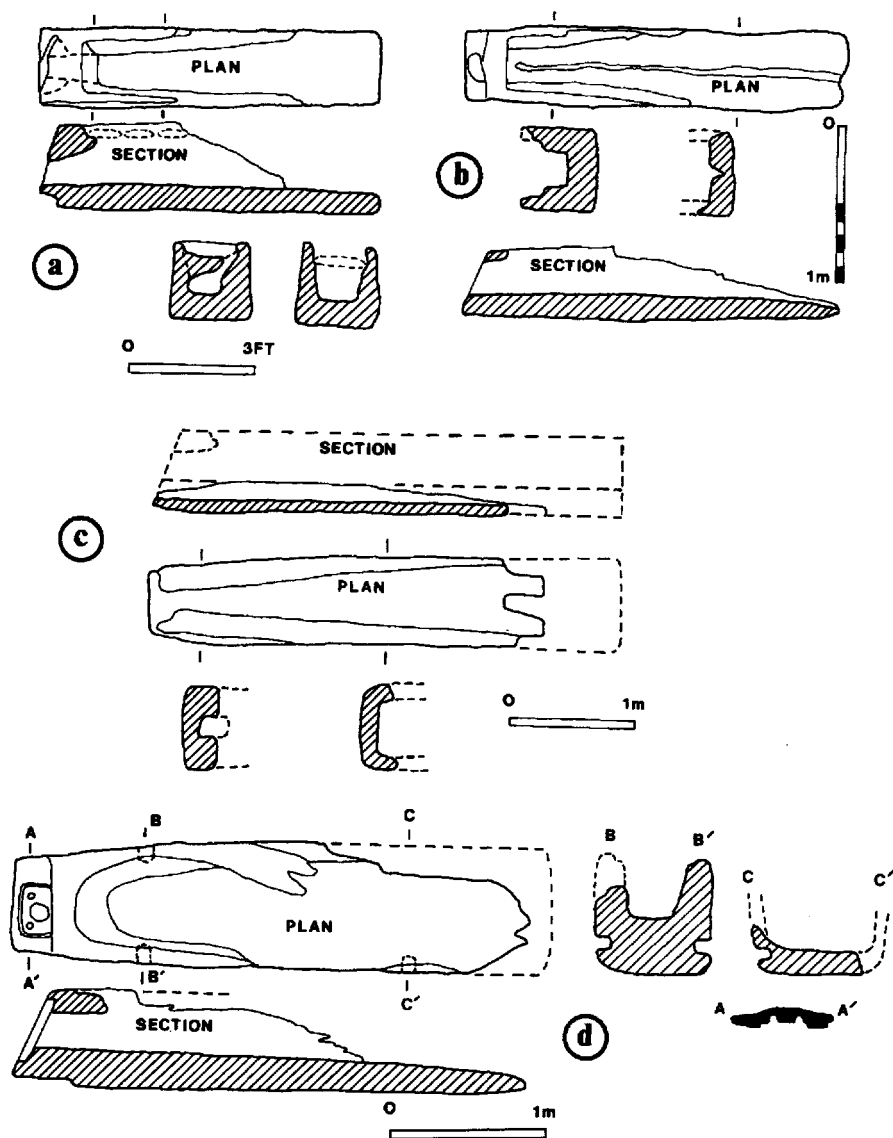


Figure 1.8. Early medieval Irish mill flumes. (a) Mashanaglass, county Cork, after Fahy (1956). (b) Cloontycarthy, county Cork (A.D. 833). (c). Dawstown, county Cork. (d) Killphillibeen, county Cork (A.D. 827).

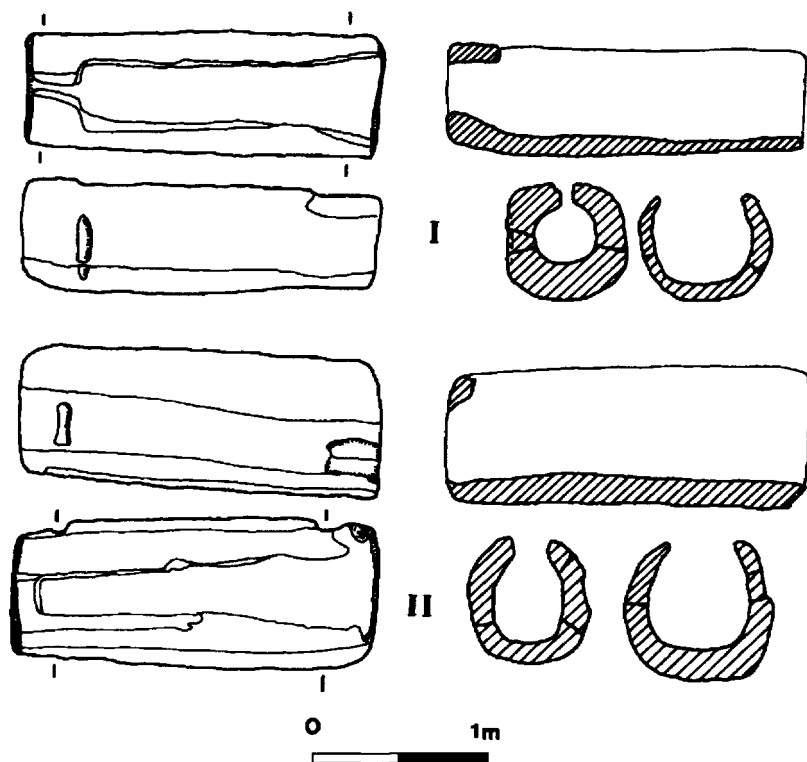


Figure 1.9. Mill flumes from Littleisland, county Cork (A.D. 630).

All of the investigated Irish mill flumes appear to have been wholly axe-dressed. The majority of Irish mill flumes are around 3–4 metres long, with a cross-sectional area at the centre of about 36 square centimetres, which clearly would have involved the use of massive oaken trunks, perhaps 4 metres long and at least 70 centimetres in diameter. Only mature oak trees could have met these specifications although rigorous selection was probably unnecessary, the main considerations being bulk rather than the quality of the timber. Individual balks were squared off on four faces with an axe on either one or both of its extremities (only on one if a slanting face at the fore end was required). On the Littleisland flumes, however, the main cuts were made into crude chamfers on two of the external faces so as to provide a more comfortable fit on their supporting beam.

To date only six Irish sites have produced flumes with lids, although the presence of lids on flumes from other sites can be deduced from

the longitudinal rebates cut along the sides of their top openings, and while the rebates on the Mashanaglass flume had been used to position sandstone slabs, it seems certain that the other examples with rebates (if not sealed with stone slabs) were equipped with some sort of covering.⁵⁴ In more recent mill flumes from Portuguese *rodizio* mills, the *cales*, or flumes, were cut from a single tree-trunk sawn lengthways to preserve a piece which could serve as a lid.⁵⁵ There is as yet no evidence that would suggest that early Irish millwrights employed the same procedure; nonetheless, even if flume lids were not fashioned from the same balks used in the manufacture of the flumes, it is likely that the lids would have to be radially split from substantial oaken balks.

The flume, as has been seen, is in fact a wooden conduit, the internal area of which was hollowed out and splayed inwards from its rear end in the direction of the perforated orifice at its fore end. The rebates for the lid probably also represent some of the initial cuts into the upper face of the tree-trunk, which were then deliberately stepped inwards to allow the shaping of the flume's interior. At a set distance from the fore end, a solid block was left for the perforation of the orifice, an operation which is likely to have been performed with an auger. The orifice was generally in line with the base of the flume, though the Littleisland examples were slightly raised, and its shape (again with the exception of the Littleisland flumes) was normally sub-rectangular, a shape which would not necessarily improve the efficacy of the waterjet issuing from it.

Only one Irish site, Rasharkin, county Antrim (A.D. 822) has produced a jet-developing bore, which comprised a perforated wooden block inserted in the orifice of the flume.⁵⁶ Orifice bores are normally associated with certain types of Portuguese *rodizio* mills and Romanian *cuitura* mills (on which see page 49 below) and with all the known varieties of *arubah* penstock mills; where they were interchangeable and could thus be adapted to suit available waterheads. (figure 1.10) These also, it is clear, produced a more concentrated waterjet and also, to a certain extent, reduced surface spray. In this regard, it is worthy of note that the Irish flumes, with their characteristic narrow orifices, are more sophisticated than the vast majority

⁵⁴ Fahy (1956), 17.

⁵⁵ Galhano (1978), 41.

⁵⁶ Baillie (1982), plate 3.

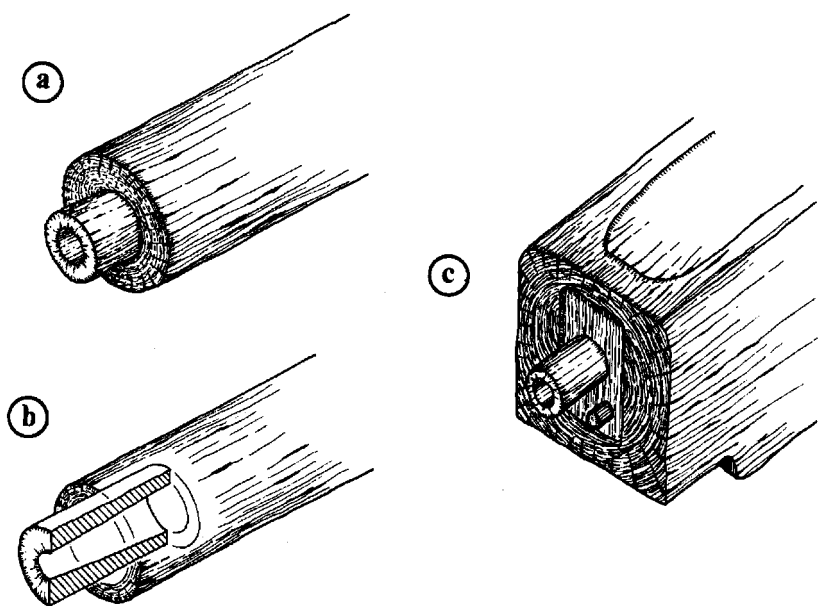


Figure 1.10. Jet-developing bores on horizontal mill penstocks. (a) Portuguese *cale*, after Galhano (1978). (b) Romanian *buton*. (c) Suggested reconstruction of inset on mill flume from Killphillibeen, county Cork (A.D. 827).

of more recent examples which did not have lids or carefully fashioned orifices, and, insofar as available evidence allows judgement, only a number of more recent Turkish mills and a stone-built flume in a medieval sugar refinery in Cyprus show this refinement. A similar orifice insert was described by John Windele. It was found on a flume at Breenymore, near Bantry, county Cork. Such a device was doubtless affixed to the Killphillibeen flume (c. A.D. 927).⁵⁷

The mill flume from Rossory, county Fermanagh (c. A.D. 876), has two curious pieces projecting from the fore-end which, unlike the other accessories described above, could not have been for positioning an orifice bore. For that matter, they do not appear to have assisted the positioning of the flume itself either.⁵⁸ On the other hand, it is likely that they served to attach some other device to the front of the flume, possibly a jet deflector. The latter are commonly associated with flumes from the Iberian peninsula, the commonest variety

⁵⁷ von Wartburg (1983), 298–314; Rynne (1992a), 54–68.

⁵⁸ Wood-Martin (1886), fig. 4.

consisting of a pivotted flap set under the fore-end of the flume which, when released, directed incoming water *over* the paddles of the waterwheel.

In the main, the recorded examples of Irish horizontal-wheeled mills operated with a single flume. There are, however, at least six sites that are known to have employed two flumes, each of which presumably serviced separate waterwheels. Of these, only the Littleisland (c. A.D. 630) and Newtown, county Tipperary (eighth century A.D.) sites have been dated, from which we can reasonably infer that this type of mill is at least as early as the seventh century A.D.⁵⁹ A suggested reconstruction of the rationale behind double-flume mills is given in Figure 1.2 where each flume is shown to be angled inwards towards a separate waterwheel. This practice is well documented in the Balkans, the Alpine regions and in the Caucasus (discussed below), where, rather than closely spacing mills near an exceptionally favourable water source, one site was chosen and all the mill machinery of separate mills was housed under the one roof.

The Early Irish Horizontal Waterwheel

The early Irish horizontal waterwheel can be divided into five sections: the hub or nave, the axle shaft (both of which can be fashioned in one piece, see below), the paddles or vanes, the rynd/spindle assembly or power-take-off, and the footstep bearing. To date some ten Irish horizontal-wheeled mill sites have produced water wheel hubs, four of which, Cloontycarthy, county Cork (c. A.D. 833), Rasharkin (c. A.D. 822), Moycraig (eighth century) and Deer Parks Farm (eighth century), have been dated. In many cases dished paddles have accompanied such finds and there also another two dated sites, Ballykilleen, county Offaly (c. A.D. 635, the earliest known examples of their type from anywhere in Europe) and Drumard county Derry (c. A.D. 732), from which dished paddles have been recovered.⁶⁰

The essential scoop-sectioned, or dished paddle, design was a device for maximising the amount of energy abstracted from the waterjet where, in terms of the hydrodynamics of impulse turbines ancient and modern, a scooped vane can in fact absorb almost twice the velocity energy of a flat vane. In most cases, the floor of each paddle (figure 1.11) was deliberately sloped and the reverse side of their

⁵⁹ Rynne (1992a), 58; Lucas (1986), 16–27.

⁶⁰ Lucas (1955), 100–113; Baillie (1975), 25–32.

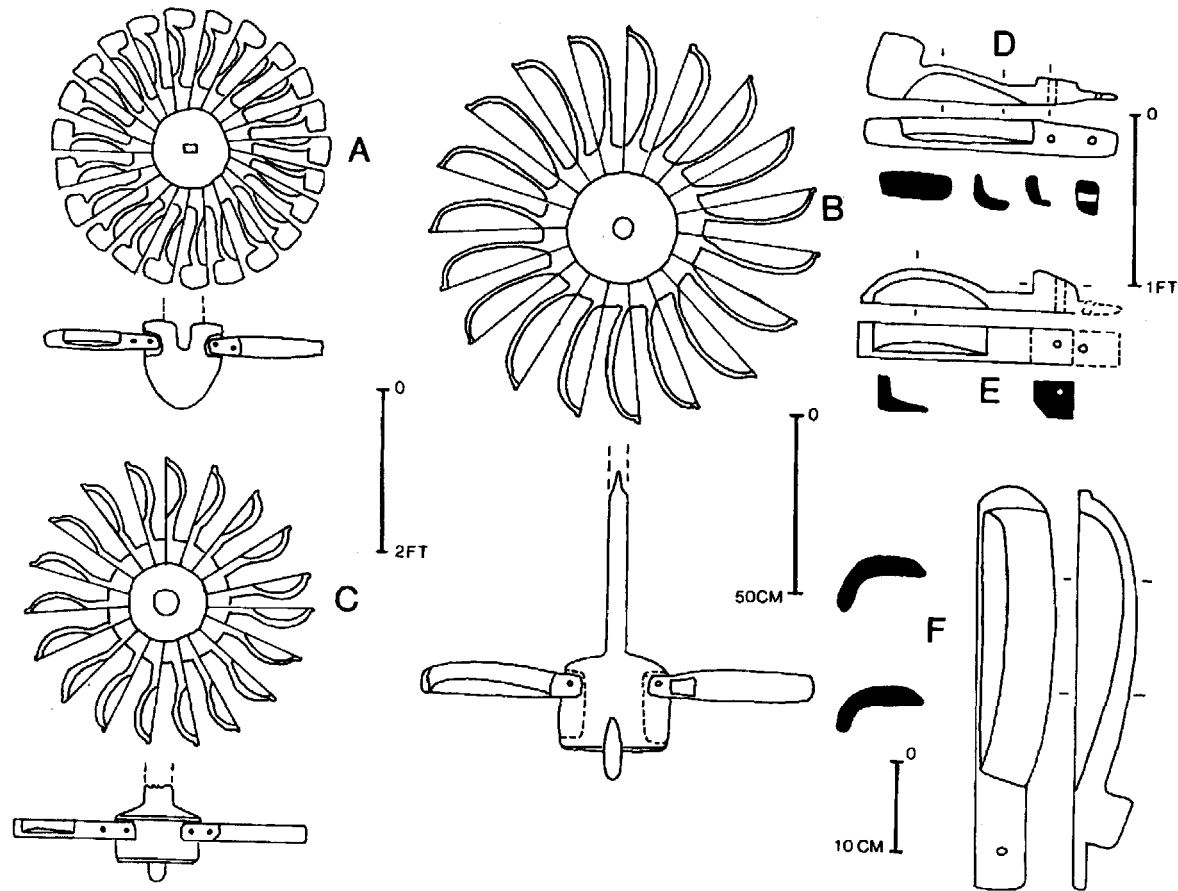


Figure 1.11. Early medieval horizontal waterwheels. (a) Mashanaglass, county Cork, after Fahy (1956). (b) Moycraig, county Antrim, after Fahy (1956). (c) Cloontycarthy, county Cork. Waterwheel paddles. (d) Mashanaglass, after Fahy (1956). (e) Moycraig, after Fahy (1956). (f) Cloontycarthy.

scooped portions was expertly curved; for the scooped portion, whilst more effectively absorbing the tangential velocity of the waterjet and transforming its energy into a dynamic thrust, also facilitated the run-off of the water discharged against it. A useful analogy for this effect is the modern Pelton impulse turbine, developed in the California gold fields in the late nineteenth century by Lester A. Pelton (1829–1908) and others, and still widely used in small-scale hydro-electric schemes.⁶¹ The Pelton waterwheel comprises a series of scoop-shaped buckets, mounted on either a vertical or horizontal axle; against these a carefully developed high-velocity waterjet is discharged. The design of the individual buckets is of course infinitely more sophisticated than the paddles of early and more recent horizontal waterwheels, but the effect of their curved backs on the action of the water leaving the rims of the buckets is, nonetheless, essentially the same. In Pelton wheel buckets, the backs are curved so as to ensure that the velocity of the rejected water is as near as possible to that of the incoming water. The backs of certain early medieval Irish waterwheel paddles are similarly shaped—an effect that is hardly fortuitous (see Figure 1.11). It may be observed that it would have been much easier to omit this curvature when manufacturing the paddles and it is most unlikely that this shape was merely decorative. The likelihood is, then, that this feature was the result of observations made over a long period of time on the efficacy of the paddle design, and that the results duly noted became incorporated into the waterwheel design.

Complete wheelhubs have been recovered from the Moycraig, Mashanaglass, Cloontycarthy and Deer Parks Farm (eighth century) sites, whilst a radius of the Killinchy wheelhub survives in the Ulster Museum. The Moycraig, Deer Parks Farm and Cloontycarthy hubs and their driveshafts were fashioned in one piece, a considerable achievement if one considers that these were not lathe-turned and that the whole balance of the axle and the hub must have been equalised by carefully shaving away the exterior faces. The entire length of the Moycraig hub and shaft was about 1.95 metres, the shaft itself thinning in substance in the direction of the hub. The Shanacashel driveshaft is said to have been 1.80 metres long, although this, like the Moycraig example, probably does not take into account the height of the footstep bearing and the power-take-

⁶¹ Durand (1939), 447–54; Durand (1939b), 511–18.

off.⁶² At the upper extremity of the Moycraig driveshaft, a vertical groove with two perforations at either side of it had been executed; the spindle was received into this slot and secured there with iron bands. These latter were affixed to the shaft by means of rivets. It is unlikely, however, that both the iron plate at the top of the shaft and the reinforcing band at the base of the wheelhub, which are presently on the Moycraig wheel, are original features. The Mashanaglass wheelhub, on the other hand, had a mortice on its upper face for receiving the lower end of the driveshaft, which must have had a wedge-shaped tenon.⁶³

Clearly the most critical part of the manufacture of these wheels was the spacing of the paddle mortices given the limited surface area of the hub. The partitions between individual paddle mortices were, in consequence, extremely thin. The Mashanaglass hub in particular, though slightly smaller than the Moycraig and Cloontycarthy examples, positioned some 23 paddles, four more than the Moycraig hub. Owing to the slightly irregular grain of the wood, the Mashanaglass hub mortices were off-centre, a defect which was not, however, as marked on the Cloontycarthy example, where these mortices were more skilfully executed. With the exception of the Mashanaglass wheelhub, the base of the hub was normally flat with a central perforation for the pintle of the footstep bearing, or gudgeon. The base of the Mashanaglass hub, indeed, was bullet-shaped and showed no signs of ever having had a footstep bearing. In this respect it is unique, for all the known examples of horizontal waterwheel designs were provided with some sort of rudimentary lower bearing. At the centre of the paddle tenons, holes were pierced through in which were inserted dowels to secure them in the mortices of the hub. These dowels were carefully interlocked to create a pull into the hub when the individual spoons gave resistance to the force of the water striking them. The Moycraig and Mashanaglass paddles also had dowels which articulated each paddle block, a measure which further reduced the pressure on the paddle tenons. In all cases, the face of the paddle block was slightly skew-cut, which ensured that any given paddle was contiguous with one positioned immediately in front of it on the hub, and also helped to absorb the shock created by the impinging waterjet. For the paddle block would have

⁶² Byrne (1849–50), 154–164.

⁶³ Fahy (1956), 22.

been firmly pressed against the inner face of the paddle immediately in front of it, where the forward movement of the paddles created by the force of the waterjet striking them facilitated by the axial movement of the waterwheel itself about its bearing, would create a torque which the thin paddle tenons could not withstand. A further refinement in paddle design is found on the Ballykilleen paddle fragments where an artificial twist was imparted to the back of the paddles by means of a series of carefully executed sloping cuts. This latter effect is likely to have been executed with a saw, whilst in other early examples this was achieved by making the lower edge of the paddle scoop out-sloping. Furthermore, the upper edges of the Ballykilleen paddle fragments exhibited notches which must have positioned staying devices, probably thin iron bands, which either formed part of a concentric band or of struts affixed to the lower rim of the wheelhub.⁶⁴ This practice was recorded by Hubert Knox in county Mayo at the turn of the century and is also widely attested in more recent examples from the Mediterranean.⁶⁵ The Mashanaglass paddles, indeed, were provided with “felloe” pieces on their outer extremities, through which interlocking dowels were inserted to tie them together. This technique gave the wheel a rigid outer rim similar to that of a cartwheel. This practice, too, is widely attested in Mediterranean Europe.

The horizontal waterwheel is clearly one of the finest achievements of any early medieval Irish woodworking craft, and the survival of many similar waterwheels in Mediterranean Europe until recent times highlights the durability of the original design. But for key mill components such as the waterwheel, where design characteristics are entirely independent of site location, there is good evidence to suggest that regional millwrighting techniques were already evolving during the early medieval period in Ireland. The early medieval Irish horizontal waterwheel has a coherent set of design characteristics (see Figure 1.11). The proportions of the surviving examples are, indeed, remarkably similar and in the case of the wheelhubs from Mashanaglass, county Cork and Moycraig, county Antrim, strikingly so. Yet while almost all of these waterwheels utilised what was essentially the same set of design features, no two waterwheel paddles or wheelhubs are exactly the same. The widespread variations on a

⁶⁴ Lucas (1955), 105–8.

⁶⁵ Knox (1906–7), 263–73.

basic design can best be explained in terms of regional millwrighting traditions. In the traditional *rodizio* mills of Portugal it is clear that special horizontal waterwheel types have developed in different regions, where separate millwrighting traditions had evolved. The Portuguese *rodizios*, which are horizontal waterwheels, also have very close analogues in early medieval Ireland, but if one looks closely at the various horizontal waterwheel types found throughout Mediterranean Europe, it is also clear that the *rodizios* and their analogues in Spain and Italy have medieval origins (see page 50). It is hardly surprising, therefore, given the widespread use of horizontal-wheeled mills in early medieval Ireland that regional waterwheel types (albeit close in their basic design) should have developed at an early stage. Early Irish millwrights may originally have plied their trade over the entire island. As and when the numbers of operational mills increased, it may well have been possible for individual millwrights to become established in particular areas, to service existing mills and to construct new ones.

Little information is currently available on the lower bearings of early Irish horizontal-wheeled mills, with only one example of a stone pintle 46 centimetres long, found on the Moycraig wheel (see Figure 1.11). The presence of a similar fixture on the ninth-century wheel from Cloontycarthy and the eighth-century one from Deer Parks Farm can, however, be inferred from a deep perforation at the base of the hub. It is also likely that iron or steel pintles were used in these wheels, and the discovery of a steel pivot block at the ninth century Saxon watermill at Tamworth in Staffordshire does to a certain extent confirm this.⁶⁶ The early Irish term for the pintle or gudgeon, *eirmtiud*, is of some assistance here for it is glossed as "the stone which is under the end of the shaft upon which the shaft turns," although it is unlikely the *eirmtiud* of St. Patrick's Crozier referred to in the *Vita Tripartita* was of stone. Thus, if this was a generic term for the point of a shaft, it is quite possible that metal was involved, which is partly borne out by a further gloss for *eirmtiud* in D.C.S.A. "the nail of the shaft".⁶⁷

The so-called "pivot-stones", which appear to have served as the lower half of horizontal wheel bearings, have been found at a handful of Irish mill sites, although none of these have any datable associations.

⁶⁶ Trent (1975), 19–25.

⁶⁷ Mulchrone (1939), 297; MacEoin (1982), 15.

Recent examples from Ireland, Scotland, the Isle of Man, Portugal and Romania confirm that such stones were, in fact, used for this purpose, but there is also wide-ranging evidence for the use of similar stones as footstep bearings for upright transmission shafts in vertical-wheeled mills.⁶⁸ In certain cases, it is clear that these stones were not used. The sole-tree recovered from the eighth-century Drumard site did not have any seat for a pivot-stone, the gudgeon pivoting upon a recess cut on the upper face of the beam. A similar arrangement was also in evidence at Mashanaglass.

The distinctive bottle-necked configuration of the eye in early Irish bedstones, provides us with the earliest evidence from anywhere in Europe for the use of bushings in early watermills. In all of the Irish examples the central hole was bored from both ends (figure 1.12), with what were presumably separate bushings inserted at either end to afford support to spindles at right-angles to its axis (Figure 4). Lower millstones with bottle-necked perforations appear to have been a standard feature of early Irish horizontal-wheeled mills.⁶⁹ In deliberately confining the internal area of the perforation, early Irish millwrights created a tight-fitting seat for the bushings, a refinement which is not present even in more recent examples of horizontal-wheeled millstones. Indeed, the closest chronological parallel for this feature is the lower millstone associated with a vertical-wheeled mill of c. A.D. 840–41 at Omgård in Jutland.⁷⁰ In more recent horizontal-wheeled mills from the Shetland Islands, Portugal, Romania and Iran, single journal bearings were employed although their function, as in the early Irish examples was to support the spindle and to prevent grain from falling into the eye of the lower stone.⁷¹ Unfortunately no metal components of early driveshafts have been recovered in Ireland. The rynd bar, however, from the configuration of the sockets cut in the lower face of all the known examples of early runnerstones, was 'T'-shaped and was almost certainly tied to the top of the spindle with a cotter. The lower end of the spindle is also likely to have been wedged into a slot cut into the upper end of the driveshaft.

⁶⁸ Knox (1906–7), 263–73; Maxwell (1954–56), 231–2; Garrad (1982–4), 218–22; Galhano (1978), desenho 18; Jespersen (1971), 69–87; Irimie, Bucur (1971), 421–36.

⁶⁹ Rynne (1990), 24.

⁷⁰ Nielsen (1986), 193.

⁷¹ Goudie (1886), 257–97; Galhano (1978), 40; Bucur (1969–73), 99–125, fig. 11; Wulff (1966), 281.

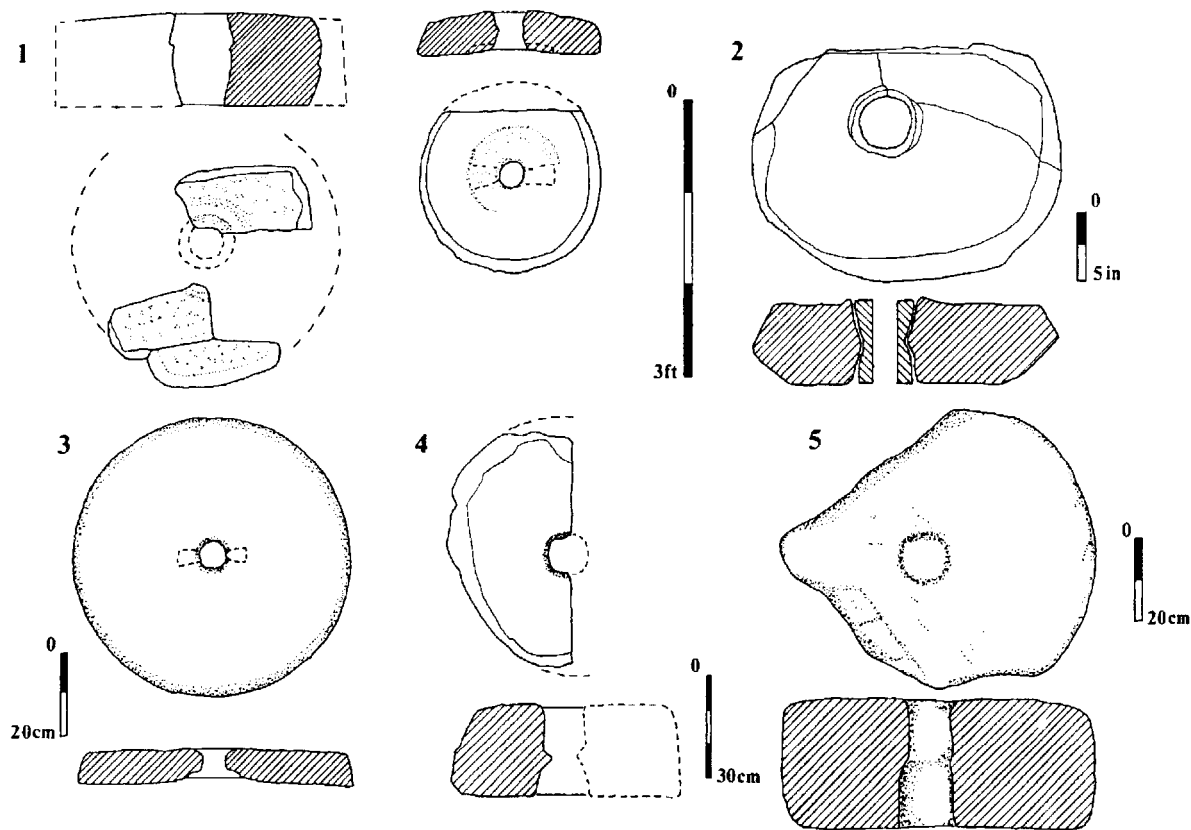


Figure 1.12. Millstones from early medieval Irish horizontal watermills. (1) Mashanaglass, county Cork, bedstone (left), runnerstone (right), after Fahy (1956). (2) Bedstone from Drumard, county Derry, after Baillie (1975). (3) Runnerstone reconstruction from Cloontycarthy, county Cork. (4) Bedstone from Newtown, county Tipperary, after Lucas (1986). (5) Bedstone from Ballinderry Crannog, county Offaly, after O'Neill Hencken (1942).

Millstones

The millstone assembly in early Irish horizontal-wheeled mills consisted of an upper revolving stone (the "runnerstone," Old Irish *lia*), between 0.60–1.01 metres in diameter and a lower, stationary stone (the "bedstone," Old Irish *indeoin*), 0.55–1 metre c. in diameter (see Figure 1.12). The vast majority of the recorded examples were normally cut from a conglomerate sandstone. The underside of the runnerstone and the upper surface of the bedstone were, in addition, carefully dressed so as to ensure the most effective passage of the cereal grains through the stones. The "zoning" of the millstone surfaces survived on both the runnerstone fragment from Cloontycarthy, county Cork (c. A.D. 833) and on the working surfaces of the Mashanaglass millstones. On the Cloontycarthy and Mashanaglass runnerstones (see Figure 1.12) the working surfaces adjacent to the eye (the central perforation in the stone) display no noticeable concentration of striations, for it was here that the grain was allowed to enter the space between the stones and to facilitate this entry the surfaces were slightly curved. The area in the centre of the work surfaces (where one finds the main concentration of striations) was that in which the grain was either shelled or crushed depending upon the adjustment of the millstones (discussed below); in this same central area the outward movement of the debris towards the periphery of the stones was restricted by the reduced distance between the striations at this point. Near the periphery of the stones the bands of striations end and the surfaces of the stones curve downwards, an effect which assisted the centrifugal discharge of the debris by allowing a draught of air to enter the gap between the stones and draw out debris into a collecting bin.

On surviving runnerstones two dovetail-shaped sockets, executed at 180 degrees to one another, are always in evidence (see figure 1.12). Their configuration would suggest that winged rynds were employed. The Mashanaglass and Cloontycarthy millstones further displayed a concentric lip around the eye, the purpose of which was to trap stray grains, which could be later brushed into the eye of the stones by the miller. On the Mashanaglass runner stone a raised band had been fashioned on its upper face, which the excavator tentatively suggested could have been a provision for an agitating device for the hopper.⁷² A not dissimilar raised band was also in evidence

⁷² Fahy (1956), 28–9.

on one of the upper millstone fragments recovered from Glenwood, county Cork.⁷³

One of the most enduring misconceptions about early medieval Irish watermills is the notion that they were not equipped with hoppers, a device which allowed grain to be fed into the millstones automatically. The idea that this was the case has been adduced from a solitary episode in the *Life of St. Senan* in which the saint is assisted by an angel in tending a mill. As Lucas interpreted it, this story was a clear indication that the angel's assistance was necessary because the grain had to be fed manually into the eye of the upper stone.⁷⁴ Such a suggestion is untenable for a number of reasons, not the least of which being that if Senan was functioning as a miller one might expect that he would have been in the mill at all times even if a hopper was involved. Milling, after all, involves many tasks, such as dressing flour, which would have been attended to while grinding was underway. The second major objection to this idea is that all of the available evidence indicates that hoppers had already been developed for certain types of man- and animal-powered mills before watermills were ever used in Europe. Models of rotary hand-querns from Han Dynasty tombs in China (c. 1st century A.D.) had hoppers, whilst the sole purpose of the upper section of the rotating stone (*catillus*) found in Roman animal-powered hour-glass mills was to serve as a hopper.⁷⁵ By the end of the first century B.C. the Roman engineer Vitruvius, in the earliest description of the mechanism of a vertical-wheeled watermill, makes an explicit reference to the use of a hopper.⁷⁶ In view of this it seems highly unlikely that the horizontal-wheeled mill, which, as the archaeological evidence clearly indicates, was introduced into Ireland in its fully developed form, was not equipped with a hopper. Proof positive that it was so equipped is the Old Irish term *cup*, listed in the "eight parts of the mill" in D.C.S.A., which can only refer to a hopper.⁷⁷

Grain milling involved two basic processes. The first involved the separation of the husks from the grains, and the second the reduction of the kernels to either flour or meal. Each process was facilitated

⁷³ Fahy (1956), 57.

⁷⁴ Lucas (1953), 32.

⁷⁵ Needham (1965), 190.

⁷⁶ Moritz (1958), 122; Wikander (1981), 93-104.

⁷⁷ MacEoin (1982), 16.

by fine adjustments to the millstones with a tentering device, upon whose lower horizontal arm the entire waterwheel assembly rotated. From this a vertical arm extended upwards to the grinding room floor. An upward movement of the vertical arm produced a corresponding movement of the entire waterwheel assembly, and, as the driveshaft was connected directly to the runnerstone, it was possible to lift or lower the latter as required. To remove the husks, the millstones were first set at a distance equivalent to the width of one cereal grain apart, and when the grain had been fed through the stones it was then removed from the mill and winnowed to separate the unwanted husks. The hopper could then be refilled and the arms of the tentering device finely adjusted so that the stones were set at a distance of half the width of a cereal grain apart. The finished product was then sieved to remove impurities.

Evidence for tentering mechanisms has been found at two Irish sites, Drumard, county Derry and Mashanaglass, county Cork. In each case the lower, horizontal arm (the "sole tree") survived.⁷⁸ These latter are the earliest known examples of tentering devices in Europe. The use of a similar mechanism at a third century A.D. Roman mill site at Chemtou in Tunisia can be inferred from a wall opening, which presumably allowed the vertical arm of the device to extend upwards through the grinding room floor.⁷⁹ The Chemtou mill is the only example from the entire period of Graeco-Roman antiquity to produce evidence for such a bridging device, and it is not until the late fifteenth century that European documentary sources provide any useful information on the likely arrangement of tentering arms in grain mills.

The Vertical-Wheeled Mill

The vertical-wheeled watermill in Ireland is at least as old as the horizontal-wheeled variety. Three early medieval sites at Littleisland county Cork (c. A.D. 630) (figure 1.13), Morett, county Laois (c. A.D. 770), and Ardclloyne, county Cork (c. A.D. 787) employed vertical waterwheels, but although the Littleisland example was contemporary with the twin-flume horizontal-wheeled mill on the same site

⁷⁸ Baillie (1975), 25–32; Fahy (1975), 50. The evidence from a further county Cork site, Cloontycarthy, would also suggest that such a device was employed.

⁷⁹ Wilson (1995), 499–510.

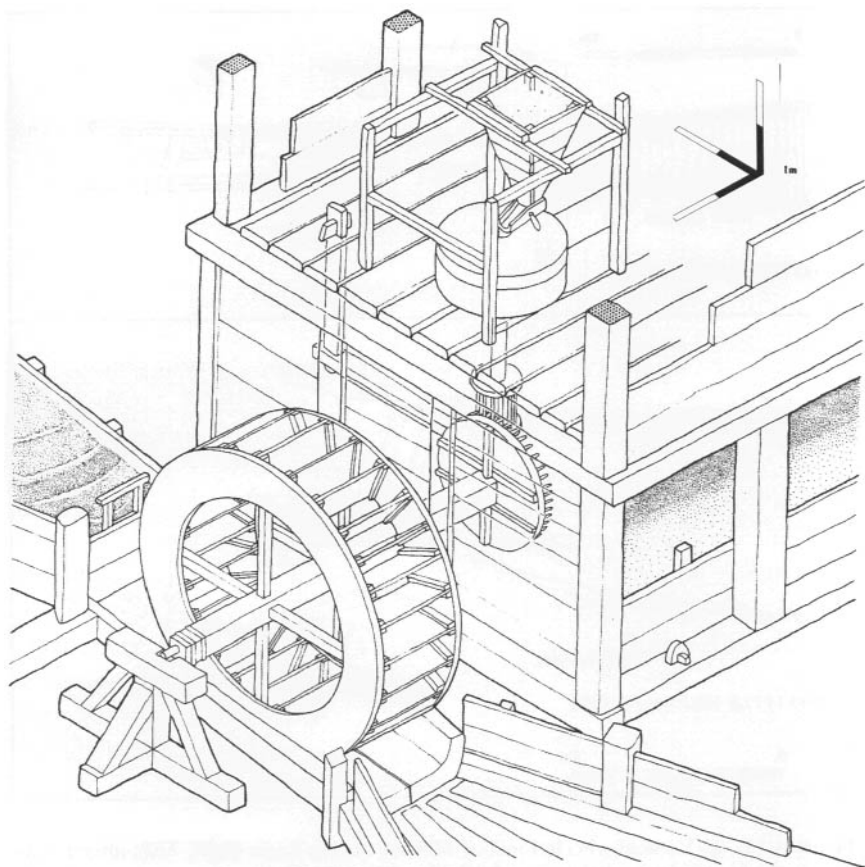


Figure 1.13. Reconstruction of vertical-wheeled watermill at Littleisland, county Cork (A.D. 630).

(figure 1.14), the overall relationships between the two varieties of mill in early medieval Ireland are still not clearly understood.⁸⁰ An annalistic entry for A.D. 651 (page 8 above) which refers to the murder of two boys in a mill by Maelodran, most likely refers to a vertical-wheeled mill. MacEoin's argument, to the effect that the incident took place in a horizontal-wheeled mill, is based largely on the assumption that vertical-wheeled mills did not exist in Ireland at this

⁸⁰ Rynne (1989), 21–31; information on the Ardclayne site was kindly supplied by Ms. Rose Cleary, Field Officer, Department of Archaeology, University College Cork.

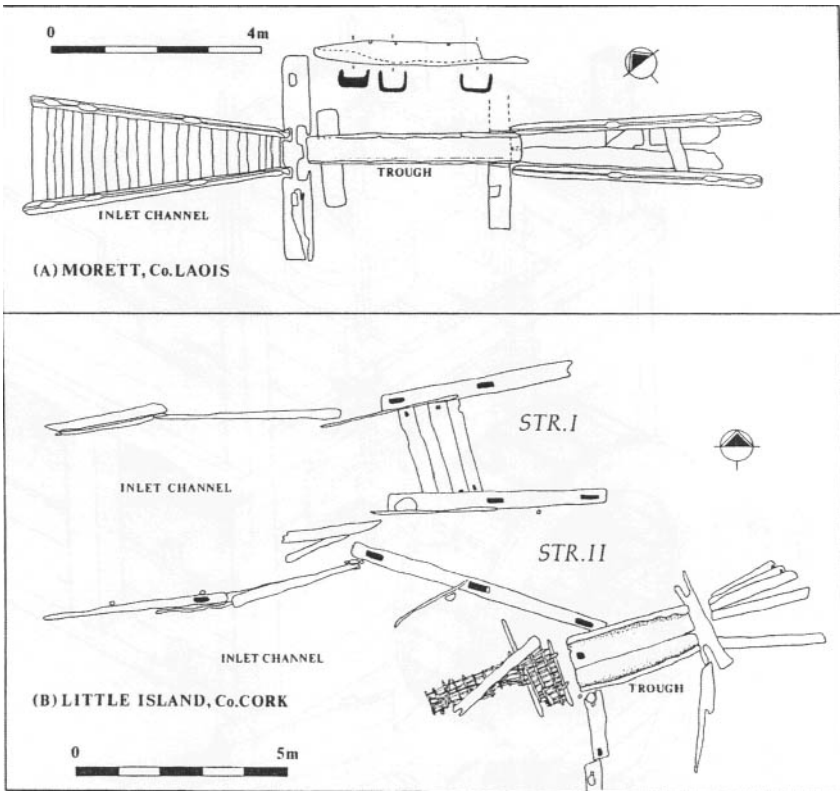


Figure 1.14. (a) Vertical-wheeled mill at Morett, county Laois (A.D. 770), after Lucas (1953). (b) Vertical-wheeled mill at Littleisland, county Cork; structure I is a double flume horizontal mill (see figure 1.2 for a reconstruction).

period.⁸¹ However, this assumption is now known to be baseless, and in any case the injuries sustained by Dúnchad and Conall could only have been inflicted by a vertical waterwheel.

Both the Littleisland and Morett watermills are likely to have employed undershot waterwheels. The Morett mill comprised two V-shaped channels each lined with oak soleplates and floored with neatly overlapping boards (Figure 14a), which were connected at their narrow ends by a central wooden trough, 4.22 metres long, 0.61 metres wide and 0.29 metres deep. At Littleisland, a wooden framed head-race channel converged upon a slightly inclined, two-piece

⁸¹ Mac Eoin (1983), 60–64.

penstock, 3.11 metres long, 1.30 metres wide at rear end and 0.80 metres wide at its fore end (Structure II, Figure 14b). Internally the Littleisland trough was 0.26 metres deep, though its depth as investigated was largely the result of damage by a digger bucket. However, it is unlikely that it would have been appreciably deeper owing to its mode of manufacture, in which the two sections of the trough were stitched together along their undersides by three sets of flimsy dovetail clamps.⁸²

In vertical undershot waterwheels, the trough positioned immediately beneath the waterwheel performs an important function. As the entry and exit of the water occurs at floor level, in practice this usually means that in addition to being carefully channelled so as to increase its velocity prior to impact with the wheel, it was also necessary to take steps to prevent incoming water from escaping around the sides of the wheel. Thus the head and tail race-channels were tapered inwards and outwards, respectively, from the wheel area itself, and the lower part of the waterwheel was provided with either a trough or a wooden casing. These practices are widely attested in the archaeological, ethnological and documentary evidence for vertical undershot waterwheels. The morphology of the mill channels and the distinctive wheel troughs at Littleisland and Morett are known to have been a standard feature of undershot waterwheels from the Roman period up until quite recent times.⁸³

As in many parts of Europe, the horizontal-wheeled mill in Ireland was gradually replaced by vertical-wheeled mills. In the aftermath of the Anglo-Norman conquest and settlement of Ireland in late twelfth century new customs and technology were introduced. Indeed the vertical waterwheel, and other industrial processes and power transmission systems associated with it, are likely to have been used on Anglo-Norman manors and on the monastic estates of the Cistercian and Augustinian houses established in Ireland. Nonetheless, the horizontal-wheeled mill survived in Ireland throughout the medieval period, and in certain parts of Ireland (particularly on the western seaboard) it was still relatively common in the middle of the nineteenth century. Up until quite recently the cluster of early medieval dates for Irish horizontal-wheeled sites, and the apparent absence of high medieval sites from the archaeological record, led to the suggestion that a shortage of timber for building purposes seriously curtailed

⁸² Rynne (1989), 25.

⁸³ Rynne (1989), 30-1.

mill-building activity. However, there are unambiguous references to horizontal-wheeled mills in Irish documentary sources dating to period after the first millenium A.D. In the eleventh-century text of *Togail Bruidne Da Derga* there is a clear-cut reference to a *sciatha* or horizontal waterwheel paddle (pages 8, 11). Furthermore, the use of the Old Irish term *oircel* (which forms part of the "eight parts of the mill" in D.C.S.A.) also occurs in *Fled Bricenn*. That this term should survive into the eleventh century is a fair indication that the audience of the copyist would have been familiar with its meaning, and there can be little doubt that such mills were in existence at this point in time. The archaeological record also confirms this. There is now at least one twelfth-century horizontal-wheeled mill site at Clonlonan county West Meath (c. A.D. 1145), plus a thirteenth-century example from Corcannon, county Wexford (c. A.D. 1228).⁸⁴ Doubtless, further sites of similar date will eventually come to light. Thus far it is clear that of the 28 watermill sites dated to the period A.D. 630–1228, just over half (56%) were built with timbers felled in the period A.D. 770–850.⁸⁵ But it is also important to note that for every dated site there is at least a further medieval mill site recorded in the nineteenth or early twentieth century which has not been scientifically dated. Both the documentary and archaeological evidence, therefore, confirm the co-existence of both horizontal and vertical-wheeled watermills in Ireland during the high medieval period.

The use of water-powered corn mills in Ireland from the Anglo-Norman period onwards is quite well-documented in contemporary sources.⁸⁶ However, up until quite recently the archaeological evidence was somewhat limited, particularly for mills in urban environments. Many of Ireland's principal coastal towns such as Dublin, Cork and Waterford developed from Viking trading ports, and for the most part the beginnings of urban development in Ireland date to the latter part of the first millenium A.D. The development of urban centres in Ireland led to the establishment of watermills within their immediate environs, and the consequent adaptation of the water sup-

⁸⁴ I am indebted to Mr. Victor Buckley, Senior Archaeologist, the Department of Arts, Culture and the Gaeltacht, and Mr. John Sheehan, Department of Archaeology, University College Cork for information on the Clonlonan mill. For the date of the Corcannon site see Moore (1996) 45.

⁸⁵ Baillie (1995), 126.

⁸⁶ See Lydon (1981), 259–263.

ply of these mills to different hydrological conditions. In both medieval Dublin and Cork, for example, two settlements established on tidal rivers, water-powered mills tended to avoid the tidal reaches. For the most part watermills were constructed on tributaries which traversed the higher ground overlooking the towns, before discharging into the tidal stretches of the main river. This basic locational pattern continued well into the nineteenth century and was only really modified when the introduction of steam-powered prime movers enabled industries to become established directly on the quaysides of Ireland's main ports. In Dublin and Cork these non-tidal tributary streams tended to become extensively regularised from the later medieval period onwards. The River Poddle in Dublin, for example, had already become effectively canalised for industrial and domestic water supply purposes by thirteenth century.

The vast majority of the watermills erected during the Anglo-Norman period in Ireland were involved in the processing of cereal crops. In 1990 the remains of a Anglo-Norman vertical undershot grain mill were excavated at Patrick Street in Dublin. The mill had been built early in the thirteenth century, and almost entirely rebuilt in the fourteenth. Its waterwheel was positioned directly over a canalised section of the River Poddle, a tributary of the Liffey, the river upon which the city and port of Dublin stand.⁸⁷ Similar mills would have been quite common throughout the Anglo-Norman Lordship, particularly on rivers in low-lying areas. However, in 1994 the remains of a water-powered forge, where lengths of bar iron were worked under a trip hammer to form tools and other implements, were excavated near the North Gate Bridge in the city of Cork. At this remarkable site the remains of the mill race and the forge building (including the forge's wooden anvil) were examined in situ. The mill had been built on the banks of the River Lee within the precincts of the medieval walled town, immediately adjacent to the quayside, where bulky cargoes of perhaps charcoal and bar iron could be discharged.⁸⁸

On present evidence, the early medieval horizontal-wheeled mill built to service the needs of the small monastic community on High Island off the coast of county Galway is the earliest surviving monastic watermill in Europe.⁸⁹ The *Cáin Domnaig*, as has been seen, firmly

⁸⁷ Rynne (1997), 81–89.

⁸⁸ Hurley (1997), 45–9.

⁸⁹ Rynne, Rourke, White-Marshall (1996), 24–27.

establishes church-owned mills as a commonplace in Ireland by at least the eighth century A.D. However, while millwrighting may have been at an advanced stage in Ireland, relative to other European regions, Ireland's larger monasteries do not seem to have developed their water resources for either industrial or domestic purposes to the same extent as their early medieval European counterparts. This is quite surprising, for the growth of the larger monastic centres in early medieval Ireland is fairly similar to that of the large Benedictine establishments of the Carolingian period. Armagh and Clonmacnoise, for example, had brought large areas of land under their control from which they derived substantial profits, in much the same way as Benedictine monasteries such as St. Germain des Pres and Lorsch had carved out sizeable territories in central Europe.⁹⁰ Furthermore, during the eighth and ninth centuries many Irish church estates were organised on similar lines to St. Gall.⁹¹ But despite these similarities it is not until the 1140s, when the larger European monastic orders such as the Cistercians and the Augustinians became established in Ireland, that the hydrotechnology associated with these orders was introduced into Ireland.

Water supply was, of course, an important locational consideration for Europe's larger monastic orders, and no less so when they established houses in Ireland during the twelfth century. Some 51 out of the 56 Augustinian and 18 of the 25 Cistercian houses in Ireland were sited on the banks of rivers. Water was needed for the domestic offices of the abbey as well as for powering the abbey's mill, and in many cases great effort was expended in procuring an adequate supply. At the Cistercian abbey at Mellifont, county Louth, a millrace 804.67 metres long, was excavated to avoid a series of meander loops in the adjacent Mattock River, whilst at Great Connell Abbey, county Kildare a millrace over a mile long was cut from the River Liffey. A conduit house, 6.5 metres square was built at Kells Abbey, county Kilkenny, to provide water under pressure for distribution to a number of installations within the abbey's precincts.⁹²

⁹⁰ Horn (1975), 248; Nitz (1983), 105–126.

⁹¹ Doherty (1982), 300–28.

⁹² Carville (1982), 29–47.

*Water-Power in Medieval Ireland in Context: Early Irish Watermills
and their Continental Affinities*

There can now be little doubt that the horizontal-wheeled mills of western Europe which share design characteristics with those of early medieval Ireland are survivals of a millwrighting tradition which is at least one and a half millennia old. But there are as yet few useful chronological parallels for the large corpus of early Irish sites. There are of course Roman horizontal-wheeled mill sites in both North Africa and southwestern Asia, but the type of mill involved is very different in terms of its waterjet delivery system and water-wheel design.⁹³ The most distinctive feature of the early Irish mills is the waterwheel, a tool whose distribution is continuous, from the eastern Mediterranean to Ireland.⁹⁴ However, as will be seen below, it is by no means the only component of the Irish mills to have close analogues in Mediterranean Europe.

When the early Irish horizontal waterwheels are compared with more recent examples from Mediterranean Europe, the similarities are often quite startling. Indeed, certain varieties of horizontal water-wheel from Greece and Portugal, which have distinctive "felloe" pieces on their paddles, are exactly the same as that recovered from Mashanaglass in county Cork.⁹⁵ The Mashanaglass mill is likely to have been an early medieval machine, but its waterwheel is very unlike the earliest known Irish examples. But when the Irish corpus of early medieval horizontal waterwheels is compared with more recent European examples, it emerges that nearly all of the Mediterranean examples, from as far east as the Balkans, are very similar and vary minimally in basic design from the Irish mills. For example, the paddles from the ninth century Cloontycarthy waterwheel find very close parallels with more recent examples from Portugal, whilst other Irish waterwheels have close analogues from areas as far apart as France and Yugoslavia.

In horizontal-wheeled mills where the *arubah* penstock (tall masonry cisterns in which a waterjet is developed under pressure) is not employed, a timber trough or penstock was generally used to develop

⁹³ Wikander (1986), 151–79; Wilson (1995), 499–510.

⁹⁴ Rynne (1989b) especially vol. 2, which deals with the development of the horizontal watermill in Europe, Africa and Asia.

⁹⁵ Curwen (1945), 211–212; Galhano (1978), 43.

a water jet. In such cases the penstock can be open-ended, closed or provided with an orifice bore for more efficient water jet delivery. All of the early medieval Irish horizontal mill penstocks were cut from single balks of timber, and in the vast majority of cases either an oval or sub-rectangular perforation had been cut at the fore end to develop a water jet.⁹⁶ As has been seen, there are at least two examples of orifice bores associated with early Irish mill penstocks, whilst early Irish mill penstocks were always steeply inclined in relation to the waterwheel. This was also a common feature of trough-fed horizontal-wheeled mills elsewhere. The dating of the Irish corpus of horizontal mill penstocks to the period A.D. 630–1100 thus establishes that this practice, found in almost all trough-fed mills world-wide, is at least as early as the first millenium A.D.

The known distribution of penstocks perforated at their fore ends outside Ireland is, on present evidence, confined to the Anatolian plateau. Mill penstocks with a slanting face at the fore end, on the other hand, have hitherto only been recorded in Pakistan and Portugal. The Portuguese *cales* are in fact the closest modern parallels for the early Irish examples, although less effort appears to have been expended on procuring a lid for them.⁹⁷ The latter, like certain Romanian examples, were splayed inwards in the direction of the fore end. However, unlike the early Irish mill flumes, these were not covered over on top, and in Romania, Yugoslavia and eighteenth century-Provence we find almost cylindrical penstocks hollowed-out from large tree trunks. The earliest known Irish examples, from Littleisland in county Cork (c. A.D. 630), are also of this type (page 17 above).⁹⁸

Concentrating the water jet through the use of a jet-developing bore is normally associated with *arubah* penstock mills. In most of south-western Asia these were manufactured in interchangeable sizes to suit variations in the available head.⁹⁹ Orifice bores (*seteiras*) are also found in certain types of Portuguese *rodizio* mills, where they are fitted at the fore end of the cale or penstock.¹⁰⁰ They are also used with a special type of mill penstock, found in the Carpathians, called a *buton*, which was normally employed where the available

⁹⁶ Rynne (1992), 60–1.

⁹⁷ Rynne (1992b), 21–25; Boucher (1983), 31–44.

⁹⁸ Rusdea (1974–78), 199–219.

⁹⁹ Avitsur (1960); Wulff (1966), 281–2.

¹⁰⁰ Galhano (1978), desenho 21.

stream flow was restricted. There is one recorded early medieval Irish example of such a device from Rasharkin, county Antrim, while for a further mill penstock from Kilphillibeen, county Cork, the use of an orifice bore can be inferred.

In Ireland double-flume mills are, on present evidence, at least as early as the seventh century A.D. The earliest known Irish horizontal-wheeled mill site at Littleisland, in county Cork, is of this type, and the Irish examples in general have close analogues in the Mediterranean and Balkan region, particularly Romania. They are also referred to in fourteenth-century Tuscan documents, and more recent examples have been recorded in Bulgaria, Yugoslavia and Greece.¹⁰¹ Horizontal-wheeled mills utilising up to three flumes have been recorded in the Austrian Tyrol and the Caucasus. Indeed, mills with anything up to six penstocks have been recorded in Romania. On present evidence, the Romanian multi-penstock *ciutura* mills, in which the individual penstocks are angled into each other, provide the closest parallels for the early Irish examples.¹⁰²

Thus far Ireland has produced the earliest evidence for the use of tide mills. The seventh-century double-penstock mill, discovered on Littleisland, in the estuary of the River Lee, in county Cork, along with its vertical undershot counterpart (which had been built alongside it), are the earliest known examples of tide mills in either Europe or Asia. The Littleisland mills effectively pre-date the earliest known documentary reference to tide mills by almost four centuries. The present-day distribution of horizontal-wheeled tide-mills (all of which have dished paddles) includes Portugal, Brittany and northern Spain.¹⁰³ It is worthy of note that Ireland had close cultural contacts with both Iberia and France during the medieval period, but whereas we may posit closer ties between Ireland and the eastern Mediterranean (on the basis of other stylistic similarities between horizontal-wheeled mills), the effective use of tide-mills would have been more or less confined to coastlines with good tidal ranges.

For the development of the type of horizontal-wheeled mill described above outside Ireland, reliable dating evidence is virtually non-existent. However, we are afforded an important clue to dating

¹⁰¹ Muendel (1974), 218, n. 4; Ince (1973), pl. 43; Hunter (1967), 446–466.

¹⁰² Kozmin (1917); Strauss (1971), 12; Rusdea (1974–78), 199–219.

¹⁰³ Castel Branco (1971), 81–83; Rivals (1973), 159–165; O'Reilly (1902–4), 58–84.

in the vernacular terms for horizontal waterwheel in Italian (*ritrecine*), Spanish (*rodezno*) and Portuguese (*rodizio*). All of these terms are etymologically related and denote what is essentially the same type of waterwheel. In twelfth century Leon, for example, there was a *Calle de Rodezneros*, a rather clear-cut reference to the trade of horizontal waterwheel manufacture in medieval Spain; while in Dante's *Inferno* there is an allusion to a *molin terragno* or "country mill," a term which in Italian Renaissance sources designates a horizontal-wheeled mill.¹⁰⁴ In modern Tuscany the term for a horizontal waterwheel with dished paddles, *ritricene*, can be traced back as far as the fourteenth century; and in the *Trattati* of Francesco di Giorgio Martini (1439–1531) completed between 1480–90, such wheels are clearly illustrated and named as such.¹⁰⁵ The origins of the term *ritricene*, and its use to denote a horizontal waterwheel, are somewhat obscure. Nonetheless, the fact that it had a medieval Spanish cognate by at least the twelfth century, suggests that its use in southern Europe was well established by this period. Indeed, there is documentary evidence for the use of horizontal-wheeled mills in Spain dating to the ninth century, where such mills, as in early medieval Ireland, were often collectively owned.¹⁰⁶ Of course the Irish evidence provides a solid *terminus post quem* for the spread of this type of mill in Europe, and we may reasonably infer that similar mills were at work throughout the Mediterranean no later than the second half of the first millenium A.D.

¹⁰⁴ Glick (1979), 233; Muendel (1974), 200.

¹⁰⁵ Muendel (1974), 200; see also Maltese (1967).

¹⁰⁶ Glick (1995), 115–21.

CHAPTER TWO

MEDIEVAL ENGLAND'S WATER-RELATED TECHNOLOGIES

Richard Holt

Introduction

Just as elsewhere in Europe, people in England developed an expertise in those aspects of water supply and engineering that proved useful or appropriate to their circumstances. Climate was important among these circumstances: England was a wet country, but not too wet. This influenced agricultural techniques and human settlements (a supply of river water or well water was always possible). The overall poverty of medieval society imposed limitations on investment in expensive engineering projects, and also shaped perceptions of what was necessary and what was not. But social factors were equally important in determining the character of hydrotechnology. Undoubtedly the development of water transport in medieval England was held back by a weakness on the part of the public authority rather than by any inability on the part of society to pay for improving and constructing watercourses, a weakness seen in the state's inability either to compel work to be done or to overcome the entrenched private rights and privileges of other users of rivers. Likewise, the very low incidence of private war and the infrequency of foreign invasion were in part responsible for the slow development of sophisticated water defences; the authority of the crown, perhaps more importantly, was in this instance effectively directed against existing private castles and against any measures that could transform a house into a stronghold. Not surprisingly, English castle-building was at its most elaborate not in England itself, but in occupied Wales, where the marcher lords were free to complete the great castles of the south, and the crown employed continental expertise to construct the remarkable group of northern castles and walled towns that were planned to consolidate the final conquest of Gwynedd in the 1280s.

England's was not a homogeneous society in cultural terms. Churchmen, in particular, had different cultural values; for water supplies, this is best seen in their fundamentally different view of the ritual importance of personal cleanliness and of fresh, clean water. Laymen were considerably less concerned with clean water, certainly to the extent that before the fifteenth century there was a general reluctance to invest in water supplies. By contrast, at least as early as the twelfth century, many, and perhaps most, religious houses had seen fit to undertake sophisticated engineering work in order to ensure a regular supply of unpolluted water. Monastic sites were also served by planned drainage systems, designed to remove waste water; by contrast, even the greatest secular settlements relied essentially on natural drainage.

In assessing the contemporary significance of expensive engineering and construction works, it is essential always to remember that in different historical periods the mentality or prevailing outlook will have its own particular character. Different mentalities lead to different patterns of behaviour, so that we should not expect people in the Middle Ages to have necessarily shared twentieth-century views of what might be useful or desirable. Thus, medieval society was profoundly and enduringly divided by class ranks, and the actions of medieval people were often directed towards the affirmation and perpetuation of status. If we try to interpret medieval behaviour simply with reference to modern attitudes we shall misunderstand it. The construction of fishponds by the English aristocracy can scarcely be explained on the assumption that considerations of profit or food value prevailed; it is only through an appreciation of the importance placed upon the status value of being able to impress important guests with unusual fish that expenditure of this magnitude can be understood.

The evidence for watermills instead shows that their owners were motivated by considerations of profitability. How far, though, is that dependent on the nature of the evidence? Manorial records, and particularly accounts, are understandably concerned with material matters to the exclusion of other considerations. Doubtless the prospect of financial return was a crucial factor in any decision to undertake expensive water engineering projects, or to carry out substantial repairs; yet other factors might also have weighed with the aristocratic owners of mills, in a way that it is impossible to measure

today. Simply because the exercising of the right to "suit of mill" was a privilege of lordship, to own and operate a mill was in itself an assertion of status. By exercising this particular set of legal rights, a lord emphasised the generality of his rights of control and jurisdiction over his tenants. Without clear evidence that any English lord ever considered it worthwhile to operate an uneconomic mill just to assert his authority, we cannot be certain that this factor loomed large in the aristocratic mentality. Indeed, the withdrawal from unprofitable milling that is so obvious by 1400, during a period of weakening lordship, suggests that towards the end of the Middle Ages the matter of status did not apply.

But that was not necessarily the situation during earlier centuries, as for instance in the years after the Norman Conquest, or during the thirteenth century when lords were asserting their legal rights over their villein tenants. Those were periods when the symbolic importance of owning a grain mill might have led to a higher level of investment than economic considerations alone could have justified. In the case of industrial mills, although there are recorded cases of a lord unsuccessfully attempting to impose the use of a fulling mill on his tenants, this was rare. We should not rule out the possibility that the general unwillingness to invest in industrial mills reflected not just the marginal profitability of such enterprises, but also an awareness that they conferred no social prestige or advantage on their aristocratic owners. Such an attitude would have helped reinforce the obvious concentration of fulling mills only in those districts where water resources were surplus to requirements for cornmilling, despite the fact that cloth production was more evenly distributed across England in both town and countryside.

Water Management in Agriculture

The damp, temperate climate of the British Isles meant there was no need for artificially watering their crops, so agriculturalists never developed the techniques of irrigation that were so important to the dryer parts of Europe. On the contrary, land needed to be drained effectively, but natural drainage sufficed in most of lowland Britain from the beginning of the agricultural era, and there is no evidence of man-made systems of drainage before the high Middle Ages.

Medieval investment in land drainage, together with other forms of land reclamation, should be seen in the context of rising population and increasing pressure on natural resources. It was principally during the twelfth and thirteenth centuries that the expensive and arduous process of bringing hitherto-marginal lands into cultivation can be observed—broadly speaking, between the compiling of Domesday Book in 1086, when England still possessed extensive and virtually uninhabited fenlands and estuarine marshes, and the middle years of the fourteenth century, which saw a massive and sustained fall in population and a consequent retreat from marginal land.¹

Specific evidence is lacking for the drainage techniques that were used in medieval England, although they can have been little different from those in use in France and the Low Countries, and in later centuries: extensive networks of ditches and larger drainage canals were dug, whilst natural streams and rivers were cleaned of silt and deepened to improve their flow. The construction of continuous riverside embankments provided protection against regular inundation of the surrounding lands. Without provision for extensive pumping, or the wind-powered water scoops that appeared in England no earlier than the seventeenth century, the lowest-lying fens and marshes could not be drained. However, the medieval engineers were noticeably successful on the more tractable lands—pre-eminently in the districts around the Wash, in Cambridgeshire, Norfolk and Lincolnshire. It has been estimated that as much as 170 square kilometres of fenland were reclaimed in the Holland district of southern Lincolnshire during the decades around 1200, a period when the great ecclesiastical estates of the region such as that of the bishops of Ely are known to have been actively investing in drainage. At the same time, people worked to reclaim other large areas of marshland, such as the Somerset Levels. As much as 10,000 hectares of new agricultural land were gained with the reclamation of the Walland marshes in Kent. In the case of reclaimed coastal marshes, the inevitable shrinkage of the soil as it dried and the possibly substantial fall in the ground level necessitated the construction of sea defences, as along the Lincolnshire coast.²

¹ Miller, Hatcher (1978), 28–41.

² Miller (1965), 95–7; Hallam (1965), 38–9; Miller, Hatcher (1978), 35–6.

Water Transport

A range of documentary sources demonstrates that water navigation played an important part in the internal trade of medieval England.³ The written evidence is not systematic, consisting as it does mainly of passing references to boats upon rivers or journeys by water; the relative volume of waterborne trade as compared with that carried by road is thus impossible to estimate. In the fourteenth and fifteenth centuries, it has been calculated, it cost six times as much to move goods by road as it did by water; set against that, however, is the abundant evidence for long distance road haulage.⁴ The limiting factor on water transport was the navigability and direction of rivers, as examples of canal building and improvement of existing water-courses were extremely rare. Where cargoes have been identified, there was a clear preference for moving heavy or bulky goods by water, including grain, wine, wool and stone; even then a combination of road and river transport was generally inevitable.

Isolated examples of the construction of navigable canals seem all to have been undertaken by ecclesiastical institutions for transporting building stone to major churches; the improvement of an existing river was recorded at Rhuddlan in north Wales, when in 1277 works were ordered by the crown to improve access along the River Clwyd to the new castle and town (see below). But the canal system inherited from the Roman period that gave the major city of Lincoln access via the Foss Dyke to the River Trent at Torksey, some 15 kilometres distant, and via the River Witham and Car Dyke to the sea at Boston, was poorly maintained in the medieval period. In 1375 it was reported that although it had once carried much of the region's trade, it was now silted up and unusable; much earlier than this, in fact, it seems to have been effectively navigable only during the wetter winter months.⁵ Goods bought for Durham Cathedral Priory at Boston fair in 1299 and succeeding years were carried by boat to Lincoln, but thence by cart to the Trent at Torksey; after 1336 the Durham monks abandoned inland transport entirely for this purpose, and instead carried their Boston purchases to Newcastle by sea. In the mid-fourteenth century, wool exported by

³ Edwards, Hindle (1991), 123–34; Langdon (1993), 1–11.

⁴ Dyer (1994a), 262–3.

⁵ Flower (1923); Barley, (1938), 1–22.

Lincoln merchants was taken by road most of the way to the port of Hull, rather than use the Foss Dyke and the Trent, confirming a petition to the crown in 1335 that the watercourse was no longer navigable. The citizens of Lincoln complained again in 1365, and again in 1376; in the latter year they maintained that a number of great territorial lords whose land abutted on to the dyke ought to clean it, but no longer did so. The problem was not simply progressive silting, but also that those with land on either side of the dyke had an interest in its being blocked so that their cattle could more easily be driven across it. Further complaints were made in 1384 and in 1432, and it is clear that if anything was done on each of these occasions to remedy the situation, the effect was short-lived. A new attempt to restore the dyke to navigation in 1518 by the bishop of Lincoln ended with the bishop's death in 1521.⁶

The same inability on the part of the authorities to maintain navigability can be seen on numerous rivers, where mill dams and weirs were frequently allowed to impede traffic. By the early thirteenth century, for instance, the upper reaches of the Thames had been effectively closed to navigation by the building of weirs.⁷ Rather than any development of water transport in medieval England, therefore, there is ample evidence that a decline occurred as private, proprietorial rights outweighed perceptions of the public benefit to be derived from usable watercourses. Scholars have exaggerated the importance of water transport in the English economy; all too often assumptions of navigability depend on references to what can have been only occasional use. It is also apparent that whilst the medieval period saw a marked improvement in the conditions of road transport, with investment in the construction and repair of bridges and a significant move away from ox-hauling in favour of the horse, no such investment took place in improving watercourses. On the contrary, there was a slow degradation of the river system which was obvious to contemporaries but which they could do nothing to reverse. Evidently the greater flexibility of road transport was the main factor in reducing the importance placed on water transport, and the consequent unwillingness to invest. The absence of a relevant overall authority able to organise investment was also a crucial factor, reinforced no doubt by a prevailing conservative mentality unwilling to

⁶ Hill (1948), 311–13.

⁷ Davis (1973), 263–5.

contemplate innovation in this area. It would be as late as the eighteenth century before canal construction and river improvement laid the basis of a truly effective water transport system.

The Harnessing of Waterpower for Milling

The use that people of earlier periods made of natural sources of power has for a long time interested historians, who have produced a literature of highly variable quality. The work of John Bennett and Richard Elton at the beginning of this century still stands as an impressive compilation of evidence, although many of their conclusions are perforce dated and have been superseded by later work. Terry Reynolds, too, has gathered together a mass of evidence for the use of waterpower in Europe, though again his conclusions concerning the economic impact of the watermill tend towards exaggeration and need to be treated with some caution.⁸ Published work on British mills in the medieval period has concentrated overwhelmingly on the excellent historical evidence produced by both public and private authority in England, the state and the manor.⁹

The accumulating body of archaeological evidence for watermills in use by the population of Roman Britain has implications for the way that evidence for early medieval mills should be interpreted. When historians used to believe that mills were a great rarity in the Roman world, the scattered early references to mills from across medieval Europe were interpreted as a sign that here was a device that was only slowly gaining a foothold. Older perceptions of the role of the watermill during those dark centuries were coloured by a general view that here was an advanced technology that was beyond the understanding of most barbarian communities. By contrast, it is now clear to historians that watermills were already frequently used during the late Empire, and continued to be used—probably without interruption—during the more troubled centuries that followed.¹⁰ In Ireland archaeological evidence has confirmed that a relatively un-Romanized population could make full use of the watermill at an early date: surviving remains confirm what the oldest Irish literature

⁸ Bennett, Elton (1898–1904); Reynolds (1983).

⁹ Holt (1988).

¹⁰ Wikander (1984); Wikander (1985), 151–79.

and laws also suggest, namely that watermills were well-known on the island by the seventh century. The remains of more than thirty Irish mills have been dated to the early medieval period, a reflection both of the sophistication of modern dating techniques (in particular dendrochronology) and the impressive level of preservation of ancient timbers in Irish peat bogs.¹¹ The virtual absence of such remains from other parts of the British Isles, therefore, should not be taken to mean that mills were indeed a rarity during the early medieval period; rather, it is likely to reflect differences in terrain and the fact that in England peat has not been dug for fuel during modern times.

In other words, the evidence for the number of early medieval English watermills is likely to be incomplete and unrepresentative, to the extent that no safe conclusions can be drawn from it as it stands. Most of the evidence comes from land charters, the mills being referred to incidentally in the boundary clauses that often accompany surviving grants of land. Thus any analysis of the chronology or distribution of Anglo-Saxon mills is dependent on this one source—a form of document that was seldom used (and hardly at all before 700), and which survives in very small numbers. The distribution of the locations of the 49 mills recorded in such sources from 762 onwards has been mapped, but the result is far from satisfactory and clearly bears little relation to what the true distribution must have been.¹²

Nor can it be safely concluded which design of mill predominated in England before the thirteenth century, or the extent to which watercourses were built or adapted, as again there is so little evidence. Only three mill sites have been excavated that date from the six centuries or so between the end of the Roman Empire and the Norman Conquest, and this tiniest of samples presents severe problems of interpretation. A mill excavated at Old Windsor on the River Thames in the 1950s is known only from brief reports made at the time, an excavation report never having appeared; but it was reported to have been a vertical-wheeled mill, and recent dendrochronological analysis of some of its preserved timbers has shown it to have been built in the 690s.¹³ In due course it was replaced by

¹¹ Rynne (1988); Rynne (1989), 21–31. See also chapter 1.

¹² Hill (1981), 114.

¹³ Wilson (1958), 184–5; Baillie (1980), 61–3.

a horizontal-wheeled mill, like those used in contemporary Ireland. To drive the mill, a channel had evidently been dug across a loop in the Thames.¹⁴ Much more informative was the excavation of a mill associated with the Mercian royal palace at Tamworth. This was a horizontal-wheeled mill, its initial building and subsequent rebuilding dated firmly to the middle years of the ninth century. Careful excavation in the vicinity of the mill indicated that in its first phase it had been fed directly by a leat running some 400 metres from the River Anker, with a gradient of about 1 in 27. This was quickly eroded at the sides and base, perhaps not having been lined or revetted in any way; the depth of erosion became so acute as to prevent—in the view of the excavator—the mill from working due to a severe loss of effective velocity. It was proposed that the second mill was constructed to avoid the problems which its predecessor apparently encountered, and certainly the water supply to the mill was organised differently: a timber lined leat following, in part, the line of the earlier leat, fed a millpool. This was evidently a small, three-sided structure intended not to store water but to enable the flow from the leat to be more easily regulated. The sides of the pond were of plank walling packed with clay, and the water exited from the pond either through the driving chute of the mill, or through a by-pass chute controlled by a sluice-gate. The outfall of the mill was largely destroyed by the construction of the later medieval town ditch, but where it survived it too was revetted with massive timbers to prevent erosion and collapse.¹⁵

It is impossible to assess how far this mill—or indeed that working at Old Windsor nearly two centuries before—was representative of contemporary hydrotechnology. The craftsmen responsible for building a royal mill may have employed skills that were rare at lower social levels. Perhaps the quite sophisticated use of timber construction in the second Tamworth leat and the millpool had few contemporary parallels, other mills instead having simpler and less expensive watercourses.

The excavation of a rather later mill site at West Cotton, Northamptonshire, goes some way towards confirming that both the vertical and the horizontal-wheeled mill were known to the Anglo-Saxon millwright. There a series of mills in use from the tenth until the

¹⁴ Clay, Salisbury (1990), 289.

¹⁵ Rahtz, Meeson (1992), 13, 14, 23, 24, 31, 48, 53.

twelfth centuries stood by the River Nene, but used the waters of the more easily harnessed Cotton Brook which were diverted to a pond by a leat. The pond overflowed into the river by means of a weir. From the pond a further leat directed water to the mill and discharged into the river. Three separate watermills were identified, each with its own freshly dug leat. The earliest was broad and flat-bottomed, with a timber revetment along both sides to prevent erosion. Towards the mill its width of over three metres narrowed at a sluice gate about a metre and a half wide; the sunken wheel pit five metres away was apparently fed by a tapering wooden chute—perhaps a single hollowed tree trunk as was used in excavated examples from Ireland. The wheel pit was a metre wide and clearly held a vertical, undershot wheel. At a later date this complex was replaced by a similar leat and a smaller wheel pit some two metres away. In time that was replaced by a third mill, driven by a leat three metres wide. The position and indications of the structure of the wheel house and its relationship to the leat left the excavators in no doubt that this mill used a horizontal wheel.¹⁶

The ubiquity of the mill in England by the eleventh century is confirmed by Domesday Book of 1086.¹⁷ Conceived of by the powerful Anglo-Norman monarchy as a survey of seignorial tenures, mills and their values were recorded together with other assets of each manor: in those parts of England covered by the survey, which was all but the northern counties either left waste following the rebellion of 1070 or still subject to the king of Scotland, a total of 6082 mills was recorded. The great range in the revenues drawn from these mills strongly suggests a variety of mechanisms but more importantly great differences both in the water resources available to each mill, and in the size of the market it served. High-value mills were to be found clustered around the larger centres of population, and situated on the major rivers; low-value mills were to be found on the lesser watercourses which can never have produced an easy surplus of hydraulic power and which were likely to have proved inadequate during dry periods of the year.¹⁸ The small annual rents such mills paid—a few shillings at most—leave little doubt that there had been no major investment in leats and dams designed to maximise the flow

¹⁶ Windell, Chapman, Woodiwiss (1990), 29–32.

¹⁷ Farley (1783); Darby (1977).

¹⁸ Holt (1988), 11–13.

of water to the wheel; any major hydraulic engineering must have been confined to the mills on the major rivers, where the provision of dams, leats and sluices would always have been a necessity.

An example of such a mill and dam from the period of Domesday Book was excavated at Castle Donington, Leicestershire. Planks from a wheel breasting and tailrace were dated by dendrochronology to the later eleventh or early twelfth century, and the mill was driven by water diverted directly off the River Trent by a dam. This had been set diagonally across the river to direct water into the mill race, and had been constructed of two rows of wattled oak posts, two metres apart, supporting a core of stones, gravel and brushwood. Dendrochronology again suggested a date of the late eleventh or early twelfth century for the structure.¹⁹

The Manorial Cornmill

By the twelfth century, and doubtless long before, milling in England was a right of lordship. Only the lord of a manor could erect a mill within the area of his jurisdiction, and just as importantly he could compel his peasant tenants to use his own mill and pay whatever fee he charged. Grinding more cheaply at a neighbouring mill, or using a handmill at home, were offences to be dealt with by the manor court. Mills were valuable assets to the manor; they required a high level of investment and consequently were expected to make a high return. In northern England and the Scottish borders mill revenues were extraordinarily high, and the greater aristocracy depended on them for perhaps a third of their total income. Further south profits were lower, and other sources of income more valuable; even so, the earl of Norfolk drew 15 per cent of his income from mills. Great ecclesiastical lords, despite their rich lands and substantial income from spiritualities, clearly valued their mills as well: the bishops of Durham in the fourteenth century received 10 per cent of their total income from mills, the bishops of Worcester 6 per cent.²⁰

Such valuable revenues depended on the ability to compel the mills' customers to pay the grinding fee demanded. In the Middle

¹⁹ Clay, Salisbury (1990), 276–307.

²⁰ Holt (1988), 36–7; 82–3.

Ages, English millers always took their fee in tollcorn, as a proportion by volume of the corn that the customer brought to be ground. This was fixed by statute in 1270 as one-twentieth or one twenty-fourth, depending on the strength of the watercourse driving the mill, but in reality local custom prevailed and rates of multure varied widely. In northern England an extortionate one-thirteenth was universal, and elsewhere a range of proportions is recorded, down to one thirty-second.²¹ Historians have always assumed, doubtless correctly, that peasant customers resented this burden, and indeed there are many cases of prosecutions in the lords' courts for evasion of "suit of mill"—not using the manorial mill as the tenant was supposed to. There are just as many cases, probably, of tenants paying a small fine into the court to obtain the right to mill where they pleased. Despite the legal monopoly the various lords had, in reality there must have been a genuinely competitive situation for such evasion—whether licensed or unlicensed—to be worthwhile. Mills generally charged a lower rate of multure to free tenants who could mill where they pleased, and millers would probably have been quite happy to offer this concessionary rate to attract the custom of the unfree tenants of a neighbouring manor.

Also, in reality there were many mills that were not under the direct control of the lord of the manor, mills which during the eleventh and twelfth century had come into the possession of free and customary tenants whose hereditary tenure of the mills enabled them to enjoy the profits. Few if any of these mills can have enjoyed the protection of the manorial court in enforcing their use on the local population, and must have operated at a lower level of profit and investment than mills directly under seigneurial control.²²

Mill Structures and Mechanisms

Specific documentary evidence for individual mills begins with the earliest manorial accounts, dating from the beginning of the thirteenth century. The details of recurrent expenditure on the manorial mill, and especially the rarer details of a complete rebuilding,

²¹ Holt (1988), 80–2.

²² Holt (1987), 3–23; Holt (1988), 54–69.

leave no doubt that by this time English mills were driven by vertical water wheels and had mechanisms of the traditional, Vitruvian, pattern. It was never the intention of the medieval accountant to leave behind him a detailed description of how a mill worked, but altogether we receive a composite picture of a simple yet sturdy device made almost entirely of wood. Only a few parts were invariably of iron, and stone and brass could also be used.²³ Disappointingly, the documentary evidence is not matched by any great quantity of identified physical remains. Archaeological excavations of the sites of medieval mills have been relatively rare, and have added little or nothing to our knowledge of their mechanisms or superstructure. Amidst the mass of details, therefore, many basic facts remain unknown.

Professional craftsmen were generally called on to repair mills. Smiths worked on the iron parts, specifically the spindle, usually called the *fusillum*, and the attached rynd or *ynkum* which held the upper millstone or runner. Not surprisingly, the stresses endured by the spindle ensured that this was one of the parts of the mechanism that required most frequent attention. The accounts show that it was not unusual for spindles to be renewed at least once a year.

Metal was also commonly used for bearings, although it was not essential. A vertical watermill required bearings where the weight of the turning water-wheel and axle were supported, and at the base of the spindle. The latter was the most important, and was often made of brass rather than iron. Axle bearings are recorded as being of iron, and unless the wooden axles themselves ran directly on these bearings, contact was with the iron hoops or collars that the accounts frequently record as having been fitted. As the reason for these hoops is never made clear they may have been intended for strengthening, though it is much more likely that their primary purpose was to provide a suitably hard surface.

But many mills had bearings of less expensive materials. Archaeological evidence suggests that many mills used bearings of stone. In the course of the excavation of the mill at the site of Bordesley Abbey in Worcestershire, for example, pebbles that had been used as bearings were found in 1984. Even bearings of hard woods have proved serviceable in modern times, and so it is perfectly possible

²³ Holt (1988), 117–31, from which the following details are taken.

that there were medieval mills with axles turning on nothing more than wooden pads attached to the surface of the supporting timbers. This sort of information cannot be directly derived from manorial accounts as the use of stone or wood required no expenditure to be recorded; it can, however, sometimes be deduced. The exceptionally well-documented Great Shelford mill in Cambridgeshire during the fourteenth century frequently required the attentions of the smith, working on the spindle and the iron hoops that bound the mill axle. Yet none of the many surviving accounts makes any mention of metal bearings being repaired or replaced, until the mill was completely rebuilt in 1386–87 when a brass spindle-bearing was fitted. Still, however, there are no references to bearings beneath the iron-bound axle, and so presumably it continued to run on wood and stone throughout the fifteenth century.

Apart from the rynd, spindle and bearings, the rest of the mechanism of the vertical watermill was always of wood. Iron was used everywhere in the form of nails, and as bands and even chains to strengthen the water-wheel, trundle-wheel and the cogwheel; until the development of cheap smelting and cast iron in the eighteenth century, however, it was not feasible to make such components entirely of iron. Oak, though rarely specified, was undoubtedly the preferred wood for most of the mechanism; boards of black poplar were also on occasion purchased for a variety of purposes, from making a new door or a new hopper to general repairs on the mill and the water-wheel. The crab apple tree purchased for Layham mill, Suffolk, was deliberately chosen for the strength and resilience of the cogs for which it was intended. The accounts give few precise details of the actual construction of either mill building or mechanism, or indeed whether an overshot or undershot wheel was used. The accountant's record of expenditure on the labour and materials for a new water-wheel will be precise to the last nail but will not describe the wheel. The fourteenth-century Luttrell Psalter illustration shows an overshot wheel, and the contemporary mill at Batsford in Sussex was driven by an overshot wheel nearly nine feet in diameter, and a foot wide, made entirely of oak and held together by iron nails and wooden dowels. It had four radial spokes jointed into the hub to the Luttrell Psalter mill's five, but otherwise was similar. The Bordesley Abbey mill-wheel was undershot, and the late eleventh-century mill at Castle Donington was said by its excavator to have

had a breast-shot wheel.²⁴ All three types of vertical water wheel may thus have been available to the English millwright.

The Luttrell Psalter mill (see bookjacket illustration) is in every respect an accurate representation. The roof is clearly thatched, as was common, although not all mills were thatched: a few were tiled with ceramic tiles. The structure of the illustrated mill, too, is accurate, being timber-framed with wattle-and-daub infill like most English medieval secular buildings.²⁵ Many mills required the attentions of the dauber from time to time; others may have been weatherboarded, judging by the frequency of payments for quantities of planks and boards. Often these were intended for repairs to sluices or wheel-pits, but just as often no reason was given for their purchase. On occasion such large quantities were bought or sawn on site that weatherboarding the whole mill can have been the only explanation. The mill's stout iron-bound door with its prominent lock was also not a whimsey of the Luttrell Psalter illustrator, but another detail that echoed life; it is quite common to find references in manorial accounts to such features, clearly considered necessary to protect the mill and its valuable contents from intruders.

Mill Dams and Leats

The Luttrell Psalter's reliability in these other details (a reliability which extends to the other marginal drawings of everyday activities) clearly applies also to the somewhat stylized representation of the millpond, with its dam held in place by stout timbers and basket-work traps set to catch eels. The existence of such features in reality can be readily deduced from numerous manorial accounts. The extreme rarity of evidence for anything other than repairs to existing watercourses and dams suggests strongly that most water-control systems were in place by 1200, and thereafter changed very little during the medieval centuries. There is no evidence pointing to significant programmes of investment in improved hydraulic systems intended to enhance the power or reliability of existing mills, probably for the

²⁴ Millar (1932); Bedwin (1980), 187–201; Astill (1993); Clay, Salisbury (1990), 287.

²⁵ Dyer (1986), 19–45.

simple reason that such works were likely to have been unjustifiable in economic terms. The rapid spread of the windmill in the century following 1180 demonstrates that English lords were alive to the possibilities of this new technology, and the relative merits of windpower and waterpower; it is significant that in the county of Huntingdonshire, to take just one example, all seven of the minor mills recorded in 1086 were replaced by windmills at some date before the whole county was again the subject of a crown survey in 1279.²⁶ A new windmill could be built for around 10 pounds in the thirteenth century, a level of expenditure which on most estates must have appeared more attractive than extensive expenditure on new water-management schemes. Several thousand windmills had been built in England by 1300, obviously in many cases as a more satisfactory alternative to major investment in waterpower.²⁷

The rare evidence for heavy expenditure on new watercourses seems only to confirm how ill-judged it could be, considering the ready availability of windpower technology. Henry de Eastry, prior of Canterbury Cathedral Priory and an improving landlord, was willing to invest large amounts in milling: in 1317 he had the mill at Lydden, Kent, rebuilt after it suffered damage from floods the year before. Considerable amounts were expended on the watercourses, with a total of 343 perches (1887 yards or 1725 metres) of leats having to be widened or scoured out, at a cost of over 48 pounds. Making dams and sluices in the leats and repairs to the millpond were additional expenses, and in all the mill cost nearly 54 pounds to bring back into service.²⁸ By contrast, Henry had shown a greater degree of shrewdness at his manor of Milton Hall, Essex, when in 1299 he had replaced an unsatisfactory watermill with a windmill at a total cost of just over 15 pounds.²⁹

²⁶ Holt (1988), 17–35, 9; *Domesday Book* 1, fols. 203–207b; Illingworth, Caley (1818), vol. 2, 591–687.

²⁷ Holt (1988), 176–7.

²⁸ Mate (1984), 1–21; Canterbury Cathedral Library, Lydden Beadles' Rolls, 10–11 Edw. II.

²⁹ Nicholls (1932), 113–67.

Multiple Mills

Whereas in the modern period watermills invariably had several sets of millstones, the mechanism of the medieval English mill was never adapted to drive more than one. Every account recording the provision of stones for a new mill, or the replacement of stones that were old or broken, confirms this. Sometimes more complex mills were constructed to meet a demand for extra milling capacity, but always by building what was in effect a pair of mills, each with its own mechanism and its own water-wheel, but housed side by side in the same millhouse. Contemporaries always recognized the arrangement as being two mills, and references in manorial documentation to "two mills under one roof" or "in one building" are not uncommon. Only one such multiple mill using a single mechanism has been identified, a combined cornmill and fulling mill at Layham, Suffolk, where in the latter part of the fourteenth century the same water-wheel worked a pair of millstones and a set of fulling stocks. Combined mills of this kind were to be found elsewhere, but always the millstones and the fulling stocks had separate water-wheels.³⁰

Fortunately much light has been shed on the probable internal arrangement of such mills by the excavation of a multiple mill at Abbotsbury in Dorset. The positioning of the two water-wheels next to each other, making use of the same leat but driving mills on opposite sides of the stream, was a sensible one, and illustrates how the mill at Layham could have worked.³¹ If instead of a pair of wheels just one had been used, its axle extending into both halves of the millhouse, the arrangement of driving two mechanisms with one wheel could have been contrived without recourse to gearing.

Tide Mills

Medieval English people were conversant with techniques of harnessing the power of the tides to drive mills, which has sometimes been taken as a sign of eagerness to discover new sources of power.³² The twice-daily ebb and flow of the tide in estuaries and creeks was

³⁰ Holt (1988), 131–5.

³¹ Graham (1986), 103–25.

³² Minchinton (1979), 777–86; White, Jr. (1967), 85; Gimpel (1977), 23.

perhaps exploited at an earlier date than most historians have previously considered possible, for tidemills existed in Ireland by the year 630. There is no such archaeological evidence for England, however, and secure documentary references are considerably later. One pre-Conquest charter, dating from 949, refers to the mouth of the mill creek at Reculver, Kent, and thus may imply a mill worked by the tide; Domesday Book of 1086 records a recently-built mill at Dover, evidently in the harbour, which is usually thought to have been a tidemill.³³ A number of twelfth- and thirteenth-century references to tide mills confirms that by that time they were no novelty around the English coast. Walter Minchinton has noted some thirty-seven from before 1300 in a list that shows their numbers increasing century by century into the modern period.³⁴ Such a list has severe limitations as evidence of the true extent to which this power source was used, not least because there is a genuine problem in detecting tide mills. Even the term itself is modern; medieval documents usually do not differentiate them from other watermills, and only on occasion use the contemporary name "sea mill"—as for instance at Fareham, Hampshire.³⁵ It is likely that the impression formed by Minchinton that people in Britain were increasingly turning to tidal power during that period is a false one. In the first place, the growing list shows no sign of the marked decline in milling activity that accompanied the fall in population after 1350—or in other words, the growing total probably represents nothing more than the general increase in documentary sources. (It is also the case that as only secondary works are cited as evidence for Minchinton's medieval tide mills, their dating may be much more uncertain than he suggested.) Secondly, there are signs that the number of tidemills was in fact diminishing during the thirteenth century, that, just as with more conventional watermills, the advent of the windmill placed a practical limit upon any projected investment in expensive hydraulic systems. At several places on the east coast, such as Walton in Suffolk, Milton Hall in Essex, and King's Lynn in Norfolk, tidemills damaged or destroyed by the violence of the sea were replaced by less expensive windmills during the decades around 1300.³⁶ Indeed, the

³³ Rahtz, Bullough (1977), 24; *Domesday Book* 1, fol. 1.

³⁴ Minchinton (1982), 339–53.

³⁵ N. Holt (1964), 109.

³⁶ Holt (1988), 134–7.

impression is gained that, far from the tidemill representing a new and revolutionary technology, it was being regarded as an outmoded technology which the windmill was rendering obsolete at many locations. If that was so, then the era during which the tidemill had been widely adopted around the English coast had been the period before 1200 when the technology of windpower was not yet an available option.

Industrial Mills

Medieval England saw numerous examples of waterpower used for industrial purposes other than corn milling, although current evidence points to this having been a development of the later Middle Ages. The case of four watermills at Lexworthy, Somerset, which paid a rent in blooms of iron in 1086, has been taken as evidence of a waterpowered forge but that conclusion fails to convince as renders in kind—including iron—for land and other assets are quite common in Domesday Book and are not evidence of production on those particular sites.³⁷ The earliest unambiguous references to industrial mills in England come from the twelfth century and later, and, as in each case they seem to post-date continental examples, the obvious conclusion to draw is that knowledge of such applications and mechanisms was imported from Europe. That may be too simplistic an interpretation, particularly given the nature of written evidence from before 1200. Behind the grossly unequal and often haphazard survival of evidence we might suspect there to have been a complex pattern of technology transfer across Europe, and quite possibly a radically different chronology from that which is conventionally advanced. With the current state of knowledge, no convincing explanation can be offered for the fact that different parts of western Europe increased their exploitation of waterpower in industrial processes at different times.

In England, and doubtless elsewhere in the British Isles and Europe, the greater number of industrial mills were fulling mills, designed to cleanse new cloth of both dirt and the natural oiliness of the wool, whilst vigorously pounding or beating it to shrink the weave and felt

³⁷ *Domesday Book* 1, fols. 91b, 94b; see the discussion in Darby (1977), 360.

the fibres together. Water-powered machines could usefully replace the traditional methods of using hands or clubs, or more usually fulling cloth underfoot in tubs. The earliest firmly dated English fulling mills are recorded at Newsham in Yorkshire and at Barton-on-Windrush near Temple Guiting in Gloucestershire, which were already standing in 1185 as the property of the Knights Templar; other mills at Kirkby-on-Bain, Lincolnshire, and Heycroft, near Malmesbury, Wiltshire, were referred to perhaps as early as 1154 and 1174 respectively, so it is quite possible that the fulling mill was known in England at least several decades before the 1180s. Eleanor Carus-Wilson, in her great study of the early fulling mill, identified 124 fulling mills dated to before 1327—many in the Cotswolds and the south-west, and in the north, particularly the West Riding of Yorkshire and the Lake District. The number has since been added to, although not substantially.³⁸

Carus-Wilson associated this upsurge in the use of waterpower with what she believed to be the rapid decline of old-established centres of cloth manufacturing in the eastern lowlands: she proposed that the fulling mills located on the rivers of the western uplands had caused the decline by drawing to themselves the primary processes of manufacturing. As a result, she believed, the medieval cloth industry was now to be a primarily rural one, no longer concentrated in the towns. Subsequent research has effectively challenged that proposition by highlighting other significant factors in the changing pattern of cloth production and marketing during that period. Furthermore, eastern England retained a major cloth-manufacturing industry. The contribution to production made by the fulling mill, too, has been challenged, as it has become clear that the application of waterpower to this process gave little or no advantage of cost or quality of work over traditional methods.³⁹ Probably we should regard investment in mechanical fulling as a reaction to an already-growing rural cloth industry, a response by lords eager to find a use for surplus water resources.

Many examples seem to bear out the conclusion that the importance of the medieval fulling mill has been exaggerated. Certainly in the period of greater pressure on water resources, before the pop-

³⁸ Carus-Wilson (1941); Lennard (1947), 342–3; Pelham (1958).

³⁹ Miller (1965), 64–82; Bridbury (1982), 1–36.

ulation decline of the mid-fourteenth century, lords were clearly unwilling to apply waterpower to fulling—or indeed any other industrial process—if it was required for milling corn. Where the profitability of different types of mill has been studied, the fulling mill always appears as an investment of marginal utility, always worth considerably less than the corn mills of the manor.⁴⁰ Thus the distribution of fulling mills in England becomes more explicable; relatively common in districts with abundant water resources, but rare in the drier regions where the demand for cornmilling was generally greater than the availability of suitable water courses. The records of the great estates confirm that the fulling mill was a rarity in dry, low-lying eastern England in the thirteenth century, despite its great prosperity and indeed despite its prominence as a region of wool and cloth production. The great landowners of Norfolk—the earl, the bishop of Norwich, and the cathedral priory—owned no fulling mills there in the thirteenth century; in the whole of neighbouring Cambridgeshire, surveyed in the Hundred Rolls survey of 1279, there were only two. In Huntingdonshire there was one.⁴¹ A similar survey of a large sample of Suffolk villages in the same year recorded sixty-five windmills, thirty-four water cornmills, and no industrial mills of any kind.⁴² The other estate records for the prosperous county of Suffolk produce only three thirteenth-century examples of industrial mills.⁴³

One of those three Suffolk fulling mills would seem to have been driven by tidal waters, making it the only identified industrial tide-mill in English history. In the latter decades of the thirteenth century the bread corn of the people of Hollesley, situated on the coast south of Orford, was ground by a windmill alone. In 1294, however, the earl of Norfolk's estate decided to bring back into service the site of a watermill that had ceased to function around 1270. The manor had seen a shift from waterpower to windpower, therefore; a sure indication that in this coastal location, as elsewhere on the east coast (including at the neighbouring manor of Walton), an unsatisfactory tidemill had been taken out of service. No major reconstruction of watercourses was needed in 1294, as of the 6 pounds 9 shillings spent on the new mill, only some 10s. was spent on the

⁴⁰ Holt (1988), 155–8.

⁴¹ Holt (1988), 156; Illingworth, Caley (1818), vol. 2, 550, 656.

⁴² Hervey (1925), 30–281.

⁴³ Holt (1988), 156.

millpond and a gutter, nearly all of it on repairing and raising the dam. In its first year the new watermill was farmed to a miller for seven quarters of rye, half the farm of the windmill, but it must have quickly shown itself to be surplus to local needs as only three years later it was being leased as a fulling mill for the low rent of 2 pounds 6s.⁴⁴ The new cornmill had evidently been a financial disaster, and its conversion to fulling was therefore a pragmatic, unplanned response. This is a very graphic illustration of how one fulling mill, far from being built in the expectation of a considerable profit, existed only because of its failure as a corn mill.

Other types of industrial mill were much rarer than the fulling mill. Hammer mills to work and purify the raw iron smelted in bloomery hearths are reported at a scatter of places in continental Europe by 1200. However, leaving aside the Lexworthy mills of 1086, for which the evidence is too weak, the earliest known English waterpowered forge for hammering blooms is that excavated at Chingley in Kent, which has been assigned to the first half of the fourteenth century. The earliest dated reference to a waterpowered forge is to the hammer mill or *oliver* recorded at Warley in the West Riding of Yorkshire in 1349.⁴⁵ A well-documented iron works belonging to the bishop of Durham was operating at Byrkeknott in Weardale around 1400, but although a surviving account roll testifies to the use of waterpower at the bloomery there is no indication of whether it was used to drive hammers, bellows or both.⁴⁶ Without question, in England waterpower began to make a significant contribution to smelting only with the introduction of the blast furnace at the end of the fifteenth century. There were waterpowered ironworks in the major iron-producing district of the Sussex Weald during the fifteenth century, although there is no earlier evidence for their existence; the great majority of the 189 identified waterpowered forges and furnaces in the district can be shown to have first come into use during the sixteenth century or later. Fewer than twenty had their origins in the decades around 1500 or before. Significant mechanization of smelting in the region was, therefore, an achievement of the early modern rather than of the medieval period.⁴⁷

⁴⁴ Holt (1988), 156; Public Record Office, SC 6/998/28, 999/1.

⁴⁵ Crossley (1981b), 29–41; Jewell, Michelmore, Moorhouse (1981), 39–40.

⁴⁶ Lapsley (1899), 509–29.

⁴⁷ Cleere, Crossley (1985), 106–8, 309–67.

There is even less evidence for the application of waterpower to the processes of smithing. The excavation at Bordesley Abbey, Worcestershire, produced the remains of a mill building containing hearths and abundant evidence of the manufacture of metal goods. Built in the late twelfth century, this early industrial mill provides an excellent example of the Cistercian order's familiarity with the potential of waterpower, although we do not know how it was used. No indication survived of which of the blowing, hammering or grinding processes were mechanized at Bordesley.⁴⁸ The absence from England of further such examples limits the discussion of this mill's significance.

Driving a grindstone from a turning shaft could have presented no technical difficulties, and one would expect it to have been tried many times, and at an early date. Sharpening mills or blademills were recorded fairly widely after 1200, although their impact overall may have been limited; in England they remained rarities until the sixteenth century. Major searches through manorial documentation have produced evidence of such mills at no more than four places during the fourteenth and fifteenth centuries.⁴⁹ The most impressive were two mills situated together at Winchester, outside the east gate; interestingly, their rents in the fifteenth century were very low—a shilling a year for one, and three shillings and fourpence for the other. Evidently built by their owners and held on long leases, the bishop of Winchester as owner of the water rights derived only a marginal benefit from them. A similar pattern is visible for the sharpening mill held by the smith John Corbet at Carhampton in Somerset in 1405 and 1420; its rent of one shilling put a ridiculously low price on the use of what would have been much more valuable water rights only a century before. Here the limiting factor on these industrial mills is even more obvious than in the case of the fulling mill: they produced so little revenue that a lord would build one, or allow one to be built, only when his water resources would otherwise be unused.

The Winchester blademills seem to have been enterprises on a large scale, occupying respectively 24 metres and 60 metres of the river bank. It has been suggested that as well as sharpening newly-manufactured edged tools these mills were positioned to attract trade

⁴⁸ Astill (1993).

⁴⁹ Holt (1988), 148–9.

from the city's many cloth finishers and leather workers; yet we know that much of the sharpening of the enormous quantities of tools that must have been in use was done by hand, so that grindstones standing outside workshops commonly obstructed the streets.⁵⁰ Hand-grinding offered convenience and—being more delicate—doubtless produced better results; mechanization of the grinding process perhaps made most sense where there was a concentration of newly-manufactured articles to be sharpened. In the midlands the growing edge-tool industry of the Birmingham region made no detectable use of waterpower before 1500; its rapid expansion into national markets during the sixteenth century, however, was accompanied by a move towards waterpower by the more prominent Birmingham smiths.⁵¹

The application of waterpower to the smelting processes of the other metalliferous industries is not fully understood. There is no evidence that the considerable medieval lead industry made any use of waterpower.⁵² What was described as a "tin mill" on Bodmin Moor was excavated in 1979–80, and dated probably from the fifteenth century; certainly during the early sixteenth century tin-smelting mills, or "blowing mills", were built in Cornwall. Whether the blowing mill was used in earlier centuries seems still uncertain as the only evidence is a reference to a *blouynghous* at Lostwithiel in the fourteenth century, and a shift (inferred) in smelting techniques in the thirteenth.⁵³

The tan mill—more accurately the bark mill—was another water-driven machine of the Middle Ages, its purpose being to crush oak bark for the easier extraction of tannin used for curing hides. Mills of this sort have been identified in different parts of Europe from at least the twelfth century onwards; the first to be recorded in England was in Cumberland in 1165, after which they are to be found occasionally, often as ecclesiastical enterprises. There was a bark mill at Kirkstall Abbey in 1288; at Battle Abbey in the fourteenth century; at Tavistock Abbey, where two were converted to fulling mills early in the fifteenth century; at Truro where there was

⁵⁰ Keene (1985), 279.

⁵¹ Holt (1985), 18; *Warwickshire* (1964), 253–69.

⁵² Blanchard (1981), 72–84.

⁵³ Greeves (1981), 85–95 instead believes blowing mills to have existed early; see also "Medieval Britain in 1980," (1981), 226; Hatcher (1970), 239; Greeves (1981), 85–95.

one mentioned in passing in 1337.⁵⁴ But these examples were exceptions, as extensive study of manorial documentation has failed to produce further bark mills. It would appear that where they existed it was in towns or monastic complexes, and that the bark mill remained a rarity.

The eagerness displayed by lords in eastern and southern England to build windmills during the thirteenth century was not matched by any enthusiasm for building industrial mills. That illustrates a simple truth, that corn milling was profitable to an extent that no industrial process could match, even during the adverse conditions of the fifteenth century. Industrial commodities were made in small quantities, in family workshops, and for a local market—conditions which discouraged mechanization. Cloth was the most notable exception to that pattern, and mechanizing part of the cloth-manufacturing process could sometimes be a realistic investment.

Growth in the Use of Waterpower

Domesday Book of 1086 presents a static situation, but actually the population of England, like that of the rest of Europe, was rising and economic activity was expanding. This phase of growth continued until the fourteenth century, by which time the English population stood at twice or even three times its eleventh-century level. Not surprisingly, the exploitation of waterpower—inasmuch as it can be measured accurately—followed that upward trend.⁵⁵

The national survey we know as Domesday Book is a unique document, and equivalent data do not exist to allow a close comparison with another point in the Middle Ages or another country. Estimating changes in the use made of waterpower, therefore, can be done only as a series of local comparisons, generally with private estate documentation. The Hundred Rolls of 1279, fragmentary survivors of what appears to have been an ambitious attempt to repeat the Domesday Book exercise but on a much grander scale, also allow useful comparisons for parts of a handful of counties. One obvious change in the period between 1086 and 1279 was the introduction

⁵⁴ Holt (1988), 148–9.

⁵⁵ The following section is based on Holt (1988), 107–116.

of the windmill and the enormous impact it had made on eastern England. In the century since it first appeared (the first English windmills were recorded in 1185), it had mounted a major challenge to the supremacy of waterpower: in the drier, flatter countryside of East Anglia where the potential of streams and rivers had evidently been largely realised already in 1086, the windmill had now eclipsed the watermill. It had also brought a natural source of power to some districts for the first time. In the great fenlands of Cambridgeshire, Huntingdonshire and Lincolnshire, very low-lying and often waterlogged, the watermill had never been a practical proposition.

The Hundred Rolls, along with other sources, also show a marked increase in the use of watermills wherever water resources allowed. It is quite apparent—just as it was apparent to estate administrators in the Middle Ages—that the windmill could not compete on equal terms with the watermill. Windmills had a capricious source of power which varied rapidly and could not be controlled; they were more subject to damage, and cost more to keep in repair. During the Middle Ages, few windmills were built in those parts of Britain well-supplied with water. But we can also see that by 1279 there had been a more subtle process of rationalisation, with important implications for the ways that waterpower was being used. In Huntingdonshire, for instance, the number of watermills went down between 1086 and 1279; the loss, however, was all of mills on small, uncertain streams which in every case had returned low rents in 1086. As we have already seen, each had been replaced by a windmill by 1279. By contrast the mills on the county's two major rivers, the Great Ouse and the Nene, had obviously prospered, and had increased in number. This greater concentration of resources, with more emphasis on developing the potential of better mill-sites at the expense of those on less satisfactory watercourses, can also be glimpsed where estate documentation allows comparisons to be made. The reduction from twelve low-value mills to three on the large, upland manor of Blockley, Gloucestershire, between 1086 and 1299, is only an exaggerated example of the rationalisation to be seen elsewhere. Interestingly, in this case the reason for the change was unlikely to have been the inadequacy of the streams, so much as a deliberate decision to concentrate milling on this manor at three centres. The inhabitants of the upland hamlets now had to grind their corn at centralised mills which were doubtless easier to control and returned a better profit to the lord of the manor.

In the well-watered county of Oxfordshire the windmill had made virtually no impact by 1279. Only four had been built, and the number of watermills had shown about a 10 per cent increase since 1086. (A range of other sources show that to have been the situation in the western part of England generally, and indeed throughout most of the British Isles.) What is unknown is the degree of rationalisation and improvement that must also have occurred as part of this more intensive exploitation of the county's streams and rivers. Nevertheless, the situation in Oxfordshire goes to reinforce the evidence from many different sources that three separate but related tendencies were at work in the twelfth and thirteenth centuries. On watercourses that were powerful and reliable, the number of watermills had increased measurably since 1086; on manors where water resources were poor, lords had built windmills; and at the same time less profitable watermills, in most cases on lesser watercourses, had been taken out of use. No firm figure for the number of mills in England in 1300 can be advanced, but clearly the total cannot have been less than 10,000 and may have been as high as 12,000. Of these, perhaps some 8,000 were watermills, and it is fair to assume that by 1300 the average mill was now larger and more efficient than had been the case in the eleventh century. However, medieval England would never have so many corn mills again, as the second half of the fourteenth century would see a precipitate fall in the total of mills, which would usher in a long period during which the profitability of milling would decline, and the number of mills continue to fall.

Decline in the Use of Waterpower

When the plague epidemic known as the Black Death reached the British Isles during 1348 and 1349, in both town and countryside between one-third and one-half of the population died. The catastrophe ushered in an extended period of population decline and stagnation which would not be reversed for at least another century. The reasons for this are as yet imperfectly understood, although its consequences are all too plain: a shortage of labour, higher wages, and after the 1370s low prices of grain and other commodities, all of which together made demesne agriculture uneconomic. During much of the fifteenth century aristocratic incomes were in decline as the level of rents fell, whilst for the peasantry there were new opportunities

in land and employment, and an unaccustomed prosperity.

As commercial enterprises, mills could not avoid the effects of these long-term changes.⁵⁶ For most, 1348 marked a clear divide, the point when the high profits of the previous centuries came to an end. After that date, cornmilling was a less sure investment and everywhere we can see a retreat from the exploitation of natural power resources as the expansion of previous centuries went into reverse. Income from milling fell as repair costs rose, and more and more mills fell derelict. A factor in this reversal, as yet uncertain in its impact, was the changing relationship between lords and their tenants. As the authority of the manor weakened, so lords could no longer exact an inflated price for grinding; their tenants would retaliate by ignoring the mill to which they owed suit, either to pursue a better price at another mill or to use their own horsemill. Casual references to peasant horsemills begin to proliferate during the fifteenth century, and quite clearly the relaxation of aristocratic control over milling had the effect of giving this more simple, domestic device an advantage over some of the more expensive watermills and windmills.

The essential superiority of waterpower over the power of the wind is seen clearly in the greater reduction in the number of windmills. In eastern England the more vulnerable windmills disappeared disproportionately, although everywhere less profitable watermills were also abandoned. Where watermills remained profitable lords continued to maintain them, although the appreciably higher costs of regular repairs discouraged any major adventures such as Henry de Eastrý's works at Lydden. One effect of the changed conditions was to encourage lords to look again at alternative ways of exploiting their water resources, using their milling sites for activities other than cornmilling. There is no evidence for increased industrial activity in most areas; only fulling appeared attractive enough to encourage the investment necessary for a change of use. The cornmill at Great Shelford, on the River Cam just south of Cambridge, brought in a high rent to the bishops of Ely and in 1387 over 15 pounds was spent on rebuilding it as a combined cornmill and fulling mill, with two separate waterwheels working two separate mechanisms. The effect was to keep the rent at a high level—at 8 pounds annually or above for at least the next century; but as well as regular and

⁵⁶ The following section is based on Holt (1988), 159–70.

increasing maintenance costs of several pounds annually there were expensive major renovations such as those in 1413 and 1432 which cost over 29 pounds and over 35 pounds. Clearly only a lord with good reserves of capital could contemplate operating an enterprise such as this, and other examples of converted mills were not necessarily so successful.

By the end of the fifteenth century the downward trend in milling fortunes had apparently been reversed. What had been, in effect, another long period of rationalisation had resulted in a reduced number of mills, although there are signs that by the early sixteenth century their numbers may again have been increasing. This was to be a new era for mills: far-reaching economic and social changes would see the emergence from the sixteenth century onwards of larger-scale enterprise able to take full advantage of the potential of waterpower.

Defensive Moats in Castles

The castles and walled towns of medieval England had moats as a matter of course. The term "ditch," however, was and is more usually applied to this sort of structure. Whether in conjunction with a stone curtain wall or an earth and timber rampart, the ditch was indispensable in hindering an attacker's ability to gain direct access to the defensive circuit and assail it with siege towers, battering rams or miners. The broad, water-filled moat was a particularly effective defence against the latter form of attack, yet very few of these ditches were designed to hold water; those constructed as part of the earliest castles, in the eleventh and twelfth centuries, were invariably dry. Given the customary practice of siting earth motte-and-bailey castles on natural prominences that is hardly surprising, although the infrequency with which water-filled ditches were constructed even on those sites where they were feasible suggests indifference. That attitude was clearly to change during the latter part of the thirteenth century as castle architecture continued to develop; a major influence was the Savoyard architect James of St. George who, together with a number of compatriots, brought a wide range of experience gained throughout Europe to the castles he designed and built in newly-conquered north Wales for Edward I.

The coastal location of most of the series of castles built in the 1280s allowed water-borne access—at Conwy via a properly constructed

water-gate—and the use of promontory sites, or sites at river confluences, points to the importance also given to water defences.⁵⁷ Both access and defence were equally prominent in the thinking of the castle designers: at Rhuddlan in 1277, most spectacularly, it was decided to improve this lowland site on the tidal River Clwyd by cutting a new channel between two and three miles long, to supersede the meandering and presumably shallow river. William of Boston, a master *fossator* or ditcher, was put in charge of the work and paid to recruit diggers in the Fenland areas of Lincolnshire. Between November 1277 and November 1280 some 755 pounds was recorded as being paid out in wages to the men digging the ditch from the castle to the sea; with the daily wage set at threepence, that would represent the work of 66 diggers six days per week over the three years. The success of this new route to the sea was fundamental to Rhuddlan's strength as a castle, protected by its massive water-filled moat and with access to the river via water-gates.⁵⁸

A similar awareness of the importance of water engineering can be seen at Beaumaris, begun in 1296 to dominate the rich island of Anglesey off the coast of north Wales. Like Rhuddlan, the chosen site was on flat, marshy land although in this case there was close access to the sea. Again, a massive water filled moat was constructed around the castle, and sea-going vessels could enter the castle's own dock constructed within its defensive circuit.⁵⁹

But it would be mistaken to attribute the introduction of innovative designs of castles solely to the royal architects and engineers. The castle of Caerphilly in south Wales, belonging to the Clare family, was begun in 1271 and bears comparison with the great royal castles of the north of the principality. In terms of water engineering, however, the spectacular defensive lakes at Caerphilly are not to be matched at any of Edward I's castles—or indeed anywhere else in Britain. An outer defensive work had the additional effect of damming the waters of the marsh in which the castle stands, so that it was completely surrounded by a complex of lakes barring any effective access to the castle except via its own gates and bridges.⁶⁰ Similar broad water defences were constructed at Kenilworth in Warwickshire,

⁵⁷ Taylor (1974), 351.

⁵⁸ Taylor (1974), 318–9, 325.

⁵⁹ Taylor (1974), 395–408; Allen Brown (1976), 105–7.

⁶⁰ Allen Brown (1976), 114–5.

where a lake of uncertain date protected the south and west walls; at Leeds in Kent where the castle stands on two islands in the middle of a broad lake, in existence by 1272; and at Bodiam in Sussex where the castle built in 1385 stands within a broad moat or small lake fed by the River Rother.⁶¹

The opportunity for such grand designs was increasingly limited, as the construction of new castles on new sites became increasingly rare throughout Britain after 1300. But improvement and development of existing castles continued, and evidently the water-filled moat was now established as a desirable feature of castle design. This can be seen most notably at the Tower of London, where successive major reconstructions during the twelfth and thirteenth centuries culminated in the work done for Edward I before the end of his reign in 1307. A new outer curtain wall was established, and the previous thirteenth-century dry ditch was replaced by a broad moat filled with water from the River Thames.⁶²

Defensive Moats in Towns

More than a hundred towns in England and Wales had defences, and an unknown number elsewhere in the British Isles. Some Anglo-Saxon towns re-used stone walls from the Roman period, whilst the new boroughs of the ninth and tenth centuries were surrounded by earth ramparts. After a period of two centuries or more during which town defences were seen as having little importance it was in the thirteenth century that many towns began to show an interest in fortifications.⁶³ In virtually every case this resulted in the construction of a stone curtain wall and a ditch along at least part of the circuit; it was very rare, however, for the ditch to be other than a dry one. At Worcester and Gloucester the natural course of streams was directed along parts of the walled circuit, but this may have been a response to a problem of local drainage as much as a defensive provision. The dry ditches could be quite substantial: 15 metres wide and 4.5 metres deep at Newcastle, and 15 metres wide at Chichester. Such ditches were commonly used illegally for disposing

⁶¹ Pettifer (1995), 257–9, 121–2,

⁶² Allen Brown (1976), 116–9.

⁶³ Turner (1970), 12–14.

of refuse, and towns frequently made provision for periodic scouring and cleaning.⁶⁴

Domestic Defensive Moats

The proliferation of moats built by the aristocracy around their otherwise unfortified houses was a striking innovation of the later Middle Ages. More than 5000 wide, water-filled moats surrounding houses are known in England. Dating evidence from examples that have been excavated shows that most were dug during a relatively short period, between 1200 and 1325. Although their appeal was clearly a wide one, it is not surprising that the greatest concentrations are to be found in those parts of the country where a heavy clay soil predominated, so that the construction of effective water-retaining ditches was feasible. East Anglia and the west midlands, in particular, have many surviving examples of medieval moats. They were built by both greater and lesser aristocracy, around every type of house except the very greatest; but most moats were built by the local gentry, and may have extended quite far down the social scale.⁶⁵ One parish in Warwickshire had as many as twelve domestic moats, suggesting that here at any rate the construction of a moat lay within the aspirations and resources of people on the borderline between gentry and upper peasantry.⁶⁶ Yet digging even a small moat must have entailed considerable expenditure; 3000 cubic yards of earth has been estimated as having to be dug from one typical example. Doubtless such moats served a limited defensive function, but were perhaps most favoured as a highly visible means of demonstrating status.⁶⁷ Most moats were filled simply by ground water seepages, although some had more elaborate feed-systems making use of existing streams or springs. The inflow into the moat of the manor house of the lords of the prosperous little town of Birmingham was sufficient to allow it to serve as a mill pond: in the sixteenth century (and probably long before) the manor house was rented by a miller whose mill was powered by the outflow from the moat down to the River Rea.⁶⁸

⁶⁴ Turner (1970), 57.

⁶⁵ Aberg (1978).

⁶⁶ Roberts (1976-7), 61-70.

⁶⁷ Dyer (1989), 106-7.

⁶⁸ Bickley, Hill (1890).

Monastic Precinct Moats

Monastic houses in both town and country often built moats around their precincts, even when there was also a wall. The chronicle of Evesham Abbey records that Abbot Reginald in the 1130s built a massive precinct wall, outside which he intended to dig a moat. However, he was advised that this would attract the attention of the king, who would be suspicious of the construction of such strong defences. Other monastic moats resembled the domestic moats that are so common, although there were often more ambitious features, for example being fed by specially constructed leats from nearby rivers and streams, or forming part of a complex system incorporating fishponds or mills as well. That at Abingdon, for instance, was also a fishpond in the fourteenth and fifteenth centuries; at Peterborough and Waltham abbeys moats were dug around orchards and gardens.⁶⁹

The dating of such features is uncertain, although they are mostly associated with minor religious houses founded in the twelfth and thirteenth centuries and so would seem to be roughly contemporaneous with the domestic moats. Like the domestic moats, too, their primary purpose is unclear; military defence is again out of the question, with protection against intruders and assertion of status being in most cases the principal reasons for their construction.

Fisheries and Fishponds

In England fish were drawn principally from rivers; for instance, Severn River luxury fish (salmon, shad, lampreys) that might be supplied to the crown and the aristocracy were sent over surprisingly long distances by fishmongers.⁷⁰ Less exotic river fish might be easily caught in great numbers, had a low market price, and evidently had a place in the peasant diet. Very large quantities of eels were caught, often in mill ponds or mill sluices, according to Domesday Book and other sources such as manorial accounts. Prices suggest that the better-quality specimens must have been exclusively an aristocratic luxury, costing as they often did the equivalent of several days wages for a working man. So expensive were these fish—including

⁶⁹ Bond (1989), 99; Bond (1993), 73–4; Macray (1863), 98.

⁷⁰ Holt (1990), 150.

pike, bream, roach, tench and chubb, amongst other varieties—that their consumption was in itself a social statement, an act expressing the wealth and importance of the consumer and his guests. Fresh-water fish tended to be served at special feasts when there would have been guests at the lord's table to be honoured and impressed. They were highly valued as presents, used like gifts of wine or game to cement social bonds; great lords rewarded their retainers with gifts of luxury foodstuffs, or suppliants might hope to gain favour through similar gifts to influential superiors.⁷¹

Therefore, many with the means to do so took steps to ensure a regular supply of these status-enhancing creatures by constructing fishponds. The expense involved, both initially and in maintaining an adequate stock of fish, ensured that in medieval England fish farming was seldom an economically viable activity and was little practised as a commercial operation. Indeed, the possession of fishponds was in itself a visible status symbol. Fishponds were not very useful sources of food, nor were they ever built or used by peasants to augment their diet or to raise fish for sale. The building of ponds for conserving fresh-water fish, although a form of water engineering widely practised in medieval England, was entirely an aristocratic practice—both of the ecclesiastical and of the lay aristocracy. In fact the secular aristocracy, kings especially, invested surprisingly heavily in fishponds.

A few examples of what seem to have been fishponds dating from the Roman period in Britain have been identified and excavated; all were associated with rural villas.⁷² The equally meagre evidence for fishponds before the Norman Conquest, however, seems to point to a genuine rarity during the Anglo-Saxon period. Virtually all medieval fishponds date to after 1066, and most to after 1100. Only five examples were recorded in Domesday Book in 1086, of which two were monastic, at the great abbeys of Bury St. Edmunds and St. Albans.⁷³ The reason for the absence of fish cultivation from Anglo-Saxon England is unclear, but a less elaborate cuisine, with less emphasis among the aristocracy on ostentatious consumption, might explain the failure to invest in this activity. Nevertheless, lack of technical expertise presumably contributed as well, for the absence of fishponds

⁷¹ Dyer (1994b), 101–11.

⁷² Zeepvat (1988), 17–26.

⁷³ Currie (1989), 147–50.

must inevitably have resulted in a scarcity of native skills for constructing suitable ponds and maintaining healthy fish stocks. The diverse techniques of fish cultivation seem to have arrived after 1066 with the new French aristocracy, who evidently employed continental engineers and other workers.

Many of the earliest fishponds were royal constructions.⁷⁴ During the twelfth century a total of ten fishponds are recorded at royal manors; thirty-three are known from the thirteenth century, and four more from the fourteenth. As well as reflecting the growth in documentation, this also points to a genuine increase in the number of fishponds after 1200. Only a minority were used to supply the court on any regular basis, with fish from a series of ponds in Northamptonshire being sent to the court at Westminster and fish from Marlborough in Wiltshire being sent to the court when it was at Windsor, Winchester or elsewhere to the south or west of London. Otherwise, ponds' important role was in the provision of fish for royal gifts to important subjects.⁷⁵ By the fifteenth century the use of royal fishponds seems to have been in decline. Of about 20 royal residences inherited by Edward I in 1272, very few remained two centuries later; there were some 25 under Edward III, but the number fell to ten after 1400, and to only six in 1485.⁷⁶ The total number of fishponds must have suffered a similar decline, and it may be that growing demands on crown income (like war) greatly reduced spending on luxuries such as fishponds. Also, as the court became more settled in and around London, more recourse may have been made to the great fishmongers of the capital, although the scanty evidence for this comes from the fourteenth century.⁷⁷ Supplying the court with luxury fish from the Severn, particularly during Lent, had always been a staple trade of the Gloucester fishmongers.

During the Middle Ages, fish constituted a large part of the monastic diet. Although the Benedictine *Rule* prohibiting the eating of meat was often evaded during the later Middle Ages, nevertheless there was a continued consciousness that monks should abstain from meat.⁷⁸ In the 1490s, food purchases for the monks of St. Swithun's Priory

⁷⁴ Currie (1989), 147.

⁷⁵ Steane (1988), 49–50.

⁷⁶ Allen Brown, Colvin, Taylor (1963), 243.

⁷⁷ Steane (1988), 50–1.

⁷⁸ Bond (1988), 69–70.

in Winchester suggest fish was the main course to be served on up to two-thirds of the year.⁷⁹ Much of this fish, of course, was fresh or preserved sea-fish, or fish from rivers and natural lakes, or from traps in mill streams. Eels were frequently mentioned as part of the rent paid by mills in Domesday Book, such as the two mills on the River Avon belonging to Evesham Abbey which rendered 2000 eels a year to the monks and continued to do so during later centuries.⁸⁰ Fishponds supplemented such sources and ensured more regular supplies, particularly of the more highly-prized fish such as pike, and many ecclesiastical fishponds were large and elaborate.⁸¹ Fishponds built by secular aristocrats at their manorial complexes were generally less elaborate.

Ecclesiastical institutions were prominent in fishpond construction at an early date: the bishops of Winchester had built several large ponds on their estates by 1171.⁸² But a number of early monastic ponds were in fact royal gifts, existing already when the abbeys were founded by the Norman kings. That was the case at several sites in Yorkshire (Selby, Nostell and Monk Bretton), but numerous other grants from lay aristocrats are recorded from the twelfth and thirteenth centuries.⁸³ There is no evidence to suggest that it was church institutions that took the lead in building fishponds before 1200. After that date, however, monasteries everywhere in England were building their own ponds, and investment during the period before 1300 must have been considerable.⁸⁴

The simplest were small ponds, often filled only by ground water or by springs but long chains of valley-bottom ponds were often arranged in elaborate systems. At the Cistercian abbey at Bordesley, Worcestershire, the earthwork evidence shows that the River Arrow was canalised away from its meandering course in the valley bottom to a trench running along the side of the valley, probably before 1200. The valley bottom was then filled with a series of interconnecting ponds, one of which was used to supply water to the abbey mill. A similar exercise was carried out by Grove Priory, Bedfordshire,

⁷⁹ Kitchin (1892).

⁸⁰ Bond (1973), 34, 37.

⁸¹ Dyer (1994b).

⁸² Roberts (1986), 125.

⁸³ Currie (1989), 147–50.

⁸⁴ Bond (1988), 95.

and by Quarr Abbey, Isle of Wight.⁸⁵ A pond built by Byland Abbey, Yorkshire, in 1234, covered an area of 18 hectares and was retained by a dam of earth and clay on a stone core, 400 metres long and nine metres high. Judging from the lead net weights found in excavating a contemporary building on the edge of the pond, harvesters used nets.⁸⁶ At Thelsford, Warwickshire, a gutter running down towards the fishponds there was found to contain an iron fish spear.⁸⁷

Building and repairing major ponds was a task for skilled specialists, such as William atte Hethe, "pondemaker", who replaced a sluice at one of the fishponds in Windsor Great Park in 1400. Much of the work consisted of piling and ramming the sides of the sluice, which itself was made with large quantities of timber and fitted with a floodgate.⁸⁸ The initial planning of ponds required considerable understanding of hydraulic engineering, and a high level of expertise was required to build and use some English fishponds. The larger monastic houses of Hampshire followed a coherent system of fishery control, particularly in the care taken to ensure that each pond in a complex could be individually emptied. Feeder streams were often diverted so that upper ponds did not empty into lower ones, and water was allowed into and out of each pond only through sluices, enabling the supply to be regulated at all times. This allowed the ponds to be drained one at a time for effective removal of fish and to allow repairs; it prevented the waste from each pond passing into the other ponds and thus reduced the risk of infection; indirect water supply also eliminated the constant deposition of silt on the pond bed, as would have occurred had feeder streams flowed directly into a pond system. Winter flood waters, especially, deposited large quantities of mud, and as manorial accounts show, silt was expensive to remove. Silt traps to filter incoming water were rare, but perhaps the smaller ponds noted at the head of larger ponds may have functioned as silt traps rather than as breeding ponds.⁸⁹

⁸⁵ Bond (1989), 100; Aston (1972), 133-6; Aston, Munton (1976), 24-37; Hockey (1970), 49-50.

⁸⁶ Bond (1989), 100-1; McDonnell (1981), 24-7, 30-3.

⁸⁷ Gray (1972), 31.

⁸⁸ Salzman (1952), 85.

⁸⁹ Currie (1988), 267-90.

Monasteries and Hydrotechnology

The most impressive examples of water engineering from anywhere in the medieval British Isles were those undertaken by English monastic communities, either within their own precincts or on their estates. Evidence gleaned from both historical and archaeological sources has formed the basis of a number of studies of monastic water supplies, of which the comprehensive synthetic surveys of the published material (together with the findings of original fieldwork) by James Bond are most notable and provide an invaluable starting point for any further study in this area.⁹⁰

There is no inherent reason why monks should have possessed any greater practical technological expertise than other people; rather, their pre-eminence in this field followed perhaps from a greater breadth of vision and a greater knowledge of what had been possible elsewhere, together with higher standards of comfort and cleanliness. Crucially, these were reinforced by a notable willingness to invest in costly schemes that might pay dividends only after several generations of operation. In all aspects of estate management there was a clear contrast between the short-term mentality of secular lords and the long-term, corporate, mentality of monastic lords. It has been said that the greatest achievements in monastic water engineering were made by the Cistercian order during the twelfth century and after,⁹¹ and certainly the English Cistercian monasteries demonstrated the care taken with the exploitation of water that is so well-known from Clairvaux and elsewhere in Europe. However, other monastic orders were equally active in ensuring adequate water supplies for consumption and milling. The Cistercian expertise in draining marshy land, too, came about more by necessity than choice as the order had to colonise sites and estates far less favourable than those occupied by the foundations of earlier centuries. Other later orders, the Premonstratensians and Carthusians for instance, faced the same difficulties in the marginal lands they had been granted and displayed the same expertise in water management.

⁹⁰ Bond (1989), 83–111; Bond (1993), 43–78.

⁹¹ Donkin (1978); Bond (1989), 84.

Monastic River Diversions and Canals

Several of these late-founded abbeys found it both desirable and feasible to improve their sites by diverting the course of rivers and streams—or indeed, had little choice but to do so if they wished to avoid regular flooding of their churches and domestic quarters. This has been observed at Bordesley in Worcestershire, where the River Arrow was diverted away from the site of the new Cistercian abbey.⁹² At Byland Abbey in Yorkshire, too, the Cistercian order improved a waterlogged site by cutting a series of ditches to carry away spring water, and by diverting two streams via a new canal.⁹³ Other major improvements to natural river systems might be made to facilitate transport, particularly of building stone, and it has been suggested that there may have been more such cases than the few examples known from written sources or from excavation and fieldwork.⁹⁴ Between 1161 and 1179 the monks of Sawtry Abbey in Cambridgeshire, for instance, built a canal seven miles to the River Nene for this purpose; at about the same time the Premonstratensian monks of Topholme in Lincolnshire acquired from King Henry II the right to construct a canal from the River Witham for the same purpose.⁹⁵ At Rievaulx, Yorkshire, the abbey can be seen to have constructed a complex of watercourses in the Rye valley, perhaps associated with successive land grants made to the abbey before 1200 and which included permissions to divert watercourses. But it has been suggested that the major canal system still visible today was constructed in the period 1135–40 when the abbey itself was being built to improve the site in some way. Whether these works were primarily for drainage or for transport remains unclear.⁹⁶ With foresight and careful planning both purposes might have been envisaged from the outset.

Water Supplies to Monasteries

Monastic communities, containing not only monks or nuns but also large numbers of servants and often numerous guests, had a clear

⁹² Aston (1972).

⁹³ Bond (1989), 97.

⁹⁴ Bond (1989), 99.

⁹⁵ Bond (1989), 98; Colvin (1951), 101.

⁹⁶ Rye (1900), 69–88; Weatherill (1952–5), 333–54.

need for copious supplies of clean water for a range of domestic purposes, including the personal hygiene mentioned by the Benedictine *Rule* and suggested by the survival on many abbey sites of *lavatoria* or areas set aside for washing. Monks customarily washed every morning and before every meal. The need to bring water to these communal washing places, often located within the cloister, was not the least of the reasons why abbeys needed to ensure a regular supply. Most, and certainly the rural monasteries, had few problems in establishing a steady supply of good water. Generally they had access to local springs or wells, such as Fountains Abbey, Yorkshire, which took its name from the springs on its hillside site, as did Sandwell in Staffordshire; and there are several examples of abbeys where wells have been identified in excavations.⁹⁷ Other abbeys considered it worthwhile to go to greater lengths, however, to ensure their water supplies, and like the urban monasteries discussed below constructed pipelines or conduits. At Warter, Yorkshire, the monks were granted permission by the crown in 1271 to lay a waterpipe under the roadway.⁹⁸ The Benedictine nuns of Godstow, three miles from Oxford, piped water to their house during the thirteenth century; Osney Abbey, on the other side of Oxford, also brought springwater from some distance.⁹⁹ Perhaps the written evidence fails to convey how commonly rural monasteries made such provision; archaeology and fieldwork at other sites have produced evidence of lead or hollow wooden pipes, and the remains of stone structures to protect the sources of the springwater.¹⁰⁰ Within monastic precincts water was distributed by lead pipes at Rievaulx, Meaulx and Kirkstall, and doubtless commonly elsewhere.

Water Supply to Urban Monasteries

The sophistication of the technology of water supply to English monastic houses is most apparent in the supplies to those situated in towns. For there the problems of securing an adequate supply of clean drinking water were most acute. The pipelines installed by urban

⁹⁷ Bond (1989), 85.

⁹⁸ *Calendar of Patent Rolls 1266-72* (1913), 579.

⁹⁹ Clark (ed.) (1905), 44-5.

¹⁰⁰ Bond (1989), 86-7.

monasteries had, as we have seen, their counterparts in the rural monasteries; in most cases, however, water had to be brought into the towns from a greater distance.

The larger English towns, especially, contained a variety of religious communities. Many were the setting for long-established Benedictine houses, or of cathedrals and other major churches served by communities of secular canons; the twelfth and thirteenth centuries saw a large number of new foundations of hospitals and friaries, both exclusively urban phenomena. The wells that are known to have been used at many of these houses began to be supplemented or replaced by piped supplies by at least the middle of the twelfth century—it being tempting to associate this development with the rapid urban growth of that period and consequent pressure on local water resources as well as growing problems of pollution. Before 1167 a major arrangement of water pipes and drains was constructed at the cathedral priory of Christ Church, Canterbury, by Prior Wibert; water was being piped into Lichfield Cathedral by 1166, and interestingly Walter Durdent, Wibert's predecessor as prior of Canterbury, had become bishop of Lichfield in 1148, suggesting a common inspiration for both systems.¹⁰¹ Other such systems are known from later in the twelfth century, and many more were recorded in the thirteenth.

As many of these systems are known from charters granting wells, or royal licences to exploit springs, the technology employed in those cases cannot be identified with certainty; however it is most probable that they were constructed in a similar way to those that are known in greater detail from contemporary accounts and descriptions, or from post-medieval descriptions, or from archaeology. A study of what is known of early piped water-supply systems has identified a range of common features.¹⁰² Often the springwater was collected initially in a conduit-head, a cistern supplying the main pipe. The remains of these structures have been identified archaeologically at Gloucester, Lichfield, Grantham and elsewhere. The water was then conveyed, invariably, through a sealed lead pipe which did not require a constant downward slope as an open watercourse does, but could rise and fall with the terrain. All that was required was that the level of the pipe remained at all points below the level of

¹⁰¹ Hayes (1977); Gould (1976), 73–79.

¹⁰² Bond (1993), 48–50.

the conduit-head. The problem with such pipes was that of access, to repair leaks and clear sediment—the additional problem of contamination with lead was presumably not appreciated by contemporaries, who frequently brewed ale in lead-lined vats. Often the pipes were encased in thick clay to reduce leakage, and in some cases were laid within stonework for easier access. The provision of settling tanks reduced the amount of sediment in the pipeline. The system installed at Canterbury Cathedral Priory had no fewer than five settling tanks along the course of the pipeline, each with provision made for periodic emptying for cleaning out accumulated sediment, and other similar examples are known. The arrangement is likely to have been a common one. Other pipelines are known to have venting or draining outlets, allowing the system to be emptied for repair or perhaps also for clearing blockages. On arriving at the monastery, the water was fed into a conduit-house or storage cistern, as at Canterbury.

Often such pipelines conveyed water over long distances, frequently 3 to 5 kilometres. This required some considerable care in levelling the pipe when the conduit-head was scarcely higher than the monastery: it has been calculated that the thirteenth-century water supply to St. Werburgh's Abbey, Chester, fell only 3 metres over the whole 3 kilometre course.¹⁰³ On occasions the pipeline was required to cross a river: many of Oxford's religious houses drew their water from hills on the far side of the River Thames. Either the pipes had to be laid under the river, as was done under the Avon at Lacock and the Kennet at Reading, or a convenient bridge was used, as at Worcester. Worcester itself illustrates the effectiveness of the sealed pipeline, as, having crossed the River Severn, the pipe then rose some 8 metres to the Cathedral Priory on its promontory site.¹⁰⁴

There is a little evidence that some pipelines were improved over time, in the light of experience gained from their operation. At Wells, three or more manholes were fitted in 1477 to give access to a washout valve, allowing sediment to be flushed out.¹⁰⁵ At Exeter the early thirteenth-century pipeline laid in a bed of clay was re-routed in the mid-fourteenth century to follow the city's streets from which direct access could be gained, and was now laid in a stone-lined

¹⁰³ Burne (1962), 41.

¹⁰⁴ Bond (1993), 50, 54–5.

¹⁰⁵ Rodwell (1980), 15.

passageway large enough to allow access to all parts of it for repair and maintenance.¹⁰⁶ Doubtless monastic communities exchanged technological knowledge and experiences, to achieve a constant refinement of their water supplies; all the evidence for piped water supplies comes from the twelfth century onwards, and it would seem that most institutions went through a series of increasingly refined arrangements. A good example is that of St. Peter's Abbey, Gloucester, and the lesser religious houses of the town. Nothing is known about the abbey's water supply in its earliest centuries (it was founded before 700), but there would have been a choice of well water or water from the nearby River Severn. In the twelfth century there was a well within the cloister garth. The abbey was reconstructed on a grand scale, first in the 1050s and again in the aftermath of the Norman Conquest by its first continental abbot, Serlo. As part of that reconstruction, by 1100 the Fullbrook canal was dug to bring water into the abbey precinct from the Twyver, a small stream outside the town walls. Perhaps this was never intended to supply water for domestic use, as it is recorded as driving the mill which the abbey built within its precinct. Certainly during the fourteenth century the Twyver water was polluted by the townspeople using it to carry away privy waste, and perhaps its quality was never high, for during the twelfth century—perhaps as soon as was practically possible—the abbey went on to make plans for a regular supply of good, fresh water. Between 1163 and 1184 St. Peter's Abbey acquired rights to springs on a hill more than 3 kilometres south-east of Gloucester, as well as rights for their aqueduct to cross private land. The scale of construction was less grand than the terminology might imply; the technology employed was clearly similar to that used by other monasteries, consisting of an underground lead pipe which carried the water from cisterns filled by the springs. About a century later the agreement was re-negotiated with another lord, who extended his permission to the Friars Minor of Gloucester as well. Their house had been built during the 1220s and 1230s, and the friars were also evidently feeling a need for an alternative to well water. They drew their water from the same springs that the abbey was using, and, after reconstruction work at the cisterns, found themselves in dispute with the monks over the fair share of the water; in 1357 it was

¹⁰⁶ Fox (1951), 172–8.

agreed that the friars were entitled to exactly one-third of the water, conveyed to their priory inside the south gate of Gloucester via their own underground lead pipe. Of the town's other religious communities, it is known that the Carmelite friars, too, installed a supply of fresh water, having in 1347 acquired the right to pipe water from a spring outside the walls.¹⁰⁷

Drainage from Monastic Sites

Water entering monastic precincts had to be channeled out again, such waste water often being most usefully applied to flushing out the monastic *reredorter* or latrine block. Ideally, this was constructed with a steady flow of water running through it, as at Selborne in Hampshire, where the Augustinian priory constructed a stone-built sewer with an arched roof, rather less than a metre wide or high. Other examples show evidence of sluices, so that a more limited flow of water could be held back and used to flush the latrines at intervals. At the Cluniac priory of Monk Bretton in Yorkshire, for instance, water was taken from the abbey mill leat through a stone-built conduit to the kitchens; controlled by a sluice, it then served to clean the *reredorter* periodically, the waste flowing back into the mill leat.¹⁰⁸ Elsewhere, *reredorters* might be built to take advantage of a natural watercourse, or one that had been canalised through the precinct, as at Fountains where the River Skell passed through each of the three *reredorters* on the site in turn.¹⁰⁹ The location of such a suitable watercourse often determined the location of the *reredorter*, as at the Premonstratensian abbey at Easby in Yorkshire. There the dormitory and *reredorter* were placed, unusually, on the west side of the cloister to take advantage of the tail-race of the abbey mill.¹¹⁰

Monastic Fishponds

It has already been stressed that in fishpond construction monasteries were not innovators in terms of scale or technique. Evidently,

¹⁰⁷ Fullbrook-Leggatt (1968), 111–18; Stevenson (ed.) (1893), 936, 966.

¹⁰⁸ Bond (1989), 92.

¹⁰⁹ Bond (1989), 91.

¹¹⁰ Thompson (1945), 11–12.

in the matter of the supply of luxury fish to the high table, great secular lords, especially kings, were willing to match the level of investment considered appropriate by the monasteries. However, the ambitious scale of monastic water control meant that the monks' fishponds were more often an integral part of a larger, complex system incorporating drainage canals, or mill leats and ponds. At Bordesley Abbey the diversion of the River Arrow from its original meandering course across the valley bottom into a new channel along the valley side removed it from the monastic precinct, but also allowed the construction of a series of fishponds and a mill pond.¹¹¹ At Shrewsbury Abbey waste water from the guesthouse kitchen and latrines was carried away via a stone-built channel carrying water from the Meole Brook to feed the abbey fishponds, and eventually to discharge into the leat of the abbey's mill.¹¹²

Monastic Mills

Whilst monasteries were certainly in the forefront of building mills and associated water management systems, again we must be cautious in assigning them a uniquely innovative role. As in the construction of fishponds, what we observe is that ecclesiastical institutions did not depart from usual aristocratic practice, except inasmuch as they seem to have been prepared to invest at a level most lay lords clearly considered inappropriate. Yet even that may have been unusual, as several wealthy and well-documented monastic estates (for instance the abbeys of Glastonbury and Ramsey) appear to have managed their mills in ways indistinguishable by the historian from those followed by their secular neighbours.¹¹³ Better documentation can be taken as an indication of earlier enterprise, as with the chronicle of Abingdon Abbey's report of the construction of a major mill leat off the River Thames in about 960. Attributed to Abbot Æthelwold, this construction of an artificial watercourse one and a half kilometres long is the earliest recorded example of a major work of hydraulic engineering. Given the large number of mills throughout the British Isles by this date, however, it would be mistaken to assume it was

¹¹¹ Aston (1972); Aston, Munton (1976).

¹¹² Baker, Cooper (1988), 59–62.

¹¹³ Holt (1988), 70–85.

exceptional for its time.¹¹⁴ Leaving aside the question of how reliable the chronicle's reporting of events some centuries previously might have been, there is the question of how many other such schemes on secular estates failed to be recorded. Very few of the major hydraulic works associated with mills in use until the present century have been the subject of archaeological research, and it has seldom been possible to propose any date for the origins of systems renewed and modified throughout the centuries. Tewkesbury Abbey in Gloucestershire, for instance, was given two mills as part of its foundation endowment in 1102, and continued to operate two mills throughout the Middle Ages. The still-existing mill in the town is driven by the Mill Avon, a major diversion of the river; without any evidence for its date, it is impossible to tell if this was originally an engineering work of the period before the foundation of the abbey, or of the abbey itself in the medieval period, or of the period before 1700.¹¹⁵

A probable example of monastic enterprise is the still-existing leat for the mill of Reading Abbey, in Berkshire. Bringing water more than eight kilometres from the River Kennet, the final three kilometres are straight and clearly wholly artificial. Excavation has shown that the tail race and overflow channel of the mill were cut in the twelfth century, when the banks of the river were being consolidated with timber and deposits of clay. Further such work had been done by 1200, and early in the fourteenth century a new tail race was constructed.¹¹⁶

Monasteries were great builders of fulling mills in the twelfth and thirteenth centuries, although we need to be cautious in assigning too revolutionary a role to monastic enterprise; again, this may be an illusion dependent on the better documentation for monastic estates. The first English fulling mills were recorded on the estates of the Knights Templars in 1185, at Temple Guiting, Gloucestershire, and at Temple Newsam, Yorkshire.¹¹⁷ The great Benedictine estates of the west midlands invested heavily in the new technology: fulling mills belonging to Winchcombe Abbey were recorded at Sherborne, Gloucestershire, and at Cleveley, Oxfordshire, in about 1190; soon

¹¹⁴ Stevenson (ed.) (1893), v. 1, 480-1; v. 2, 270, 278-80, 282, 285; Bond (1979), 59-75.

¹¹⁵ Bond (1993), 72.

¹¹⁶ *Medieval Archaeology* 28 (1984), 208-9.

¹¹⁷ Carus-Wilson (1941), 45-6.

after 1200 Pershore Abbey has fulling mills at Cowley and Hawkesbury, Gloucestershire, and Evesham Abbey had built one at Bourton-on-the-Water.¹¹⁸ Worcester Cathedral Priory had built five fulling mills at various locations in Worcestershire by 1240.¹¹⁹ On the Cistercian estates of the region, there were fulling mills at Stanley Abbey by 1189 and at Thame Abbey by 1197. Nine other Cistercian houses throughout England are known to have built or acquired fulling mills by 1300.¹²⁰

Water Supplies to Cities

Very few medieval English towns could boast an engineered water supply. A temperate climate ensured that even the largest cities, like London, could rely on a profusion of private wells, and on water carriers (recorded from a number of towns) who sold river water or well water in the street. There are also recorded cases from London of householders collecting rainwater in cisterns, and whilst such cases are rare the provision of rainwater barrels may simply have been too common to be reported.¹²¹ The reliability of the rivers on which most towns were situated made them suitable as sources of water, even though its quality may have been poor, and it was common for towns to set aside specific places from which water could be drawn. At Worcester, for instance, in the fifteenth century the recognised place from which water was drawn was situated on the bank of the River Severn, upstream from the bridge; city regulations also stipulated that the town's refuse could only be cast into the river downstream from the watering place.¹²² To an extent the low quality of the water supply was mitigated by the fact that there was a strong cultural prejudice against drinking water, all but the very poor using it only for washing and cooking; large quantities of wine were imported, but unhopped ale was overwhelmingly the drink of preference.¹²³ Having been initially boiled, and after the process of fermentation sterilised with alcohol, it was a safer drink than any other.

¹¹⁸ Hilton (1966), 209–13.

¹¹⁹ Hale (ed.) (1865), 12, 32, 41, 92, 108.

¹²⁰ Donkin (1978), 136–8, 188.

¹²¹ Sabine (1934), 313.

¹²² Smith (1870), 396.

¹²³ Dyer (1989), 57–8.

Increasingly in the fifteenth century townspeople in particular were turning to the continental habit of brewing beer with hops, whose antiseptic and preservative qualities would have rendered their customary drink even safer to consume.

The failure of most urban authorities to establish more sophisticated supplies of clean water was not simply the result of a general lack of technical expertise in this area; nor should we assume that the public treasury was insufficient for expensive schemes of this sort. After all, defensive walls, bridges and other public buildings were financed out of each town's own resources. It seems inescapable that the deciding factor was indifference; few town authorities saw any reason to invest in new public systems. Where improvement to existing arrangements of both the supply of fresh water and the disposal of waste water was deemed necessary, this was achieved by regulation of existing practices rather than by the provision of more technically advanced facilities.

One of the few towns that did see fit to provide a more sophisticated water supply during the Middle Ages was Gloucester, and the limited nature of the effort which was made is very revealing of the prevailing urban mentality. As we have already seen, the religious houses of the town had made elaborate arrangements for supplies of piped water since the twelfth century; the people of Gloucester must have known of the existence of the monastic pipelines, just as the people of other major towns would have known of the supplies to their own religious houses. Yet they made no attempt to replicate the system for public use. With its location on the River Severn, Gloucester can never have been short of water of a certain basic quality, and indeed the Severn did supply a great many of the town's needs. There are scattered references to horses being watered at the river; it was in the Severn, too, that clothes were washed, that tanners and glovers cleaned their skins, and that butchers washed entrails. In the 1520s it was recorded that the brewers of Gloucester had their place on the Severn, upstream of the public quay, from whence they were accustomed to draw their water.¹²⁴ Alternatively, water was drawn from the private wells that seem to have been common. But in 1438 the townspeople decided to provide a better supply of water—although rather than go to the expense of constructing their

¹²⁴ *Historical Manuscripts Commission* (1891), 434, 441.

own pipeline the town's ruling bailiffs chose to purchase from the Friars Minor three-quarters of their water. On arriving in the friars' garden the water would pass into four pipes, three of which were for the town's use. The destination of one—presumably the main one—was specified to be the ornate High Cross which stood at the centre of the town where the main streets crossed, and where a public fountain was to be installed. The fountain was clearly adequate only for minor domestic needs, and care was taken to prevent undesirable use; the butchers, for instance, were forbidden to use it to clean their filthy vessels. By 1509 a part of the water supply had been directed to a private house, for in that year we find it recorded that the widow of Gerard Van Eck, a former mayor and cloth merchant, was paying a pound a year for the distinction of being the only householder in Gloucester with piped water.¹²⁵

Southampton, too, had a piped water supply, and again the town took over a system already established by one of the local friaries. In 1300 the Friars Minor had begun to pipe in water from springs a mile outside the town, and in 1420 a leading burgess bequeathed funds for the conduit to be repaired and converted to public use. The lead pipes were taken up and replaced and new cisterns constructed; the friars were to retain half the water for their own use, whilst the other half was to supply a cistern for the use of the townspeople. The system was still in use in the early nineteenth century.¹²⁶

Sewage and Waste Water Disposal in Towns

For medieval town authorities, the problems associated with the disposal of waste water loomed larger than those of water supply. In addition to privy waste and the spillage of often contaminated water from craft workshops, there was the ever-present problem of rainwater. Significantly, the earliest known civic regulation was the Canterbury by-law, already in existence before 868, stipulating a gap of two feet between houses as eavesdrip.¹²⁷ In the more densely settled London of the later Middle Ages, rainwater running off roofs was

¹²⁵ Stevenson (ed.) (1893), 1112; Stevenson (ed.) (1890), xvii–xx; Gloucester County Record Office, Gloucester Borough Records 1313.

¹²⁶ Platt (1973), 144–5.

¹²⁷ Brooks (1984), 27.

a frequent source of friction between neighbours; a more fundamental problem was that much waste water could not be disposed of by natural ground drainage, and numerous gutters were constructed to carry the water away.¹²⁸ The only evidence for London's gutters comes from records of litigation, from which it is clear that there was no regular publicly-engineered or maintained network but only individual works prompted by the obligation of each householder not to cause undue inconvenience to the neighbours. Gutters might discharge into natural watercourses such as the Walbrook and other city streams, or into soakaways, or on to vacant land. Some ran along streets, or between houses, but many ran across private property and under houses and there was a clear obligation not to block or otherwise obstruct a customary gutter. From the frequency of complaints that gutters had become blocked with privy waste, there is little doubt that most served in fact as open sewers.

The only known example of an enclosed sewer in London was when the common council in 1462 gave orders for the Wallbrook to be paved and vaulted over; this work on a natural watercourse was to be undertaken piecemeal by the people occupying the land on either side. The purpose was to get rid of the numerous privies that had been built over the stream, presumably to prevent blockage and so improve drainage along its upper reaches. Both private and common privies constructed over watercourses were common in medieval London, but no special sewers or gutters for disposal of waste were constructed. Instead, natural watercourses such as the Thames, the Fleet River and the Wallbrook were used, together with already existing features such as the city ditch. No attempt was made during the medieval period to replicate the arrangement at the nearby royal palace of Westminster, where in 1259 an underground sewer was built to carry away kitchen waste to the Thames; by 1307 privy waste from the palace was also disposed of in the same way.¹²⁹ In other large towns, too, the situation was the same, with no planned system of drainage or waste disposal. Most townspeople used cesspits, and relied on natural drainage. St. Mary's Abbey, York, had a magnificent stone-vaulted main drain to carry its waste to the River Ouse, but the people of the city made no such arrangement.¹³⁰

¹²⁸ Chew, Kellaway (eds.) (1973), xxii–xxiv.

¹²⁹ Sabine (1934), 310, 305.

¹³⁰ Addyman (1989), 244–63.

CHAPTER THREE

HYDRAULIC ENGINEERING IN THE NETHERLANDS DURING THE MIDDLE AGES

William H. TeBrake

The story of water management in the Netherlands during the Middle Ages is principally the story of land drainage and flood control. Although residents engaged in a full array of water management activities, it was hydraulic engineering in the form of drainage and flood control that established and still fundamentally determines the character of the Dutch region. Indeed, most of the Netherlands would be exposed to routine flooding by the sea or rivers today were it not for the presence of a complex system of dams, dikes, and drains, many of medieval origin. On the adjacent coastal plains of Belgium and Germany, similar measures protect additional areas from flooding. No other part of Europe has been so profoundly affected by hydraulic engineering, and it was during the Middle Ages that water management and its associated hydrotechnologies were pioneered and first developed on a substantial scale.

Land Drainage and the Creation of the Lowlands

Nearly two-thirds of the Netherlands occupy a lowland zone prone to flooding. This zone is essentially a flat coastal plain that lies between several meters above to several meters below sea level (about 25 percent of the total area of the Netherlands actually lies below mean sea level, and another 40 percent is at or slightly above mean sea level). The remaining one-third, the upland zone, consists of slightly sloping land that ranges from a few meters above mean sea level to a few spots in the extreme southeast where elevations of 300 meters and more are achieved; the upland landscape resembles that in nearby sections of western Germany, inland Belgium, and northern France. Because it is not protected by the system of dikes, dams, and other water management devices, the upland zone will not be investigated here.

The primary focus in what follows, then, will be on the lowland zone of the Netherlands, along with occasional reference to the coastal plain of Belgium and areas upstream along the major rivers that are protected from flooding by river embankments. During the Middle Ages, this zone included the coastal plain of the County of Flanders in the southwest, all of the Counties of Zeeland and Holland in the west, most of the Frisian lands in the north, the entire Almere (later Zuiderzee, today IJsselmeer) basin, the western half of the lower portion of the Bishopric of Utrecht (the Nedersticht), the northwest corner of the Duchy of Brabant, and portions of the County (later Duchy) of Gelderland along the Rhine, IJssel, and Meuse (Maas) Rivers (figure 3.1).

Sources and historiography

The scholarly representation of medieval hydraulic engineering in the Netherlands has changed substantially in recent decades. The traditional view, developed during the late nineteenth and early twentieth centuries, was based primarily on documentary evidence. Unfortunately, few documents were generated before the fourteenth century, and even fewer survived. While they became more common during the fourteenth century, documents became plentiful only during the fifteenth century. The problem is that the initial drainage and settlement of most of the lowland zone occurred well before the fourteenth century. Yet the meager written record revealed very little about original physical conditions or the timing or procedures used for the earliest stages of drainage and settlement. To compensate for this lack of information, certain assumptions were made that reflected accepted knowledge in the physical sciences at that time.

Early scholars of medieval water management and hydrotechnology simply assumed that physical conditions had changed little from the time of initial drainage and settlement until the time when documents began to provide a clearer view at the end of the Middle Ages. Specifically, they believed that the elevation of drained land, the distribution of soils, and the regime of waters in the lowland zone remained fairly constant from the early to the late Middle Ages. The implications of this view were far-reaching. For example, if dikes, as well as the means of draining land behind such dikes, were a prerequisite to settlement at the end of the Middle Ages, then they

Potential Flood Zones, Protected by Dikes

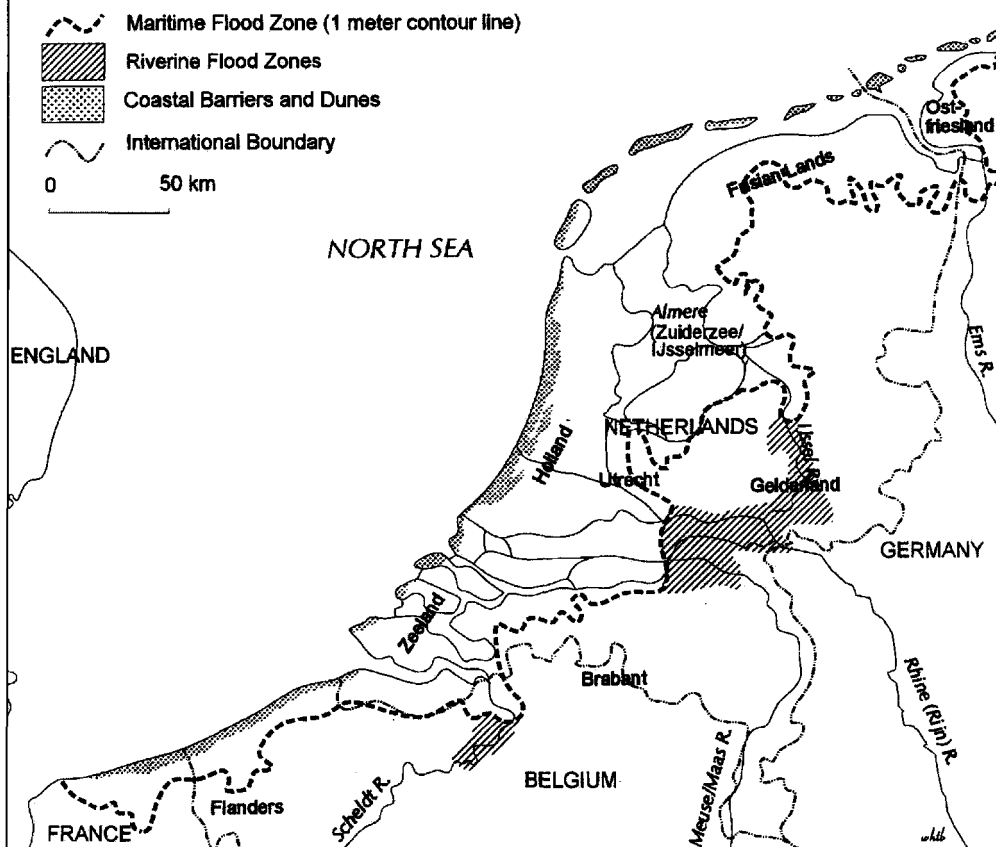


Figure 3.1. The floodable areas of the Netherlands.

also were a prerequisite to initial settlement. Because there was little evidence for extensive dike building before the twelfth century, the first meaningful settlement of the lowland zone was assumed to date from the twelfth century.¹

These assumptions were accepted by most historians until the middle of the twentieth century, when H. van der Linden reconstructed the early settlement history of the Holland-Utrecht section of the

¹ Well represented, for example, in Beekman (1932) and Gosses (1946), 293–344.

coastal plain. He was able to show that much of the area had been drained and settled during the late tenth and eleventh centuries, well before the first extensive networks of dikes were constructed, around 1200. The original surface of the area, he argued, was much higher than it was at the end of the Middle Ages, so much so that the first residents did not need dikes to protect them from flooding. He made clear, however, that human activity did set in motion processes that caused the surface of much of the lowland zone to subside, eventually making dikes and various drainage devices necessary for continued habitation.² In other words, dikes, dams, and most drainage devices were a consequence of, not a precondition for, human occupation.³

Since the 1950s, research by geologists, archaeologists, soil scientists, and other historians has confirmed the basic accuracy of van der Linden's position, not only for the area he studied, but for the entire lowland zone.⁴ In the end, a significant broadening of the sources of information concerning water management during the Middle Ages has resulted in drastically altered ideas about when and where water management began, what physical conditions it was meant to address, the means by which it was carried out, and its short and long term effects.

Physical conditions

Physical scientists now contend that peat mires, peat-forming ecosystems, were the distinguishing feature of the lowland zone of the Netherlands for a prolonged period of time before the Middle Ages.⁵ Peat formation is the accumulation of incompletely decayed plant residue, and it occurs whenever waterlogging prevents the decay of dead plant material by inhibiting its exposure to oxygen. Waterlogging was characteristic of the lowland zone of the Netherlands throughout late prehistoric times as a result of the post-glacial rise of sea level that raised the ground water table and slowed river flow through broad lagoon-like environments that were protected from direct marine

² Van der Linden (1956); Borger (1992), 131–32.

³ Beenakker (1988), 174.

⁴ Edelman (1958), 239–45; Edelman (1974); Borger (1977), 377–87; van der Linden (1982), 48–82; Pons (1992), 7–79; van de Ven (1996), 41–7.

⁵ For a comprehensive summary of the current state of knowledge, see Pons, (1992).

influence by coastal dunes and salt marshes. Such environments produced fen peats, built up by the residue of plants that drew nutrients from ground water or sediment-rich river water: these were mostly reeds and sedges, but also alder and willow on the silted-up banks of rivers and streams.

By the beginning of our era, centuries of peat accumulation had created enormous expanses of fen peats that filled the entire area between the sand dunes or salt marshes at the coast and the upland zone, some 30 to 80 kilometers or more inland. Especially where peat layers were thickest and sediment-rich river water unavailable, the original plant communities had increasing difficulty obtaining nutrients. As a result, species that depended solely on nutrient-poor precipitation began to predominate, especially peat moss. As long as precipitation exceeded evaporation fairly consistently, the residue of peat moss and related species continued to accumulate, forming bog peat that became raised above the ground water level. Capillary action within the peat mass actually raised the water table of bog peat above the levels of the surrounding fens, allowing their centers to become raised above their peripheries.

By the early Middle Ages, peat moss bogs of varying height covered virtually all of the lowland zone. Some of them, shaped like cushions, domes, or ridges, grew to 4 meters or more above the levels of the fen peats⁶ and achieved diameters of 10 to 15 kilometers. All were equipped with radial drainage systems consisting of networks of small streams fanning out from the centers that carried surplus surface water after rainfall or snow melt into the larger rivers that cut through the peat area.⁷ Only a few parts of the lowland zone never saw full bog development: along the major rivers in the central portion of the Netherlands where river sediments allowed wood peat development to continue; in the tidal estuaries of rivers and where coastal dunes were incomplete or breached; and in the large complex of shallow lakes and swamps that constituted the Almere.⁸

Until well into the early Middle Ages, residents of the lowland zone lived within the parameters imposed by physical processes

⁶ 4 meters is a conservative estimate. Some have suggested heights of five to ten meters instead; see de Bont (1994), 60.

⁷ Pons (1992), 24–72; van de Ven, van der Linden, Stamhuis (1994), 37–8; Verhulst (1995), 76–89.

⁸ Van de Ven (1996), 46; Verhulst (1995), 18–22, 77–89; Hoppenbrouwers (1992), 38–46, 375–86, 397–98.

applied over geological time spans. Only a small proportion of the lowlands could support a permanent human population, primarily the highest stream banks and coastal salt marshes or the edges of the coastal dunes. The remainder, the fens and bogs, was essentially uninhabited. Then, beginning in the ninth century, physical processes increasingly were interfered with and deflected in a multitude of ways, as humans themselves became the shapers and formers of their physical surroundings, all within human, not geological, time spans.⁹ Using simple tools and techniques, they drained the uninhabited peat mires, transforming them into new land that could support settlement and agriculture.

Brief History of Drainage

There is, of course, no inescapable human requirement to drain waterlogged areas. After all, wetlands represent some of the most productive earthly environments, and many cultures have found ways of living from such bounty without actually draining them. In many quarters today, they are highly prized for their intrinsic ecological worth and are protected against draining or filling. But such was not the case during the Middle Ages. The social and cultural context of ninth and tenth century Europe—a growing population and the emergence of a dominant subsistence paradigm focussed on crop-raising—set the stage for a major assault on wilderness of all kinds.¹⁰ Thus, the inhabitants of the small sections of the lowland zone of the Netherlands that supported a resident agricultural population made a very human choice: to extend their subsistence patterns into the peat lands that surrounded them. But first, these peat lands had to be drained.

Though the exact timing for the beginning of drainage is not easy to establish, it is possible to track the result of drainage, the spread of settlement into the lowland zone. Archaeological, place name, and documentary evidence indicates that new settlements were being established in areas of bog peat during the ninth and tenth centuries. Spreading from north to south, several groups of settlements were founded in the peat wilderness of northern Holland, sandwiched

⁹ Van de Ven, van der Linden, Stamhuis, (1994), 33.

¹⁰ TeBrake (1985), 35–52.

between the coast on the west and the Almere to the east.¹¹ During the tenth century, settlement spread to additional sections of the lowland zone of the Netherlands. Among these were parts of the Frisian lands in the north and Zeeland in the southwest, in the bands of peat lying behind the coastal salt marshes. Peat Lands adjacent to the great rivers in the southern parts of Holland and Utrecht also were being settled during the tenth century.¹² (figure 3.2) In the eleventh century, settlement began to spread like a great wave over the entire lowland zone of the Netherlands.

From the very beginning, drainage was accomplished by ditch digging. Residents of existing communities located on salt marshes, along the edges of a coastal dunes, or on naturally-raised levees of major rivers began working their way into bogs via the natural streams that radiated out from their raised centers. It was from such streams, canalized by deepening and straightening to enhance flowage, that reclaimers dug ditches into the peat-bog wilderness at regular intervals, often some 110 meters apart. Serving as the side boundaries of new, long and narrow parcels of agricultural land, these ditches, along with smaller ones within individual parcels, collected and conveyed water from the uppermost layers of peat into the reclamation bases constituted by the straightened, deepened streams. The ditches lowered the water table within local sections of bog; a lowering by about one meter stopped peat accumulation and allowed the development of a sod capable of supporting humans and their paraphernalia. The reclamation bases, in turn, carried drainage water away from the sites. Finally, low embankments, thrown up along the back of parcels, kept water from undrained sections of bog beyond from flowing onto the new land.¹³ As the process advanced, especially where natural streams were lacking, canals were dug that collected water from the drainage ditches and carried it away to existing streams or other suitable waterways.¹⁴

The wave of drainage and human settlement lost its impetus around the beginning of the fourteenth century, by which time virtually the

¹¹ De Cock (1965), 7-8; de Cock (1969), 154-71; Borger (1975), 215-7; Schoorl (1997) 14-5; Besterman (1997), 21-5.

¹² Ligtendag (1995), 91-7; van de Ven, van der Linden, Stamhuis (1994), 70-1; Pons (1997), 99.

¹³ These activities are described by Kaptein (1993), 51-2; see also TeBrake (1985), chapter 6.

¹⁴ Van de Ven, van der Linden, Stamhuis (1994), 66.

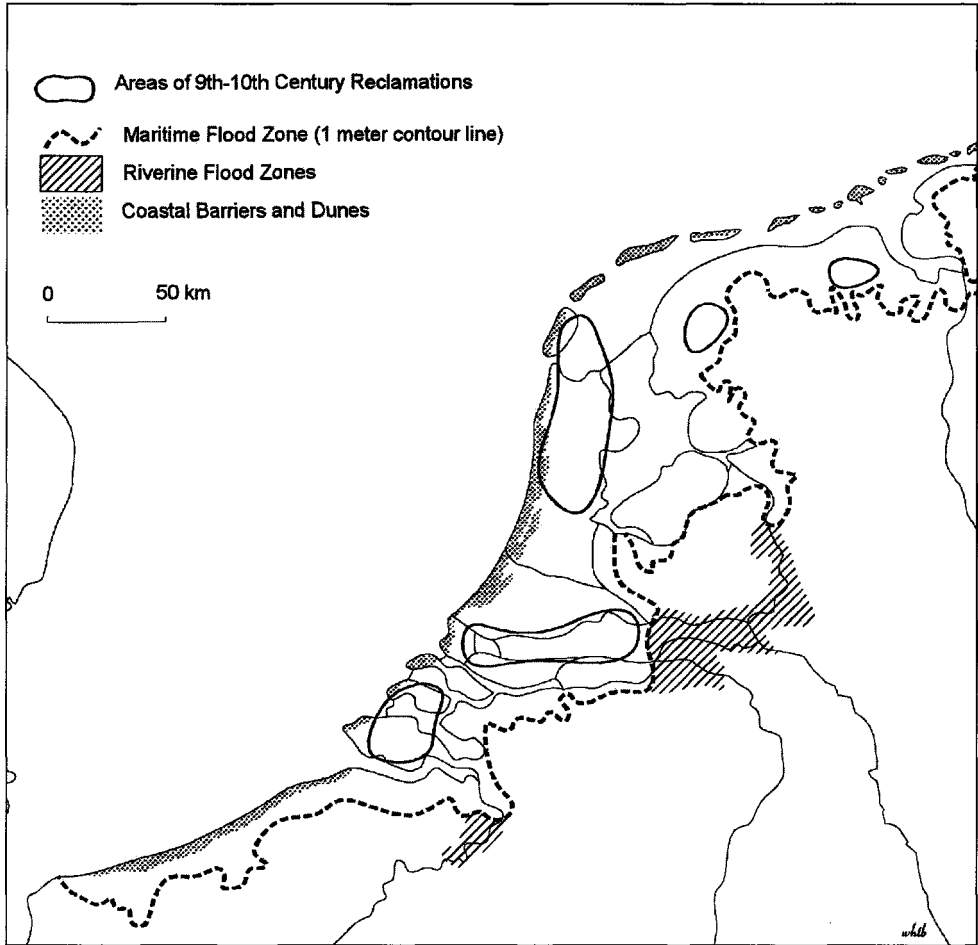


Figure 3.2. The lowland zone of the Netherlands and early medieval reclamations.

entire lowland zone had been transformed into settled land.¹⁵ The new space thus produced helped to both fuel and accommodate the enormous population and economic growth of the high Middle Ages; for not only were drained bogs used for agriculture, they became the primary location of cities as well. Indeed, by the end of the Middle Ages, the lowland zone of the Netherlands emerged as one of the most densely populated regions in all of Europe.

¹⁵ TeBrake (1985), 185–220; Borger (1992), 135–49; van de Ven, van der Linden, Stamhuis (1994), 44–79.

Consequences of Drainage

While residents of the lowland zone had achieved considerable success at deflecting natural processes, they had not eliminated them. Successful drainage schemes actually concealed the beginnings of unintended consequences, and, increasingly, people were forced to adapt to changed physical conditions that were partly the product of their own actions. The most important of these was the subsidence of the surface of drained peat. Subsidence occurred, first of all, because a lowering of the water table within a mass of peat reduced its volume, resulting in compaction of the plant material that constituted peat. (Water can account for as much as 90 percent of the volume of some bog peats.) Secondly, once the top layers of the peat had dried out, oxidation of the peat material itself resumed. This oxidation process gathered speed thanks to the customary burning of peat surfaces (in an attempt to concentrate nutrients before planting crops), while trampling by animals and humans compacted the peat surfaces even further. Within just a few generations, the combined effects of compaction and oxidation began lowering the surfaces of new lands substantially: in some cases the soil surface dropped by as much as two centimeters or more per year.¹⁶

The immediate problem caused by subsidence was the reduction of gradients and thus of the flow of water away from drained peat. As residents found it more difficult to achieve adequate drainage, one response was simply to move further up the slope of the bog. Archaeologists have been able to track the uphill progress of settlements in a number of locations (figure 3.3).¹⁷ Over the longer term, however, subsidence created a situation much more vulnerable to flooding. Indeed, part of the devastation caused by a series of strong storms between the middle of the twelfth and the middle of the thirteenth century is now ascribed to a significantly subsided ground level in many drained sections of the lowland zone.

The onset of increased storminess brought a temporary halt to drainage activity and fundamentally changed the regime of waters

¹⁶ That the subsidence of peat could be significant is indicated by measurements taken in eastern England; the surface of the peat near Whittlesey Mere has declined roughly 3.5 meters since 1851, when drainage was instituted. See Butlin (1995), 160; Borger (1992), 132.

¹⁷ Besteman (1990) 111–16; Bont (1994) 69–72.

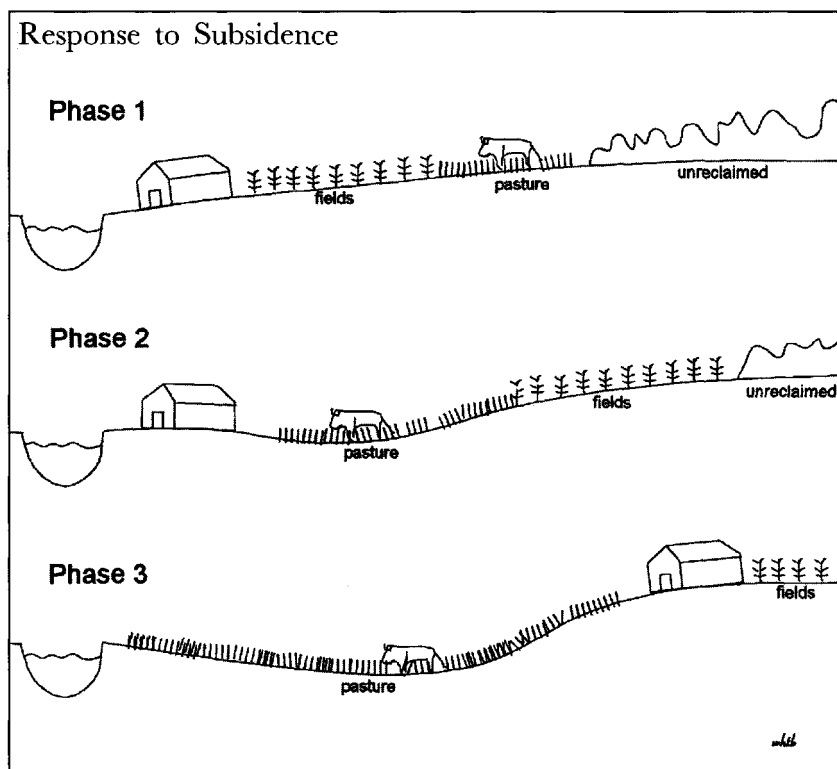


Figure 3.3. The phases of subsidence and their impact on landscapes.

in a major portion of the lowland zone. Until the middle of the twelfth century, a substantial peat ridge along the north end of the freshwater Almere basin maintained a water level in the basin that was above mean sea level. Though the peat ridge had gradually degraded since around 800, it was the storms of the late twelfth century that broke through what remained and introduced salt water and tides into the heart of the lowland zone, forming the Zuiderzee or southern sea.¹⁸

The creation of the Zuiderzee was a mixed blessing for those living in the region. On the one hand, because it lowered water levels in the entire Almere-Zuiderzee basin, they could now drain bogs around its periphery that previously lacked a suitable lower water

¹⁸ Borger (1977), 380–82; Hogestijn (1989), 121–2.

level into which to convey drainage water. This is what happened, for example, just south of the Zuiderzee near the edge of the upland zone, where Keveren was quickly drained and settled during the early thirteenth century.¹⁹ On the other hand, as the channel connecting the new southern sea to the North Sea widened and deepened, marine influence increased, thus heightening the dangers of flooding all around.

The combination of waves and tides soon broke up and flushed away much of the peat of the Almere basin and began pushing the shores of the new sea toward the edges of the upland zone in the east and south. The IJ, a western extension from the south end of the Zuiderzee, made easy headway through subsided peat land; only the barrier ridges and dunes at the coast held and prevented the transformation of northern Holland into an island. In Holland north of the IJ, a number of bog streams along with adjacent land that had subsided were transformed into a series of lakes by the eroding effects of waves during times of high water.²⁰ The Zuiderzee's floods continued to threaten nearby areas until it was closed off by the Afsluitdijk (Closing Dike) and transformed back into a freshwater lake during the twentieth century.

Technology of Drainage and Flood Control

The period of increased storminess that began around the middle of the twelfth century marked a turning point in the history of hydrotechnology for the lowland zone. Until then, water management amounted to land drainage, accomplished with the simplest of techniques, tools, and equipment. All that was needed was to dig ditches, to straighten and deepen existing bog streams, and to excavate drainage canals where streams were lacking. Gravity took care of the rest. The tools and equipment normally associated with rural life were more than adequate to the task: knives and spades or shovels for cutting and digging the soft peat, and baskets or wheelbarrows for transporting excess material. During the late twelfth century, all aspects of water management began to change, with simplicity giving way to complexity, and ease giving way to difficulty.

¹⁹ Schaftenaar (1993), 37–9.

²⁰ Beenakker (1997), 43; Beenakker (1988), 164; Kaptein (1993), 49–50.

By the twelfth century, the population of the lowland zone had discovered that water, by its very nature, imposes heavy demands on those who would control it. For example, in order to achieve any results at all, particularly with drastically subsided ground levels, they were forced to pay close attention to details of slope or gradient, to find the shortest and most efficient routes for conveying drainage water, and to learn something about fluid dynamics and basic principles of engineering. In addition, drainage alone no longer sufficed in many cases. Increasingly they were forced to pursue drainage in tandem with flood control measures. Dikes and dams to protect against external water became just as important as ditches and canals to drain off internal water. The building of dikes and dams, in turn, required people to learn to distinguish between materials that allow water to pass through them and those that are impermeable, between those that easily erode away and those that remain in place.²¹ In short, residents of the lowland now had to measure, plan, and execute with meticulous attention to detail. The simple digging of ditches designed to enhance the normal flow of water from higher to lower elevations had given way to real hydraulic engineering.

Dikes, dams, and sluices were used to protect against flooding long before the drainage of the lowland zone began, especially along the lower courses of the great rivers. Archaeologists have revealed their use before and during the Roman period, near what is now Rotterdam, for example.²² In addition, documentary evidence indicates that dikes were built at various places in northwestern Europe during the early Middle Ages.²³ However, from the twelfth century onward, dikes, dams, and sluices took their places alongside ditches and canals as characteristic landscape features of the lowland zone of the Netherlands.

Some form of dike construction was associated with the drainage of peat bogs from the very beginning. The low embankments typically thrown up along the backs of newly-drained sections of bog, to protect them from water running off the higher undrained sections beyond, were primitive dikes. So too were numerous low embankments designed to protect against or divert water arriving from a single direction, found both in coastal areas and along the major

²¹ Bont (1994), 57.

²² Ter Brugge in Hensing (1995), 385–6. Also see notice in “Kort archeologisch nieuws,” (1997), 47.

²³ Blok (1984), 1–7.

ivers. All of these were partial dikes, in the sense that they did not completely enclose a piece of land; all were of strictly local significance as well. Once subsidence began to be noticeable, low summer dikes sometimes were used to enclose and protect small areas of low-lying land against high water levels during the growing or pasturing season; typically, these same areas would have stood under water for the most of the wetter, winter season.

Eventually, more substantial complexes of dikes began to be constructed by connecting together and reinforcing many smaller sections of dikes. But linking smaller dikes into larger dike complexes left fewer and fewer exit routes for internal water, a serious problem in a region where precipitation far exceeds evaporation during most of the year. Thus, concurrent with the construction of enclosing rings of dikes, residents of the lowland zone had to build drainage sluices that allowed "internal" water to exit without allowing "external" water to enter.²⁴

Between 1100 and 1250, most of the Zuiderzee and all of the IJ were lined with dikes designed to stem shore erosion by waves and tides. At the same time, dikes were constructed along the major rivers, from their estuaries upstream as far as the riverine flood zone extended. In Flanders and Zeeland in the south and the Frisian Lands in the north, dikes offered protection from flooding in both salt marsh and peat areas. Where dike trajectories intersected with streams, creeks, and gullies, either embankments were constructed alongside these waterways as well or dams, often with sluices, were built to block them, thus completing the circle of protection. In total, hundreds of kilometers of dikes and dams were constructed during this period.²⁵

Few dikes or dams from the medieval period have been excavated by archaeologists, primarily because they often lie buried under larger, still functioning dikes. Those that have been examined, however, show that they were built of local materials. A small section of the West Frisian Omringkijk was excavated during the 1970s. Completed by 1250, this dike formed an oblong circle of protection in northern Holland with a circumference of nearly 150 kilometers. The excavation revealed that the thirteenth-century core of the dike was

²⁴ Borger (1985), 78–9; Beenakker (1995), 174; Beenakker (1997), 43–4; Verhulst (1995), 44.

²⁵ Van de Ven, van der Linden, Stamhuis (1994), 55–57, 61–65, 74–79.

constructed primarily of sods, cut from both peat and clay land. It was raised with a layer of clay during the fourteenth century. Additional materials, including wooden shoring and layers of seaweed to prevent erosion, were added from the sixteenth century onward, eventually lifting the Omringkijk to a height of four meters. Though this represents only a small cross section of one dike, it can be taken as a good indicator of the kinds of materials used in medieval dike construction. Meanwhile, the shapes or slopes of dikes were increasingly adapted to local circumstances. Sea dikes received gradual or gentle slopes on the water side to absorb the energy of waves, swells, and storm surges, with more abrupt slopes on the inside. River dikes, on the other hand, were given steeper slopes on the water side, with broad, gentle slopes landward that were designed to limit soaking and seepage and thus enhance stability during prolonged periods of high water.²⁶

Sluice construction went through considerable development during the Middle Ages. The examples from the Roman era or before were simply culverts made from hollowed out tree trunks equipped with clapper valves that opened as water flowed in one direction and closed against the end of the culvert as water began to flow in the opposite direction.²⁷ They, like their medieval counterparts, extended through the base of a dike or dam, with the top of the embankment running over it, but that is where the similarity ended. The oldest-known medieval sluices exhibited a significantly different design and construction and a much greater capacity.

Archaeologists have uncovered several sluices from the thirteenth century which indicate that sluice chambers were being constructed of a sequence of heavy, rectangular timber frames covered on all four sides with planking. The automatic valves, or gates, that opened or closed according to the direction of water flow, were mounted on either horizontal or vertical axes well within the chambers. Documentary evidence reveals that sluices often were rebuilt after storm damage, and sometimes the specifications for rebuilding have survived. Such specifications reveal a preference in some quarters for sluice gates, mounted on the exit end of a sluice chamber, that were lowered and hauled up by windlasses; in some cases, these were used

²⁶ Van de Ven, van der Linden, *Stamhuis* (1994), 79–80.

²⁷ Reported by ter Brugge, in Hessing (1995), 385–86. See also Arends (1994), 8–10.

as storm surge barriers that were lowered only when such protection was needed, with internal, automatic valves or gates in control at other times. Various configurations of skirting, made of poles or planks, were used to prevent water from flowing alongside or under sluice chambers. Over time, the sluices became much larger. The earliest examples, made from hollowed out tree trunks, did not much exceed 25 centimeters in diameter; medieval sluices grew from roughly 3 meters high and wide to 4 meters high and 6 meters wide by the sixteenth century. The length of a sluice was determined by the width of the embankment through which it protruded; 20 meters or more in length was not unusual (figure 3.4).²⁸

By the late thirteenth century, the entire lowland zone saw a comprehensive network of dikes, dams, and sluices designed to provide a basic framework within which further drainage could be effected. Besides such works, outlining the peripheries of the various parts of the lowland zone, many more dikes, dams, and sluices were built in the interiors: along streams and canals; around lakes and ponds; and between drainage units. However, because subsidence continued, though not always at a uniform rate, the size of drainage units tended to get smaller. Increasingly, parcels of land at one level would be grouped together but separated by embankments from parcels at other levels. Land thus enclosed by embankments became known as a *polder*. The advantage of such groupings was the greater control over depth of drainage and disposal of drainage water that it allowed; each grouping would then be equipped with its own exit routes for drainage water. The disadvantages of this approach were the huge inputs of not only labor but also capital and materiel that it required.

Eventually all of the lowland zone was divided into *polders* of varying sizes. By the fifteenth century, however, some of them had subsided to such a depth that gravity flow could no longer provide the degree of drainage necessary to sustain agriculture. As a result, some land was simply abandoned. Another response was to begin pumping drainage water from a *polder* into a higher level outside, from which gravity flow still would be possible—perhaps a large drainage canal that was itself perched atop an embankment. Eventually, most of the lowland zone was kept dry by pumping, and, from the late

²⁸ Arends (1994), 7–14; van de Ven, van der Linden, Stamhuis (1994), 82–85; van Dam (1997), 116–22.

End View of a Medieval Sluice

(after Van de Ven, et al.)

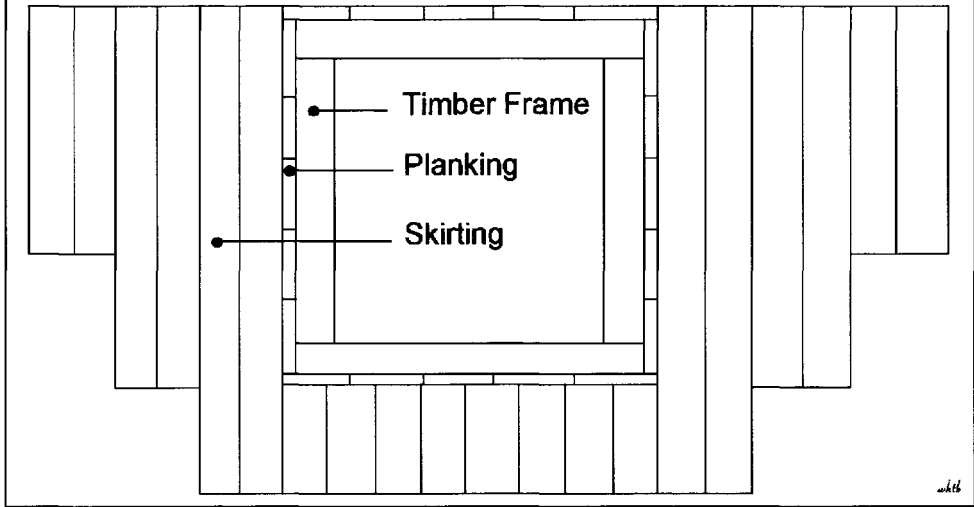


Figure 3.4. A medieval sluice. End view.

fourteenth century onward, windmill-powered pumps became the standard means of maintaining the drained landscape.²⁹

Management of Hydrotechnology

The continued occupation of the lowland zone was not dependent on technological adaptation alone. The will to persevere became just as crucial. From the very beginning, residents understood that drainage was not a one-time achievement but something that had to be persisted with, or the original waterlogged conditions inevitably would return. However, once they started using dikes, dams, and sluices to maintain their artificially drained environments, they passed a point of no return, for subsidence continued. Soon they faced the distinct

²⁹ Keunen (1988), 571–606; Bicker Caarten (1990).

likelihood of loosing everything if they were not prepared to extend and enhance their evolving drainage and flood control system. In short, the locals became trapped in what might be described as a "technological lock-in," compelled to expend ever more time, energy, and wealth simply to maintain the status quo.³⁰ Further, once in place, their hydraulic works needed constant maintenance because ditches and canals silt up or become clogged with vegetation while embankments erode, slip away, crumble under livestock, or simply begin leaking or seeping. In addition, the lowland people learned of the need to co-operate with each other, for one person's drainage water all too easily became the next person's flood water. In short, the perpetuation and co-ordination of drainage and flood control became a major preoccupation of the residents of the lowland zone.

Lowland residents developed organizations to coordinate and enforce collective hydraulic decisions. The earliest of these, most with local responsibilities, predated the emergence of anything resembling a state. Over time, small, local organizations gradually became organized into larger ones. By 1350, a series of regional drainage authorities had developed that managed drainage and flood control in most of the lowland zone; additional combinations and reorganizations produced further institutions during the sixteenth century (figure 3.5).³¹

The Regional Drainage Authority of Rijnland

The evolving complexity of drainage and flood control and the development of institutions to manage them can be illustrated by observing what occurred from the twelfth century onward in the Rijnland district of Holland. The Rijnland is situated midway along the western coast of what is the Netherlands today (figure 3.6). The district was named for a branch of the Rhine which ran through it, the Old Rhine (Oude Rijn). Originally, raised peat bogs occurred both to the south and north of the Old Rhine. Beginning during the late

³⁰ See Elvin, Ninghu (1995), 44–45. The term, "technological lock-in," is used by them to describe situations in which "the commitment . . . to a particular technology has proceeded to the point that (1) its abandonment would lead to immediate losses . . . , and (2) a substantial proportion of the economy's currently available resources are *constantly* required for the *maintenance* of the system. The effect is that a sizeable part of the future is, so to speak, 'mortgaged' indefinitely."

³¹ Fockema Andreae (1934), 21–24.

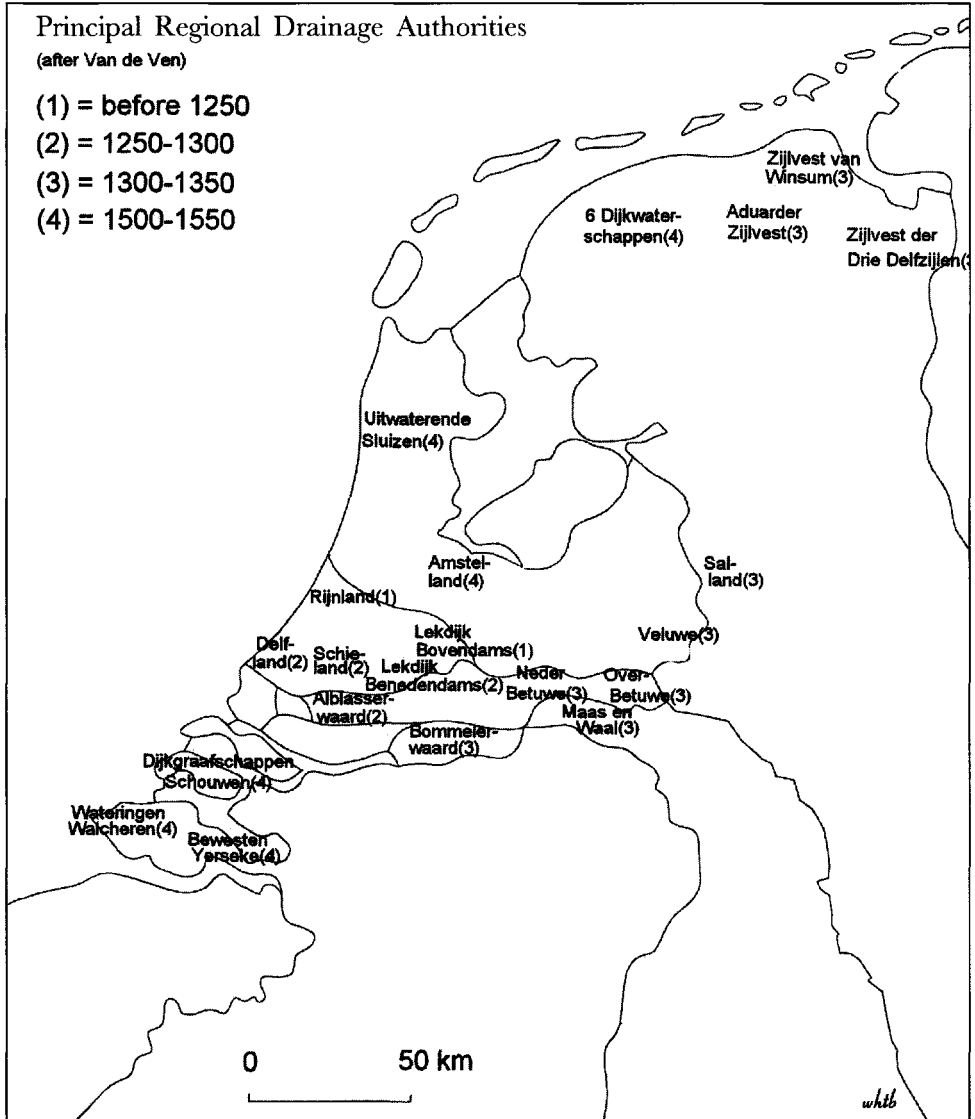


Figure 3.5. Netherlandish regional drainage authorities and their zones of jurisdiction.

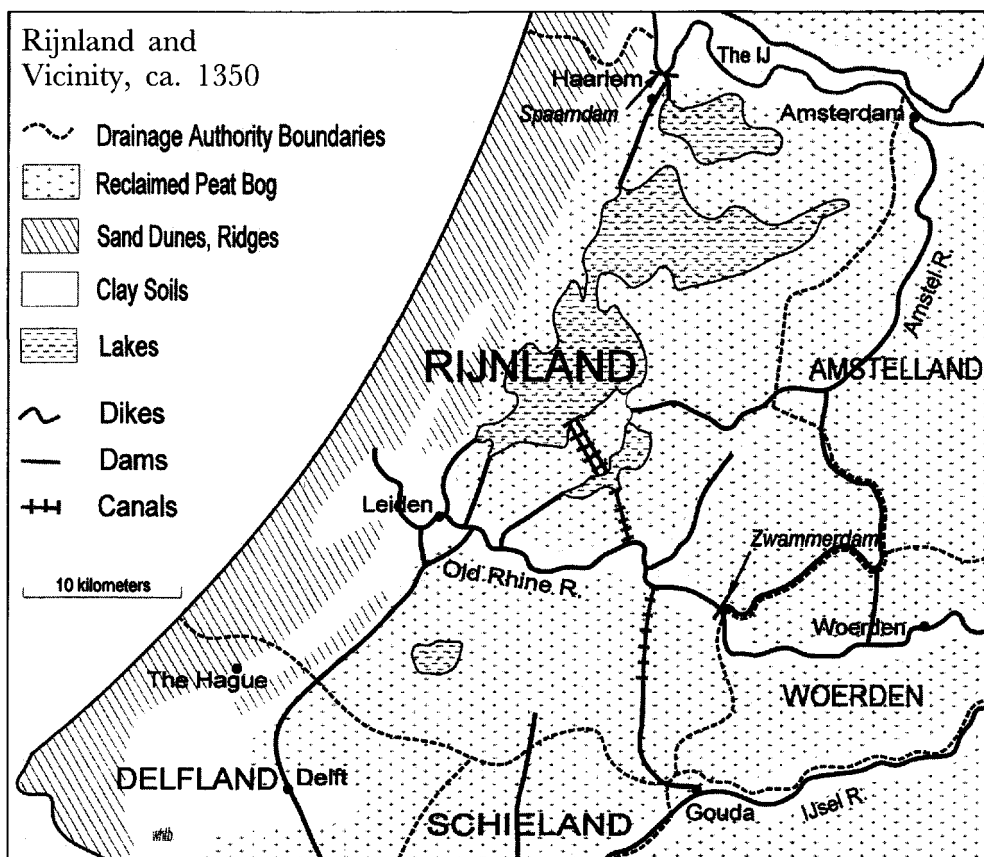


Figure 3.6. The Rijnland in the mid-fourteenth century.

tenth century, residents of the banks of the Old Rhine or the nearby coastal dunes began draining these bogs, with the Old Rhine acting as the ultimate repository of the drained water.

By the mid-twelfth century, large sections of the bogs straddling the Old Rhine had been drained and settled, and, even though subsidence was beginning to be noticeable, there had been an enormous net gain in agricultural land. But here, too, physical conditions changed abruptly, forcing Rijnlanders to adapt. The Old Rhine, because of shallows and sand bars at its mouth, had long been a very sluggish channel of the Rhine delta; it finally silted shut around 1160 and apparently some of the same storms that produced the Zuiderzee were responsible for shifting enough sand along the coast

to completely stop all flow. Now drainage water from the bogs began to produce hydraulic disasters as the former river, no longer able to drain into the sea at low tide, became a long strip of accumulating water. Faced with a serious threat to their continued existence, therefore, 15 communities from along or near the Old Rhine combined their resources and, in an attempt to prevent the arrival of additional water from upstream, jointly constructed a dam in the Old Rhine, the Zwammerdam.³²

Naturally, building the Zwammerdam merely transferred the problem of accumulating water in the Old Rhine channel to the upstream side of the new dam, to the Woerden district ruled by the bishop of Utrecht. The bishop protested and asked the emperor to intervene. In 1165, Emperor Frederick Barbarosa ordered the removal of the dam.³³ Either it never was removed or it soon was rebuilt, as the dispute with Utrecht continued for some time. It finally was resolved in 1202 to the satisfaction of both parties. Rijnland retained the ability to dam the Old Rhine, most likely in the form of a removable gate. Woerden received permission to drain through the Zwammerdam as long as it helped to construct and maintain a series of major drainage canals that would carry water from the Old Rhine trajectory northward to a series of lakes. These lakes, in turn, ultimately drained into the IJ, the newly formed sea arm that ran westward from the Zuiderzee.³⁴ From then onward, Woerden drained through Rijnland and contributed a proportionate share to the maintenance of the common drainage system.³⁵

Though documentation from the late twelfth century is limited, it nevertheless reveals a sophisticated network of co-operation already in place. The drainage pact with Woerden was not imposed from above but grew out of the collective responsibilities associated with ancient common law traditions. Individual communities saw the need to co-operate with neighboring ones in the face of a serious, shared threat to their continued existence. In a document of 1226, the count of Holland recognized an existing web of co-operative agreements and he gave this network his blessing. He specifically mentioned a group of inspectors or trustees (*scrutatores*), who together constituted

³² Van der Linden (nd), 5–9; van der Linden (1984), 292–97.

³³ Van der Linden (nd), 6–7.

³⁴ Van der Linden (1984), 297–99.

³⁵ Fockema Andreae (1934), 50–2.

a drainage trusteeship or authority that became known as the Drainage Authority of Rijnland (Hoogheemraadschap van Rijnland).³⁶

The original Drainage Authority of Rijnland gradually expanded to include new communities as they joined the common drainage system. At the same time, the system itself became more complex. The document of 1226 that recognized the authority of the trustees also authorized the erection of a set of seven sluices to prevent water from flowing backward out of the lakes toward the Old Rhine district. By the mid-thirteenth century, however, continuous drainage had vastly increased the area that had subsided, while the eroding effects of waves as well as peat digging for fuel³⁷ had caused the lakes to the north to expand.

Out of this complex of events, a super, or regional, drainage authority was formed from a combination of the original Drainage Authority and a number of communities surrounding the lakes and along the new sea arm to the north. By 1253, this new, Regional Drainage Authority of Rijnland, represented by seven trustees, oversaw the maintenance not only of the bridge with a removable dam or gate at Zwammerdam and the drainage canals dug in lieu of a dam at Zwammerdam (Heymanswetering, Woudwetering, and Goog), but also of a series of dikes running from Amsterdam to Haarlem (Spaandammerdijk and Schinkeldijk) and a set of sluices in the Spaarndam on the Spaarne River, the new, principal drainage route to the sea. The Authority also had oversight responsibility for the Gouwe, a canal and canalized stream that linked the Old Rhine to the IJssel River at Gouda (figure 3.7).³⁸

The Regional Drainage Authority of Rijnland had achieved its full, public stature by the end of the thirteenth century. Since 1286, its chief administrator, the dike-reeve, was also the bailiff, the highest-ranking administrative officer for the count of Holland in Rijnland district. This brought the full force of the prince's law to the decisions made by the Authority, decisions which until then were founded in common law.³⁹

While the basic activities of the Rijnland Drainage Authority can be deduced from the scattered documentation of the thirteenth and

³⁶ Van der Linden (1984), 306, 309–10; TeBrake (1988), 86.

³⁷ Van Dam (1996), 82–86.

³⁸ Van der Linden (1984), 312–13.

³⁹ Van der Linden (1984), 314.

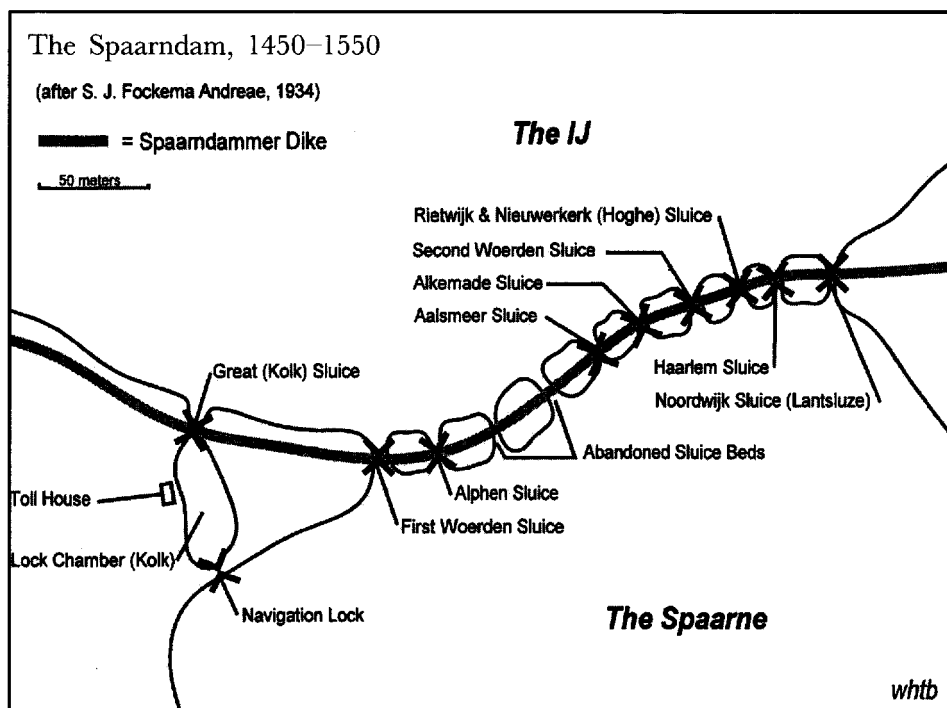


Figure 3.7. The course of the Spaarndam in the late fifteenth century.

fourteenth centuries, they become clearly visible in the registers and protocol or minute books of the Authority surviving from the fifteenth century.⁴⁰ Its primary task was the establishment and maintenance of a system of drainage sufficient to permit residence and agriculture. Based on the regular inspections they made several times each year, the trustees of the Rijnland Drainage Authority decided what

⁴⁰ Hoogheemraadschap van Rijnland (Leiden), Oud Archief [OAR], Inv. 11, Old "Register X no. XII" (1443–49); Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 12, Het Groote Register (1449–1561); Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 13, "Een oude blaffaart van consenten, uyt spraaken, keuren als anders (1437–40); Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 14, "Blafferts": protocollen van keuren, vergunningen, vonnissen en resolutiën (1444–57); Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 15, "Blafferts": protocollen van keuren, vergunningen, vonnissen en resolutiën (1461–83); Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 16, "Blafferts": protocollen van keuren, vergunningen, vonnissen en resolutiën (1483–1515).

work was necessary, when it was to be done, and established standards for its completion.

The Authority did not itself do the work; nor did it finance hydraulic works. Rather, it co-ordinated the work done by the members of its constituent communities. The rural communities that comprised the Authority supplied all the manual labor, animal teams, and materials that were needed in proportion to their size: each *morgen* of land (0.85 hectares, or two acres) was assigned an equal share of the collective construction and maintenance responsibilities by the trustees of the Authority. Work teams from each community would show up with tools and equipment at an appointed time to carry out the assigned work.⁴¹ The constituent communities also had to pay the *morgengeld*, an assessment on each *morgen* of unbuilt land. *Morgengeld* was used to reimburse the trustees for any personal expenses they incurred while doing the business of the Authority and for the maintenance of some small, minor hydraulic works for which the Authority had assumed responsibility. Throughout the Middle Ages, the Authority managed with a small staff—a clerk, a couple of assistants, and a surveyor—and managed to keep costs as well as *morgengeld* assessments low.⁴²

Eventually, in keeping with the growing complexity of the regional drainage system, the Rijnland Drainage Authority began to expand from its original concerns, and to become involved in areas originally left to local communities. For example, the Authority became the repository of a considerable amount of technical knowledge, largely gained from the regular inspections the trustees made of the hydraulic works under their jurisdiction. This knowledge was embodied in the performance standards for dikes, dams, and sluices that appeared in the fifteenth-century register books. As sufficient drainage became more difficult to attain, because of subsidence and oxidation of peat, this knowledge became indispensable, and was shared with others. In addition, the Authority became increasingly involved in overseeing the work of the local trustees, the officials responsible for hydraulic works in individual rural communities, by establishing standard procedures for them to follow. Finally, because the hydraulic measures of one community inevitably affected the well-being of its neighbors, the Authority often was called on to arbitrate; many of

⁴¹ Van der Linden (1984), 306, 309–10; TeBrake (1988), 86.

⁴² Van Amstel-Horák (1994), 95; Fockema Andreae (1934), 54.

its arbitration decisions (*scheidingen*) were recorded in the register books as well.⁴³ For example, a dispute surfaced in 1408 over the maintenance of a drainage canal in the area north of Leiden, named the Delft, and some bridges that spanned it. The residents of the villages of Voorhout and Noordwijkerhout contributed to its upkeep, but those who lived on the other side of it, in Noordveen, did not. The trustees of the Rijnland Drainage Authority ordered the inhabitants of Noordveen to contribute to the maintenance of the Delft, with specifications for its width. At the same time, however, they made clear that the residents of Noordwijkerhout and Voorhout were responsible for maintaining the bridges over the Delft and provided specifications for the width and height of the spans.⁴⁴

Over the years, the Regional Drainage Authority of Rijnland remained loyal to its primary task despite pressures from many quarters to change these priorities. The first challenge grew out of the economic diversification and the rapid pace of urbanization taking place within the County of Holland from the thirteenth century onward. This is illustrated in two examples. First of all, merchants from Holland's cities did not always appreciate that the primary purpose of hydraulic works was drainage. To them, drainage canals were potential highways, except for the numerous dams, sluices, and other obstructions preventing free movement along them. The late thirteenth-century appearance of new sluices that could control the flow of water as well as allow ships to pass helped alleviate tensions between merchants and cultivators somewhat.⁴⁵ Because they were very expensive to build, however, there never were enough of them to satisfy most merchants. Thus, for example, around 1437, dissatisfaction led to a protracted quarrel between the Rijnland Drainage Authority and the city of Amsterdam, stemming in part from the actions of merchants of the city who had breached part of a dike on its southwestern edge to accommodate the transport of wool. The city defended the merchants by claiming that the dike was a city possession. The Authority, however, was able to prove a prior claim and to fine the merchants for their acts.⁴⁶

⁴³ Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 11; Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 12.

⁴⁴ Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 11, fol. 18r; Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 12, fol. 93r-3v.

⁴⁵ Van der Molen (1982), 109; van der Linden (1984), 302.

⁴⁶ Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 12, fol. 58v-61v; TeBrake (1988), 93, note 44.

A second kind of challenge came from people living within the territory protected by the Regional Drainage Authority of Rijnland, specifically those who embraced the profit motive that had begun to spread from city to countryside. By the fourteenth century, the excavation of peat and its sale as a fuel on the growing urban markets had developed the potential to produce substantial incomes.⁴⁷ While many were quite willing to engage in such activities, very few paid much attention to the environmental consequences of their actions. Initially, peat-digging was done in open pits which quickly filled with water because of the high water table, producing pools of standing water where fields or pastures existed before. When done on a small scale, the consequences were minor. On a larger scale, however, serious problems emerged, especially when winds churned up the water in these man-made pools and eroded the surrounding land, endangering all with the likelihood of floods. By the fifteenth century, in fact, new ways of extracting peat were being devised. One was the process of *baggeren*, scooping peat out of the bottoms and from along the sides of existing ditches, widening and deepening them considerably.⁴⁸

While individuals would reap the profits of peat excavation, the entire public was asked to bear the costs of repairing the damage when it became necessary to do so. At the same time, as land was taken out of agricultural production and exploited for the peat fuel it could produce, the taxes on the production of the land were no longer paid; land still used for agricultural purposes was more heavily taxed as a result. During the last years of the fourteenth century, therefore, the Regional Drainage Authority of Rijnland began issuing a series of guidelines and regulations regarding the digging of peat. Maximum amounts that could be extracted from each unit of land, minimum distances from lakes, and other standards were established.⁴⁹ But the Authority was never able to stop the excavation of peat.

Wider Implications of the Dutch Evidence

The study of drainage and flood control in the lowland zone of the Netherlands during the Middle Ages has interesting implications for

⁴⁷ TeBrake (1988), 77–79.

⁴⁸ Hoogheemraadschap van Rijnland (Leiden), OAR, Inv. 12, fol. 19r–19v; Ibelings (1996), 1–10.

⁴⁹ TeBrake (1985), 234–38; TeBrake (1988), 90.

some larger issues. More than forty years ago, Karl Wittfogel made the general observation that water, by its very nature, imposes social and economic demands on those who would control it and that only a unified and coordinated approach could successfully meet these demands. Studying ancient irrigation systems in arid environments, he concluded that only a centralized or unified program of hydraulic engineering could create and maintain the hydraulic infrastructures he was examining and that only a centralized, bureaucratized state could marshal the wealth, labor, and materiel that would be needed.⁵⁰ Noting the absence of centralized, bureaucratized states in Europe until the early modern period, others have since concluded that hydraulic engineering on any significant scale, whether aimed at irrigation or drainage, had to wait until modern times.⁵¹ Clearly, the Dutch evidence proves such a position wrong. Hydraulic engineering was being done on a very significant scale during the Middle Ages.

The purpose of raising this issue is not to deny the importance of modern states' involvement in large-scale hydraulic engineering projects—it would be foolish to do so after viewing the IJsselmeer and Delta Works projects in the Netherlands. Nor is there any evidence for suggesting that the Netherlands saw an exceptionally early development of a modern, centralized state. Rather, the Dutch evidence suggests that a centralized, bureaucratized state is not the only form of social organization capable of producing the results reviewed here. A more appropriate form may be the one identified in connection with irrigation in medieval Valencia: a number of local, collective units joined together, as cells do, to form higher-order units for common purposes, without the direct intervention of any higher political authority.⁵² The joining together of small dike units into larger ones during the twelfth and thirteenth centuries mirrors this process precisely. And elements of this form of organization survived and continued to be important well after the appearance of the modern state in the Netherlands.⁵³

Finally, the cellular organization exhibited in both the irrigation systems of Valencia and the drainage and flood control systems of the Netherlands can be seen as early and successful examples of

⁵⁰ Wittfogel (1957).

⁵¹ Cosgrove (1990), 4–5; Wade (1990), 77.

⁵² First suggested by Glick (1970), 5, 94.

⁵³ IJff (1993), 13, 15–16.

common property regimes. As such, they can take their places alongside the other numerous examples⁵⁴ that call into question another commonly-held opinion—that the collective management of any resource or benefit is doomed by an inner logic to fail, and only private or state control will succeed over the long term.⁵⁵ The regional drainage authorities in the lowland zone of the Netherlands survived as autonomous organizations, neither private nor state-controlled, until they were incorporated into the modern state structure during the nineteenth century.

⁵⁴ Ostrom (1990).

⁵⁵ Hardin (1968), 1243–48.

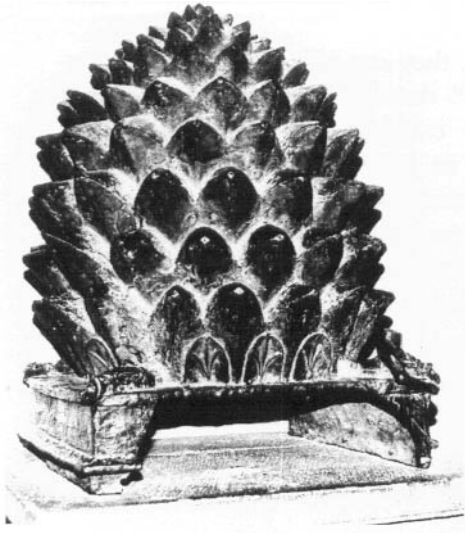


Figure 4.1. Bronze classical fountain head in the shape of a pine cone from the Aachen Muenster.



Figure 4.2. Detail from 4.1. With its scales perforated, it would serve as a water spout in the high Middle Ages.

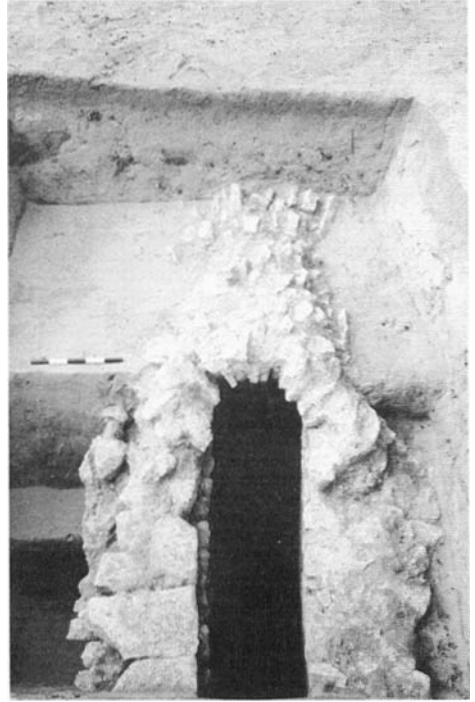


Figure 4.3. Ingelheim, royal palace. The chute from this Carolingian aqueduct is reconstructed according to old building techniques.

CHAPTER FOUR

WATER TECHNOLOGY IN MEDIEVAL GERMANY

Klaus Grewe

Introduction

The same central questions exist for the study of water technology in medieval Germany as for the rest of medieval Europe: was there a transfer of technical knowledge from classical Antiquity through the time of the Germanic migrations into the Middle Ages, and then on to the modern era? or did the collapse of the Roman empire also lead to a cultural collapse, which itself led first to the neglect and then the decay of the tremendous technical achievements of classical antiquity? Only faint traces of the survival of Roman culture can be found between the Sahara and Hadrian's Wall—Byzantium, North Africa, and Spain (which experienced Arab influence), were exceptional. In most former Roman provinces, decay is obvious, and, in many places, complete. Even Rome, once the sole center of a world power, became a cultural backwater in the medieval period.

Since a decay in building can be seen almost in every place where Roman governmental power had subsided, it remains to be seen whether the technical knowledge of classical antiquity survived, at least at the theoretical level, or if the Middle Ages required the development of techniques and skills *ex novo*. At any rate, under Roman occupation, a high level of culture can be seen in an area encompassing what is now Germany, as well as the Germanic tribal settlements to the east of the Rhine, and the area between the *limes* and the edge of the Alps, for a time span of approximately five hundred years. But even cities like Cologne and Xanten or military camps like Mainz and Bonn, each of which had kilometer-long aqueducts and far-reaching infrastructural links, grew desolate during the course of the early Middle Ages. The new urban centers which arose in the same, or nearby, areas were often located above the graves of early Christian martyrs. This, however, did not lead, at least not in the beginning, to such a display of pomp as in Roman times;

that development was left to the late Middle Ages. It is noticeable, however, that the re-establishment of human habitation in many areas began near still-functional Roman wells.

Roots in Classical Antiquity

Even today Roman monuments have the power to impress. Although they have generally lost their original function, such monuments are not rarely technical structures which have survived into modern times in many of the places once ruled by the Romans. Especially well-preserved constructions do not generally survive in the central part of the Empire, but some of the ancient bridges, like the bridge over the Tájo River near Alcántara in Spain, have survived for over two thousand years and still serve their original purpose. Aqueduct bridges like the Pont du Gard near Nîmes in France are tourist attractions of the first order; this statement also holds true for the aqueduct bridges in Tarragona, Segovia, and Mérida in Spain, or similar constructions in North Africa, Turkey, or various Mediterranean countries. Two Roman dams near Mérida in Spain are still being used.¹ Tunnels dug for streets, water mains, drains, and diverted rivers all testify to the high level of Roman engineering.²

In the study of classical building techniques, it is normally the case that the technical know-how that each structure represents can be recognized only by examining the structure itself. Since no construction plans of classical aqueducts have survived, and other written records about building techniques are also rare, reconstructions of classical techniques are often purely speculative.³ The texts of classical commentators such as Frontinus⁴ and Vitruvius are also not always helpful. While Frontinus generally describes the condition, the management, and the administration of the aqueducts in Rome in the first century B.C., Vitruvius' work fills the role of a handbook. Vitruvius' text is one of the most valuable sources for the description of classical building techniques—it was with good reason that his "Ten books about architecture" were still being translated into

¹ For details on Roman water works, see Frontinusgesellschaft (1987, 1988). For details on medieval water works, see Frontinusgesellschaft (1991).

² Grewe (in preparation).

³ Grewe (1985).

⁴ Frontinusgesellschaft (1982).

German in the 16th century and that they were still used as manuals from which architects and master builders obtained basic theoretical knowledge in early modern times.⁵

The medieval city had nothing to compare with the display of pomp in the Roman city, a display that manifested itself in a functioning urban life, based on a developed network of streets, a water supply, including the disposal of waste water, and the luxury of other aspects of the urban infrastructure. The medieval emphasis was on other things: majestic city walls, cathedrals, and many Romanesque churches, often comparable to cathedrals, determined the medieval urban image. Later the town halls, so representative in so many places, would be added to the list.

Despite this, the Middle Ages had numerous opportunities to profit from the high level of classical technique. It would have been possible to take over and maintain the Roman roads or the municipal aqueducts. However, in order to do this, central power, financial means, and technical know-how would have been necessary to a degree that apparently was no longer attainable. The result was that the great construction projects could not be maintained over time. The road system soon decayed, and a large aqueduct, like the Eifel channel to Cologne, apparently did not survive the end of Roman rule, but was a victim of the Frankish inroads on the Empire.⁶ This magnificent aqueduct could not survive as such, but it did become a quarry, a desired source of raw materials; the masonry work was reused in the construction of churches, monasteries, and castles in the Rhineland. The sinter deposits left by the water at the time of the conduit's use, which were up to a foot thick, were coveted in this time when precious stones were scarce. This calcium-based lining, which became "aqueduct marble" in the hands of skilled stone workers, was used for many things, including columns, altars, and tombstones, both in the Rhineland and far beyond its borders. Even in the cathedral of Canterbury we find an altar stone made of material from the sinter deposits of this Rhenish aqueduct, and there are beautiful grave markers of the same material in the burial church of the Danish kings in Roskilde. There is hardly a Romanesque church in the northern Rhineland in which the material was not used.⁷

⁵ Vitruvius was translated by W. Ryff, an edition printed in Basel in 1548.

⁶ Grewe (1986).

⁷ Grewe (1992).

Thus, the aqueduct of Cologne, one of the longest water-bearing channels of classical times, was no longer usable in the Middle Ages. Similar levels of decay in vital parts of the urban infrastructure prevail also in other German provinces of the Roman empire. Nevertheless, there are also examples of the survival of classical structures in Germany.⁸

The conditions for the maintenance of a classical aqueduct were easier to meet when the total length was smaller. In fact, some sources indicate that the Ruwer water pipe in Trier (for example) survived the Roman epoch by at least a few centuries.⁹ The general opinion about this construction is that the complicated technicalities of a classical aqueduct were not known in the Middle Ages, and that therefore this was not a factor in the survival of the Trier aqueduct. The archaeological evidence does not contradict this, although some documents seem to indicate that the Ruwer aqueduct was used at least into the early Middle Ages. Some medieval documents lead to the conclusion that the classical channel was in good repair at least up to the amphitheater. A farm in that area is called "curtis nostra de longo fonte" ("our farm by the long fountain"), which shows a dependence on the Latin term *castellum divisorium* for the basin which allocates water.

The association between the aqueduct and the Himmeroder farm in medieval documents' toponymy does not necessarily refer to a situation that still prevailed in the twelfth century A.D.; the writers of the documents could have drawn on earlier names, applied when connections of this sort were more obvious and therefore could have been exploited in name-giving. It is not impossible that the Ruwer channel could have been at least partially standing, at least until the Norse incursion of A.D. 882. A mention in the *Gesta treverorum* demonstrates that the structure was still known in the twelfth century.¹⁰

Aqueducts, as constructions of the infrastructure, only survived Roman domination in rare cases in Germany. But north of the Alps there are also examples of the survival of classical aqueducts into our days, including the one at Windisch in Switzerland.¹¹

⁸ Grewe (1987), 101–127.

⁹ Neyses (no date).

¹⁰ Zens (1955).

¹¹ Grewe (1988), 53–56.

Water Conduits in Early Baptismal Churches

It can be seen, for example in Poitiers¹² and Aix-en-Provence¹³ in southern France, that classical aqueducts were used in late classical times, or, more precisely, in the early Middle Ages, as water channels for newly-built Christian baptisteries. In post-Roman times, it was no longer possible to supply an entire city by maintaining the aqueducts, but in some places, it was possible to maintain water supplies on the smaller scale required by a baptizing Christian church. New research has demonstrated that connections between Roman waterworks and early medieval churches existed throughout Germany. For example, in Boppard, an early Christian church was built near the castle's thermal springs.¹⁴

A long distance aqueduct, which most likely began in Kottenforst near Witterschlick, supplied the drinking water needs of the garrison at Bonna/Bonn in imperial times, when the Legio I Minerva occupied the site (A.D. 83–295). Its course meets the camp in its northwest corner, and it is here that the classical *castellum divisorium* most likely stood.¹⁵ It is noteworthy that this very spot became a nucleus of the post-Roman settlement Bonn, as well as of the further development of the place from the early Middle Ages on. It was not only the location of the first marketplace of medieval Bonn, but also of an early Christian church. Up until the eleventh century A.D., at which time the second nucleus of the city, located near the martyr-church of St. Cassius and Florentinus (today's "Münsterkirche,") which had steadily become more important since the fourth century A.D., became the center of Bonn, the administrative center, the main marketplace, and also the central religious point, the first parish for the entire area, were located in the Castrum Bonna.¹⁶

According to the archaeological evidence, the Dietkirche (today's "Volkskirche," in the sense of baptismal church) was constructed in later Roman times. And what would be better than to build the church in a location where the water always flowed (in imitation of the River Jordan, as required by early Christian baptismal rites) and

¹² Rérolle (1976), 19–25.

¹³ Guild, Guyon, Rivet (1983), 171–209.

¹⁴ Eiden (1988), 6–9.

¹⁵ Grewe (1988), 50–51.

¹⁶ Böhner (1978), 395–426. Ennen, Höroldt (1976), 27.

was available in sufficient quantity for baptism by immersion, prevalent at that time. The evidence that the baptismal font of the medieval Dietkirche was located at the exact spot where the Roman aqueduct and the Roman *Castellum divisorium* presumably ended, reveals new and important information about the selection of this particular location for the earliest Frankish settlement of the Castrum Bonna.

In the case of Bonn, the classical water supply system was even more important in the Middle Ages, for it was only logical that the earliest medieval marketplace be placed in the southwest corner of the former Roman camp near the Dietkirche, since a marketplace also requires a water supply. The decline of the settlement Bonnburg began in the ninth century when Norman attacks demonstrated that the Roman fortifications no longer offered protection.¹⁷

Hydraulic Structures in Early Medieval Secular Buildings

Because of the adoption of classical construction techniques in the early Middle ages, it is often difficult to decide if the structure in question is originally Roman and still in use, or a restored Roman building, or a wholly new construction. And even a new early medieval building can, at first glance, appear to be classical, since no real change in building techniques occurred in those times. Matters are complicated by the fact that the simpler techniques were most used in post-Roman times.

This all seems to indicate that it is the archaeological evidence, if anything, that will lead to exact dating of the engineering developments of postclassical times. An example of this is the discovery of a lead pipe in Ravenna.¹⁸ Theodoric the Great, who expanded his East Gothic kingdom in north Italy with the consent of the Eastern Roman emperor (A.D. 498), considered himself part of the tradition of his new realm. This fact finds expression in construction.

Both of the pieces of a pressure water conduit made of lead pipes preserved in the Museo Nazionale in Ravenna come from a classical aqueduct, and must have been completed during Theodoric's time. Evidence for this claim comes from the inscriptions on the pipes, "Dn rex Theodoricus civitati reddidit," or "Theodoric gave

¹⁷ Borger (1973), 10.

¹⁸ Bustacchini (1984), 66.

[these pipes] back to the citizens." Such munificent restoration was enough to identify for all time who had been responsible for the waterworks, since the inscription names Theodoric. This discovery also indicates that the technology of building aqueducts had hardly changed in Late Antiquity. In addition, these few letters surviving from the inscription document that not only the name of the patron should be recorded, but also his mastery of the complicated techniques of pressure pipelines. This is also clear evidence that there were engineers at Theodoric's court who possessed classical technical knowledge, and who surely maintained and passed this knowledge on.

Another piece of evidence which testifies not only to a transfer of technology but also to the survival of a classical technical element is the bronze pine cone which stands today in the atrium of the Aachen Münster.¹⁹ This classical fountain head was most likely provided with a new plinth around 1000 in Italy and came thereafter into the Aachen palace. In the high Middle Ages it would serve as a water spout in the atrium of the palace chapel. It should not be forgotten that this fountain must have been supplied by a pressure pipeline.

Another noteworthy Carolingian royal palace, Ingelheim, was mentioned for the first time in 742/43 in a document of King Karlmann. The palace stepped into the light of history in the years 787/88, when King Charles (later the emperor Charlemagne) held a great council there. Before 807 the royal lands were expanded into a palace. Wells, which used the readily available ground water, supplied the palace with water. However, there is also archaeological evidence for a long distance aqueduct made of stone, which carried the water of the Karlsquelle in the southern part of the Heidesheim district to Ingelheim. This eight-kilometer-long channel, which was conceived of as a gravity-feed pipe, nestles against the relief of the land and follows its contour lines to Lower Ingelheim.²⁰

There the pipe connects to the royal palace in the east corner of the southern wing. The entire course of the pipe has not been conclusively reconstructed; however, there is archaeological evidence for a drinking water canal of the same dimensions and type of construction

¹⁹ Clippers (1960/61), 90.

²⁰ Wiemann (1972), 113-121; Weidemann (1974), 43. Schmitz (1974), 79-80; Rauch (1976), 83.

as one that can still be seen in farmlands near Heidesheim: the pipe, which has an internal width of .4 meters and an internal height of 1 meter, is built of massive elements, and its walls are made from limestone plates half a meter thick. The interior channel arched up and the inside was not smoothly finished. Unfortunately, this remnant allows no calculations of the volume of water which the aqueduct was capable of delivering.

The path of the conduit in the palace can be followed from the archaeological evidence. It runs parallel to the outer wall of the semi-circular structure, and its arched line cuts through two of the outer towers. In both cases, the pipe goes through the walls of the towers and enters into their inner portions; there it meets the inner sides of the tower walls, in order to leave the tower on the opposite side, by passing through the outer wall again. An almost identical situation was found in the two eastern towers. The further course of the pipe cannot be determined, although it can be assumed that it ran to the bathing facilities on the north side of the palace. The assumption that this aqueduct was connected to the predecessors of the palace, built by the Romans, has not been confirmed by more recent archaeological excavations: no remnants of such an aqueduct have been found in the Roman buildings. It appears that this long distance aqueduct was linked to the rulers' self-representation.

Evidently, the know-how required for the construction of such an aqueduct, with which water could be drawn from distant sources to a central supply location, was available following the reinforcement of central power in Germany during Carolingian times. It is not easy to tell if this technical knowledge survived from classical times, or if the classical technical literature had been exploited, or if master builders had been brought from Italy. In any event, in the Carolingian period the deployment of engineering skill went so far that an attempt was made, before A.D. 800, to link the Rhine to the Danube by means of a ship canal. The vestiges of this attempt to build a canal can be seen even today near Graben in Bavaria. The surviving section of this canal is called "Charles' Ditch" (*Karlsgaben*), after the man who commissioned it.²¹

²¹ Grewe (1996), 111–115.

Water Supplies in Monasteries

While the cities turned only reluctantly to collective forms of water supply, it appears that this was natural for monasteries in many places, and that the fountain of many monastery's wash house was supplied from outside by a pressure conduit. Normally the network of monastic conduits consisted of lead pipes. It appears that this type of water procurement technology found its medieval niche in the small, insular community of the monastery, which also had access to the relevant technical writings, and the opportunity to exchange ideas with other monasteries.²²

It is noteworthy that contact between monasteries offered a means to preserve and pass on knowledge of the techniques such installations required. If one follows the history of water channels in monasteries and churches from the earliest Middle Ages up to the first public installations, a surprisingly complete picture is revealed, and one must ask how any doubt regarding a transfer of technology from classical times—at least with regards the techniques described here—could have arisen.

In Regensburg, two examples of monastic water supplies, originating in the twelfth century, are known: St. Emmeram and Prüfening. The importance of a supply scheme of such magnitude, one built to supply water to a medieval monastery from distant sources, can be seen from the example of St. Emmeram.

The tombstone of the abbot Peringer II (who died in 1201) in the apse of the Ramwold crypt of St. Emmeram tells of the construction of this water channel.²³ The inscription found on the tombstone shows more clearly than do the remnants of the aqueduct what import its planning and construction had for the daily life of the monastery, and especially for the actions of the abbot. For of all the building projects that were undertaken during Peringer's administration, only the aqueduct is mentioned on his tombstone. In addition to the date of his death, the inscription says that he was the one who "built the lead water conduit." This posthumous honoring of the abbot by his brethren also shows clear respect for this technical achievement and its beneficial effects.

²² Grewe (1991), 11–86; Kosch (1991), 89–146; Kosch (1996), 69–84.

²³ Piendl (1986), 133; Bauer (1970), 535.

Not much more can be said about water distribution in the monastery of St. Emmeram during the twelfth century. There must have been places to draw water at various locations. At least the fountain in the monastery and the kitchen must have been supplied, and there were probably other tap connections on hand. On account of this the so-called "duke's figures" (*Herzogsfiguren*) in the Regensburg Stadtmuseum have been identified as well-head ornaments, and, because they are stylistically connected with the Romanesque, they have also been connected with St. Emmeram. No original plan for supplying water—like the one from Canterbury²⁴—has been found in St. Emmeram, although one must have existed, and the eighteenth-century plans of the pipe network for St. Emmeram which are preserved in the Thurn und Taxisschen Zentralarchiv and the historical museum of Regensburg must have had predecessors. But even the available plans permit us to draw some conclusions about the high medieval monastic water works.

The surviving documents of the late Middle Ages referring to St. Emmeram testify to the maintenance of the aqueducts and the attendant costs; they also yield information about the extension of the pipe network. In the years 1354/55, the repair costs (26 pounds, 2 schillings, 3 pfennigs) exceed normal levels, so that it is possible to speak of a general overhaul of the Dechbettenner aqueduct. In 1580, the abbot Ambrosius Mayrhofer had "the fountain of Dechbetten restored with lead" ("den Prun zu Dechpeten von neuem in Pley herein lassen füern"). In 1663 extensive repairs were made once again "Ad defectus canalium plumbeorum, qui nobis aquam ex Ebetten ubministrant, emendandos expendi vix minus 1000 fl." That is, in that year, maintenance costs for the water main exceeded 1000 gulden. Even if the medieval system of lead pipes of St. Emmeram is no longer used in our times, the water of its spring is still used, and the Roman well house still serves its original purpose. The portion that can be seen today is primarily the result of a complete overhaul, done in 1580 at the orders of the abbot Ambrosius Mayrhofer. A marble plate embedded in the bottom of the reservoir refers to this renovation.

Additional well shafts of this time period have been quite nicely preserved in Regensburg.²⁵ In the twelfth century, a square build-

²⁴ Grewe (1991b), 229–236.

²⁵ *Kunstdenkmäler* (1914), 229–236. Another Roman well house was found in 1994

ing, made of smooth and neatly-arranged blocks of stone, used to hold water, was erected southwest of the Prüfening monastery's church. There is a semicircular door set in the north wall of this building, through which the innermost section can be entered. The Romanesque building materials of this well house remain impressive. The Romanesque lion figure, once mounted on the well that formerly stood in the courtyard of the monastery, is now found on the grounds of the castle of the prince of Thurn und Taxis.

Only recently have the multifaceted efforts of German monks to provide themselves with water not only to drink, but also to use in the various handicraft buildings of the monastery, become the subject of scientific investigation. In Maulbronn, where the picturesque wellhouse in the monastery cloister is the main attraction for many visitors, a widely-extended system of trenches was discovered by means of which the water supply was led to the ponds located above the monastery buildings.²⁶ Nor was it only the waters of the Salzach, whose valley was settled in 1147, which served the needs of the monastery. The abbey also attempted to supplement the water provided by the small river with the collected surface waters of the catchment area. On the heights south of the Maulbronn monastery, in what is today Schmie, trenches can be seen in the forest area, some of which are plainly distinguishable, in which water was collected for the monastery's fish ponds. Substantial tributaries branched off from one part of the canal and collected the surface water from a large area before it could seep away. The numerous ponds above the monastery served to provide the monastery with drinking water and water power, as well as to raise fish, one of the main food sources of medieval monasteries. Instead the ponds located closer to the valley were only used for raising fish.

An impressive testament to the state of hydraulic engineering in Maulbronn is the "Deep Lake" (*der Tiefe See*), specifically its well-preserved dam. All the water that was collected above the monastery was stored and saved behind this impressive structure. The fact that the monastery buildings are located directly beneath the dam suggests that great trust was placed by the monks in engineering achievements. The original drain of the "Deep Lake" is on the left side of

on the site of the old Prüll monastery in Regensburg: see Codreanu-Windauer, Montgelas (1994), 148–150, and (1994b), 86–88.

²⁶ Seidenspinner (1989), 181–191; Müller (1997), 575–593.

the dam: the water flows over a small cascade into the broad, sandstone-lined bed of the canal. The water flows in an open trench for a short time before it enters the monastery's underground canal system near the almshouse. The distribution basin, where the water was channeled into the various fountains of the monastery, must have been in this area. However, nothing of this technical achievement can be seen today: the various fountains spread over the monastery grounds are now served by a modern pipe network which preserves something of the impression the medieval water works must have created. This is also the context in which to consider the Gothic springhouse chapel in the cloister. This chapel, built under the direction of the "Master of Paradise" (so called because he was also the architect of the paradise scene in front of the Maulbronn monastery church) in about 1350, includes a three-tiered basin. The entire ensemble is the picture of worthiness and elegance, and still has the power to attract people, which results in the fountain leaving many people with perhaps their most lasting impression of Maulbronn.

Art-historical analysis has however revealed that very little of the substance of the present fountain is original. The only piece of the original fountain to have survived is the floor plate of the lowest section; even the rim of this section was added in modern times. The middle part of the basin is wholly nineteenth-century work, while the upper bronze basin is definitely medieval, but—just like the medieval well cover—comes from another fountain in Maulbronn.

Returning to the dam: a second drain of the "Deep Sea" was on its right side. Connected to it was a channel made of masonry, which led the water from about the level of the lake surface along the right slope of the valley to the monastery mill. The trench has since been filled in, but its original function can still be deduced from the landscape: it ran outside the monastery walls to the level of the mill, crossing over the monastery moat, going through the monastery's outer wall, and ending in a channel, directed at the large overshot wheel of the mill. Located directly on the wall, we find the thirteenth century mill, and on its east wall, both the channel and the axle bearing of the mill's wheel can be seen. The canal and the water bridge outside of the wall are empty today, and are used as a footpath. The relatively late construction date traditionally given for the mill (1553) must refer to a renovation.

Below the mill wheel, the water flowed into an underground channel, which connected to the main canal that came out of the almshouse.

Water not required for drinking emptied into this main canal, which flowed under various monastery buildings. This canal ran past the abbot's former quarters, the monks' refectory, the kitchen, and the lay refectory, carrying sewage and feces with it. While it was still within the monastery grounds, this canal flowed next to the mill race, in a stream bed that had been channeled to the south wall and lined with planks. The canal split into two in its further course, in order to receive the waste water from the forge and other buildings. Outside of the monastery walls, all of the monastery's waste water flowed into the natural bed of the Salzach. The medieval canal system of Maulbronn, which had been made of rough undressed stone, was expanded in the 19th century. The absolute watertightness achieved thereby prevented ground water from trickling in, which led to the loss of the canal's original drainage function. This led to further problems with the walls, because of dampness.

The technical possibilities of the medieval monasteries were sufficient to ensure the water supply for a small, manageable, monastic community. Apparently specialists who had enough technical knowledge to install pressure-resistant water conduits, in order to furnish water to fountains, were available in the monasteries, which often had direct access to classical literature and their records. If necessary, an exchange of ideas between monasteries would have provided the necessary information to those whose libraries were poorly equipped.

Water Supplies in Castles

Like every other settlement, castles needed an adequate water supply for man and beast, both in terms of quantity and quality. Two facts are especially important for understanding this part of a castle's infrastructure. Because the selection of a location for the construction of a castle normally depended on its suitability for fortification, these structures are normally found on easily-defended mountain spurs or in similarly inaccessible locations. Naturally, water supplies, excluding rain water, were normally not readily available in such places. The situation was further complicated by the fact that a safe water supply was essential, especially for emergencies, such as sieges. A castle's water supply had to be secured by means of building arrangements which met these tremendously important requirements.

The technical possibilities for supplying castles with water were

restricted, but an astounding variety of developments relevant to the history of technology emerges from the study of castles. In castles, an essential distinction existed between external and internal water supplies.

According to the available archaeological evidence, the following techniques are to be distinguished. Drinking water had to be either

- (a) piped into the castle from springs and brooks located outside the castle,
- (b) carried in from outside in containers,
- (c) obtained from well shafts, or
- (d) collected in cisterns.

(a) Supplying a castle with water by means of pipes was a highly complex technical solution, at least by medieval standards. In this manner, an abundance of water could be brought in, of a quality that admittedly depended on the chosen spring, but that could also be controlled to some extent. This manner of supplying water, which sometimes involved the installation of a pressure supply system, doubtless met the needs of the castle for comfort and glory, and would surely have been welcomed in every castle. However, the altitude of many castles, which would have rendered the construction of such a system technically impossible, worked against this solution, as did the need to ensure the safety of the water supply even in times of crisis. It was difficult to protect such a system from enemies.

These, then, are the reasons why such systems were so rarely built. But a classic example of this type of castle supply system can be found in the *Grossen Harzburg* (in Bad Harzburg). Although the castle was equipped with a deep well, an additional aqueduct, which piped water from a spring in the *Kleinen Spüketal*, 1.300 meters away, was built to supply the castle.²⁷

(b) If the brooks and springs which were to be connected with the castle by means of a network of pipes could not be used because of their topographical situation, then no other solution was available except to have porters or pack animals carry the water to the castle. This manner of supplying water was mostly used to obtain water from springs or brooks located in valleys at the foot of the castle's

²⁷ Müller (1899), 174–176; Stolberg (1968), 139–140; Weidmann (1978), 227–228; Busch (1991), 268–271.

outcrop, from which water was drawn with pitchers and then carried to the castle in these, or other containers. Numerous horseshoes found in medieval castles lead to the conclusion that donkeys were normally used to transport the water. The narrow paths that climbed steeply—and are often called “donkey paths” (*Eselweg*) today—were not suitable for other methods of transportation.²⁸

(c) It was definitely safer to obtain the water from the castle grounds themselves, since this guaranteed independence even in wartime. The exposed location of castles, especially those located at high altitudes, made substantial excavations necessary for this means of supplying water. In many places, the depths reached in the rocky ground are quite impressive, while in other places, where the well shaft was made of wood, it is the quality of the carpentry that is most impressive.

The Lübeck castle well, which can be dated to the year 1155/56 by means of dendrochronology, survives intact enough to provide a good look into the technique of medieval well construction, as well as into the art of processing lumber.²⁹

If water was drawn from the well by means of a pulley—normally a rope wound over a reel and a bucket, it was generally poured into other vessels for transport, and had to be carried to its place of use. It was more comfortable to replace this laborious way of obtaining water with a conduit in the walls. An example from England illustrates this technique of supplying water: the massive keep of Dover Castle was built under the direction of Henry II around 1180, and is an outstanding example of Anglo-Norman royal castle building in England.³⁰ Water was stored by cisterns on the third floor. More important, however, is “Harold’s well,” on the same floor, which reaches almost 100 meters into the rock. The mouth of the well could be reached only from a room reserved for the water supply; there was space enough in this room for a pulley, which must have been necessary given the depth from which the water had to be drawn. The water lifted out of the well was poured into a distribution basin from which the two taps in the two lower floors could be supplied.

In order to find a parallel example of comfortable water supply in German castles, one must keep in mind the constraints Henry II’s

²⁸ Satrapa-Schill (1979), vol. 2, 74–83.

²⁹ Fehring (1980), 5.

³⁰ Platt (1988).

builders confronted. Trifel castle is comparable in its water technology.³¹ This castle's location made supplying it with water a difficult proposition, since natural water supplies could not be easily used, given that the castle is located on a red sandstone cliff 310 meters above the village of Annweiler (in the Rhineland Palatinate). Originally it was supplied with water from cisterns. Both the quality and quantity of Trifel's water supply was improved during the Hohenstaufen ascendancy; it was also made safer and above all more representative, a better reflection of the castle's imperial connection. For water was then supplied by a well tower, in the northwest corner of the castle grounds. The square well tower with a ground area of 8,5 meters, is 19,75 meters tall, and encircles a well, whose shaft is 79 meters deep. It is the stonework which permits a datation of this tower to Hohenstaufen times. The tower must have originally had an additional section, where the treadwheel necessary to draw water up from a well that deep was located. But the other supply arrangements made for water use in the castle can no longer be determined.

The deepest castle wells in Germany are in Kyffhausen Castle in Saxony-Anhalt (176 meters), the Königstein fortress in Saxony (152 meters), Augustsburg in Saxony (130 meters), Wülzburg in Central Franconia (130 meters), and Neuenburg in Unstrut (118 meters).³²

(d) Also independent, but not as safe as wells, were water supplies collected in cisterns located on the castle grounds. This method of supplying water was necessary when springs could not be located, even if very deep wells were dug. In such cases, large containers or, better, underground cavities could be constructed, into which rain water, collected from the castle roofs, could be channeled.³³

In such tank cisterns, coated on the inside with mortar, and on the outside with compressed clay, the water could generally be kept fresh and cool. A mechanism to draw water could be placed over an opening left in the ceiling, possibly similar to those placed over wells: by means of winches, windlasses, or, in rare cases, treadwheels—powered by men or animals—the rope and the attached bucket could be lowered into the water and then raised again.

Water preserved in such cisterns could be easily contaminated by dust and dirt. This difficulty was overcome by the use of filters.

³¹ Sprater, Stein (1980), 46–47.

³² Ruckdeschel, (1994), 23–54.

³³ Meyer (1979), vol. 2, 84–90.

Filtered cisterns were massive underground water tanks, which were filled with sand and rocks. A layered free space was left in this filling, which was covered in mortar like a well, and reached to the base of the cistern. The water was poured into the filtration material, and then seeped downwards. The wall of the interior shaft was mortarless in the lower part, and therefore permeable. Water would enter the well, pass through the filtration material, and rise to the level of the water in the filtered area. The filtration shaft worked like a well, and therefore the usual extraction arrangement had to be placed above it as well.

The problem of supplying castles with water in the Middle Ages gave rise to special features, conditioned by topographical, geological, or hydrological differences in the location. Problems were solved pragmatically, according to each location's circumstances. In any case, lack of a natural water supply did not prevent the building of castles in easily-fortified, strategic places.

Urban Water Supplies Without Artificial Pumps

The beginnings of urban water supplies in the high Middle Ages are gradually becoming clearer, due to archaeological studies of city centers. These demonstrate that the collective supply of water, by means of a centrally-maintained network of pipes, was planned for in the founding of new cities during medieval times. In the already existing cities, though, this concept was accepted only gradually. In the high Middle Ages the standard way of supplying water in many cities was private wells.

It is noteworthy that very little information about the construction and use of wells is given in twelfth-century documents. This changed at the end of the thirteenth century, when cities generally switched to using collective wells. With the shift from a purely private construction and use of wells, to a collective water supply (to some extent, at least), came also the need for rules, in order to avoid disputes. This led to the signing of contracts or to the joining of well collectives (*Brunnengemeinschaften*), which were subject to strict rules.

The situation was different in new cities founded during the high Middle Ages. This becomes especially clear in the case of the Hohenstaufen and Zähringer cities in southern Germany, which developed in the twelfth century. Testimony of the technical achievement in

these cities is given, in places like Freiburg im Breisgau, by the small artificial brooks that flow along the city's streets. These were constructed first and foremost for cleanliness in the city, and also for the fighting of fires.

These gutters (*Bächle*, first mentioned, in Freiburg's case, in 1238), which either continuously or periodically gush with water, are quite separate from wells or fountains within the water supply system.³⁴ Freiburg's wells, called the "Sodbrunnen," were maintained alongside the channelled water systems, so that they could be used in times of emergency. In 1317 it is mentioned that a pipe branched off from the existing city channel, for the use of the Augustinian hermits. In 1333 a well-master was appointed in Freiburg, who was supposed to arrange for the maintenance of the existing water system.

Even if very early evidence is available for the water channels of Freiburg, the only thing revealed by the sources is that they were covered with stones—nothing about their location. Since the springs in question were presumably in Möslé or on the Bronnberge, and therefore on the left bank of the Dreisam, the conduits leading water from them must have crossed the river on bridges. In 1501 the master potter Ulrich of Saulgau delivered 7000 clay pipes to the city, each of which was about 75 cm. long, with which an older wooden pipe used by this aqueduct was to be replaced. The attempt was abandoned because the pipes could not be made water-tight. After the entire network was wrecked during the Thirty Years War, it was restored in 1665; there is a blueprint of this project, dated to 1677.

An excellent example of urban water supply systems from northern Germany is Goslar, although the dating of the city's network is not without its difficulties. While its construction is sometimes dated to the 14th century at the earliest, others date the system to around 1200. With this, Goslar would assume a special place in the history of aquatic technologies, to which the title of "richest city in Saxony," as Otto of Friesing called Goslar in 1175, could be added.³⁵ The riches and importance of the city were determined, at least to an extent, by two factors: the amount of ore produced in the Rammelsberg and the emperor's residence there. Given the city's status, the earlier dating is not improbable for Goslar's supply network. Moreover,

³⁴ Rösch (1848); Untermann (1995), 9–26; Untermann (1996), 496–500.

³⁵ Flachsbart (1928); Griep (1959), 15.

today's market fountain was built about 1200, and the small aqueduct to the palace had been built by 1036.

In order to serve its purpose, the two-tiered bronze fountain that stands today in the center of the marketplace must always have been supplied with water by a pressure pipe system, also in its possible earlier location inside the royal palace. The well basin was cast out of bronze around 1200; the eagle that forms the peak of the fountain was made around 1220. The fountain must have arrived at its current location on the marketplace with the fading of the emperor's power in Goslar and the beginnings of the free "imperial" city. It is therefore one of Germany's oldest marketplace fountains.

Goslar originally drew water from the Gose, which was led in various channels through the city. In the next phase of supplying water, water from the Gose was diverted above the city, directed into the "Beeken," open channels made of plaster or masonry, whence it could then flow through the streets. The Gose, however, collected waste water from the Rammelsberg and therefore became, during the heyday of the mining operations, unfit as a source of drinking water. Therefore the river was diverted from a place above the befouled stretch, and the clear water was sent through a canal to the "Beeken." This canal also fed the conduits of the thirteenth century, which were used until the second half of the nineteenth century. The conduits were made of wooden pipes, which were connected with rings known as "Bussen."

The description of urban water works during the late Middle Ages is not always easy. One of the main reasons for this is the fact that the surviving documents seldom do justice to the technical achievements of the time, and yet we must rely on the documents, since only rarely do remnants of the structures themselves survive.

The books kept by the master builders and the masters of the waterworks are important sources for the medieval history of Nürnberg. The oldest book of master builders was begun by Lutz Steinlinger in 1452; the books produced from 1464–1470 under the direction of Endres Tucher³⁶ are especially detailed; prominent among them (regarding the water supply) are the books of the masters of the waterworks begun by Heinrich Scharpf in 1459. The main purpose of these books was to make available to the successors of master

³⁶ Tucher (1464–1470).

builders and masters of the waterworks the knowledge that they would need to fulfill their duties.

Especially vital information preserved in the early books is the number of wells and channels that were available to supply water to the late medieval city. The following numbers of wells were specified in the books of Tucher: on the Sebald side of the city, there were 50, as well as 49 in the St. Laurentius parish. Since four wells are explicitly described as "out of service," 95 wells of various types were available. It must also be observed that numerous wells on private land were omitted from this count, and that the public accessibility of a well was guaranteed by its location on public land (it was not determined by who had arranged for or financed the construction of the well).

The public aqueducts named in the list are also quite interesting; fifteen of these originated on the Sebald side, and two in the St. Laurentius parish. Since one of these structures was out of service, there were sixteen functioning "rörn," as Tucher calls them. A particularity of Nürnberg's water supply system results from the geology of the area. Where springs could not be used, posts were driven into the sandstone to obtain water. Thus, the clay layers in the subsoil were cut into; since these were impermeable, the water then seeped through the sandstone, and collected in the cavities, to be used to supply the city.

The oldest aqueduct was not commissioned by the city council, but was rather a private donation for the hospital of the Holy Spirit. The time of construction of this project cannot be exactly determined, although it can be quite closely approximated from dates in the construction history of the hospital. Since it is not mentioned in the hospital's charter, it seems likely that it was not built at the same time as the hospital, between 1332 and 1339. On the other hand, there is documentary evidence that it was being used in 1368, so it was probably built in the mid 14th century.³⁷ The aqueduct was supplied by two springs near the "infirm ditch" (*Siechgraben*), later known as the *Landgraben*.

It is still uncertain which of Nürnberg's public channels is the oldest, since the relevant documents are not always clear. In addition, not the construction of the structure, but only later repairs are

³⁷ Fischer (1912), 1; Lehnert (1966), 535.

described in the documents, so that it can only be determined by what point in time the channel was definitely operational.

With regards to the supply-pipe of the "beautiful fountain" (*Schöne Brunnen*), the dating is clear. The fountain, built between 1385 and 1396 in the Gothic style, was an impressive eye-catcher in the medieval main market and an expression of the riches and power of this city during its heyday; it is still a characteristic of the city. The documents attest that the supply-pipe for the fountain must have been built in 1388, and that it draws its water from the springs in Gleishammer. This method of supplying water demonstrates some interesting technical elements, which are described by Tucher, but were also rediscovered during later renovations.

The supply-pipe consisted of two wooden tubes placed next to each other, of which the one led "to the upper section" (Tucher), i.e. to the pipes in the tower, and the other to the pipes in the fountain. The waste water from the "Beautiful fountain" was transported away by means of three pipes attached to the fountain. Particularly interesting in this context is a fitting, pictured in a drawing from 1770, but also already described in Tucher. In this case, it is a basin, installed under the plaster and linked to both of the wooden supply-pipes underground. Three exits led from this basin into the waste-pipe of the fountain. (In Tucher only one of the connections to the waste-pipe is described, indicating that the other two must have been added later). The sense of this technical addition is not explained in Tucher; it may have to do with the desire to supply the places that were connected to the fountain, even when the fountain was being repaired. The fountain was possibly shut down in winter; the connected places could then still be supplied by this underground basin.

Tucher's description suggests that the supply-pipes to the fountain were all made of wood, that only in the fountain itself were they made of lead. Later documents (1538 and 1595) indicate that the wooden pipes were exchanged for lead ones. The total number of connections to the "beautiful fountain" is given for the year 1811; of the 25 connections named, five led to public fountains and one into a public building. The fountain could produce approximately 107 liters per minute.

The number of derivations extant in 1811 should be kept in mind when considering the number of aqueducts built for Nürnberg. At that time, there were 8,577 kilometers of wooden pipes and 3,754 kilometers of lead pipes, to be maintained by the city.

Though the early water works in Freiburg, Goslar, and Nuremberg, can be described in more detail, early documentary evidence for municipal water works are also found in Königsberg (1255)³⁸ and Stralsund (before 1250),³⁹ although this refers to getting water from a river. Stralsund received an aqueduct in the year 1418, when a wandering "water artisan" (*Wasserkünstler*) came to the city and offered to construct one from the springs on the Galgenberg, the highest point of Stralsund's territory. The pipe was completed by December 1420, although the joy caused by its completion did not last long.

In Schaffhausen (1315),⁴⁰ Frankfurt (1342)⁴¹ and Überlingen (1375),⁴² work on wells is also mentioned in connection with water channels. In Würzburg the springs, which the city could have used, were too low to install a gravity-feed pipe, and an artificial pump is first attested for 1617, but the Marienberg fortress obtained its water after 1320 via a lead pipe from the neighboring village of Höchberg.⁴³ Two of the three springs that lent themselves to supplying Brunswick with water were dammed in the Middle Ages and their water was brought into the city with pipes. The first to be dammed was the Jödebrunnen, in 1332; from it a 110 meter-long wooden pipe was brought to the Hagenmarkt, where it dispensed water from another wooden structure.⁴⁴ In early modern times, Brunswick obtained a variety of artificial fountains: the time of artificial water pumps began in 1525 with the construction of the "Ägidien-Wasserkunst."

The beginnings of Danzig's water supply lie in the time when the Teutonic Knights controlled the area, when a diversion from the Raduane river was used.⁴⁵ Further documentary evidence for municipal water works can be found for Lüneburg (1397),⁴⁶ Hildesheim⁴⁷ and Grünberg⁴⁸ (both in the fifteenth century), Konstanz (1442),⁴⁹ Bielefeld (1452),⁵⁰ Schleswig (1516),⁵¹ and other cities.

³⁸ Grahn (1898–1902).

³⁹ "Die Geschichte der Wasserversorgung Stralsunds" (1937), 95.

⁴⁰ Ruedi (1944), 98.

⁴¹ Froning (1884), 140; Rautenberg (1965).

⁴² Obser (1917).

⁴³ Lamb (1892), 152; Fischer (1933).

⁴⁴ Appelt, Müller (1964).

⁴⁵ Meyer (1924), note 94.

⁴⁶ *Kunstdenkmäler* (1906), 316.

⁴⁷ Deichert (1908), 167.

⁴⁸ Küther (1972), 294.

⁴⁹ Hecht (1939), 22.

⁵⁰ Engel (1936), 49.

⁵¹ Peter (1935), 849.

Many German cities are not represented in this list, because they drew their water from wells into modern times. This situation did not depend on the size of the city: Cologne, which is conspicuous because of the powerful Romanesque churches and the city wall, is one of the medieval cities without an aqueduct, as is Regensburg, where an aqueduct was built for the St. Emmeram monastery in the twelfth century, but a municipal channel of similar size was not built until about 1550.

Urban Channels with Artificial Water Pumps

There is a reason why we find mostly northern German cities on the list of cities with documented medieval artificially-supplied fountains. The topographical situation of the northern cities in relation to available water supplies was less easy. The flatlands were unlike the mountainous regions, where springs were at the right altitude to be used for a water supply, or rivers could easily be diverted.

The introduction of water supply systems relying on artificial pumps required tremendous financial strength, and often this feat was only possible by founding financially strong companies. In many contracts, it became a matter of record that the main commercial user of the water also had full control over it. Especially the brewers, who needed large quantities of cool water in order to manufacture their product, which was one of the basic foodstuffs of the time, contributed immensely to the development of water technology.

Lübeck takes a place of honor in the list of cities that early on provided themselves with an artificial fountain, since the development of mechanical pumps had been pushed forward in this city. Lübeck was founded in 1143 on a tongue of land formed by the flowing together of the Wakenitz and Trave rivers. This geographical location did not permit a water supply from springs. We can see, therefore, in its early history, that the city was supplied with water from wells and out of the river. While ship traffic used the Trave, and Lübeck's harbor was used for trade in the Baltic Sea, the Wakenitz was used early on for drinking water and the operation of mills.⁵² The first mills, built before 1181 and 1197, were destroyed by a flood in the winter of 1228/1229. Before the mills

⁵² Jaacks (1967), 9; Berndt, Neugebauer (1968), 53.

were restored, the Huxter dam was built, with the permission of Emperor Frederick II and the duke of Saxony. Noteworthy documents from this time include two from 1291, preserved today in the Holstentor Museum, that record the depth to which the Wakenitz could be dammed.

The petition to the governing council made by various citizens, seeking permission to build an artificial fountain, was granted, and, as the documents attest, by 1294 a waterwheel existed, thanks to the council's decision. This artificial fountain, which consisted of a bucket wheel powered by the Wakenitz, was built immediately after the Huxter dam. By means of this mechanism, those parts of the city that were above the level of the river could be served by wooden pipes. Not more than two hundred houses were connected, when the brewers, as the buyers, gave the fountain a name, namely "Brew water fountain" (*Brauwasserkunst*). Originally the pipes, some of which can be seen in the Holstentor Museum, consisted of tree trunks, hollowed out lengthwise and then nailed together again with boards.

Since the *Brauwasserkunst* could only supply water to the houses on the Wakenitz side of the city, the inhabitants of the Trave side of the city were at a disadvantage. In order to fill this gap—once again, especially for the brewers—a second channel was built in 1302. The level of the dammed Wakenitz made supplying the houses on the Trave side of the city without artificial water-lifting devices possible. According to the technical details, this "*Brauwasserkunst* by the Burgtor" was never a "fountain" in the sense of an artificial mechanism, but rather a diversion of the river: after passing through a simple clarifying tank, the water was channeled through an 1840 meter-long conduit to its users.

This conduit, which drew its water from the river in front of the towers of the city fortifications, was also originally made of old fashioned pipes, that is, with wooden gutters nailed together with boards. Every time that the pipes needed to be repaired, they were replaced with tubes that had been hollowed out lengthwise.

The *Brauwasserkunst* at the Huxter gate must have passed into the possession of the town council, since a town council decision in 1419 permitted the bishop, the provost, and other church officials to have additional pipes laid. It is probable that the bucket wheel was replaced in 1463 by a pumping station, since in this year, construction changes on the structure, done at the suggestion of the city master builder Hinrich Helmstede, are mentioned. In 1492 the device

passed into the brewers' possession, who, as before, had a strong interest in maintaining a supply of fresh water.

Because the upper parts of the city, where many of Lübeck's merchants lived, could not be supplied by either of the two networks, in 1531 negotiations were begun with the council for the construction of another artificial fountain. The mill at the Hüstertor was moved, according to a council decision in 1532, in order to create space for the new fountain. The master builder Claus Moller from Hannover, who had already built a similar structure for the abbot of Lüneburg, built a large stone tower, in which four pumps, powered by water, pumped water from the Wakenitz through two rising pipes into a sixteen-meter high basin. Because the exit point of this system was four meters above the highest point in the city, all the houses in the city could once again be supplied via pipes. This "Merchant and citizen fountain at the Hüstertor" ("Kaufleute- und Bürger-Wasserkunst vir dem Huxter-Tor"), completed on 22 February 1533, cost approximately 8406 Lübeck marks, about one million 1967 Deutschmarks. Today remnants of this aqueduct are still being found. They permit the inferences that the trees used in the main conduit were approximately seven meters long, with an inner diameter of ten centimeters, and the trees for the secondary derivations were approximately six meters long. The connections between the individual wooden pipes consist of lead or copper couplings.⁵³

In Ulm the first artificial fountain can be dated to before 1340, because of its location.⁵⁴ This structure in the Gremlinger (or Green) tower, also called the "Upper work" was built in the city walls during the expansions of the city that took place between 1140 and 1340. In 1470 it was removed from there and installed in a building within the city wall, next to the Schwestermühle.

In 1423 the city of Hannover received "in perpetuity" the right to dam the Dieckborn before the village of Linden and channel its water into Hannover from the duke of Brunswick and Lüneburg.⁵⁵ However, the project was not carried out, and Hannover's water supply is not mentioned again until 1532, when a bucket wheel on the Leine river is mentioned. This was not used to channel water into a conduit; rather, the water was transported into the city with

⁵³ Lüdecke (1980), 97.

⁵⁴ Kromer (1962).

⁵⁵ Walter (1957), 193.

a "water wagon." With this wheel, water was raised from the Leine automatically, which was only possible in times of abundant flow. If the water level of the Leine was not enough to drive the bucket wheel, then water had to be laboriously drawn out by hand, using the buckets that hung there on chains.

The high maintenance costs were added to the price paid by the consumers. In times of low flow in the Leine, the price for a barrel of water containing 200 liters at the furthest end of the delivery route increased from eight to nine pfennig, which was roughly equivalent to twelve hours' pay for a worker. The water was drawn at a location called "Wassertucht" which the city rented out. The tenant received the use of three wagons and two teams of horses to transport the water. These became superfluous with the construction of Hannover's first pipe system. In 1535 another waterworks, equipped with six pumps, came into use, which could draw up 8000 water barrels, each of which probably held 200 liters, in 24 hours.

The history of Breslau's water supply has been shaped by two events: first, in 1272, when Duke Heinrich IV (1266–1290) gave the city, in the context of a general concession of water rights, the right to construct an aqueduct, and second, in 1386, at which point an existing artificial fountain is mentioned.⁵⁶ In any event, it must be assumed that the older water rights primarily served to strengthen the defense situation, as well as to extend the fishery and mill businesses. But at some point between 1272 and 1386 the "Big fountain" (*Grosse Kunst*) must have been built near to the Mill Gate, in order to draw water from the Oder and thereby supply a system made of wooden pipes. Later the documents become more precise, and this establishment is mentioned in 1445 as the "water house" (*Wasserhaus*). The demolition of the first structure and the building of a large artificial fountain out of massive stone blocks, much like a small fortress, are reported in 1497. In 1538 construction takes place once again; it is reported that 12,300 oak stakes were rammed into the banks of the Oder, to serve as a foundation. The stones from various demolished buildings was reused as building material, so that Romanesque stone work can still be recognized in some of the blocks. This fountain house began functioning on 2 December 1538, and must have been renovated several times during the course of its history.

⁵⁶ Schneider (1886); Schneider (1896).

In any event, technical data is available for this fountain. We therefore know that the water wheel was approximately 15 meters high and did not drive a pumping station, but extracted the water by means of 160 wooden tubes. It lifted water to a height of nine meters, and the could extract up to 500 liters per minute.⁵⁷ Five conduits led from the fountain to the city. A second fountain, the Matthias fountain, also pertains to the earliest water supply system of Breslau. It was built between 1529 and 1539.

Thanks to well-preserved written records, much is known about the history of the water supply of Bremen in the late Middle Ages. This is especially true for the central water supply system from the Weser. Founded at the end of the fourteenth century, it was an accomplishment of increased technical refinement. Thanks to it the daily routine of drawing water from the well could be replaced at least in some parts of the city, and for the more prosperous inhabitants of those parts. The wells had not become unnecessary by any means, because they still had to meet the needs of the less prosperous inhabitants. But even the households with access to the new water supply did not plug their old wells, whence they could supply themselves in times when water was scarce, and also in case of fire. Both public and private wells were the most important aids to firefighting, because the amount of water supplied by the pipe network could not be increased on short notice.

The oldest Bremen documents indicate that wells were normally used by several households simultaneously, and that at the end of the fifteenth century there were only eleven public wells in the old city.⁵⁸ The wells were managed and administered by well collectives. Even households with their own well or access to the pipe system were required to contribute to these neighborhood collectives.

For 429 years after the end of the fourteenth century the water wheel at the Weser bridge was one of the showpieces of Bremen, along with the cathedral and the Roland statue. This mechanism for obtaining water, which had been known for a long time in other Hanseatic cities like Lübeck and Rostock, was introduced to Bremen during a time of great prosperity. The documents pertaining to it which survive are important for the history of technology, and also present a view of the social and economic history of the city. The

⁵⁷ Scheuermann (1985), 7.

⁵⁸ Vogel (1988), 50-66.

preserved texts lead to the conclusion that the construction of the water wheel should not only provide a comfortable supply of water, but should also be representative of the community and its status.

A later copy of the foundation charter of 1394 for the association formed to build and maintain the water-wheel (*Wasserrad-Gesellschaft*) has been preserved. This document reveals some differences of opinion, which does not, however, lessen its importance in describing the technology and, above all, the organization of the late medieval water supply. The charter stresses the permission granted by the city council to build the wheel in a gap along the Weser bridge that had previously been open to ship traffic. Some of the city councillors numbered among the 50 founding members of the water-wheel association. Of the four parishes in Bremen, only three were supplied with water by the new water wheel; the remaining one could not gain access to the water due to its distance from the wheel.⁵⁹

Various conditions regulated the fair division of water. For instance, water could only be used on one's immediate property, and could not be carried somewhere else. Other provisions mandated that the outlet taps be at a defined height. Above all, the high costs for water delivered to one's home barred the general use of this source of drinking water, and only the more prosperous citizens could afford a connection to the aqueduct. For business customers, though, like brewers or bakers, a connection was essential.

To understand the technique of water-pumping used by the water wheel one must read between the lines in two documents from the first years of the water wheel's operation, because no sketches or drawings survive from this time. The two documents, from 1398 and 1399, contain two maintenance contracts, with a smith ("dat he schall de keden holden") and with a carpenter ("brugghemestere"). In these contracts the association for the water wheel secured ten and four, respectively, years of maintenance for the pumps. It can be seen from the chain mentioned in the first contract ("keden") and the materials prescribed for repair in the second (copper, wood, nails) that, at least at the beginning, the water wheel powered a rotating chain with pitchers on it, and that in this manner the water was lifted into a collecting basin by the Weser itself. The lump-sum payments of 3.4 or 4 Bremer marks mentioned in the contracts are

⁵⁹ Schwarzwälder (1988), 15–49.

equivalent to a sum normally earned over between 30 and 35 working days.

Thus the initial outlay of 48 Bremer marks made by the association to build the wheel had to be increased by four Bremer marks for the maintenance of the carpentry alone. Remaining maintenance costs were borne by the company, in order to maintain the equity according to a resolution made in 1430. This association did not always function smoothly, as can be seen from a decision made by the members in 1487, which expelled all those who were not willing to contribute. Once expelled, members could only be readmitted after paying a high entrance fee. Similar draconian methods were used on the association's customers: attempts to increase the amount of water taken from the supply station by manipulation were punished by demolishing the offender's water tank. The wheel was a success, for its last documented renovation is dated 1790, when approximately 450 taps were connected to the supply system. The water wheel had finished its service by 1822 and was partially demolished; the pipes remained in service for a time, supplied first by a horse-driven windlass, then after 1847 by means of a steam pump. In 1873 the waterworks on the Weser were completed, which made a surface supply with filtered river water possible.

In 1412 the central water supply system in Augsburg was founded.⁶⁰ These water works were also mentioned in the city chronicle.⁶¹ In 1433, after a period of negotiation which began in 1430, Hans Felber, a master carpenter from Ulm, came to Augsburg, in order to solve problems with the municipal water works.

Bautzen obtained a mechanically powered fountain in the later Middle Ages, one which is especially interesting because it has been maintained in its sixteenth-century condition, and is now used as a technical museum.⁶² This artificial fountain house was integrated into the city's fortifications: it consisted of a massive ground floor made of granite and a wooden tower set on top of that.⁶³ In 1515, while some soldering work was being done on one of the pipes, the building caught fire, and the wooden portion was completely destroyed.

⁶⁰ Ehlers (1936), 13; Klöpsch (1959), 133; Ruckdeschel (1975), 61; Ruckdeschel (1981), 87.

⁶¹ Müllich (1866), 57.

⁶² Reymann (1902), 553.

⁶³ Mendel (1957), 298.

This interrupted Bautzen's water supply for three weeks, since it took that long to rebuild the building. But because the rebuilt tower was also made of wood, this work did not survive very long either. The constant dampness of the tower meant that it was soon in need of repair. Because of damage to the walls, which was noticeable as early as 1550, the old structure was demolished in 1558 and a new one was built. Under the direction of the council's master builder Wenzel Röhrscheidt, a stone tower, 84 ells (47.58 meters) tall and with outer walls that were four and a half ells (2.54 meters) thick, was erected. This structure made a comfortable supply of drinking water available to the city. In order to meet the growing need, especially of the manufacturers and the brewers, it was expanded again in 1597: a second water wheel, whose diameter occupied the entire inner room of the tower, was installed there.

Bautzen's water was pumped, by means of a brass pipe, into the open copper basin in the second-highest floor of the tower. From here, 35 meters above the Spree river, the water was channeled into an outflow pipe down to street level. In this manner, even fountains located at the highest points of the city could be supplied with water. The necessary drinking water was originally taken from the Spree, but at the end of the nineteenth century the Spree was only used as a source of power for the water wheel; the necessary drinking water was drawn from springs outside the city into the pumping station, using wooden pipes.⁶⁴ The old mechanical fountain of Bautzen was most recently powered by a turbine installed during the second World War, until it was taken out of service in 1965. The tower of this fountain house is a museum today, an impressive memorial to the early water works of a city. Only the tower remains today of a second fountain, the new mechanically-driven fountain, completed in 1610.

Paderborn is one of those cities which has been devastated by fire over and over again, from medieval times to the present day.⁶⁵ This clearly demonstrates how important it was for a city to have a sufficient quantity of water to fight fires with at all times. After the fire of 1506, the city council sought permission from the cathedral chapter to build a pumping station on the Pader river, and in 1523 an undershot water wheel was in use, by means of which a plunger

⁶⁴ Heinz (1977), 6.

⁶⁵ Gembrig (1941), 11-13.

pump could pump water approximately nineteen meters up from the Pader into a reservoir. And just as the fire of 1506 led to the construction of the artificial fountain on the Börnepader in 1523, it can be seen how a later fire also led to the construction of a water works, namely the modern central water works, built after the fire of 1875.

The New Technical Beginning in the Nineteenth Century

The description of Paderborn's water works from the sixteenth century brings us into the early modern period. The techniques developed for pumping water cannot be described as truly "modern," since they still require the construction of a large water wheel to move the water by means of pumps. In this sense, the water wheels built in other locations after 1500 are "modern" in the chronological sense, but from the technical point of view they should probably be classified as "traditional." In most cases, the older technique of diverting water from a river or spring by means of a water wheel that fed pipes leading out of a water tower was replicated; Brunswick (see p. 150 above) is an example of this.

True innovation can be first seen in the middle of the nineteenth century. In Hamburg, it is true, there were a few private wooden pipe systems as early as the sixteenth century, but supplying the general population thereby was impossible at that time. And here, as in many other places unnamed because they utterly lacked collective water supply systems, conditions held sway that only changed in the nineteenth century with the installation of a modern central water supply. The leadership in this new movement, which propelled all Germany's cities to a hygienic water supply, was assumed by the Free and Hanseatic city of Hamburg. Hamburg's chance came when it hired the English engineer, William Lindley, to build a central water supply after the devastating fire of 1842. In 1848 the municipal water works was founded in Hamburg; this is the birth of the modern central water works in Germany.⁶⁶ Gradually the other large cities of Germany followed suit and came to enjoy a hygienic and sufficient water supply.

⁶⁶ Hamburger Wasserwerke GmbH (1954).



Figure 4.4. Goslar, market fountain. The well basin was cast out in bronze in 1200; the eagle that forms the peak of the fountain was made around 1220.



Figure 4.5. Maulbronn, monastery. The three-tiered basin in the cloister.

CHAPTER FIVE

MEDIEVAL HYDRAULICS IN FRANCE

Paul Benoit and Joséphine Rouillard

Historiography and sources

Until recently, the history of water in medieval France, during the period from about 500 to 1500, had only unevenly interested historians and archaeologists. Except for major forerunners like Viollet-le-Duc,¹ who attached a certain importance to water problems in his dictionary of architecture, it has been law historians² and local scholars who, by way of their monographs, have furnished the most information on the subject. During the 1930s the Annales school opened new fields of inquiry, in particular within economic and social fields. In this context, Bloch showed the importance of hydraulic forces in the development of the medieval countryside, in his seminal 1935 article, "Avènement et conquêtes du moulin à eau."³ In the 1950's, Gille forcefully argued the role of hydraulics in creating a medieval industrial activity that broke with the ancient past. He pointed particularly to the use of hydraulic energy within the international medieval metallurgy industry.⁴ Gille's ideas enjoyed a pronounced international diffusion. Starting from a different point of view, that of a legal and not technical historian, Sicard published in 1958 a major work, *Aux Origines des sociétés. Les moulons de Toulouse au Moyen Age*. Though juridical and economic problems held principal sway, the author always related them to the techniques used. In particular, he focused on the passage from the floating to the fixed mill.⁵ This work received more praise than emulation. However, the

¹ Viollet-Le-Duc (1864), vol. 11, 170–174.

² Wodon (1874).

³ Bloch (1935), 538–563. This article's influence is considerable in France as well as in Anglo-Saxon countries and Italy.

⁴ Gille (1954); Gille (1960), 23–32; Gille (1962), 584; Bauthier (1960), 567–626; Gimpel (1975).

⁵ Sicard (1953a), 30, 37.

mill, relocated within its rural, non-urban environment, attracted most attention for French historians in the 1960's and 1970's. Even if Duby's thesis accorded no importance to the mill—the term is absent from the index⁶—he then argued its role in *Rural Economy and Country Life in the Medieval West*.⁷ He underlined the importance of the mill in the Carolingian world, taking up Bloch's themes, but emphasized the role the mill played in rural development in the eleventh and twelfth centuries.⁸ Many historians of rural life followed this path, often giving differing interpretations. More than any other, Fossier has championed the mill's role in the village. In his thesis, he showed the presence of a grain mill in the great majority of villages in Picardy, and maintained the importance of the miller's role in village life.⁹ On the basis of his own and other scholars' work, he arrived at the conclusion that the major development of hydraulic milling corresponded to the economic development perceptible in the countryside in the eleventh century, and fully visible in the twelfth century, and he affirmed the role that lordship had played in installing the network of mills.

In the past few years, publications, like approaches, have multiplied. In 1983, Guillerme, basing his work on old monographs, discussed the problem of water in the medieval city.¹⁰ As a scholar of cities, he argued using current concepts and interests, including health and pollution. Coming from Germany, Lohrman brought a new dimension to research on mills in the early Middle Ages.¹¹ Likewise, Sarrazin understood the importance of the monastic initiative in domesticating watery areas like coastal marshes.¹² The 1990's mark a period of renewed attention to hydraulics. Benoit is interested in a central innovation of the Middle Ages—the installation of fisheries.¹³ In her 1995 thesis on mills and irrigation in Roussillon,¹⁴ Caucanas wholly revisited older positions that had argued that the use of the

⁶ Duby (1977).

⁷ Duby (1962).

⁸ Duby (1981), vol. 1, 78–79, 201–202; vol. 2, 68–69; Duby (1971).

⁹ Fossier (1968), 828.

¹⁰ Guillerme (1983), 263.

¹¹ Lohrman (1979), 297–316; Lohrmann (1984), 1023–1050; Lohrmann (1989), vol. 1, 384–39; Lohrmann (1984), 149–192; Lohrmann (1990), 43–52.

¹² Sarrazin (1988), vol. 65, 57–79.

¹³ Benoit (1992), 102.

¹⁴ Caucanas (1995), 421.

mill was not developed until after the ninth century in Francia. Moreover, she showed the possibilities of exploitation of an arid Mediterranean country, and demonstrated that the possession of water was the political and financial knot at the origin of numerous conflicts. In 1992, Comet placed the history of the mill within the larger context of the history of grains, from growth through milling.¹⁵ During the same decade, the collective inquiry launched by the University of Paris I—Pantheon—Sorbonne on monastic hydraulics gave birth to several works and numerous articles, while works from this same team also centered on research into mining and metallurgic hydraulics from the Middle Ages to the Renaissance.¹⁶ Its research also examined the place of water in the village. The researchers of Aix-en-Provence made ancient milling techniques, very poorly understood, and the even less understood ones of the Middle Ages, the object of pointed archaeological study.¹⁷

From the 500's to the 1500's, hydraulic techniques experienced a long development that written sources only reveal imperfectly. Throughout the very early Middle Ages, written documentation is rare, and only deeds of donation, purchase, or sale, citation in the monastic rules or the barbarian laws show the existence of equipment, construction, or devices with regards to the use of water. In the hydraulic domain, as in many other areas, the Carolingian epoch brings a far richer pool of documentation. The renaissance of written administration and a firmer management of the monasteries left traces across royal and imperial diplomas, historical texts, and in particular annals and legislation; but the sources of greatest importance remain above all the polyptychs.¹⁸

A regression in written production corresponds to the fall of the Carolingian empire. Texts were very rare in the tenth century, more numerous in the eleventh, and increase greatly in the twelfth and thirteenth. During these centuries, which correspond to the apogee of medieval growth and to the height of feudal society, the nature of the texts change: the first tier is charters, acts of private law which record a donation, a sale, an exchange, or the end of a conflict. The nature of this documentation conditions the information that it

¹⁵ Comet (1992), 711.

¹⁶ Verna (1994).

¹⁷ Amouric (1997), 39–47; Benoit, Bailly-Maître, Dubois (1997), 62–68.

¹⁸ Boretius (1883), 84, art. 18.

provides: location, people present, but very rarely technical data. However, the charters signal the use of hydraulic energy when it serves a purpose other than the production of flour. Thus, the conditions of elaboration and of conservation of the charters orients the information available to the historian. Ecclesiastics, guardians of writing, more than all others, produced charters, and above all else, preserved them well in bundles or recopied in chartularies. Among religious figures, the monks of the order of Cîteaux were the most sensitive to safeguarding their archives, as a means of safeguarding their heritage.

Numbered documents, accounts, and numerical records were exceptional in the thirteenth century, but multiplied in the fourteenth and fifteenth centuries. They give a new vision of hydraulics. Of ecclesiastical, monastic, canonical, or episcopal origin, but also princely or urban, accounts allow us to know how milling installations were managed, and how much it cost to produce and maintain them. Legal reports and court decisions reveal more precisely the division of water rights between users.

The production of images follows a different chronology than that of texts. The early Middle Ages yields few representations of man's use of water. After the twelfth century, the iconography becomes much more rich. Though sculpture has left few representations of mills, manuscript illustrations comprise a fundamental source of documentation. Certain drawings are stereotypical or not very accurate, while others have exceptional value, such as the one in Herrad of Landsberg's manuscript *Hortus deliciarum*, an Alsatian work from the end of the twelfth century. During the final centuries of the Middle Ages, iconographic production continues to grow, but what it brings to our knowledge is disproportional to the number of representations. In many cases, the image of the water mill or pond remains very conventional. However, this contribution should not be ignored as it is emblematic of certain kinds of water use, from usage techniques to how the people to whom these works were destined viewed their use of water.

An archaeology of hydraulic systems and devices has been lacking for a long time. Mills interested archaeologists of the last century much less than did cathedrals. The accumulated delay of years, most pronounced with comparison to England, now tends to be reduced. Planned digs remain infrequent and are concerned with very particular sectors, such as monastic hydraulics, or Alsatian castles. On the other hand, salvage archaeology, undertaken on the

occasion of major public works, has brought decisive data for our knowledge of water mills in the early Middle Ages. Next to the digging operations, fields surveys and their mapping bring a precision to our view of medieval hydraulics that we would not have otherwise enjoyed. The nature of the mills, the importance of ponds, of dikes, of races, now become perceptible.

Ethnological and archaeological data for recent times complete the knowledge achieved from the older archaeology. Traditional irrigation systems functioned in France until the mid-twentieth century, just as hydraulic mills produced significant quantities of flour until the beginning of the century. Traditions remain quite present in rural memory and the vestiges of mills are numerous in certain provinces.¹⁹ Ponds are still sometimes used in ways that differ little from those of the Middle Ages. But ethnographic study should not limit itself to national boundaries, and the contribution of knowledge from countries which have until recently maintained the traditional use of water can be considerable, as in the case of Portuguese ethnographic research.²⁰

The history of hydraulics in France has taken a new profile in the past several years; this is due to a new approach to problems posed by water and its use, to a new consciousness of the part it played in the life of man, but is also due to historians who have realized that in order to respond to the problems documents posed, it was necessary to integrate more varied sources. Collaboration between historians, art historians, archaeologists, hydraulic engineers, and ethnologists is thus essential.

The Geographic, Climatic, and Hydrologic Context

France, a temperate country marked by oceanic influences, experiences average precipitation on the entirety of its territory. However, important differences nuance that description, determined especially by relief or latitude. The mountainous zones receive much more abundant quantities of water than the plains, and the regions exposed to the Ocean are much more moist. It is perfectly normal for the hilly western Pyrénées to receive much more water than the Northern

¹⁹ Orsatelli (1987), 196.

²⁰ Oliviera, Galhano, Pereira (1983), 520.

Alps, the Jura, or the Vosges. Moderate hills, exposed to the Western winds which have kept their Atlantic humidity, can experience notable moisture, for example the high points of the Armorican Massif, the Limousine plateau, or on the edge of the Parisian basin, the Morvan and the Langres plateau. It is necessary to distinguish the Mediterranean zone, where the summers are hot and dry and the main precipitation, often violent, comes in winter, from the oceanic zones, where the rainfall is evenly spread throughout the year, and from the more continental zones, where there is a more marked tendency towards summer rains. Hills and precipitation are, along with the nature of the soil and the vegetal covering, the conditions which determine the flow and patterns of the waterways as well as the supply of the water table.

Flow patterns of the waterways spring from these conditions, as well as from the natural storage capacity of the waters. In regions close to the ocean, the rivers' flows reach their height in the cold season. These waterways were able to produce very significant floods: after modern river engineering, one has a tendency to forget. In Mediterranean areas, where the summer droughts are very marked, the streams can be dry for weeks at a time before violent rains in the hills bring devastating floods. Hydraulic planning in these regions must consider these conditions. It is the same for the seasonal dry periods affecting the ground water, and thus leading to a certain lack in springs which, in turn, leads to a different way of managing water in Mediterranean zones.

Finally, France possesses a large number of waterways, as do all countries dominated by the Ocean, from the littlest creeks to important rivers such as the four large French rivers, the Loire, the Seine, the Garonne, and the Rhône, to which must be added the Rhine and the Moselle, of which only a small part crosses France.

Sufficiently moistened, covered with regular waterways often simple to plan for, France possessed a relatively easy hydraulic potential to be exploited by the people of the Middle Ages.

*Hydraulics from the early Middle Ages to the Year 1000:
The City and the Heritage of Antiquity*

The passage between Antiquity and the early Middle Ages, such as it is defined by historians, at the end of the fifth century, does not

correspond to a rupture in hydraulics in Gaul. Urban aqueducts, which had fallen into disrepair in late imperial times, were often reused as the basis for new installations. Thus, in Le Mans (Sarthe), the bishop Aldric restored the Roman aqueduct, which was out of use, in 832, in order to bring water to the city and free the residents from the need to collect water directly from the Sarthe. Likewise at Béziers and at Pézenas (Hérault), the foundations of the structures of Antiquity supported the medieval aqueducts in order to bring water to the cities.²¹ In Paris, though the early Middle Ages brought the management of the right bank of the Seine with a proper hydraulic system, the Roman aqueduct of the left bank was in service until the ninth century.²² The permanence of ancient techniques was thus visible in urban supply. The defense of cities called for hydraulic systems as well, of which we only have literary and archaeological traces. In the sixth century, Gregory of Tours described the course of the Ouche encircling the village of Dijon (Côte-d'Or) in order to defend it.²³ But it remains true that most of the hydraulic equipment of the early Middle Ages is unknown, and that new departures in this area are best visible in religious constructions.

The Church and Water: Monasteries and Baptisteries

Like the city, monasteries grouped people in a limited space in concentrations that necessitated supplying and removal of water, as, for example, at the abbey of Saint-Denis (Seine-Saint-Denis). About a hundred meters from the basilica was an underground aqueduct punctuated by three water spigots. One spring, the "fons sancti Remigii," supplied the aqueduct 600 meters upstream from the first spigot. The construction, which dates to the end of the Merovingian period, is made of mortared limestone slabs, and perhaps served the baths. The aqueduct had already been abandoned by the end of eighth century. Thereafter, the derivation of a small stream, the Croult, supplied the cloistral ensemble, an arrangement which dates to the Carolingian period since the first mention of it was in 832.

²¹ Cazal (1997).

²² Lavedan (1975), 78–79; Cazal (1997); Favier (1997), 165.

²³ Arndt (1885), 129.

This water conveyance system responded to the hygienic and consumption needs of the monastery,²⁴ and similar ones served in episcopal ensembles.

Water played an important role in Christian liturgy, in particular in baptism. The ceremony that allowed man to enter into the community of the faithful necessitated its own liturgy and building where water was the focal point. From the early Christian baptistery borrowed from Antiquity to the early medieval baptistery, the principles remain the same, even if the architecture evolved. Some baptisteries reused existing bath complexes, like the one at Cimiez (Alpes-Martimes) and were often, like this one, heated. The cathedral complex at Lyon (Rhône) has delivered a beautiful example of a baptistery from the end of the fourth century. Water was evacuated by two lead pipes, then by a stone channel. In the early Middle Ages, the evolution of religious practices towards the sprinkling of the faithful instead of total immersion reduced the size of the fonts, without at all modifying the system of water conveyance. The buildings were little by little abandoned, and as early as the Carolingian epoch, baptismal fonts were placed directly in the church. As is the case in Lyon, they were shrunk twice, then abandoned between the eighth and the ninth centuries.²⁵

The Palace and the Baths

The tale of Einhard, biographer of Charlemagne, in which he reports that the king loved swimming and thermal waters, is famous. It brings a precious bit of evidence: that Charles bathed at Aachen, where he had his palace built, often in the company of numerous people, sometimes up to one hundred of them. But the text does not confirm the presence of baths within the palace.²⁶ The reports from the digs are equally disappointing, only showing a few little sculpted capitals from what was supposed to be the bath. If tradition indicates that Charlemagne had splendid baths in his palace at Aachen, literary and archaeological evidence is far too tenuous to

²⁴ Wyss (1996), 305–306; Wyss (1996), 77–81.

²⁵ Reynaud (1989), 528–531.

²⁶ Einhard in Halphen (1967), 69.

produce solid conclusions.²⁷ Elsewhere, research has not advanced much beyond this, and the palatial hydraulic installations of the early Middle Ages remain unknown.

Hydraulic Energy: A Well-equipped Countryside

It is just as difficult to seize the passage between Antiquity and the Middle Ages in rural areas since our knowledge about irrigation and the mill in ancient Gaul remains incomplete. The mill was in use in Gaul from at least the beginning of the first century of our era.²⁸ In the second century, next to Arles, in Barbegal (Bouches-du-Rhône), an exceptional milling complex found during digs included two series of eight parallel wheels, profiting from a mountainous site with a strong incline.²⁹ Several textual mentions from late Antiquity and the early Middle Ages allow us to note other installations. Ausonius cites the existence of a mill in the second half of the fourth century in the basin of the Moselle, as do Fortunatus and Marius of Avenches.³⁰ Gregory of Tours indicates the creation at Loches (Indre-et-Loire) of an installation on the Indre, by St. Ours, around 500. He describes the construction of the dam, with the aid of stakes and an assembly of large stones, as well as the channeling of the water in the race in order to make the wheel turn very quickly.³¹ He also describes the mills installed in the defensive walls of Dijon (Côte-d'Or), next to the doors of the city, mills whose wheel-rotation was rapid.³²

To these literary texts can be added the barbarian laws, which deliver interesting data on river and mill development. Visigothic law is explicit: destruction of a mill belonging to another involved a fine of 20 coins; if the reparation was not undertaken in a timely manner, the guilty party had to pay a supplementary 20 coins.³³ Alamanic law indicated that the construction of a mill or of a lock should harm no one, under penalty of destruction. Specifically, when

²⁷ Hugot (1965), 534–572.

²⁸ Champagne, Ferdière, Rialland (1997), 157–160.

²⁹ Benoit, F. (1940), 19–21; Leveau (1996), 11–29.

³⁰ Schenkl (1883), 237; Wikander (1985), 149–154; Brun, Borreani (1997), 47–50; Castella (1994).

³¹ Arndt (1885), 284–285.

³² Arndt (1885), 129.

³³ Zcumer (1902), 344.

one of the two banks of a stream did not belong to the builder, he had to reach an agreement with the other owner in order to use the water. The presence of a hydraulic installation was represented as a potential danger, capable of drowning women, children, and livestock in case of a flood.³⁴ Finally, this law sanctioned the theft of mill iron with a fine of 6 coins.³⁵ Frankish laws denounced the same crime, and punished it with a huge fine of 45 coins, the same sum demanded for the theft of a bull.³⁶ The mention of this essential piece of a mill, expensive both because of the iron and the work of the forge, shows that it was already the center of the milling mechanism.

Monastic chronicles also represent mills as present in the countryside. The abbey at Saint-Bertin, established in the swampy valley of the Aa (Pas-de Calais) around 650, rapidly established a mill supplied by an aqueduct, in the *villa* of Arques. Also, upon its foundation, the abbey had received a dozen plots of land between the Oise and the Flemish coast, of which several were furnished with mills.³⁷ In the south of France, the Languedoc was no less well-equipped; texts cite mills among the assets of the countryside.³⁸ From all the evidence, due to recent archaeological discoveries, even if currently archaeology has not uncovered medieval mills in France dating to before the ninth century, it remains certain that barbaric Gaul had hydraulic mills.

The Carolingians' arrival in power, in the middle of the eighth century, leaves the historian more records from which to understand rural hydraulic equipment. Charlemagne's legislation includes the water mill as customary equipment for royal estates. The capitulary "De villis", around 800, cites it as being among the assets that the estate supervisor should give full account for annually to the prince.³⁹ The *Brevium exempla* (ca. 810) contain mentions not only of mills and their profits, but also of fishing appliances such as seines.⁴⁰

But the sources which allow us to discern the density of mills in the Carolingian countryside with unequaled precision are the polypptychs. They indicated the mills' condition, the profits they earned, and the taxes that they were required to pay. The polypptych of

³⁴ Lehman (1888), 144.

³⁵ Lehman (1888), 32.

³⁶ *Pactus legis salicae* 22, 2 in Eckhardt (1962).

³⁷ Lohrman (1989).

³⁸ Vic, Vaissette (1872-1895), vol. 2, col. 330, 862; and col. 377, 874.

³⁹ Boretius (1888), 89.

⁴⁰ Boretius (1888), 252-254.

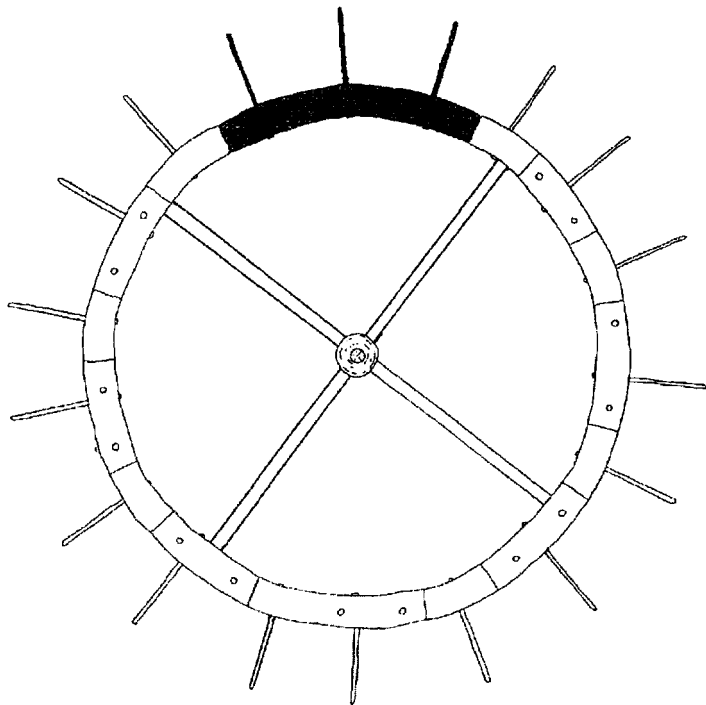
Saint-Germain-des-Prés alone cites 84 mills. The quantity of milling equipment on seignorial reserves and abbey tenures is very high: three quarters of the reserved land had direct access to a mill, as did close to 90% of the properties held on tenure. In that same abbey, but also in others such as Saint-Rémi or Montier-en-Der (Haute-Marne), the polyptychs reveal that the quasi-totality of peasants could mill their grain within a radius of 5 kilometers or less. The mills' technical equipment on large Carolingian domains is thus better known.⁴¹ On the other hand, it is impossible to conduct a similar study of small farms and to quantify the installations that the free peasants could have used.

The vast majority of installations were on small waterways; the mastery of large streams and rivers was not yet complete, as the polyptychs show. Archaeology supplements lacunae in the texts, and allows us to create an image of the Carolingian mill. Thus at Belle-Eglise (Oise), a mill was placed on a branch of Esches creek. From the embankments to the equipment for winnowing to the remains of the mill construction, all the elements found are of wood. Fragments of the paddle wheel have been retrieved from the end of the race. The gentleness of the slope leads us to believe that this vertical wheel was fed from underneath. Dendrochronological dating, here possible due to the numerous elements of wood, indicates usage of the mill between 930 and 980.⁴² At Audin-le-Tiche (Moselle), a dig unearthed a mill upon the former bed of the Alzette, a small, rapidly flowing stream in northeast France. (Figure 5.1) The lightness of the infrastructures located along the stream, the numerous stakes delimiting the race, the fishery, and the platform of the mill's main chamber, as well as the type of wheel used—assembled curved pieces of wood in which the vanes were affixed by tenons and mortises—all lend a degree of uniqueness to the site. An exceptional discovery, a large part of this wheel was found: a complete curve in beech wood facilitates the reconstitution of the entire wheel, with a diameter of 1.4 meters including eighteen vanes. More than a hundred vanes, often broken, were recovered on site. Here again, numerous pieces of wood date the use of the apparatus to between 840 and 960, thus a period of 120 years.⁴³

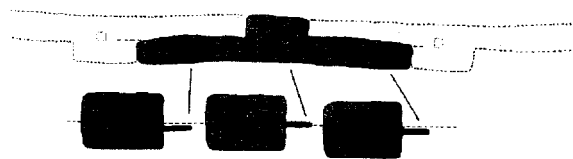
⁴¹ Champion (1996), 93.

⁴² Lorquet (1994), 51–7.

⁴³ Rohmer (1996), 247.



Reconstruction of the water-wheel



Positioning of the vanes on the wheel



Figure 5.1. Audun-le-Tiche (Moselle). Fragments and reconstruction of the mill wheel, after Rohmer (1996).

Urban mills appear much more rarely in the sources. In 856, the king, Charles the Bald, granted mills which relied upon the city bridge across the Seine to the church of Paris and its bishops.⁴⁴ Were they affixed, next to the bridge, or floating, on boats? Both hypotheses are plausible, even though the second is the most probable.

Thus, the early Middle Ages appear to be the time when people, though they had abandoned the numerous techniques that brought water to the city of Antiquity, in return learned how to domesticate small waterways and to give France a significant part of its milling equipment.

*Hydraulics and Growth (eleventh-fourteenth centuries): The New View
From Charters and Archaeology. The example of monasteries*

The centuries that ran from the year 1000 to the middle of the fourteenth century were characterized by exceptional growth, both in the number of people and in production, and by new mastery of water that expanded the possibilities for utilizing lands. Organized around the seigneurial class and the monasteries, the rural world dominated. However, the course of the twelfth century saw the rise of cities and royal power, a power which expressed itself in what we tend to call the feudal monarchy, whose apogee came with King Louis IX.

With the proliferation of writings, the monks' contributions to hydraulic equipment in the countryside become clear: the existence of mills, ponds, and fishing rights is affirmed in the charters guaranteeing the monks' rights. On the other hand, these monastic sources give a deformed vision of hydraulic capital almost exclusively managed by monks or canons.

*The Countryside: Land Drainage, Irrigation, Mills, Ponds, Fisheries,
Water, and Animal Husbandry*

Medieval expansion was first and foremost a phenomenon of cultivated regions.⁴⁵ The image of large clearings of forests should not

⁴⁴ Giry (1943), vol. 1, 491-492.

⁴⁵ Duby (1977), 145ff.

make us forget that the mastery of water played an essential role in the development of new lands. Arable lands gained space either at the expense of swampy zones (the bottoms of valleys or littoral marshes), or, on the other hand, by directing the flow of water over lands hereto infertile due to dryness. The variety of terrains and climates in France contributed to the variety of methods employed for controlling water.

Draining new lands in the bottom of valleys gave people new pastures at a time when the livestock-feeding forests were subject to attacks by clearers. It also allowed the cultivation of flood-prone lands. In northern France, in the swampy sections of the Aisne, the regular canons of Prémontré (Aisne), an abbey founded by St. Norbert in 1120, established ditches which drained the earth and enclosed it.⁴⁶ Henry II Plantagenet, count of Anjou and of Touraine commissioned the *Grand Tucie*, a nearly 45 kilometer-long dike along the right bank of the Loire, destined to protect the Val-d'Anjou from river floods. Protective works continued there for centuries thereafter.⁴⁷ In the south of France, the hydraulic works of Montady (Hérault) in the middle of the thirteenth century, conquered numerous lands in a marshy landscape. It created, via a system of radiating canals, a plain of 600 hectares. Trenches, about 200 km of them, tapped the center of the depression, and conducted water towards more important canals, about 5 kilometers long. The water finally arrived in the principal canal which measured 1400 meters long, 1.3–1.5 meters wide, and 2 meters high. This system of radiating canals allowed not only the cleansing of the bottom of the plain, but also powered the mills located on the canals themselves.⁴⁸ Overly dry, south French lands often hid uncultivated and repulsive swampy zones in their lower parts. In Provence, the plains of the minor waterways of the Rhône and the Durance underwent a vast exploitation operation around Arles (Bouches-du-Rhône) and Avignon (Vaucluse). To the east of Arles, the inhabitants of the city dried the marshes of Montmajour, while other city dwellers allied themselves with the monastery of Saint-Victor in Marseille (Bouches-du-Rhône) in order to overcome the lands on the edge of the Camargue. Near Avignon, starting in the first half of the eleventh century, the marshes of the Sorgue

⁴⁶ Brunel (1994), 123–150.

⁴⁷ Dion (1961), 109–121, 210–13.

⁴⁸ Cazal (1997).

(Vaucluse) were dried; a little later, it was those of Entraigues (Vaucluse), then Tavel (Gard) on the right bank of the Rhône.⁴⁹

Next to these work-sites in the interior of the country, in the north as in the south of France, other sites, undoubtedly even more important, opened up on the coasts of the Atlantic and on the North Sea, at the mouths of the waterways where fresh water met the salt water of the sea. In these regions, the conquest of lands in the marsh was, in the eleventh century, already old news, but it took on new significance and specific forms. Certainly, the extraction of small parcels of land from the watery areas was able to continue as in previous centuries, but neither texts nor archaeology have preserved any traces of this small-scale drainage. Even more than the conquest of a forest, the subordination of vast spaces threatened by water required organization and significant material means. Thus, many of the actual remains of which we are aware were seigneurial (religious or secular), or communal (in particular urban) initiatives.

The Atlantic coast was the site of important drainage projects in the swamps. Here, work undertaken by the Cistercian monasteries conforms to the image, often forced, seen elsewhere. In 1135, on the estuary of the Loire, the Cistercians of Buzet (Loire-Atlantique) set themselves to work on swampy terrain chosen by St. Bernard himself. Hydraulic equipment was already present on the estuary, but the monks took the existing techniques to a superior level. First, in order to assure themselves control of the system, removed from the secular world, they systematically acquired all the locks regulating the amount of water in the marshes. Control of the waters allowed them to benefit from substantial pastures; for this reason, their worldly vocation was essentially pastoral. During a second time period, from the end of the twelfth century to the middle of the thirteenth, the monks operated land reclamation projects in order to raise the lands, via a network of dikes and ditches that led to a central canal. These major works, which required considerable sums of money and labor power, allowed them to create, within a half century, a cleansed land area sheltered from the water, and not simply pastures submerged in the winter.⁵⁰

Further south, on the coast of Poitou, a vast swamp zone extended far into the interior lands, an amalgamation of marshes supplied with

⁴⁹ Poly (1976), 216.

⁵⁰ Sarrazin (1988).

water by the sea, and by small rivers, of which the Sèvre was the largest. Calm streams with little flow, the flatness of the land, and the strong tides rendered the removal of water difficult. Before Cistercian intervention, drainage in this marsh was marginal, aided by several levies and locks, but lacking an overall plan. A century of human work made possible the first exploitation of the marsh. The Cistercians played a vital role: after 1180–1190, the six abbeys of La Grâce-Dieu, Saint-Léonard-des-Chaumes, La Grâce-Notre-Dame-de-Charron, Trizay, Moreilles, and Bois-Grolland (Loire Atlantique), joined together with an eye to draining the basin of the Sèvre in order to improve the lands in their domains. As in the estuary of the Loire, the monks brought organization and the means, neither of which the peasants possessed, and which the secular lords had not wanted to deploy.⁵¹

Land improvement was also accomplished by irrigation, which seems to have been present everywhere it was possible, in particular to water the grasslands at the bottom of valleys. Southern French lands, due to their hot, dry climate, developed the greatest irrigation systems. In the Roussillon, then subject to Catalonia, as on the other side of the Pyrénées, networks of irrigation brought water from the mountains onto the plains. In the Gévaudan, foothills at the base of the Cévennes, the summits were largely well watered, but situated on a particularly dry Mediterranean zone: yet mount Aigoual (Lozère) received the highest levels of precipitation in France. Thus, canals, or *béals*, collected water from the torrents gushing down the mountain and brought the necessary water for irrigation and for the animals to drink.⁵² In order to reach the furthest zones, despite the insufficiency of the flow, intermediary reservoirs stocked water, which was then redistributed at the right moment. Thus a system was activated in the countryside that strongly marked it, a system which has endured until the present time, and is very similar to the system in the Iberian world, heir to long Roman and especially Arab traditions.⁵³

Nonexistent according to the written sources from the early Middle Ages, ponds appeared in the country at the moment of the “feudal revolution”. In the whole French countryside, valley bottoms and swamps were used and adapted in order to create ponds, often preserved until present times. The people of the Middle Ages ate large

⁵¹ Sarrazin (1996).

⁵² Helas (1994), 171–196.

⁵³ Caucanas (1995).

quantities of fish. At a time when lengthy transportation was difficult, freshwater fish levels had to be high, and had to be fished quite close to the places of consumption. The monks in particular consumed and sold a lot of fish. It was as necessary to establish ponds to produce fish as it was to build mills to create flour. A study of the ponds of the Dombes (Ain) is revealing on this point. The Dombes, an infertile plateau north of Lyon where the swamps had taken over, presented an extreme case of a poor landscape in need of radical transformation before being able to offer people an inhabitable space. The creation of the ponds led to the development of these lands. The first documents which allude to it are late, from 1230. The creation of ponds continued throughout the central and late Middle Ages.⁵⁴

Aside from this particular case, starting from the twelfth century, France experienced an increase of ponds which, it seems, break with the traditional water storage systems that the Romans used. Here again, the example of the Cistercian monks enlightens a part of the history and archaeology of medieval ponds. Current research on the Cistercians shows that outside of developments linked to the security needs of their abbeys, the white monks expanded their pond-filling and -acquisition activities. The case of Cîteaux (Côte-d'Or) in Burgundy is remarkable on this point. The patrimony of the abbey included twenty-three ponds, created between the twelfth and the fourteenth centuries. Many of these ponds are on waterfalls, supplied by small streams. The accounts of Cîteaux from the end of the fourteenth century show each pond's uniqueness: a specialization for each pool of water—for fish spawning, for raising, and finally, for fishing. The monks not only consumed the fish, but also sold it in large quantities.⁵⁵ (Figure 5.2)

Earthen dikes enclose the quasi-totality of medieval French ponds fed by small creeks or springs. It seems that ponds were never dug out, the height of the dike being sufficient to create retention. Only archaeology shows us the exact construction details. According to current research, the builders were often content with amassing earth from the immediate environs, using stones or wood for the water passages. It is difficult to get an exact idea of what the dams and the medieval ponds were like since certain ones are still used and

⁵⁴ Benoit (1992).

⁵⁵ Berthier (at press).

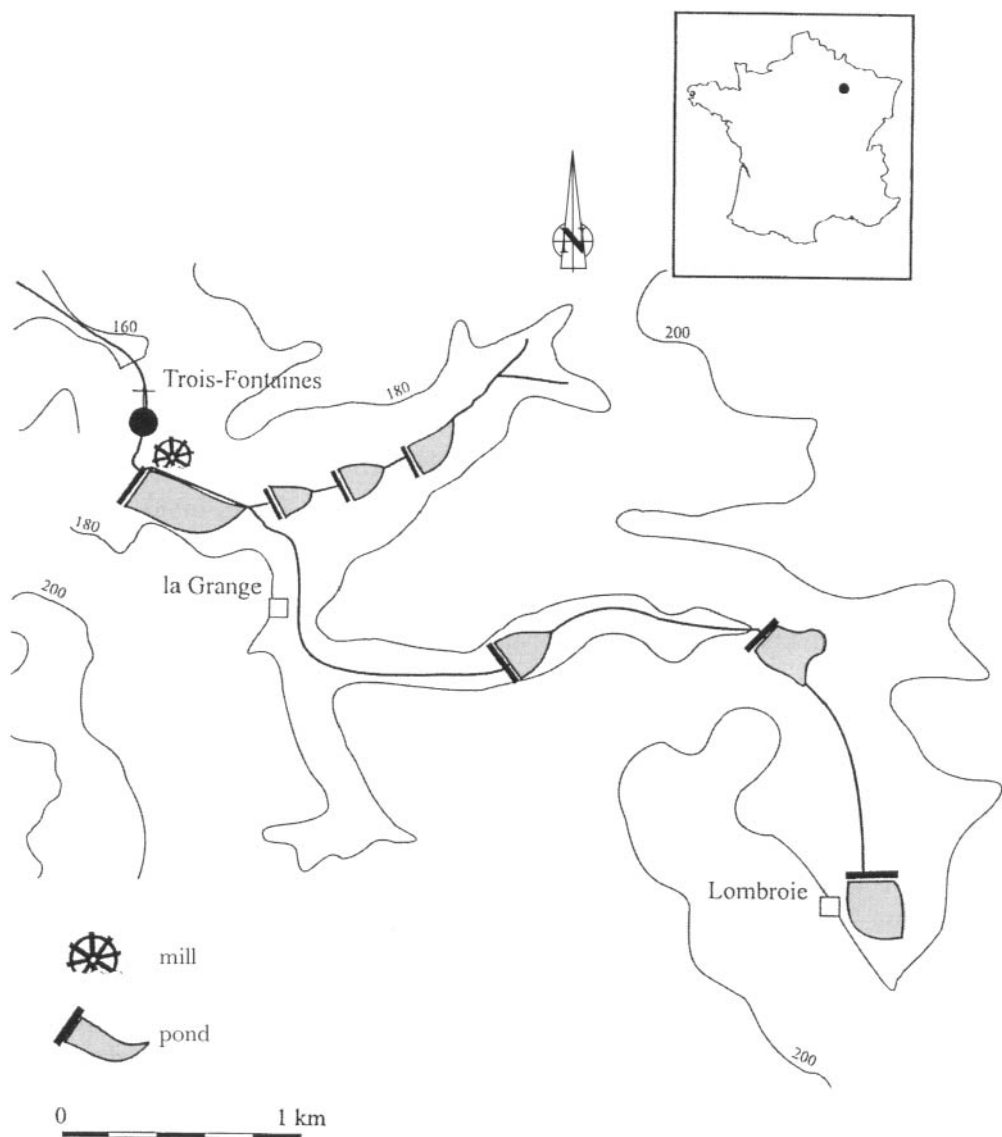


Figure 5.2. Cistercian abbey at Trois-Fontaines (Marne), hydraulic equipment on site.

others were not abandoned until recently, after centuries of maintenance. It does not appear that major developments occurred in the conception and realization of ponds between the Middle Ages and the early twentieth century.

According to sources from the fourteenth and fifteenth centuries, the pond depended on shifts between periods of filling and briefer ones of draining. Pond-draining provided particularly abundant fish crops. Rural ponds were sources of fishing and agricultural revenue, as well as creators of waterfalls which fed mills.

Current studies on water mills show that by the eleventh century, the West was already largely filled with mills. The Domesday Book confirms what Carolingian polyptychs indicate: at the end of the eleventh century, it counted 5642 mills in all of England, but the gaps in the royal survey lead British historians to estimate the number of installations at as high as 6000.⁵⁶ That said, written sources also show the appearance of new mills in the eleventh, twelfth, and thirteenth centuries (figure 5.3). In a time of demographic and economic growth, the mill became the essential element to the medieval village. Unlike grain, flour could not be stored, and it therefore had to be regularly milled. In a society where bread was the basic food, the mill's proximity was indeed paramount. In medieval France, water powered the vast majority of mills. Thus, in the Bordelais, 95% of the mills were hydraulic,⁵⁷ and by the beginning of the fourteenth century, France had equipped itself fully. Later installations were generally merely reworkings of former sites. In certain cases, over-equipment led to conflict about water rights between feudal lords. With the decomposition of royal power and the rise in power of lords affirming their ban, the water mill became one of the central elements of rural lordship. Lords sometimes held bannal mills, and the inhabitants of the feudal lands were obliged to mill their grain in the lord's mill. However, this situation, which has dominated historical reconstructions for a long time, now appears as the exception, not the rule, since the lords most of the time allowed the villagers to mill wherever they wanted.

As early as the Carolingian epoch, people learned to master relatively large waterways, such as the Garonne in Toulouse. People

⁵⁶ Miller (1995), 7.

⁵⁷ Mouthon (1993), 249.



Figure 5.3. Saint Loup's Mill, belonging to the Cistercian abbey of Maizières (Saône-et-Loire). The first mill, installed in the twelfth century, was replaced by a modern building that was in use until the twentieth century. Photo by the authors.

were capable of building rock dams on the streams and also creating new means to master waterfalls or the force of the current. (Figure 5.4) The majority of mills were installed on races diverted from streams that powered a vertical wheel from underneath, as represented by the miniature in the *Hortus deliciarum* by Herrad of Landsberg. (Figure 5.5) But other solutions were also employed, like mills with a vertical wheel installed on the waters' level on a dam, or on the outlets of ponds. Certain southern regions also used the horizontal wheel.

Abbeys and castles

The eleventh and twelfth centuries were, more than any others, monastic. France, and particularly Burgundy, saw the birth of religious orders which played an important role in the history of western Christianity: Cluny, founded in 909, and Cîteaux, founded in



Figure 5.4. Dam directing the Ognon towards the Cistercian abbey of Acey (Jura).
Photo by the authors.

1098. Their archives as well as their exceptionally well-preserved monastic sites bear witness to the hydraulic systems created by the monks. Monastic communities brought together large numbers of men or women living in close proximity. Water was necessary for the liturgy, but also for daily hygiene. In the face of these needs, monasteries benefited from enough money to allow them to find technical solutions to their problems. Thus, nearly all monasteries were situated near significant water springs able to satisfy the monks' needs.⁵⁸ In the twelfth century, Cluny had baths, bathrooms, points of water distribution in the cloisters, the kitchen, and without a doubt elsewhere, and latrines located over sewers supplied with water. A sewage system allowed for the removal of used waters.

This usage of water demanded careful site choice and planning. Already the monks at Cluny had diverted the Grosne, the stream

⁵⁸ Hoffman (1996); Benoit, Rouillard (1996), 157–186.

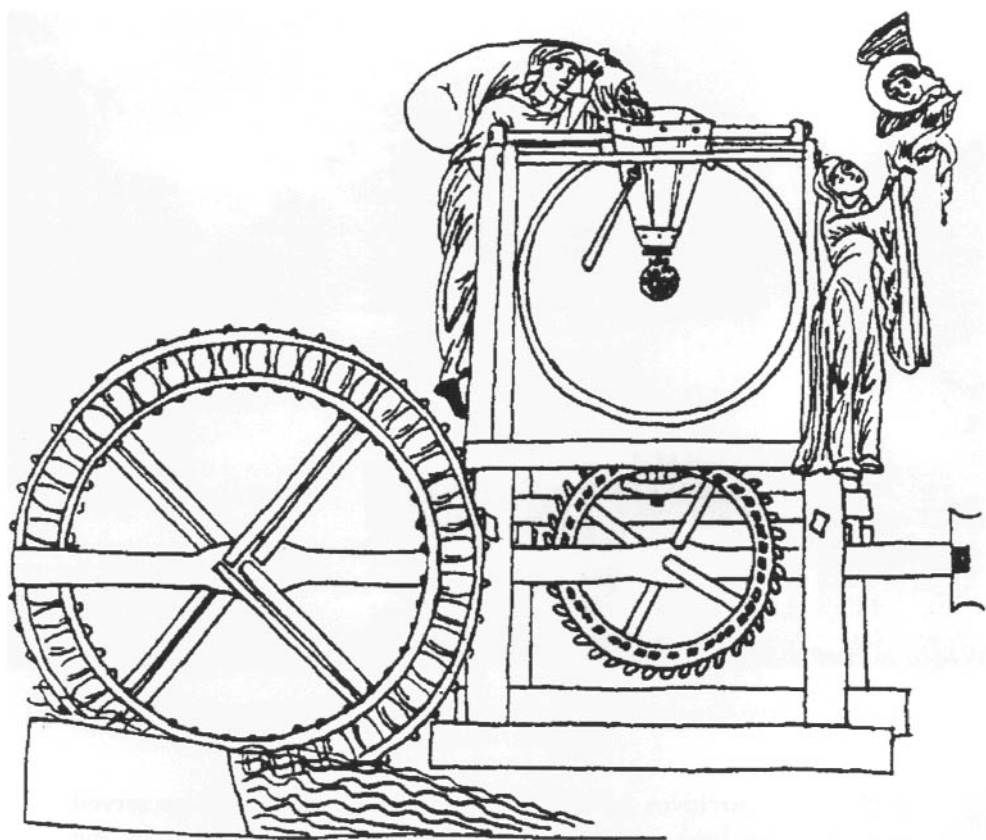


Figure 5.5. Mill, from the manuscript of *Hortus deliciarum* by Herrad de Landsberg, (late twelfth century).

next to which they had established their monastery, and had constructed vast dams in order to protect the site. However, the Cistercians left the best-studied vestiges. In Burgundy and in Champagne, all monasteries benefited from a sufficient water supply. The monks often situated themselves on terraces overhanging by several meters the bed of a stream upon which they established an upstream dam. After the dam, a race directed the water towards the monastery from which the sewers were supplied, and which furnished hydraulic energy. This was the case at Clairvaux (Aube) or at Pontigny (Yonne). Other abbeys chose the bottoms of valleys, and set their buildings away from the water with the aid of dams, as at Fontenay (Côte-d'Or), where two imposing dams isolated the site, and diverted the stream

towards the south, thus freeing up a central, safe space. Fontenay is the first Cistercian site in Burgundy whose system for supplying drinking water and for removing used water has been the object of study. Passages in the two dams blocking the small valley directed the water towards channels which crossed the abbey. These channels passed underneath the monks' rooms and the lay brothers' building. (figure 5.6) The latrines were located, probably, on this sewer. Secondary canals brought used water from the monastic buildings, especially from the washing rooms, as well as rainwater and infiltrated ground water, to the central channel. These canals functioned both as sewers and drains. South of the abbey, the canal that fed the wheel of the forge also served as a collector: conduits that even today guarantee the drainage of the monastery courtyard rejoined it while passing under the forge. These magnificent remains are not exceptional; one finds comparable ones in the Cistercian abbeys of Trois-Fontaines (Marne), Cîteaux (Côte-d'Or), or Morimond (Haute-Marne).⁵⁹ (See figure 5.7, figure 5.8, figure 5.9)

Methods of supplying water to castles differ as a function of the type of castle, on elevated ground or on a plain. Water had a defensive function and was necessary to daily life. Elevated castles, often removed from the water by their location, sought self-sufficiency, indispensable during military sieges. Two types of water supply to elevated castles are found: running water supplies, and the formation of water reserves in cisterns and wells. Bringing water from a spring directly into the castle was rarely possible. In the castle of Chastel-Marlhac (Cantal), the natural mound on which the fortification was built in the early Middle Ages was spacious enough for there to be flowing a stream that contained a pond.⁶⁰ Most often, the inhabitants of the castle had to carry water from the spring, as in the Alsatian castle of La-Petite-Pierre (Bas-Rhin).⁶¹ In the middle of the eleventh century, the inhabitants of the castle of Geoffroy Martel, count of Anjou, a castle situated on a hill above the valley of the Loire, drew drinking water from a spring situated in the valley, in the middle of pastures.⁶²

⁵⁹ Berthier, Rouillard (1996).

⁶⁰ Fournier (1978) 262.

⁶¹ Metz (1992), 139–152.

⁶² Fournier (1978), 295.



Figure 5.6. Large underground collector of the Cistercian abbey of Fontenay (Côte-d'Or). Photo by the authors.

Wells are common in the plains, but rare in mountain castles. The technical difficulty in attaining the necessary ground water table meant heavy investments, often over-burdensome. Well digging resembles that of mines; for this reason, miners were often employed in this task. Such was the case at Hohkoenigsbourg (Bas-Rhin), whose 62.5 meter-deep well was dug by miners from Sainte-Marie-aux-Mines (Haut-Rhin) in the sixteenth century.⁶³ The extreme depth required the use of powerful winches in order to remove the scuttle—here, again, we see the similarity between water wells and mine shafts. Likewise, in Lorraine, the few known wells are quite shallow, with the exception of that of the castle of Moyon (Meurthe-et-Moselle), dug 50 meters deep in sedimentary limestone.⁶⁴

For mountainous and hilly castles, collecting rainwater constituted the best way to create water reserves. A cistern was placed in the

⁶³ Metz (1992).

⁶⁴ Guiliato (1992), 166–173.

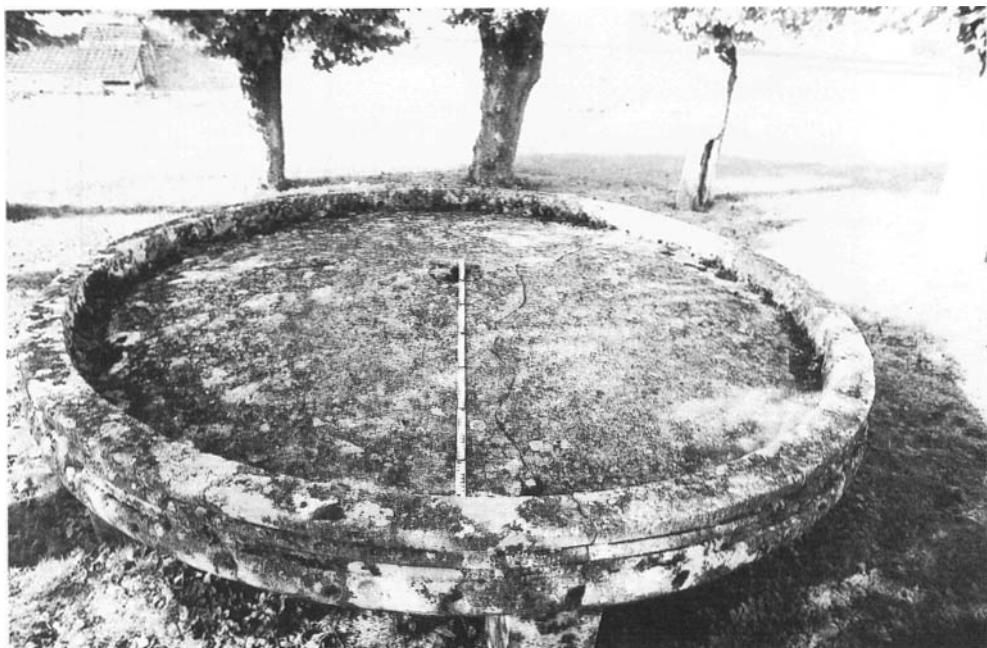


Figure 5.7. Lavatory basin of the Cistercian abbey at Pontigny (Yonne). Photo by the authors.

center of the courtyard, whether it was a cistern reservoir simply collecting waters, or a more elaborate filtering cistern. The water collected in these reservoirs had to be clean. The type of roofing that was employed around the cistern determined water purity. Water should flow only along tile or slate. The proximity of thatched covering or wooden shingles required a filtering cistern, as was the case in almost all the castles of the Vosges. In Alsace, where castle chronology is established, the filtering cistern appeared in the middle of the twelfth century, before reservoir cisterns in the beginning of the thirteenth century, and also before wells, at the end of the Middle Ages.⁶⁵ The principle of the filtering cistern can be understood via the example of the castle of Rougemont (Territoire de Belfort), in medieval Alsace. (Figure 5.10) At 736 meters high, the castle sat on a hill made of a very hard primary geological layer. The absence of water flowing nearby and the presence of a soil which was difficult to pierce, as

⁶⁵ Metz (1992); Kill (1985), 125–143.

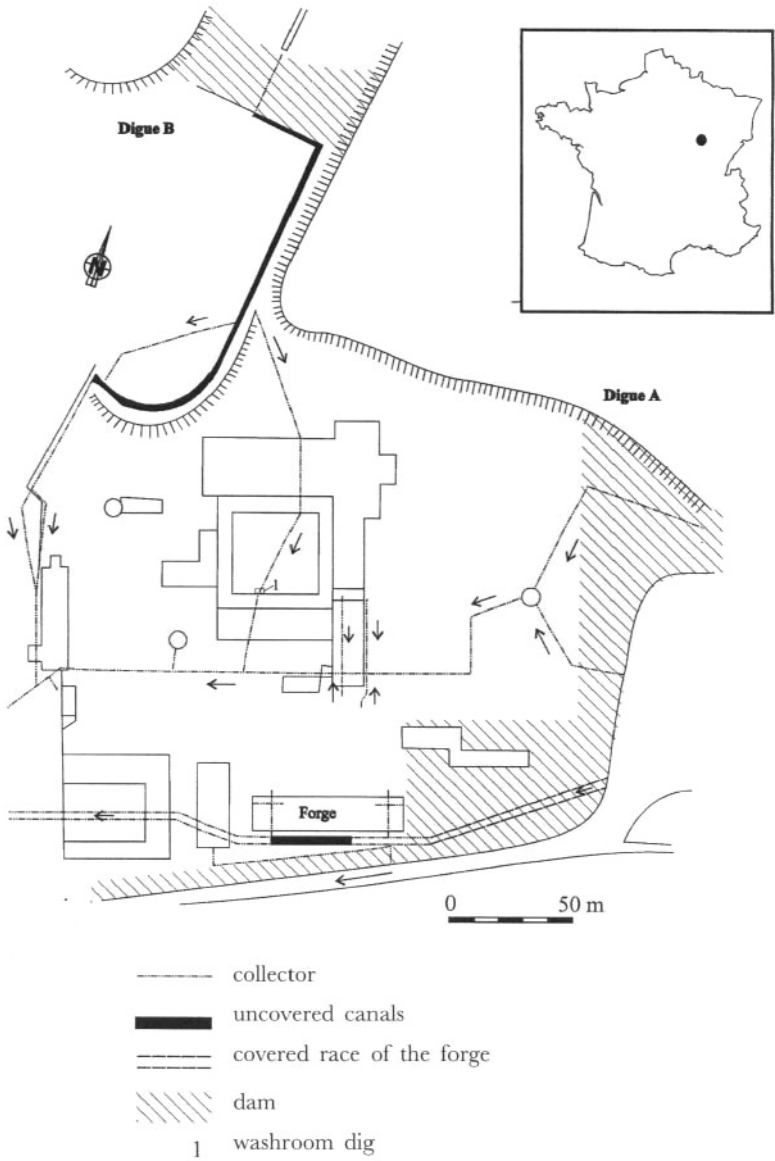


Figure 5.8. Abbey at Fontenay (Côte-d'Or), archaeological rendering of the hydraulic system.

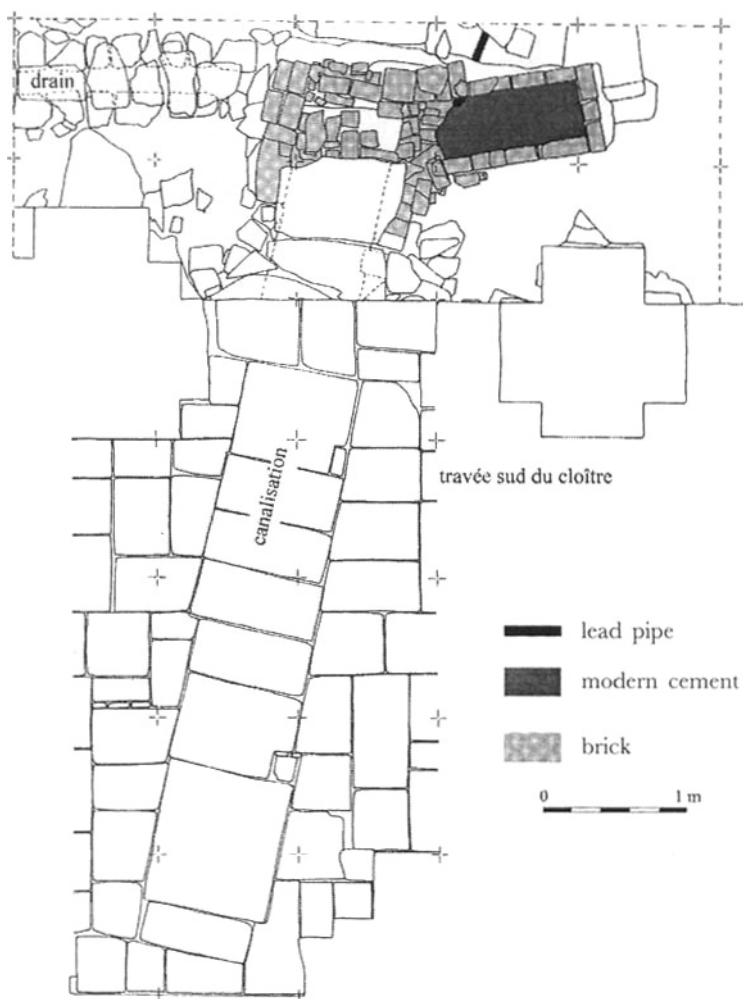


Figure 5.9. Abbey at Fontenay (Côte-d'Or). The washroom of the abbey at Fontenay was entirely destroyed over the course of the centuries. The dig only discovered several vestiges along the south bay of the cloisters, of which two pillars are visible on the plan. The channels removing the water from the washroom are still perceptible in the cloisters; they penetrate under the south bay where the course comes out in the pavement. Drains taking in rainwater direct them towards the removal canal. The system was still used in the contemporary period. From these recent installations remain a lead pipe and a brick basin with a cemented bottom.

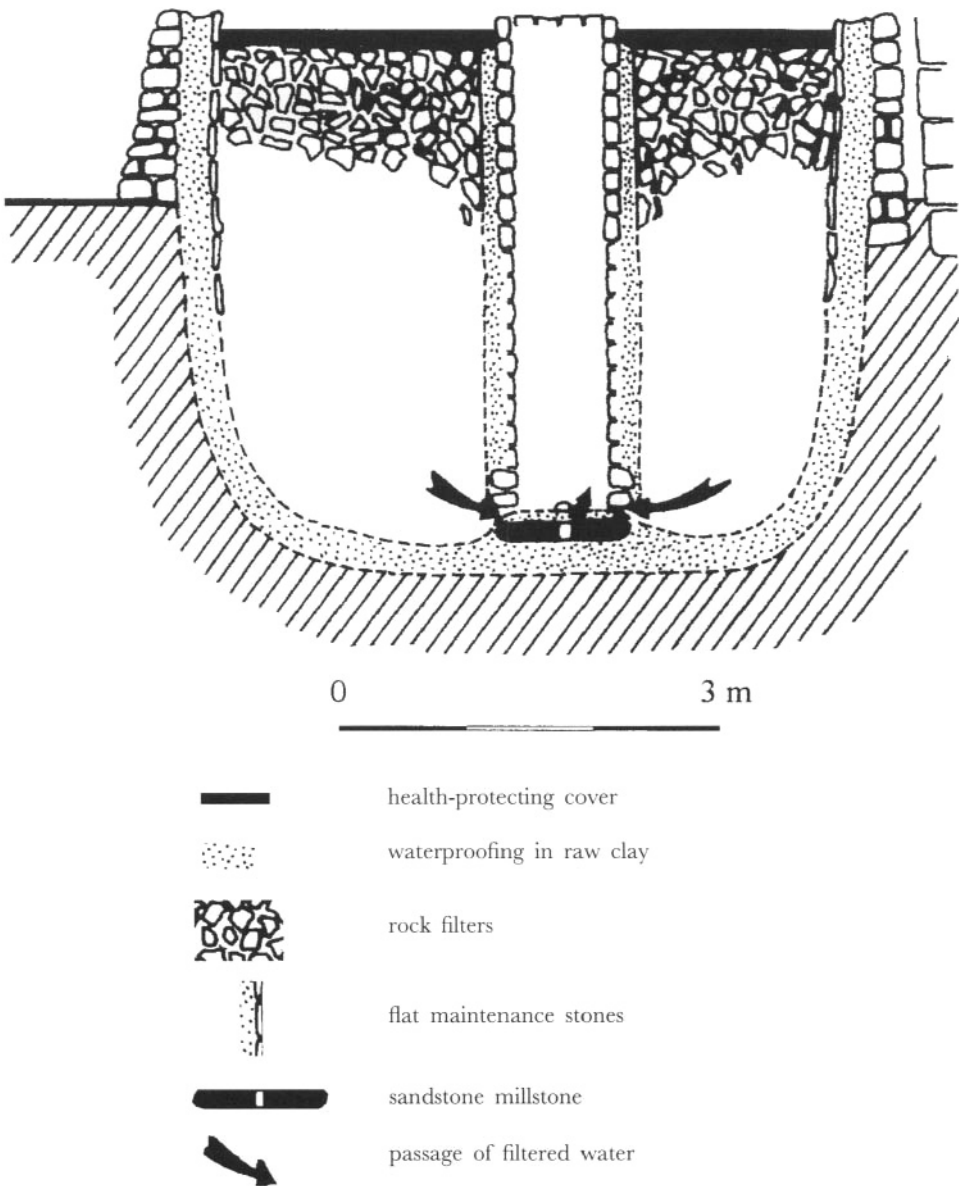


Figure 5.10. Rougemont castle, cup of the filtering cistern, after Walter (1993).

well as the interests of defense dictated an intra-mural supply. A cavity opening out at the base was drilled in the rock and made water-tight with clay. In the center, a sump was constructed in masonry, made water-tight on the outside edge with clay. The base was in stone: in this case, the former sandstone grinding stone of a mill. The space between the central sump and the insides of the exterior walls of the tank was filled with a mix of sand and rocks which filtered the water falling from above. In this castle, the supply came not only from castle roofs, but also from the water that flowed off the top of the dungeon. Since the dungeon was covered with wood shingles, water filtration was necessary. Water seeped through the sand filling, penetrated the sump via small holes at its base, and rose towards the surface by a system of linked vases. The cistern was 5 meters deep, which was average, the deepest known filtering cistern being that of the Alsatian castle of Hohbarr at 7 meters.⁶⁶

The kitchen, primary place of passage and use of water, was a fundamental site in every castle. Water use, in particular the need for a reservoir and discharge pipes, determined the location of the kitchen. Waste elimination required the kitchen to be at ground level in order to allow effective sewer channels to cross the building; these "sewers" ranged from a simple hole covered by a cover requiring regular emptying, to the most perfected sewage system, water flushing waste out towards the moats. Sinks allowed for the removal of used water. Water was led away through conduits, as in the castle of Bourg (Ain), in the Bresse, at the end of the thirteenth century, or by gutters of earthen bricks, as in the castle of Trefort (Ain) at the beginning of the fourteenth century,⁶⁷ or even by fir wood conduits called *hourneaux* in Annecy (Haute-Savoie), in a mountainous region where wood was abundant. The concern with comfort in the kitchen led to diverse installations, such as a pump lifting directly into the kitchen, as in the castle of Douai (Nord) at the end of the fourteenth century.⁶⁸

Castles' lords also used water as a means of defense, in order to isolate the castle site and to fortify it against the risk of fire during sieges. The lower in altitude the castle was, the more often a system of water-filled moats was employed. This was the case at Ardres

⁶⁶ Walter (1993), 62-64; Metz (1992).

⁶⁷ Lescuyer, Poisson (1992), 21-28.

⁶⁸ Levalet (1978), 225-241.

(Pas-de-Calais), where the construction of the first castle around 1060 included a system of locks which used the water from the neighboring marshes to fill the moats.⁶⁹ The castle site was often chosen in regard to the proximity of the water supply: the bottom of the valley or a swampy plain. The castle of Brie-Comte-Robert (Seine-et-Marne),⁷⁰ around the turn of the thirteenth century had moats fed partly by a stream, the Tubeuf, and partly by a spring. The castle of Croismare (Meurthe-et-Moselle) was constructed on the swampy banks of the Vezouze stream, in order to supply its moats. The moats' large size (at Brie-Comte-Robert, about 10 meters; at Tonnoy, between 18 and 23 meters wide; at Croismare, 15 meters) discouraged intrusions.⁷¹

The primary function of moats around flatland castles was thus defensive. They also played a role conferring prestige. At the end of the Middle Ages, castles did not guarantee military security, and the function of representing the lord of the place's prestige was primary, as was the need for comfort and pleasantness.⁷²

Water and the City

Urban development, a major fact characterizing Europe in the twelfth and thirteenth centuries, was accompanied by a domestication of water that is to this day understudied.⁷³ Relationships of cities to streams are complex and derive from natural conditions. Large rivers, though they offered the possibility of navigation, were often difficult to master. Many medieval French cities grew along the banks of diversions of medium-sized waterways, with further ramifications in the interior of the city, creating what André Guillerme has called little "Venices". The first signs of such arrangements appeared during the eleventh century.

Between 1030 and 1050, William the Conqueror diverted a part of the Eure in order to supply the defenses of the castle of Breteuil (Eure), an important stronghold on the border of the duchy of Normandy and the royal domain.⁷⁴ Breteuil was also an agglomeration,

⁶⁹ Fournier (1978), 131, 189.

⁷⁰ Benoit, Wabont (1990), 185–225.

⁷¹ Guiliato (1992), 95, 215; Benoit, Wabont (1990).

⁷² Alexandre-Bidon (1992), 43–44.

⁷³ Guillerme (1983).

⁷⁴ Benoit (1987), 3–15.

irrigated by the main branch of the Eure. Comparable works were undertaken at Châlons-sur-Marne (Marne), Beauvais (Oise), Etampes (Essonne), and Caen (Calvados).⁷⁵ (Figure 5.11) These works, which brought water for the defenses, considerably modified the countryside and the conditions of urban planning. The derivation of the Odon at Caen and the creation of the New-Odon allowed the city to be linked with the sea while the new network drained the lowlands and guaranteed the creation of new urban lands. The work, which proceeded rapidly, probably between 1066 and 1080, showed the determination of the Norman dukes, most of all William the Conqueror, who led the operation in collaboration with the monks of Saint-Etienne de Caen.⁷⁶ At Beauvais, defense needs accompanied the planning of the course of the Therain, which not only fed the moats, but also flowed through the city according to a new plan and furnished it with the energy it needed.⁷⁷ The planning of Etampes showcased the multiple interests the people of the Middle Ages had in mastering these medium sized waterways. On the road from Paris to Orléans, the city, already noted as a rural administrative center in the sixth century, developed in the zone of confluence of the Juine River, with the Lurette and the Chalouette. In the eleventh century, the Chalouette, reunited with the Lurette, was redirected northward. A new network, largely artificial, was created: the Chalouette, which kept its name despite the change in its path, irrigated the interior of the city, while the waters that protected the city to the south carried the name of the Etampes stream. The former riverbed of the stream flowing towards the Juine received the Filière creek, an outlet for floods but also for ordinary drainage and source of irrigation for the gardens in the south of the city. In the interior of the two walled agglomerations that formed Etampes and between these two centers, hydraulic wheels proliferated and a port formed inside the walls.⁷⁸

Thus, urban water arrangements were indispensable to the urban economy, for defense as well as land development and use. First, they supplied energy: numerous mills were situated on the canals which crossed cities. The economic weight of the mill, the search for sources of energy, and the necessity of removing waste attracted

⁷⁵ Guillerme (1983), 47–62.

⁷⁶ Guillerme (1983), 66–68.

⁷⁷ Guillerme (1983), 68–73.

⁷⁸ Billot (1989).

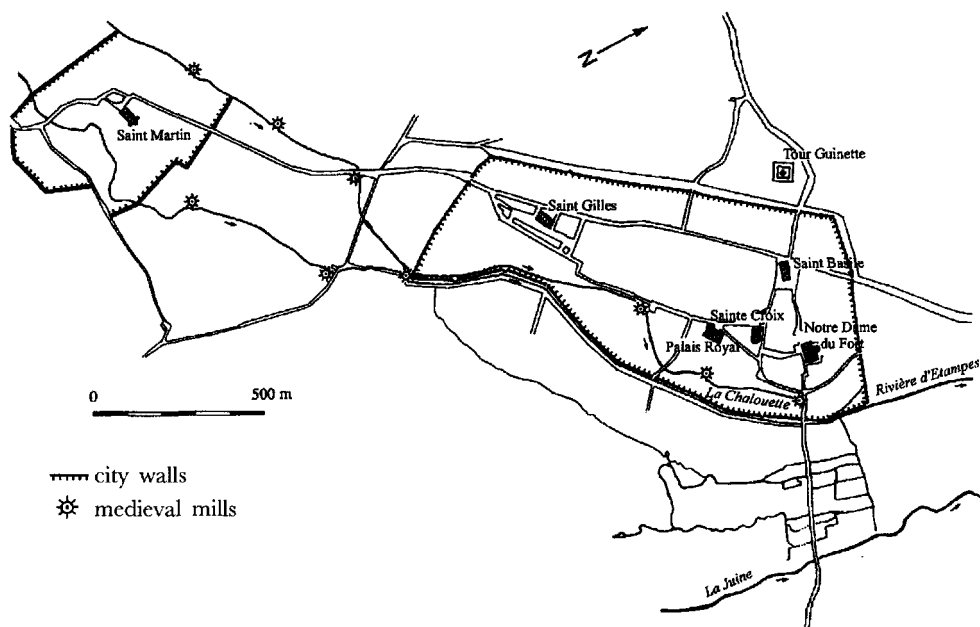


Figure 5.11. Hydraulic installations in Etampes, after Billot (1989).

artisans to the water's edge. As early as 978, mills were noted at Narbonne when Jews sold the mills that they had on the Aude to the chapter of Saint-Paul.⁷⁹ Elsewhere, when the city was situated on a large river difficult to master, other methods were used. In Paris, like in other cities, boat mills were installed. Of several types, these mills frequently made poor use of available energy, but nevertheless profited from its abundance; the mill could follow the regimen of the water, rising during floods, dropping during dry periods. The arches of the Grand-Pont of Paris which, at the end of the thirteenth century, were divided into the Grand-Pont and the Pont-aux-Meuniers, served as the attachment point for the majority of Parisian mills. They thus blocked the north arm of the Seine, leaving the south arm free for navigation.⁸⁰ Toulouse (Haute-Garonne) presents a different and particularly interesting case. At the end of the twelfth century, some sixty floating mills existed on the Bazacle ford and opposite from the Château-Narbonnais, where the steep inclines accel-

⁷⁹ Sicard (1953b), 78.

⁸⁰ *Vie de Monseigneur saint Denis* (late 1200s), Bibl. nat., ms. fr. 2091; Favier (1997), 173.

erated the flow of the river. At that time, forty three fixed mills, probably equipped with horizontal water wheels, replaced the floating mills. The richness of the Toulousian documentation permitted the reconstruction of the history of these mills. Their ownership was divided in parts, locally called *uchaux*, possessed by members of the mercantile class, urban nobles, and artisans.⁸¹

Thus the cities of medieval France saw mills proliferate thanks to more costly arrangements than those deployed in the country. The city, with its needs for space, energy, hygiene, defense, and transportation was an important place for hydraulic investment, and also a place of innovation. But though innovation can be seen in hydraulic arrangements, it was even more clear in the utilization of this energy: it was in the cities that fulling mills were developed, to process woolen cloth.

The First Steps in the Transformations to Come: The Use of Hydraulic Energy

We lack the documentation that would tell us if hydraulic energy was used for other functions than that of milling grain in the early Middle Ages. Written documentation reveals that as early as the ninth century, but especially after the eleventh, people sought to replace human labor power, in repetitive tasks, with machine power, set in motion by water. The wheel was adapted with cams, which considerably modified the conditions of production in several economic sectors: the processing of agricultural products, or the leather, textile and, particularly, metallurgical industries.

It was the fulling mills that seem to have been the first object of mechanization. Though under different names (fulling mill, baster, cloth mill), as far as we can tell the machines seem to be built upon the same principles. Cams raised pestles which beat the woolen cloth contained in a vat filled with water mixed with different products. As with all fulling, the goals remained at once degreasing the wool and giving it some homogeneity, but the pestles replaced the work of human feet. The fulling mill appeared for the first time in Italy, in the founding charter of 962 of a Benedictine monastery in the Abruzzi.⁸² The innovation did not arrive in France until the end of

⁸¹ Sicard (1953b), 37, 46.

⁸² Malanima (1988).

the eleventh century, its first appearance outside Italy. The first mention of the fulling mill in France is Norman, and dates from 1086–1087. Even restricting the search to the simple term “fulling mill” within the charters, it is possible to trace a diffusion of mechanical fulling in northern France in the twelfth and thirteenth centuries.⁸³ Recent research, undertaken in the regions of Burgundy, Champagne, and Franche-Comté using Cistercian sources, confirm this chronology. The Cistercian abbeys looked to invest in the industries of the future. The acquisition of industrial mills, whose production capacity outpaced the monks’ needs, shows that the Cistercians sought to extract the highest profits possible from their hydraulic capital. Though first to use hydraulic energy, the wool industry was not the only one to benefit from it. Henceforth, the water wheel ground both oak bark for making tannins and woad for making dyers’ tints.⁸⁴ With the diffusion of hydraulic saws, the force of the water also supplemented human muscles in cutting timber. The first medieval mention of this technique is found in a Norman document from 1204. In the thirteenth century, the engineer Villard de Honnecourt represents one in his notebook and showed how it functioned. The circular movement of the wheel was transformed by the slant of the cams into an alternating movement capable of cutting; add to that the automatic advancement of wood into the saw. The hydraulic saw required abundant and very regular energy, thus its use was essentially limited to mountainous regions. Very little is known about its diffusion before the end of the Middle Ages.⁸⁵

It was in the domain of metallurgy that hydraulic innovation had the most significant consequences. In the twelfth century, and for more than two thousand years before that time, iron was obtained from the smelting of ores by direct process. This term covers a series of operations, one of which was the smelting in naturally- or hand-ventilated ovens. The oven functioned at a lower temperatures than that for the fusion of iron, 1530° C, thus the iron was reduced to a pasty state. In the oven remained a salamander, a mass of metal mixed with slag and other impurities. This salamander was re-treated

⁸³ Bautier (1960).

⁸⁴ Benoit, Berthier (in press); Berthier, Rouillard (1998, in press); Rouillard (1996), 363–381.

⁸⁵ The first real mention of a hydraulic saw was by Ausonius in the basin of the Moselle, around 367: Erlande-Brandenburg, Pernoud, Gimpel, Bechmann (1986); Adam, Varenne (1985), 319.

in the forge in order to obtain a usable ingot. With the force of their arms, metallurgists hammered the salamander when hot. In the same way, the elaboration of finished or semi-finished products, and similarly, reparations on broken ones, required both forge and human energies. Elevated production costs and a limited capacity for evolution ensued. The application of the cam system to the hammer function overturned the technical conditions of production. The Cistercian monks appear to have originated and diffused, if not invented, the water-powered hammer. For several years, this hypothesis, which was first offered by Bertrand Gille, has been receiving confirmation. In Arnould de Bonneval's 1135 description of Clairvaux (Aube), water activated a forge in the heart of the abbey, amidst other milling installations.⁸⁶ This text is our first clear citation of a hydraulic forge; revealingly, it does not appear to have been an exceptional thing for the author. A few Cistercian texts attest to the existence of water-driven forges, notably in 1218 at Bellevaux.⁸⁷ To these certitudes are added hypotheses buttressed by archaeology, concerning several sites, essentially situated in eastern France, in Burgundy, Champagne, and Franche-Comté. Thus the forge in the heart of the monastic enclosure of the abbey of Fontenay (Côte-d'Or), inscribed in a very ancient tradition, rested on a race diverted from the brook of Fontenay, a race abundant enough for feeding several hydraulic wheels. (Figure 5.12) It had two large ovens entirely sufficient to reheat metal. The iron mines of the abbey were excavated only a few hundred meters from the cloisters.⁸⁸ France was not alone in this movement, and innovation equally touched England, Sweden, and Italy, as shown by recent archaeological discoveries. It is now certain that the Cistercians applied hydraulic energy to working iron as early as the first half of the twelfth century, and favored diffusion and innovation in this period of growth.⁸⁹

It is difficult to follow the diffusion of this innovation. South French sources furnish precious indications. At the end of the thirteenth century, the first mention of a *mouline*, a workshop equipped with water-powered hammers, appeared in Montagne-Noire (Tarn). In the early fourteenth century, the accounts of the seneschal of Carcassonne cite

⁸⁶ Migne (1863); Mabillon (1885), col 285.

⁸⁷ Berthier, Rouillard (in press).

⁸⁸ Benoit (1988), 215-243; Benoit (1994), 51-108.

⁸⁹ Benoit (1993), 96-124; Benoit, Berthier (in press); Berthier, Rouillard (in press).

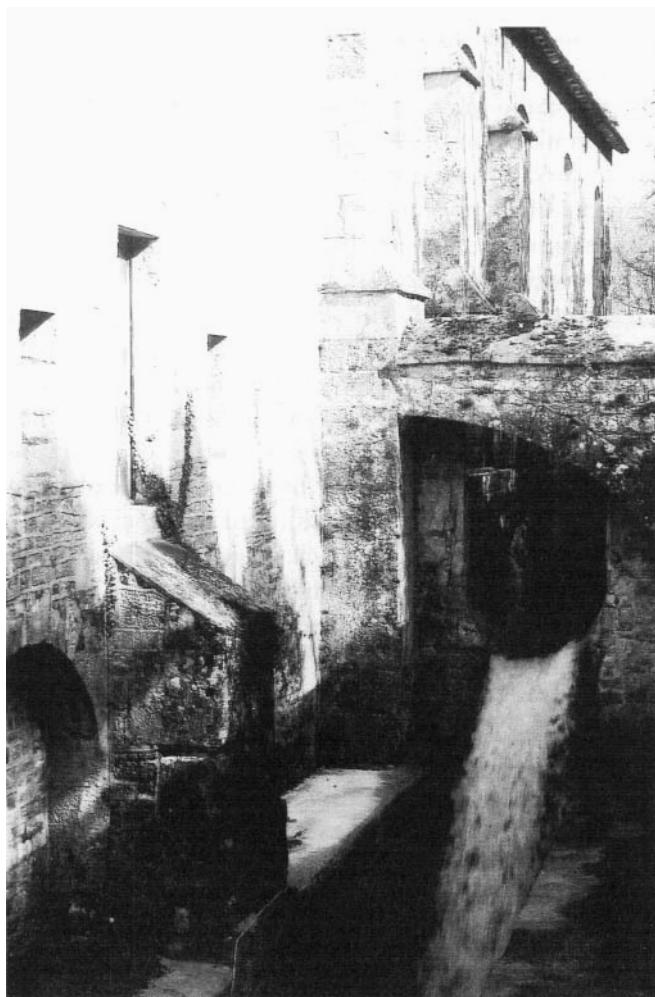


Figure 5.12. Run supplying the forge of the Cistercian abbey at Fontenay (Côte-d'Or), twelfth-thirteenth centuries. The water inlet was raised in the nineteenth century when the forge was re-used as a paper mill. Photo by the authors.

several of the *moulines*, belonging to the king of France and valued at much higher prices than grain mills, which indicates the importance of these installations.⁹⁰ The same term *mouline* was used to qualify hydraulic forges in Ariège after 1300 on the torrents descending from the Pyrénées. They served to reduce the excellent local ore,

⁹⁰ Cabie (1903), 241ff.; Fawtier, Maillard (1954).

which produced steel naturally. These *moulines* multiplied in Ariège between 1325 and 1340 and also spread throughout a large part of southwestern France.⁹¹

At the moment when France felt the warning signs of crisis, when population growth slowed, and when famine reappeared, these unfavorable conditions did not prevent the development of the use of hydraulic energy in iron metallurgy. Water served to make not only utensils but also weapons, important in a country where war was already present, in progress, or simply impending, in Flanders as well as along the border of the possessions of the king of England.

*The Crisis in the City and in the Country (1350–1500):
Mills and Ponds*

The crisis that ravaged the West halved the number of people in Europe, caused a collapse in grain production, lowered land rents, and subjected cities and countrysides to the misery of war. In the Bordelais (Gironde), in the middle of the fifteenth century, during the French recovery, grain production was less than half of what it was at the beginning of the fourteenth century.⁹² Between the middle of the fourteenth century and the middle of the fifteen century, the hydraulic potential of the countryside was even more markedly devastated. In Sologne, the abandonment of ditch-maintenance returned the reclaimed land to swamp.⁹³ Research has only just begun in this area; the researchers who examine rural life in this dark century have barely begun to ask themselves the question of how the misery of the times weighed on hydraulic equipment and the uses of water. Only recent works offer data to answer the question. In the region of Sens (Yonne), a city whose archbishop's jurisdiction included the diocese of Paris, the accounts of the cathedral chapter of Saint-Etienne indicate the gravity of the situation. Under threat from the English armies or unemployed mercenary bands, many rural mills were abandoned, some definitively. The drop in population, considerable in the region of Sens, hardly favored economic

⁹¹ Verna (1994); Verna (1995), 51–59.

⁹² Mouthon (1993), 365–377.

⁹³ Guérin (1960), 131.

revival. It became difficult to find millers despite the drop in price of the mill rents. The cost of running the mills often was more than the revenue they generated.⁹⁴ This situation was common to many other regions. In the Bordelais, most of the mills that appeared in moments of attenuation of the crisis were described as deserted and taxed as such.⁹⁵ Thus, the examination of these sources shows an incontestable abandonment of mills in the difficult period of the fourteenth and fifteenth centuries.⁹⁶ But the lack of people and the foundering of grain prices had less negative effects as well. In the Dombes (Ain) and the Sologne, the crisis did not slow regional development through the creation of ponds.⁹⁷ In Sens, at a time when agricultural revenues were nearly nothing, when the cathedral chapter stopped maintaining its rural capital, ponds were the sole object of expenses for repairs and brought in non-negligible sums, due to the sale of fish.⁹⁸ At a time when people were few and the price of wheat very low, the production of fish, requiring less abundant manpower than agriculture, yet still in demand at market, was able to maintain itself and even to develop.

The crisis also struck urban hydraulics. At Beauvais (Oise), while at the end of the thirteenth century, the city and its environs possessed thirteen grain mills and at least ten industrial mills (for either fulling, tanning, or blade sharpening), at the end of the fifteenth century many of these installations were in ruins. Only sixteen working mills remained. All the fulling mills had disappeared, and only the grain mills, three tanning mills, and one oil mill remained. Significantly, the mills situated far from the shelter of the walls had been abandoned.⁹⁹

In certain cases, a minority profited from the economic slump. The price of the *uchaux* of Toulouse, those shares of mills, did not stop rising in the time of crisis.¹⁰⁰ We surmise that this rise in price corresponds to the decline in the number of mills within the city, while the possession of a part of a mill guaranteed receiving at least a supply of flour.

⁹⁴ Rouillard (1996).

⁹⁵ Mouthon (1993), 310.

⁹⁶ Mouthon (1993), 241.

⁹⁷ Benoit (1992), 24–25; Guerin (1960), 132.

⁹⁸ Cathedral chapter of Sens, accounts of the Chambre, Arch. de Yonne, G975 (middle of the fifteenth century).

⁹⁹ Bourges (1996), 81–82.

¹⁰⁰ Sicard (1953b), 247–254.

The Conditions of Reconstruction

In the middle of the fifteenth century, the situation improved politically and economically, and hydraulic activity reclaimed its prominence. The crisis destroyed older structures. This, at the time of the revival after 1450, facilitated important structural modifications in cities and in the countryside. Such modifications are all the more visible in a period of detailed documentation associated with the birth of the "modern State."¹⁰¹ In the countryside, the number of restored old mills and abandoned ones varied considerably from one region to another. In some, like the region of Sens (Yonne), nearly all the mills abandoned during the previous decades were reconstructed and put back into use. But the economic conditions had vastly changed; the duration of the miller's lease lengthened to one or several lives instead of several years, the proprietors wanting to keep for as long as possible tenants who maintained and made profitable their installations. Lease conditions were more favorable to millers than before the crisis, which soon enough brought an elevation in their social status, particularly in the city. In the Bordelais, reconstruction allowed the middle class, notaries, lawyers, and members of parliament to acquire mills that had belonged to the nobles before the crisis.¹⁰² Faster than the countryside, the cities repopulated themselves and again affirmed their need for flour and energy. Elsewhere, economic rebirth, so favorable to city dwellers and the needs of reconstruction, led to new urban hydraulic installations.

The Effects of Reconstruction: The City

The crisis had ravaged numerous cities in the kingdom. Paris, where political battles and the military situation had magnified the effects of the demographic and economic crisis, had lost almost half its population between 1350 and 1440; the decline was comparable in Rouen or Périgueux.¹⁰³ Urban reconstruction was particularly rapid. The return of the population in cities, the development of administrations, and the establishment of princely residences created new needs which were accompanied by a new preoccupation with well-being.

¹⁰¹ Bois (1976); Le Menée (1982).

¹⁰² Mouthon (1993), 301–302.

¹⁰³ Favier (1997), 61; Higounet-Nadal (1979); Benoit, Lardin (1997), 287–304.

Urban reconstruction often went hand in hand with improvements in water distribution systems, as in Rouen (Seine-Maritime), Bordeaux (Gironde), or Rennes (Ille-et-Vilaine). In the latter, after 1443, springs were brought under control about 5.5 kilometers north of the city and directed via wooden canals. The following year, another derivation completed the system, and water arrived in the center of the city. These expensive but insufficient works were completed all through the modern epoch.¹⁰⁴ At Tours (Indre-et-Loire), it was necessary to wait until the beginning of the sixteenth century for water derived outside of the city to supply the public fountains. The enterprise posed extremely difficult issues to resolve. The city was situated between the Cher and the Loire, and obtaining potable water from the springs situated at the feet of the neighboring foothills required crossing one of the two waterways. The municipality assigned the work to a master fountain-builder from Rouen. He then undertook the construction of an aqueduct passing under the Cher via siphons, with reservoir basins and a system of distribution.¹⁰⁵

In Paris, city accounts show the evolution of the distribution network at the end of the Middle Ages which was based on the preceding system. Born from the springs of Belleville, the network went along the right bank. (Figure 5.13) Rivulets and underground aqueducts conducted the water through *pierrées*, drystone conduits that allowed water to infiltrate, to the city, situated below. Water crossed ditches under pressure in lead or more rarely ceramic pipes, which ended at the public fountains. The left bank was also fed by canals passing through the Ile de la Cité via the Notre-Dame Bridge. The network-upkeep required the presence of a plumber-fountain-builder hired by the city. Despite efforts undertaken by the public authorities, water supply was insufficient; the weak flow of the springs, the summer dry periods, and the winter freeze meant the aqueducts did not service the entire population. To this already feeble flow, all the private derivation from the aqueduct, in particular by the highest nobility, eager to supply their mansions, presented a serious problem. Several royal decrees to stop these abuses went without effect. The inhabitants of Paris had therefore to rely upon well water, but the water table below was very polluted: wells served as receptacles

¹⁰⁴ Marteville (1848).

¹⁰⁵ Chevalier (1974), 485.

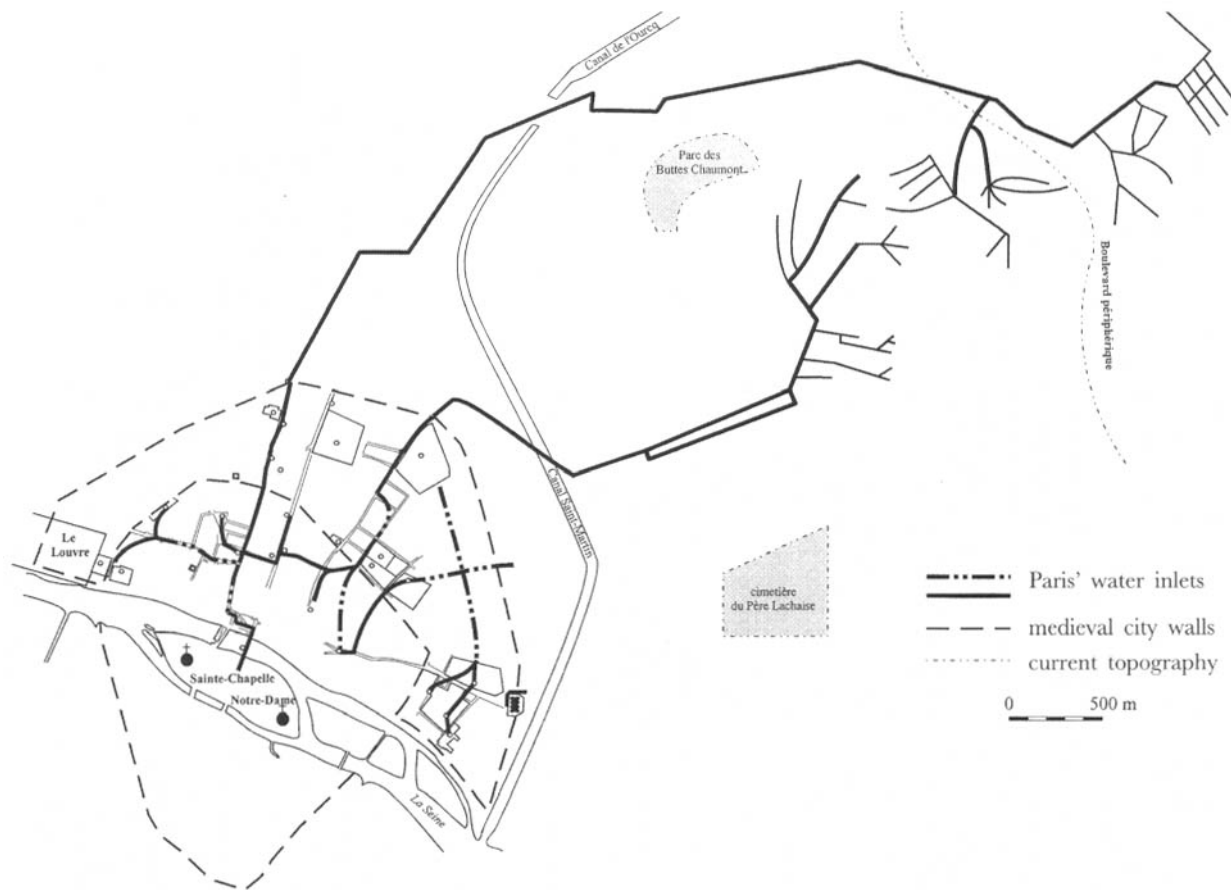


Figure 5.13. Water installations in Paris at the end of the Middle Ages, after Lafay (1991).

for dead animals and refuse, waste water bearing ditches were permeable, and human corpses in the cemeteries decomposed above the water table. Therefore, many Parisians preferred to drink the water of the Seine, still considered potable in the nineteenth century.¹⁰⁶

Water became more indispensable to aristocratic life. More than monasteries, princely residences seemed to have played a predominant, though still poorly understood, role in the evolution of water distribution. From 1353, Pope Innocent VI reorganized water distribution in the Palace of the Popes in Avignon. A system of canals supplied the kitchen, the bakery, the storeroom, and the pantry, while other conduits led from the storeroom to the orchard fountain.¹⁰⁷ The pipes were mostly made of tin, but also of lead.¹⁰⁸ It seems that at the end of the Middle Ages, lead pipes competed with terra cotta more than in earlier periods.

Princely residences also possessed their own sanitary equipment. Hypocaust-equipped rooms, supplied with warm water via piping ending in faucets, were constructed in the residences of several important personages.¹⁰⁹ The first example of hypocaust construction dating from the medieval period situated within France's current boundaries was in the Palace of the Popes at Avignon (Valcluse), from 1342. The duke of Burgundy had bathrooms installed in his residences, in Dijon, in Paris, and in Gand (Belgium). In the latter city, according to the accounts of the duchy from 1418–1419, the plumber Jean ser Gerhards installed a steam room in the castle of Walle. The heater was iron, the faucets, copper, and supply pipes and bathtubs were lead.¹¹⁰ Comparable equipment was found during the fifteenth century in noble or princely residences in western France, such as Vitré (Ille-et-Vilaine) or Bourges (Cher) in the mansion of Jacques Coeur. The style even reached rural castles in the region, but in general, most of France remained attached to more traditional and less costly forms.

Hygienic needs were not only felt by important people. Steam rooms were thus numerous in Paris and despite their reputation as

¹⁰⁶ Lafay (1991). In 1643, taking water from a boat rather than from the bank was required, because it was cleaner in the faster-flowing, deeper parts of the river: Favier (1997), 600.

¹⁰⁷ Benoit (1985), 339–355; Schäfer (1911–1937), vol. 2, 503–504.

¹⁰⁸ Mesqui (1996), 51–70.

¹⁰⁹ Shown by Mesqui (1996).

¹¹⁰ Benoit (1985), 339–355; Schäfer (1911–1937), vol. 2, 503–504.

places of prostitution, they were, above all, baths.¹¹¹ Little is known about their hydraulic systems. We can guess that they were essentially rooms equipped with wooden bathtubs that were filled with warm water by pitchers.¹¹²

The upturn in consumption required systems for used water removal. Streams served this purpose. In 1390, the duke of Burgundy forbade the throwing of detritus in streams during Charles VI's visit to Dijon.¹¹³ But in larger cities, more complex arrangements were necessary. In Paris, though a part of used waters stagnated, trickles were led towards sewers which conducted water either directly towards the Seine, or towards the grand sewer which ringed part of the right bank. Upon the king's request as well as that of the inhabitants, a portion of the sewers received covers in 1370.¹¹⁴ Parisian municipal accounts from the fifteenth century attest to their regular maintenance.¹¹⁵

The role of the city, of its social and political weight, appears clearly through the importance accorded to the use of water, sign of aristocratic needs but also of a population sensitive to improvement in its way of life. However, water also remained the principal source of energy for industrial-type activities and for milling. There, also, innovations appeared, but of very uneven importance, depending on the essential purpose of the mill.

Grain Mills at the End of the Middle Ages

Varying types of mills existed in France at the end of the Middle Ages. First of all, there was a fundamental difference between the north and the south of the country; the horizontal wheel does not seem to have existed outside the southern zones, as was still the case in the nineteenth century. The horizontal wheel's tradition is old, but proof of the use of this wheel can only come from archaeologically-informed research on the rare stone mills preserved since the Middle Ages, and on the technical vocabulary, so difficult to define. The Bordelais region, especially, had horizontal wheels; this is a

¹¹¹ Favier (1997), 653–655.

¹¹² Mesqui (1996).

¹¹³ Petit (1885).

¹¹⁴ Favier (1997), 215.

¹¹⁵ Bernard (1988), 9–27.

region filled with streams of gentle slope.¹¹⁶ Studies conducted in the basins of the Orb, the Hérault, and the Vidourle (Hérault) show that the horizontal wheel dominated in waterways in mountainous zones, whereas on the plains, the vertical wheel was used.¹¹⁷ (Figure 5.14) Outside of the weight of local traditions, the horizontal wheel was simple to install, and did not require gears; on the other hand, it could not be made large.

The vertical wheel, which, with its better output, dominated in the north of France, came in two main forms, overshot and undershot. The vertical wheel proved indispensable for machines using cams, since the axle held the cams directly, without gears, dissipating energy and causing maintenance problems. Mills for fulling, tanning, making paper, woad, and iron worked this way. The undershot wheel was far more common, because it did not need a large waterfall. It was installed on the runs or, more importantly, on the bed of a stream more easily. Its installation did not require considerable amounts of work and its maintenance, though not negligible, remained minimal compared to that of an overshot wheel. It was used in a number of rural grain mills in the plains.

Mighty waterways were more troublesome to harness, and were subject to significant variations in water level, which made runs difficult to install without bridling the waterway with a dam. To these technical obstacles were added the problems posed by the relationships with boats and their users. Since Roman Antiquity, the West had vessel bound mills, also called boat mills. The *Vita* of St. Denis, dated from the end of the thirteenth century, represents the different bridges of the Seine in Paris and the activities which were attached to them. Under the arches of the Millers' Bridge, profiting from the waters' acceleration due to the narrowness of the arch, boats, attached to the piers of the bridge, carried on one of their sides a vertical wheel. (Figure 5.15) The wheel propelled a millstone, as in a fixed-location mill. The drawing shows one of the drawbacks of such a machine; people had to carry the grain to be milled in a small boat. Other inconveniences were experienced, including a very mediocre output, and the threat of being carried away by floods, without counting the possibility of being seriously damaged by floating items or drifting boats. The map of Paris, made by Truschet and

¹¹⁶ Mouthon (1993), 287–289.

¹¹⁷ Phalip (1992), 63–96.

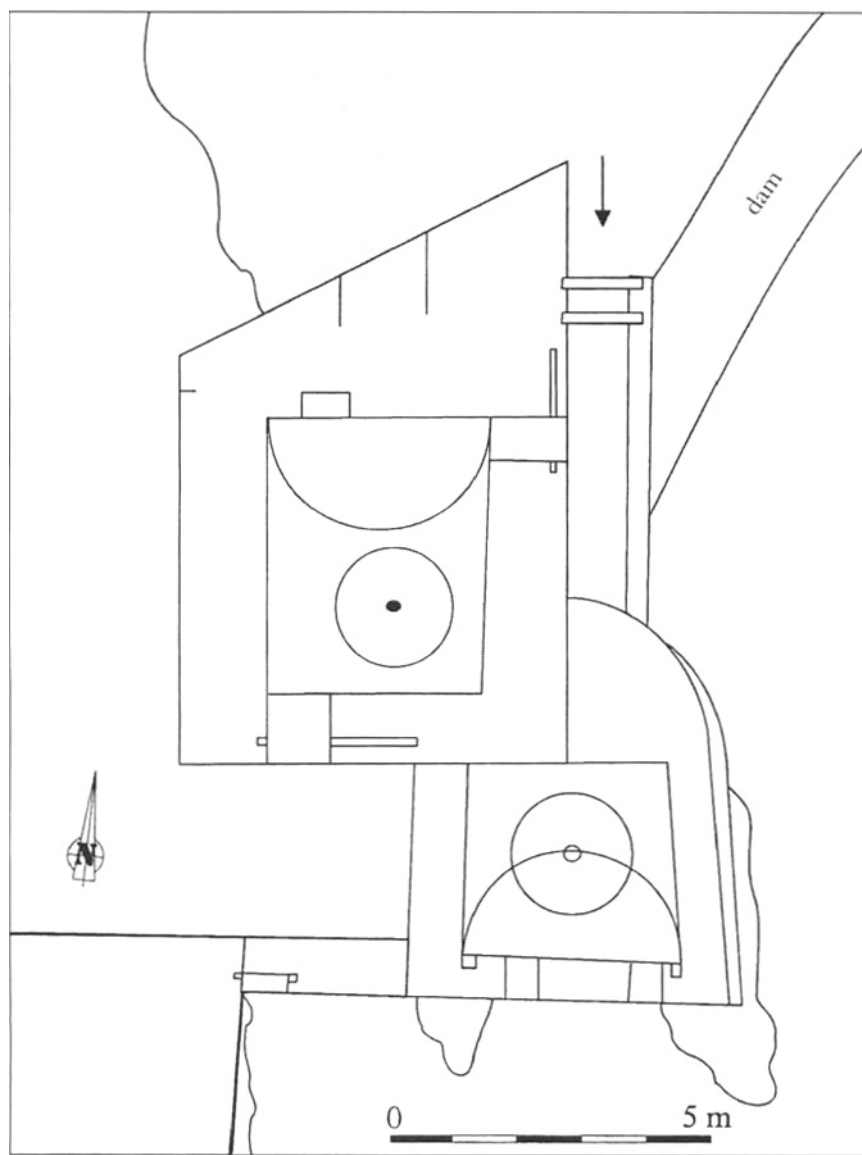


Figure 5.14. Plancameit mill, or Tour mill, Saint-Guilhem-le-Désert (Hérault). Floor plan, after Phalip (1992).

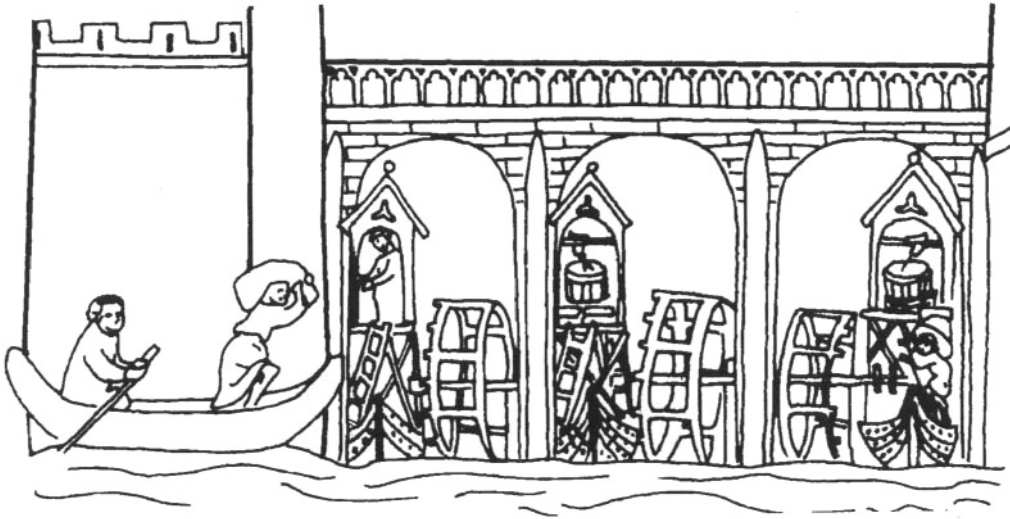


Figure 5.15. Parisian floating mills, from *La vie de Monseigneur saint Denis*, Bibl. nat., ms. fr. 2091, end of the thirteenth century.

Hoyaux in the middle of the sixteenth century, shows an entirely different situation. The mill boats have disappeared, replaced by hanging mills.¹¹⁸ (Figure 5.16) The wheel occupies the entire width of the arch of the bridge and better uses the energy of the Seine. Later documents allow us to understand how they worked. The wheel could rise up along a fixed structure according to the level of the water. The miller regulated the height with the aid of four winches that supported the frame in which the wheel turned. The wheel was thus accessible via a solid path, namely, the bridge. The mechanism remains, however, under the threat of floods and floating objects. Therefore, despite its advantages, it did not spell the demise of the mill boats. The first hanging mills appeared, as far as current research shows, in the fourteenth century.

Overshot wheels were already in use in Antiquity, and developed more in regions with marked relief. Before the nineteenth century, its performance was unequaled. The proliferation of mills on ponds in the twelfth and thirteenth centuries in the highlands of Burgundy and Champagne contributed to the development of this type of installation at the end of the Middle Ages. In the middle of the fifteenth

¹¹⁸ Trushcet, Hoyau (1994).



Figure 5.16. Mills of the Pont-aux-Meuniers (Millers' Bridge) in Paris, from Trushcet, Hoyau (1994).

century, for example, one finds overshot wheels in the mountainous mining regions; they drove the bellows of the mining and metallurgy site of Pampailly (Brussieu, Rhône).¹¹⁹ Several decades later, vertical wheels were omnipresent in mining sites in the Vosges at the beginning of the sixteenth century. On these elevated sites, only wheels fed from above generated enough energy first for the functioning of the bellows machinery, then for the mining mills, and finally, in the beginning of the sixteenth century, for the mineral-crushing mills.¹²⁰

Sixteenth century images suggest that improvements to mill wheels were already in use. Were they there immediately after the crisis? Given the current state of research, it is impossible to know if the construction of wheels evolved during this final period of the Middle Ages. But, generally, it does not appear that decisive modifications were introduced during the time of reconstruction, and the age-old techniques remained. It was in the industrial sector's use of the hydraulic wheel that the mutations made themselves felt.

Industrial Mills at the End of the Middle Ages

The crisis which ravaged the West had fundamental consequences on the development of certain industrial techniques, in particular in the use of energy.¹²¹ The crisis destroyed entire sectors of the economy, but, on the other hand, allowed innovation to spread. The Cistercian documents from Burgundy and Comté from the end of the Middle Ages show an increase of fulling mills in the countryside, either coupled with grain mills or replacing them.¹²² The drop in the number of people, and thus of flour consumers, modified the need for hydraulic power and liberated a part of this energy for other activities. One of these activities was textiles-production, which opened itself up to greater degrees of mechanization. However, unlike the west of England, where hydraulic fulling mills expanded into the countryside in order to give rise to a significant export industry,¹²³ it was above all metallurgic activities which, in France, were marked by decisive innovations which profited from the use of water.

¹¹⁹ Benoit (1997).

¹²⁰ Benoit (1997); Benoit (1990), 41–63.

¹²¹ Benoit (1984), 319–334.

¹²² Benoit, Berthier (in press).

¹²³ Carus-Wilson (1941), 39–60.

Mines and metallurgy benefited, more than any other activity, from the reconstruction after the century of crisis. The State, as well as individuals, needed silver in order to supply its mints; also, the fact that peace returned to France did not mean an end to expensive military efforts. To the contrary, the birth of a permanent army, the development of artillery, a new weapon, only increased the very strong demand which the reconstruction of cities and countrysides had stimulated. This demand met with favorable conditions; wood abounded, water was available, and industrial investment seemed more favorable than land rent. Finally, the destruction of traditional social and economic structures definitively broke any remaining social resistance to innovation.¹²⁴

The revival of activity in steel and iron production took different forms in northern and southern France, but in each case, hydraulic energy was largely employed. The southwest of France stayed loyal to the direct process, and the *mouline* was developed. The economic revival in Quercy was accompanied by the repair of the devastated *moulines* and the multiplication of new installations on small waterways. Texts, more precise than in the fourteenth century, indicate what these installations were; the *mouline* had one or several furnaces, one or several forging chambers, but above all a hammer set in motion by the energy of the water. Its high value indicates that it constituted the essential piece of equipment. Though the vocabulary had remained constant throughout the preceding century, it is difficult to know if the appliances had changed. A deed from 1487 gives much more precious indications; it signals a bellows canal next to the *mouline* canal. Two runs thus feed the industrial site: the first to set in motion the hammer, the other to stoke the bellows of the furnace.¹²⁵ In Ariège, where hydraulic metallurgy survived the crisis without too many difficulties due to the sale of iron in warring areas, expansion slowed for a time with the return of peace, only to speed up again at the end of the century.¹²⁶ The *mouline* however, maintained itself in the Pyrénées until the arrival, in the seventeenth century, of the so-called Catalan process.¹²⁷

The north of the country, which extends to the Loire, applied the

¹²⁴ Benoit (1984).

¹²⁵ Lartigaut (1978), 404–427.

¹²⁶ Verna (1994), 333–357, 486–487.

¹²⁷ Cantelaube (1993), 27–36.

force of water to the production of metal in a very different manner. In these regions, indirect steel and iron metallurgy developed; the iron was henceforth produced in two stages, smelting and refining. The forge at Champigny, possession of the abbey of Clairvaux (Aube) is an exemplary case. In 1476, the lease granted the installations in exchange for a mixed cash and metal rent—near to nine tons of iron per year. It lists the components of the factory: a washhouse, a place for the ore, a charcoal depot, an upper furnace, two refineries, a boiler room, and a hydraulic hammer. Water was omnipresent. It fed the washhouse, made the wheels turn that activated the furnace, refinery, and perhaps the boiler room bellows, and activated the hammer. A significant hydraulic installation was necessary to furnish enough energy for what would later be called a “big forge”. By way of simple explanation, in order to obtain the fusion of iron ore, it was necessary to attain temperatures above 1500 degrees Celsius, which, in a furnace in which the ore was mixed with charcoal in order to be melted, only bellows activated by hydraulic energy could produce. The mechanism was simple; cams transformed the continuous movement of the wheel into an alternating movement, which spread apart the two sides of the bellows. A spring or a counterweight brought the bellows back to its original position. As a general rule, hydraulic bellows equipped the refining rooms, where a strong current of air fed combustion by creating an oxidizing atmosphere which eliminated carbon. A part of the iron oxidized as well, and it was necessary to lash the salamander obtained in the oven. The energy of the water continuously activated the hammer, which, as in the direct process, separated the iron slag at the final stage of refining. Steel- and iron-producing installations required the creation of diversions, runs, and ponds. The upper furnace worked continuously, and since, in the fifteenth century, the process of reducing raw ore lasted from several days to one or two weeks, the wheel had to be constantly in action. When the forge was not located on a regular and abundant water way, it was necessary to stock water in a pond to insure the regularity of the flow. Ponds serving as reservoirs appeared in the first representation of a blast furnace in Normandy.¹²⁸ (Figure 5.17) Changes in metallurgical technique at the end of the Middle Ages can be explained by multiple factors, in particular by the will to exploit forest resources, resurgent thanks

¹²⁸ Forge de Rainvilliers (Oise), map of 1508, Belhoste, (1991).

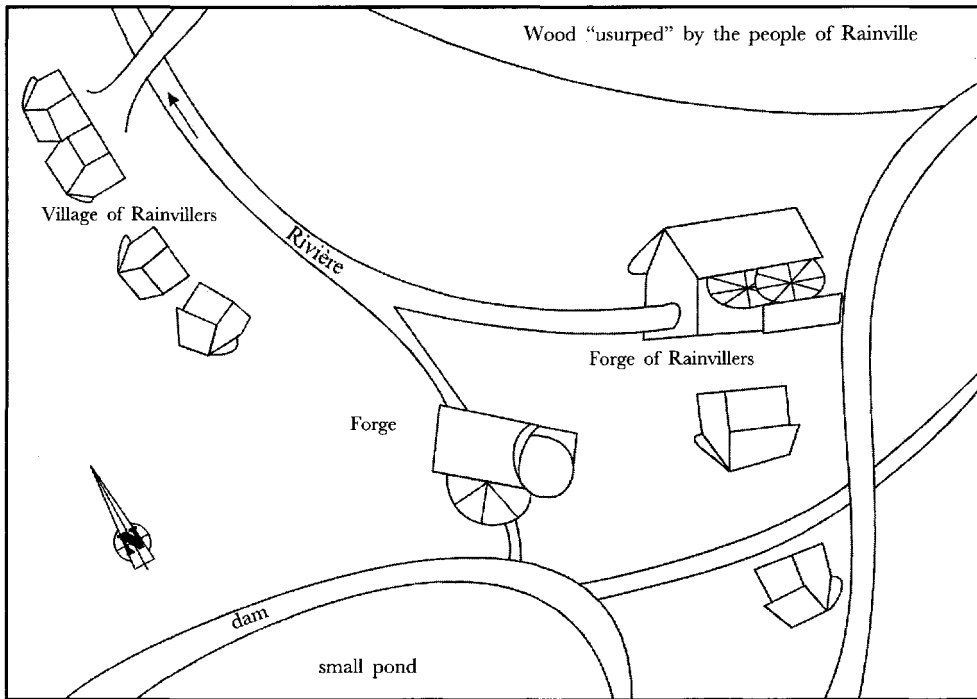


Figure 5.17. The forge and foundry of Rainvilliers according to maps of the woods of Belloy, 1508 (Arch. dep. Oise), after Belhoste (1991).

to the drop in the number of people, and by a rise in salaries which favored mechanization. Yet this development could not have taken place without a mastery of the inherited hydraulic techniques from a long, medieval evolution.

The application of hydraulic energy to metallurgy did not limit itself to the production of raw metal and the elaboration of semi-finished products. Hydraulic wheels activated hammers of more modest dimensions than those of the big forges to shape objects. A little-known development, it remains very difficult to evaluate the degree to which the mastery of hydraulic energy favored the development of differentiated metallurgical technologies. In Rouen, blade-sharpening mills functioned on the Robec, flowing from the Seine, and on an arm of that river, but were these mills simply mills to sharpen blades, or did they also have hydraulic hammers?¹²⁹ Likewise,

¹²⁹ Monteillard (1988), 109–126.

the installation of the monarchy in Tours sparked the development of an arms industry that, within several years, had risen to primary importance in France. The makers of armor and knives benefited from the mills that they possessed on creeks and streams close to the city. But we do not know anything precise about these "harness mills" (that is, mills designed to produce metallic armor, installed by Italian armor makers called upon by the king), though we can suppose they possessed hydraulic hammers, grinding stones, and other polishing equipment.¹³⁰

The production of non-ferrous metals also displayed an exceptional dynamism, even in a country like France, where non-ferrous metals, in particular precious ones, were relatively rare. Their rarity pushed people to search for rare metals at great depths. Water accumulated in these mines and posed the problem of how to pump it out. Even if these questions were first resolved in the German mines, where the subterraneous richness in lead and silver-bearing copper far outstripped the rest Europe, French miners used these techniques, as shown by the example of the copper and silver-bearing lead mine in Pampailly (Brussieu, Rhône). In this undertaking, exceptional for the kingdom of France in the second half of the fifteenth century, water brought under control by two runs on the torrential stream was conducted towards the ore treatment workshops dug into the side of the hill. The water fed the ore washing installations and the three mills for crushing the hardest minerals, and activated the hydraulic bellows of the smelting and refining furnaces. A study of the area's texts show that though ore and metallurgic techniques owed much to the German technicians employed on site, the hydraulic techniques were rooted in the local past. The same methods of dam construction with large-sized rocks roughly put together without mortar endured for centuries. The runs, established in a very simple way, dug into the rock or using natural water-bearing depressions as local conditions dictated, also passed through wooden gutters where the geography did not allow any other solutions. Such channels seem similar to those dug by peasants to supply their fields. However, the heights of the waterfalls obtained allowed the establishment of overshot wheels in order to activate the diverse utensils.¹³¹

¹³⁰ Chevalier (1974), 260.

¹³¹ Benoit (1997).

This technical and economic dynamism of the second half of the fifteenth century conquered the last resistance to innovation. Thus, in Normandy, where rural communities controlled the production of iron, hydraulic forces could never be applied to the iron works before the crisis, though this region had been a pioneer in the use of fulling mills. In the second half of the fifteenth century, the economic revival depended on nobles who no longer met with resistance in imposing new techniques. Normandy switched, thus, like a good part of France, to the blast furnace and indirect steel and metal working, which lowered costs and raised productivity by replacing the muscles of man with the energy of water.¹³²

At the moment where hydraulic energy swept through metallurgy, it gave birth to another industry in France, that of paper. The fabrication of paper required a lot of water. The rag was first set out to rot in water-filled tanks, then this paste was blended with water before the pulp was transformed into sheets on forms, after a warm-water bath. But above all, coming from China through the intermediary Arab world, the fabrication of paper adopted new techniques in Europe. The fundamental innovation consists of replacing the manual work of reducing the rag into pieces with that of a hydraulic machine, the paper mill. As with hydraulic hammers, a mill wheel activated a tree which held cams, here called *lèves*. These cams raised mallets or pestles outfitted on their exterior with iron knives which tore the rags in the wet tanks. The functional details of medieval paper mills remain poorly understood; we do not know if the iron pestles were shaped differently for each stage of treatment.¹³³

From the first appearance of paper making in the Christian West (in Italy where the Fabriano paper factories existed as early as 1276), hydraulic mills prepared the pulp.¹³⁴ The innovation penetrated into France during the first half of the fourteenth century. The first French paper mills attested to with certitude were from 1348, in the Troyes region (Aube).¹³⁵ A few years later, in 1354, letters from King John II

¹³² Belhoste (1991).

¹³³ The consumption of water to produce paper with a paper mill has been estimated. Briquet estimates that about 2000 liters of water was necessary to make one kilo of paper: quoted in Febvre, Martin (1971), 46.

¹³⁴ Blum (1935), 30. For this author, the first paper mills were found in Spain, at the turn of the twelfth to the thirteenth century, in particular in Jativa, near Valencia. The innovation thus came from Muslim Spain. Blum founded his reasoning on the water rights paid by the paper makers; Blum (1946), 18–21.

¹³⁵ Le Clerc (1926), 195.

the Good accord to the University of Paris the right to have its factories at Troyes (Aube) and at Essonnes (Essonne), a privilege which insured for decades the fortunes of these paper shops. Other regions were endowed with paper mills: in 1356, near Avignon, in 1376 at Saint-Cloud, near Paris.¹³⁶ The difference in price between parchment and paper explains this diffusion, which remains, however, limited due to the prestige of the reliance on animal skin for official deeds and the elevated price of the copyist's work. During the economic revival of the middle of the fifteenth century, printing radically modified the paper market. The 42 line bible, called the Gutenberg Bible, appeared at Mayence in the 1450s; a print shop installed itself in Paris in 1470, at the request of humanists Guillaume Fichet and Jean Heynlin. During the second half of the fifteenth century, print shops spread throughout the territory.¹³⁷ In a parallel way, paper mills multiplied, in Champagne and in other regions that until then had no knowledge of paper making. In the south-west of France, production developed in Périgord and Angoumois after 1470.¹³⁸

Hydraulics at the end of the Middle Ages replicated the traits of the earlier period, notably the importance of cities and the industrial use of energy produced by mill wheels. However, these characteristics were accentuated, and water played a determinant role in the development of innovations which heralded the arrival of modern Europe.

Conclusion

From the fifth to the fifteenth century, France largely participated in the development of European hydraulics. Water was domesticated in order to allow the development of land. Ponds, whose chronology is uncertain, spread across the surface of the countryside, protecting monastic sites and supplying countrysides and cities with freshwater fish. Mill equipment, already important in the early Middle Ages, grew considerably. People also learned to better master waterways, both those with strong flows and those with weak trickles. The hydraulic wheel, essential for grinding grain, was applied to numer-

¹³⁶ Blum (1935).

¹³⁷ Febvre, Martin (1971), 243ff.

¹³⁸ Febvre, Martin (1971), 55-58; Nicolai (1935), vol. 1, 279.

ous other uses, liberating a considerable amount of manpower, which thus allowed for gains in productivity and the elaboration of new products. At the time when the aristocracy imposed its power, castle hydraulics had to respond to the necessities of defense, either by using water as an obstacle, or creating the possibility of access to water during sieges. However, monasteries developed the most remarkable systems, both for the adduction of potable water as well as for the removal of used water. After the twelfth century, urban expansion necessitated the mastery of waters for the defense, drinking, hygiene, and energy needs of city dwellers.

Though when placed in a long chronology, the history of medieval hydraulics appears to be one of innovations of considerable import, it is more difficult to locate it in a precise conjuncture. Documents are missing which would establish the date and the place of the appearance of new techniques. However, it is certain that the period of European growth, that of clearings and demographic expansion, was also the one of new techniques, particularly in two areas, the mastery of water circulation and a better usage of energy due to the systematic use of the cam which activated hammers and pestles. But, at the end of the period of expansion, obstacles appeared. While overuse of numerous waterways limited the diffusion of new techniques, grain mills were more and more necessary to a large population. To these facts, linked directly to the possibilities of development of hydraulic potential, was added the people's resistance to innovation. People were threatened by the prospect of losing work in an overpopulated world. The crisis which struck the medieval West from the middle of the fourteenth century to the middle of the fifteenth century considerably modified this situation. The reduction in the number of people entailed a drop in the number of grain mills. When France overcame the crisis, waterfalls were available for other industrial activities at a time when the owners of water, the lords, were deriving more profit from industrial activities than land rent. Thus was opened a new epoch of hydraulic history in France.

The French case does not seem exceptional with regards to the techniques used, as they were found throughout Europe. Though it is often impossible to define the origin of innovations, it seems however that throughout the Middle Ages France was, among European countries, one of the most welcoming of new techniques, as suggested by French precocity in using fulling mills and hydraulic hammers.

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CHAPTER SIX

THE TECHNOLOGIES OF WATER IN MEDIEVAL ITALY

Roberta Magnusson and Paolo Squatriti

Technologies related to water use and management abounded in medieval Italy. Though there have been no scholarly syntheses of this subject, a composite image, made from the many specialized analyses, suggests two underlying themes. Firstly, the legacy of Rome shaped the medieval experience. Roman aqueducts, faithfully refurbished and reproduced, are only one example; underground sewers, baths, dams, and drainage canals had similar historical trajectories. Medieval people improved Roman technologies (e.g. the watermill). But whether in the simple irrigation systems of the early medieval South or in the monumental fountains of late medieval cities, the imprint of the Roman past was deep.

The second leitmotif running through medieval Italian hydrotechnologies is the presence of the state. Here too there are Roman echoes, for the collapse of Roman government in the fifth century ended large scale, centralized deployment of hydraulic engineering in the peninsula. Most early medieval governments lacked the resources, and the will, to foster hydraulic technology. Even after the dramatic demographic and economic upturn around A.D. 1000, when governmental authority grew again (and with it the capacity to harness water to human ends) no state equalled imperial Rome in its hydraulic interventions. Thus the very extensive presence of water-controlling devices in medieval Italy depended on the efforts of small-scale farmers, ecclesiastical institutions, feudal lords, or micro-states (by Roman standards), all responding to local cultural and economic pressures. When paired with the extraordinary environmental variety of the Italian peninsula, the lack of centralized power produced heterogeneous technological conditions.

The Sources

The “dark ages” are not called that for nothing. A lack of documentation for many areas of human activity, in fact, characterizes the period from A.D. 500 to 1000, with the seventh and early eighth centuries being especially obscure. Narratives of various types (letters, chronicles, and saints’ biographies) cast only dim light on the history of technology in early medieval Italy, though hagiographical literature does offer some useful illustrations of technologies in action (e.g. Pope Gregory’s *Dialogues* 3.37). Even when early medieval writers noted, in passing, the construction of an aqueduct or the presence of a watermill, none considered such topics central to their concerns: technology is a characteristically modern interest.

Legal texts are few, but Rothari’s *Edict* of 643 is important for our understanding of seventh-century milling, and Carolingian court cases occasionally show technologies at work. Monastic legislation is mute on matters of technological interest, but can be of assistance in gauging the dissemination of specific devices in the specialized and (by about 750) often wealthy monastic communities.

By far the richest sources of information on hydraulic and technological subjects are Italy’s many early medieval charters. These survive most copiously for the period after about 750. Generally such contracts record exchanges of property and often do so with precise, detailed descriptions, including references to aqueducts, cisterns, mills, ditches, and other hydraulic installations. Charters survive from many places, but the early medieval collections from Ravenna (invaluable for the sixth–eighth centuries), Piacenza, Milan, Lucca, and southern Campania are especially large and continuous. Yet these excellent sources too have limitations. Most charters deal with rural property, obscuring urban realities, and the people who wrote and used charters were not always socially representative. The surviving charters represent the archival and economic interests of specific clerical communities (those that kept the documents) both at the time of the charters’ redaction and afterwards. Therefore, the charters present a partial (in every sense) view of the world and its technologies.

Medieval archaeology is now flourishing in Italy, but has not yet produced data to illuminate the peninsula’s technological history decisively. Both ecological factors and socio-cultural ones explain this failure. The absence of evidence on mill sites (in contrast, say, to Ireland) is partially explicable by Italian stream regimens. Flash floods

and unstable flow sweep away evidence, and have been doing so for centuries. Italy, in addition, has no peat bogs to preserve wood structures of mills, nor modern users of the bogs to uncover remains. Furthermore, archaeologists have focused energies on urban sites, a preference that mirrors the predilections of Italian historians. Continued habitation in these sites complicates many excavations in which time constraints urge diggers to reach lower, more splendid levels, without careful evaluation of early medieval ("dark earth") traces.¹ However, archaeological data seem destined to increase in scope and relevance. Early signs of this have been excavations in Brescia, at Fiesse, Reggio Calabria, and Rome, as well as field surveys in the Biferno and other inland valleys.²

References to hydraulic structures and projects are much more abundant in the Italian high Middle Ages than they had been in the early medieval period. In part, this is due to the great proliferation of documents issued in this period, and their better preservation in archival collections. Nevertheless, the sources suggest a sharp increase in hydraulic activity: from the twelfth century on, hydraulic projects became increasingly common, and a much greater degree of interest was taken in related issues such as water law and sanitation.

Charters continue to provide a wealth of information about hydraulic installations and associated water rights for after A.D. 1000. Increasingly, however, the charter evidence can be supplemented by civic records from Italian communes. Municipal archives preserve petitions, proposals, and council debates concerning hydraulic projects. These are particularly useful sources for the analysis of adoption decisions and system administration. Financial accounts provide detailed evidence for construction, maintenance, administration, and costs associated with hydraulic projects. Some include the names of master craftsmen, workmen, occupational specialties, wages, and specific tasks; others record the purchase and transport of materials, and information about tools. The specific dates in these records permit calculations of the lengths of time needed for various operations. Communal registers and property inventories have allowed statistical studies of mills.

High and late medieval law codes and legal commentaries include specific provisions concerning water rights and sanitation. Civic statutes cover construction, oversight, use, and maintenance of hydraulic

¹ See Ward-Perkins (1996) for criticism of archaeological practice.

² Barker (1995); Sagui (1993); Brogiolo (1992); Spadea (1991); Perini (1983).

structures, and include measures governing urban hygiene. Court records and fines provide evidence for hydraulic infractions and disputes about water.

Later medieval narrative sources such as annals, chronicles, *vitae*, and *gesta* occasionally include hydraulic references, as do laudatory descriptions of cities by authors such as Bonvesin da la Riva and the Anonymus Ticinensis. Literary works, such as Boccaccio's *Decameron*, contain useful descriptions and can reveal underlying social attitudes. But in such sources hydraulic references may be symbolic literary devices rather than straightforward descriptions of everyday life. Likewise, depictions of fountains and other hydraulic structures in drawings and paintings may be closely modeled on existing structures, or may be fanciful symbols.

Physical remains of some urban and monastic water systems survive, as do some medieval aqueducts, canals, and dams. A number of medieval fountains are still in use. Though often subject to later modifications, these are excellent sources of technical information. The symbolism of fountain decoration provides clues to the attitudes and political agendas of their sponsors, as do inscriptions. When more precise information is lacking, style can serve as a rough guide to the date of construction.

Though there are disagreements among specialists in various scientific fields producing and analyzing data on past climates, it is clear that shifts in climate, and especially in temperature averages and precipitation levels, form a crucial backdrop against which to understand the technologies of water management. The image currently accepted for Italy's early medieval climate is a bipartite one. From about A.D. 400 to 750, glaciers in the Alps suggest a climate colder by as much as 1.5 degrees Celsius than today's, with greater precipitation than customary in the past 200 years. After about 750, however, a rapid warming occurred so that average temperatures were even 2 degrees higher than modern ones and precipitation dwindled (snowlines were 150–200 meters above contemporary ones, and so were treelines).³ While there are seldom simple cause-effect connections between climate (rather than weather) and historical developments, including technological ones, and while human agency (in the form of settlement patterns and deforestation) has considerable impact on stream regimens, the abundant and disordered flow of many

³ Pinna (1990), 434–42; see also Duby (1973), 16–9.

Italian water courses during the postclassical centuries should be kept in mind when considering the deployment of irrigation, drainage, and milling technologies.⁴

Further climatic changes began to affect Italy by the end of the thirteenth century. Alpine glaciers began to expand, and excessive rainfall amounts during several years in the early fourteenth century led to famine and the accelerated erosion of topsoil. As some marginal lands were abandoned, more intensive efforts were made to cultivate productive fields.⁵ It is possible that natural agencies, such as movements of coast levels, contributed to the problems of late medieval alluvial deposition and the obstruction of ports and lagoons⁶ (figure 6.1).

Flood Control

Early medieval techniques of flood control were limited by the inability of most governments to organize manpower throughout entire catchment basins. Earlier, Roman rulers had manipulated their more humanized landscape more extensively. Several rivers in Roman Italy had artificial embankments to contain spates, and were routinely dredged too. But it is unwise to exaggerate Roman control of the peninsula's hydrology.⁷ Floods could sweep through imperial Rome itself, occasioning only despondent offerings to the river god.⁸ Thus, the limited strategies of flood control employed by early medieval people are part of a continuous tradition of human vulnerability.

In the postclassical period lower population levels, fragmented, weakened political authority, and perhaps heavier rainfall (mitigated by denser plant cover and hence healthier watersheds) all affected flood control. But even in the early seventh century Byzantine authorities could muster the resources needed to dig small canals (in Luni) and a large canal in the Po delta; a century later Lombard kings also seem to have been able to perform such feats further upstream.⁹

⁴ A powerful critique of "climatic determinism" is Bintliff (1992), 125–7.

⁵ Zupko, Laures (1996), 92–93.

⁶ Jones (1966), 365.

⁷ Purcell (1996), 180–212.

⁸ Le Gall (1953a), 29–32; Le Gall (1953b), 62–4. Tacitus, *Annals* 1.76, 1.79 gives famous anecdotes.

⁹ Frova (1977), 89 on Luni; Tozzi, Harari (1984), 90–104 on Heraclea; "Schede 1985," 476 on Lombard Modena.

Late in the eighth century Pope Hadrian I (772–95) repaired the Tiber embankments to secure St. Peter's and Castel S. Angelo from the river's waters, replacing the officials who had overseen such works in ancient times and were still active in 554.¹⁰ Similarly, early medieval Ravennans seem to have excavated artificial beds and maintained sluices on the city walls to regulate water levels in urban canals at times of exceptionally high flow.¹¹ Thus while some projects to restrain and redirect flow were carried out before A.D. 800, compared to the Roman period the number and scope of such projects declined. No-one seems to have tried to co-ordinate land use and hydrology over entire watersheds.

The lessened impact of man-made structures on Italy's hydrology was one aspect of a new balance between people and water resources. Early medieval people accepted a more "natural" hydrology, and their unregulated river basins functioned as sustainable flood control mechanisms. Riverine marshes absorbed floods, which were probably less violent and frequent because of denser plant cover in most watersheds. As people moved dwellings to higher ground the new relationship with the waterways was forged; it began to fall apart only in the tenth century, when growing population increased pressure on land resources and authorities became willing and able to interfere radically with the waterscape.¹² The technologies of flood control in the period between 500 and 1000, therefore, were attuned to economic, social, and cultural needs.

River flooding was a perennial concern, and, in the high Middle Ages, flood control was attempted by regulating the flow of water in river beds and ditches, and by the creation of dikes and embankments. Many cities had regulations about keeping rivers and ditches clear of debris, without obstruction. Siena established various commissions to tackle inundations: a frequent recommendation was to straighten stretches of the riverbed.¹³ Spoleto re-channelled the waters

¹⁰ See Pani Ermini (1992), 500; Krautheimer (1980b), 111. The papal effort represents a technological response to the most famous flood of early medieval history, in 589–90, which was (and is) considered a sign of the dire times (see Gregory of Tours, *Histories* 10.1; Gregory, *Dialogues* 3.10 and 3.18; Paul the Deacon, *History of the Lombards* 3.23–4). See Vieliard (1954), 122 on the *curatores alvearum*.

¹¹ The same mechanisms used for defense.

¹² Fumagalli (1967), 139–42; Fumagalli (1980), 27–8; Fumagalli (1988), 32–3, 50–8.

¹³ Bowsky (1981), 196.

of the Saletto into a new course following a devastating flood, and restored the water of the Tesini to its former bed when it left its course.¹⁴ Earthworks were built to contain flood-prone rivers within their banks: Dante (*Inferno* 15, 7–9) refers to Paduan embankments along the Brenta built to protect their towns and castles. Ferrara built an extensive system of dikes to regulate the Po, regulated by a “judge of the embankments.” The Ferrarese embankments had extensive legal protection against tree roots, debris, and illicit removal of their materials.¹⁵

The Arno periodically swept away Florentine bridges and river-side structures. Following a severe flood in 1333, steps were taken to repair the embankments, and the rebuilding of mills or other obstructions was forbidden in stretches of the river in or near the city. Opportunistic landowners undermined the commune’s attempt to control flooding, however, by encroaching on the riverbed when rebuilding the embankments.¹⁶

Some cities sought to control the deposition of river-borne silts by deliberately channeling the floodwater of their rivers. The Pisan statutes of 1162 called for the banks of the Arno to be broken when the river was high, to protect the city and allow the waters to deposit their sediments on the surrounding plain. In lower Venetia, there is evidence for controlled alluviation in marshy areas from the middle of the twelfth century.¹⁷

Charters document small dams, built to impound water for mills, such as those built in the vicinity of Florence in the eleventh and twelfth centuries, but their structural characteristics remain obscure.¹⁸ A Roman reservoir dam near Subiaco apparently survived intact until 1305 (when two monks caused it to collapse by incautiously removing some of its stones), but it does not seem to have inspired any medieval imitations.¹⁹ A few large dams were built in northern Italy as diversion dams to feed canals, not for flood control (except inasmuch as the canalization of water in the plains contributed to that end). The dam of Ponte d’Archetto was built c. 1176 to divert the entire volume of the Nerone through the urban watercourses

¹⁴ Zupko, Laures (1996), 68.

¹⁵ Zupko, Laures (1996), 69–70.

¹⁶ Parsons (1939), 324–325.

¹⁷ Jones (1966), 358.

¹⁸ Muendel (1981), 86.

¹⁹ Smith (1972), 28–29, 150.

and sewers of Milan.²⁰ Milan also built dams to feed its expanding network of irrigation canals. The first was constructed as part of the Naviglio Grande canal project. Repeated rebuilding over the centuries has obscured the original twelfth-century structure, but, like the present dam on the site, it apparently lay obliquely across a bend in the Ticino. The dimensions of the medieval dam may have been roughly equivalent to those of the present structure (270 meters long, 10–20 meters thick). A thirteenth-century dam was built obliquely across the Adda at Cassano, to feed the Muzza canal. In its present form, it has a length of 330 meters. Additional diversion dams were built to supply Milanese irrigation canals on the rivers Sesia, Ticino, and Dora in the fourteenth and fifteenth centuries.²¹

Apart from Milan's dams, the oldest large medieval dam in Italy was built near Cesena, around 1450, across the River Savio. It is a straight gravity dam (length 70 meters, width at base 15 meters), built of mortared bricks bound in a framework of wooden bars and oak poles, and supported by brick abutments. The water flows freely over the top of the structure across a sloping, 12-meter air face, finally dropping vertically to the level of the foundations below. The dam supplied water to a canal and mills.²²

Land Drainage

Draining soil for agricultural use continued throughout the early medieval centuries, but the evidence is best after A.D. 800 (as it is for most areas of human endeavor). The techniques involved were simple and could be organized locally, by peasants. Small-scale drainage schemes, different from the vast centrally-planned networks of Roman times, were important to cultivation, as the willingness to dig and keep up ditches testifies.²³ Drainage ditches led surface runoff into natural channels, curtailing erosion, and lowered the water table, facilitating root growth and soil workability: hence their laborious upkeep was worthwhile to cultivators. All relied on gravity flow.

²⁰ Smith (1855), vol. 1, 198.

²¹ Smith (1972), 150; Smith (1855), vol. 1, 246.

²² Smith (1972), 151–152.

²³ On Roman drainage, Potter (1981), 11–6; Potter (1986), 141–50; Leveau (1993), 3–16. Traina (1988) covers Roman actions against wetlands. But not all Roman drainage depended, Wittfogelianly, on the state: Thomas, Wilson (1994), 190–1.

Depending on the locality, early medieval drainage ditches could be either surviving Roman structures or new ones. Both lords concerned for "improvements" and peasant initiative created the networks; local ecology, social conditions, and the time period (lords became more interested in productivity in late Carolingian times and, for example, contracts from the area of Ravenna begin to impose ditch upkeep on cultivators in the late 800s) determined who took the lead.²⁴

A major drainage scheme, perhaps community-based in origin, appears to have refashioned the plain southeast of Lucca in the sixth century, and thereafter charters describe a landscape criss-crossed by drainage channels.²⁵ Elsewhere in Italy, most of the evidence comes from after 800 and indicates gravity flow drainage ditches were normal in humanized landscapes. Charters mention these furrows especially in delineations of property, as borders between two farms, suggesting that more than one proprietor was involved in maintaining the ditches.²⁶ Sometimes hedges lined them, to firm their sides and limit erosion, or walls, and around Piacenza, in the ninth century, some ditches seem to have been linked to simple retention dams to check the velocity of flow.²⁷ That digging and repairing ditches was altogether unremarkable is confirmed by the inclusion of these activities in Lombard royal legislation from the early eighth century.²⁸

The drainage of wetlands was part of the high medieval agricultural expansion at the expense of woodland and marsh. This process was accompanied by the internal colonization of "new" lands and the creation of new rural settlements, with contracts for leases often containing terms that promoted land reclamation. The main impact of the hydraulic *bonifiche* was in the plains and low-lying areas of northern Italy, but the process was slow, sporadic, and uneven: many coastal areas remained marshy well into the early modern period. Nor was success uniform—some attempts at drainage outstripped the technical expertise of the cultivators, and fields reverted to swamps.²⁹

²⁴ See Squatriti (1998), 76–9. Toubert (1990), is the strongest advocate of manorialism as technological catalyst.

²⁵ Squatriti (1995), 22–8; Elmshäuser (1992), 5.

²⁶ Squatriti (1998), 78.

²⁷ Hedges: Squatriti (1995), 26–9; Menant (1993), 172–3. Walls: Martin (1993), 84–7, 395. Dams: Galetti (1994), 121.

²⁸ Bluhme (1868), 174.

²⁹ Bacchi (1988), 187–198; Braudel (1972), vol. 1, chap. 3; Jones (1966), 354–359.

The main weapons in the battle to reclaim the wetlands were ditches, drains, and canals. The process was frequently the result of collaborative efforts, and was necessarily accomplished in stages, as new branches were able to take advantage of existing networks. Between the eleventh and thirteenth centuries, many of the lowlands in the Po valley were diked and drained.³⁰ In Lombardy, the embankment of rivers and the construction of dikes and canals opened important new areas for cultivation, and some Tuscan drainage projects allowed hilltop villages to be abandoned as their inhabitants moved into valley bottoms.³¹ In the plains of central Italy, the first diffusion of *magolato*, the systematization of fields by means of parallel ridges separated by drainage furrows, occurred in the high Middle Ages. The furrows drained away excess water during the wet season, and represented an advance over the earlier lack of any system of soil drainage, even though they accelerated the loss of soil moisture during the dry season.³² In the thirteenth century Pistoia channeled and controlled the water in its marshy plains, while Prato undertook the canalization of the Val di Bisenzio. The commune of Siena supported private landholders who wished to reclaim marshlands with drainage ditches and canals, and encouraged a company to undertake land improvements in the Piano del Padule d'Orgia.³³ Land reclamation projects also extended the Venetian hinterland by late medieval times.³⁴

In order to increase the productivity of their estates, many churches and monasteries likewise undertook hydraulic systematization projects. Ecclesiastical landlords drained wetlands in Tuscany and the Po Valley from the late tenth century on. By the mid-eleventh century, Nonantola's peasants maintained river banks to control flooding.³⁵ In the twelfth century, the Cistercian order began to play an active role in land clearance and reclamation. Chiaravalle Milanese, Tre Fontane, and Fossanova attacked marshes. Cistercian monks were also engaged in the creation of irrigation networks of ditches and *rogge*, irrigated water-meadows, and the establishment of fishponds.³⁶

³⁰ Luzzatto (1961), 98.

³¹ Lerner (1980), 163.

³² Sereni (1997), 122–124.

³³ Bowsky (1981), 195–196; Balestracci (1990), 21–22.

³⁴ Braudel (1972), vol. 1, 78–79.

³⁵ Jones (1966), 358.

³⁶ Tosti-Croce (1993), 47–55; Castagnetti (1977), 54–60.

The impact of such works was summed up by the provost of Mantua cathedral, who noted in 1233 that in less than a century the cathedral's lands had been "cleared, plowed, redeemed from wood and marsh, and converted to the production of food".³⁷

By the late Middle Ages, the spread of cultivation in the hills was creating hydraulic problems. Deforestation, overcropping, overgrazing, and the vertical plowing of slopes all contributed to soil erosion, which may have disrupted the stream regimens of the valleys and lowlands. The agronomist Pier de' Crescenzi disapproved of hillside fields with furrows running down, rather than across, the slope; this practice accelerated soil erosion but continued to be utilized. Some imperfect attempts were made to address the hydraulic problems posed by the increasing deforestation of hillsides; rough terraces were employed to prevent erosion from running water, and in some cases traverse ditches or drains were associated with hillside fields.³⁸

Yet rivers in Emilia were becoming more irregular and difficult to control and, in the Po plains, along the Tyrrhenian coast, and along the Adriatic, ports and lagoons became obstructed by sediment. Swamplands increased while fields and settlements were abandoned. Malaria appears to have become more acute and widespread. These changes may have been partly due to natural agencies, such as climatic deterioration or changing coast levels. To some extent, however, they may have resulted from overly zealous land reclamation efforts in the high Middle Ages, combined with a failure to maintain hydraulic works in the aftermath of the Black Death.³⁹

Moats and Canals

The technologies of water captation, derivation, and storage were useful to embattled communities throughout the postclassical period. Considerable ingenuity was lavished on moats. Lucca, prosperous and vulnerable because located on a major north-south highway, had water-filled moats on its north and east walls by the ninth century.⁴⁰ In part these took advantage of deepened and widened natural stream

³⁷ Quoted in Luzzatto (1961), 99.

³⁸ Sereni (1997), 98–100, 110, 121.

³⁹ Jones (1966), 365–366.

⁴⁰ Belli Barsali (1973), 473. The evidence is documentary.

beds. In very aqueous environments like the Po delta, relatively simple excavations formed new beds for extant watercourses, or filled with groundwater to isolate communities like Heraclea and Ravenna from the terra firma. Heraclea's water defenses date to the seventh century, but Ravenna's, which are also datable to roughly that time, continued to be adjusted into the 800s.⁴¹ Hydraulic technology appears to have been part of Duke Arechis of Benevento's (d. 788) new "capital" at Salerno. Moats, as well as the sea and an imposing hill, enhanced Salerno's security, although those the charters record probably date to after Arechis' death.⁴² By the tenth century Salerno's moats could fill with the waters of the S. Eremita and Rafastia torrents, and their level could be controlled with gates. These lay open in times of peace, drawing water into urban canals that flushed the city of refuse, but in perilous times could be shut to fill the trenches on Salerno's weaker east side with water.

Certainly the Salernitan hydraulic installations were more elaborate than most. The ninth-century archbishop of Milan Anspert, who restored a late antique moat around his city, seems not to have employed regulating gateways.⁴³ Yet *fossata* became standard equipment of even tiny fortified settlements in the north of Italy during the tenth century. Such defensive ditches recommended themselves in unstable times in areas where building stone was scanty, the soil easy to dig, and water abundant. Often the builders of the *castelli* used the removed earth to construct ramparts, surmounted with palisades, but in the central Po valley the first and basic defense was the simple moat.⁴⁴

Though a north Italian charter refers to a "channel for carrying ships" in 852, it was during the high Middle Ages that such artificial waterways developed fully. Communes built ambitious networks of urban watercourses and long-distance canals, a process that peaked in the Renaissance.⁴⁵ Canals served a variety of purposes, many of which contributed to the economic development of the cities and their hinterlands. Irrigation and drainage canals improved agricul-

⁴¹ Tozzi and Harari (1984), 55–9, 102; Fabbri (1975), 14–35; Christie (1989), 130–3. Sidonius *Letters* 1.5.5 offers a description from the 460s.

⁴² Bertolini (1962), 71–8 sketches Arechis' career. See also Delogu (1977), 18–41; Amarotta (1982), 175–88.

⁴³ Chiappa Mauri (1984), 72.

⁴⁴ Menant (1982), 205–16.

⁴⁵ Elmshauser (1992), 3.

tural productivity in the urban hinterland. Canals drove grain and industrial mills, providing a more reliable source of water for mill leats than the unpredictable Italian rivers. Lombardy saw the early construction of navigable canals, and the development of the lock in late medieval times allowed some irrigation canals to be enlarged for shipping.⁴⁶ Inland cities like Milan linked themselves to long-distance commercial networks by means of canals, while Cremonese merchants built the Taleata canal to evade the tolls imposed on Po shipping by their rivals at Mantua.⁴⁷

In addition to these direct economic benefits, channelled waters contributed to a city's defense by filling moats and, within the walls, a latticework of channels brought a supply of water to urban residents and artisans, and bore away waste products and sewage. Cities such as Padua, Ravenna, and, of course, Venice had elaborate networks of urban watercourses, composed of both natural and artificial channels.⁴⁸ But Milan was the celebrated center of hydraulic engineering.⁴⁹ By the year 1100, Milan was served by several urban watercourses, with artificial channels diverting local streams into the city. Some ancient channels had already been re-utilized and extended. The impetus for more ambitious hydraulic engineering, however, seems to have come from the unsettled political situation in the mid-twelfth century. The reconstruction of the city defenses, after Milan's destruction by Emperor Frederick I in 1162, included the construction of a moat which measured some 6 kilometers in circumference, and was 18 meters wide. The new moat was originally supplied by local streams, but when these proved unsatisfactory, Milan attempted to supply it with water from the Ticino River, which lay over 25 kilometers away. The new canal linking the river to the moat, originally called the Ticinello, would later be known as the Naviglio Grande. The exact dates of its construction are uncertain: work seems to have begun in either 1177 or 1179. Certainly by 1209 it had reached the gates of the city.

Originally intended to supply the moat, the Naviglio Grande soon came to be used for irrigation and to power mills. In 1269 its bed

⁴⁶ Parsons (1939), 367.

⁴⁷ Baird (1986), 491.

⁴⁸ Bortolami (1988); Fabbri (1975); Pavan-Crouzet (1990), 32–54.

⁴⁹ For the following discussion of Milan's hydraulic works, see Smith (1855), vol. 1, 196–208; Parsons (1939), chap. 22; Payne (1959), 64–66; Chiappa Mauri (1984), 71–77, 87ff.; Fantoni (1990).

was enlarged and deepened. According to a late sixteenth-century description, the width at the mouth was 75 *braccia*, narrowing to 25 *braccia* at the city gates (one Milanese *braccio* = 0.6 m). At the head, the downstream bank was protected by stone blocks, and then by a palisade of wooden piles for several kilometers. Along the remainder of the canal, the banks were flanked by earthen dikes built of the spoil from excavating the channel. The gradient of the channel bed was slight, with a maximum slope of 1:1100, so that the velocity of the current remained moderate. To prevent flooding, escape-lines discharged excess water into natural drainage channels. The escape at San Cristoforo, for example, took advantage of the old bed of the Olona River, which had been abandoned when the Olona was diverted into an artificial channel. In the late sixteenth century, there were six such water reliefs, fitted with thick walls and wide doors.

By the 1270s, the Naviglio Grande was being used for shipping. During the construction of Milan's cathedral, which began in 1385, its waters transported stone from the quarries by Lake Maggiore. At first the stone was unloaded at wharves outside the city gate, but the construction of a new branch canal made it possible to bring the stone to the building site. However, differences in the water level between the Naviglio Grande and the intramural watercourses created a problem. A crude lock, consisting of a single gate raised and lowered by pulleys, was built. When the gate was closed, the water on either side slowly reached the same level, and then the gate would be raised to allow boats to pass through. To reduce the chance of dangerous fluctuations in the water level, the diversion of water for irrigation or mills was banned when the lock was in use.

Milan's merchants appreciated the advantages of a linked intra- and extramural transport network, and they soon demanded the same shipping privileges enjoyed by the Cathedral works. Increased traffic on the waterways then led to demands for technical improvements which would permit continuous navigation on the canals without the withdrawal of water from irrigation channels and mills. The development of the double-gated canal lock, which may have appeared in the early fifteenth century and is well documented by the 1450s, created a more efficient means of overcoming differences in water levels. This meant that several irrigation canals, which had previously had gradients too steep for shipping, could be made navigable by the installation of locks. Further refinements in lock design

allowed canals to be constructed in a broader range of topographic zones during the later fifteenth and sixteenth centuries.⁵⁰

Milan's Naviglio Grande was not unique. The Padova-Monselice canal, which was completed in 1201, was 18 kilometers long and took eleven years to build.⁵¹ Cremona's Taleata canal was over 90 kilometers in length.⁵² Milan itself began the construction of the Muzza canal, which derived its water from the Adda, in 1220. In 1359 a canal linking Milan with Pavia was begun. From Lombardy, the techniques of canal engineering spread west to Piedmont, where a number of canals were built in the fourteenth and fifteenth centuries.⁵³

Canal construction could take years, and caused considerable disruption. The thirteenth-century chronicler Salimbene described the damages inflicted on the countryside during the construction of the Taleata canal: "This canal was of great profit to the Cremonese, though it caused much damage to the people of Reggio because of the loss of fields, vineyards, and houses. The Taleata stretches all the way to Primaro, and it submerged and destroyed many villages, where before, there was an abundance of grain and wine".⁵⁴ However, once finished, the inhabitants of the farms and villages benefitted from the canals, whose water irrigated fields, powered mills, and, as Salimbene points out, in at least partial compensation for the villagers' loss of grain and wine, "there is now a good supply of fish".

Irrigation

Irrigation was not a vital agricultural practice in early medieval Italy. It had not been in classical times either, for rainfall patterns and terrain make much of the peninsula unsuited to large-scale irrigation. Thus, in this area technological know-how was far less of a constraint than were other human and natural factors. In special environments, where gradients and perennial sources of water permitted, and there existed both the spare labor needed to manage irrigation

⁵⁰ Parsons (1939), 368, chap. 23; Payne (1959), 66ff.; Fantoni (1990), 34–39.

⁵¹ Bortolami (1988), 301.

⁵² Baird (1986), 661 n. 24.

⁵³ Smith (1855), vol. 1, 100–102.

⁵⁴ Baird (1986), 491–492.

channels and markets hungry for the surplus irrigation made possible, small-scale irrigation systems arose. Thus, early medieval Italians sometimes watered their crops in the open countryside. The location of farms close to, alongside, or "in" major watercourses, and the formulas including water rights in land exchanges, suggest this; the presence in the tenth-century landscape of lowland Lombardy of special water-bearing channels confirms it.⁵⁵ In the south there are signs that during the ninth century near Venafrò, in the floodplain of the Volturno and Rava rivers, farmers dug, maintained, and used irrigation channels, and took turns drawing water into their fields.⁵⁶ On the other, drier side of the Apennine watershed Apulians also made and used small networks of channels leading water to farmed land.⁵⁷ Such irrigation systems depended on gravity flow to derive water from natural courses and spill it on cultivated land before it drained out into another channel and, eventually, reverted to a natural bed. There is sparse evidence for sluices and regulatable barrages. Irrigation ditches were earth dug, unlined furrows open to the skies, sometimes accompanied by plants whose roots solidified the sides, avoiding erosion.

Arab and Maghrebi settlers did not, therefore, introduce irrigation to Italy in the ninth and tenth centuries, though some specialized crops they favored (citrus trees, rice, spinach) benefitted greatly from their knowledge of irrigation techniques.⁵⁸ The spread of the new crops and associated irrigation techniques was slow and uneven, difficult to chronicle with precision.⁵⁹ For example, citrus orchards and roses first arrived in Amalfi during the thirteenth-fourteenth century, where their appearance was linked to substantial investments in irrigation works for orchards and gardens, but such cultivations may have been known elsewhere earlier.⁶⁰

There are few signs that early medieval irrigators used water-lifting devices (norias or "Archimedean" screws) to raise water onto their soil. However, since many artificial reservoirs lay close to or in lands dedicated to agriculture, we may presume that some irrigation from

⁵⁵ Menant (1993), 183–93; Schwinekoper (1977).

⁵⁶ A handful of charters from S. Vincenzo al Volturno suggest this: Squatriti (1998) 94–5.

⁵⁷ Martin (1993), 74–7.

⁵⁸ Sereni (1997), 72–3; Watson (1995), 63–6.

⁵⁹ Watson (1974), 8–35.

⁶⁰ Del Treppo, Leone (1977), chap. 2.

cisterns and wells took place, aided by pulleys and swipes. This is very likely in the case of vegetable gardens, often associated with artificial reservoirs in charters. Even during the high Middle Ages, when irrigation became more widespread, evidence for water-lifting devices in Italy remains scarce. The use of the shaduf in conjunction with wells seems to have been common only in some rural areas, such as Liguria, at the end of the period.⁶¹ Pulleys and windlasses were probably also employed to raise well water. More complex hydraulic contrivances, such as water-screws, force pumps, and water-lifting wheels, do not appear to have played a prominent role. Given Roman expertise with such devices, and the Muslim heritage in the south, the apparent dearth of complex water-lifting machinery in medieval Italy is surprising.⁶²

Even without elaborate water-lifting machines, after 1000 Italy witnessed an intensification of irrigation. Throughout most of the peninsula, topography made large-scale projects impracticable, but modest channels could be fed by local streams, well-cisterns (*pozzi cisterne*), or small reservoirs, serving mainly as a seasonal back-up during the drier months. These small irrigation works permitted an intensification of cultivation in privileged areas supplying growing urban markets in the high medieval period, and allowed some tracts of marginal land to become productive.

Horticulture was a privileged agricultural activity, dear to peasants because its products were practically exempt from landlords' exactions, and dear to everyone (including urban residents, who also owned *horti*) for the essential foods it furnished. References to "irrigated gardens" in documents from diverse times and places suggest that cultivators dedicated their work and resources to *horti*, the prime

⁶¹ Bellatella (1989), 381–383.

⁶² Schioler (1973); see also Oleson (1984); Al-Hassan, Hill (1986). Still, the fifteenth-century drawings of Mariano Taccola of Siena exhibit a fascination with ingenious hydraulic devices, including various lifting-devices and pumps (like the sack pump, the solid ram pump with cannellure, the suction lift pump proper, and the suction lift hollow tube ram pump). Taccola himself may have been the inventor of the ram pump, and he drew the first known representation of the suction lift pump. It is not clear to what degree his hydraulic drawings represent working Italian structures, however. The continued prominence of hydraulic contrivances among the mechanical wonders portrayed in the popular Renaissance "machine-books" (*theatrum mechanorum*) reinforce the impression that this type of device, while becoming familiar to an educated few, was still considered new and exciting in the post-medieval period. See Hollister-Short (1993).

irrigated lands.⁶³ Cities of the high Middle Ages typically had heavily irrigated market gardens in their immediate hinterland, and some had intramural gardens as well. In Salerno, water from the river Irno irrigated the gardens which produced vegetables, citrus fruits, and cucumbers, and a similar situation prevailed near Saluzzo.⁶⁴ Viterbo had an intricate network of ditches used for irrigating gardens and driving mills. Some of the irrigation channels were elevated, crossing over topographical irregularities on a bridge.⁶⁵ Other conduits supplied urban industrial demands. In 1295, the citizens of two of Orvieto's *contrade* were permitted to draw irrigation water from the river to cultivate hemp (later, however, they appealed for permission to build a channel so as to control the flooding their irrigation caused).⁶⁶ In addition to hemp and flax, dye plants such as woad, saffron, and madder were cultivated.⁶⁷

One area which witnessed the development of large-scale irrigation projects after 1000 was the Po valley. The Po itself was unsuitable as a feeder for medieval irrigation canals, for the river flows at right angles to its many tributaries, and canals derived from it would have had to cross multiple streams. Medieval engineers could build a canal across watercourses, but at prohibitive cost. Consequently, the great irrigation canal systems built by cities such as Milan drew their water from the Po's tributaries, such as the Ticino and the Adda, while the Po itself served to carry away excess water.

The zone of the most ambitious irrigation works was the Po's left bank. The tributaries on this side of the river have their ultimate sources in the snowfields of the Alpine ranges, and attain their maximum volume in summer, the season when irrigation water is most needed. In contrast, the tributaries on the right bank, which are not fed by permanent snowfields, suffer a decreased flow in the summer months. Although the streams of the right bank were intensively exploited, particularly in Piedmont, their irrigation works remained more limited and local.⁶⁸

The large canals of Northern Italy fed many smaller, secondary irrigation channels. Water entered these *rogge* through an aperture

⁶³ See Montanari (1979), 22–7, 309–36; Sereni (1997), 70; Squatriti (1998), 80–3.

⁶⁴ Matthew (1992), 83–84; Gabotto (1901), lxiv.

⁶⁵ Lanconelli (1992), 23–4, 32–3.

⁶⁶ Riccetti (1992), 143.

⁶⁷ Jones (1966), 370; Riccetti (1992), 143–144.

⁶⁸ Smith (1855), vol. 1, 84–85.

(*bocca*) in the canal bank. The *roggia* was designed to discharge the surplus water back into the main canal further downstream.⁶⁹ The amount of water permitted irrigators was prescribed by the terms of the grants which they obtained, though in all probability cultivators were not above illicit diversions when canal supervision was lax, as in the case of Milan, whose Naviglio Grande canal appears to have been poorly supervised, with various diverting dams encroaching into the main channels, to funnel water into the *rogge*. These barrages impeded navigation and diverted too much water from the main canal. During the thirteenth and fourteenth centuries, measures were taken to remove the diverting dams and restrict the number of places where the water could be tapped.⁷⁰ Rectangular outlets of fixed dimensions were prescribed by statute: they were to be four Milanese inches high by 18 inches wide, and their sill was to be eight inches above the bed of the canal.⁷¹ In spite of attempts to tighten up oversight and regulation of the outlets, little permanent progress seems to have been made. An inquiry into the state of the *bocche* in 1574 revealed that all the old outlets were poorly constructed. Most were of wood, or of poor quality masonry. The discharges were irregular, but almost always in excess of the limits prescribed in the original water grants.⁷²

In the high Middle Ages advances were made in the irrigation of meadows, a practice which would be more extensively developed in the Renaissance.⁷³ By the thirteenth century, meadows in Lombardy were irrigated by letting a sheet of water run over the meadow during the winter to prevent freezing. This permitted the grass to be cut even during the season when forage was most scarce. The practice made it possible to sustain more animals over the winter months, and contributed to the increasing importance of livestock and dung in late medieval and Renaissance agriculture. In irrigated areas of Lombardy, dairy cattle supported an important industry whose products had wide market dissemination.⁷⁴

Irrigators were often obliged to share a limited resource. Not only did other cultivators also require access to water, but the same water

⁶⁹ Fantoni (1990), 46.

⁷⁰ Parsons (1939), 368.

⁷¹ Smith (1855), vol. 1, 206.

⁷² Fantoni (1990), 50; Smith (1855), vol. 1, 248.

⁷³ Jones (1966), 359, 383.

⁷⁴ Sereni (1997), 133–134; Jones (1966), 383.

source was often required for other uses, such as driving mills. In Orvieto the water allowed to citizens for irrigating their *orti* was only available on days when the mills were not in operation.⁷⁵ The Viterbo statutes of 1251–52 cover the election of four *boni homines* to supervise the division of irrigation water among the city's *orti*.⁷⁶ In the fourteenth century, supervision of the distribution of Viterbo's irrigation water fell to the *ortolani*, who issued their own statute in 1358 (and again in 1471).

The goal of Viterbo's complex distribution system was to provide equitable access to a limited resource. The water was discharged in turn to individual proprietors in accordance with a set *rota*, with fixed periods of time between the ninth hour on Friday and the third hour on Monday. During the remainder of the week, the water-courses were permitted to flow freely to power the mills. Each proprietor was permitted to construct a *lega*, in which to store water, on his property, and was required to help keep the water channels clean and well maintained. Fines were imposed on those caught illicitly diverting irrigation water from the channels, someone else's *lega*, or the mills. Women were not permitted to extract water from the irrigation channels without the express permission of the *balivi*.⁷⁷

It is difficult to gauge the success of such distribution schemes. Medieval records preserve the inevitable disputes, and remain silent when all went smoothly. It seems fair to assume, however, that not only did the high Middle Ages see considerable expansion of irrigation systems, but that the social controls necessary to keep such systems functioning were improved, if imperfect.

Fonts, Fountains, and their Technologies

Because of the surviving documents and the survival of some examples of the churches themselves, church buildings offer excellent opportunities to observe early medieval people grappling with problems of water supply. The tradition of placing fountains in the courtyards in front of basilicas, and the continued use of immersion baptism in the early Middle Ages, endowed some churches with complex

⁷⁵ Riccetti (1992), 146.

⁷⁶ Egidi (1930), Stat. 1251–52, I.98–99.

⁷⁷ Lanconelli (1992), 23–24, 33; Andreocci (1970).

hydraulic systems. A few churches also upheld the late antique custom of offering charitable, ritual baths to lay people in apposite bath complexes, posing further challenges for ecclesiastical builders.

The most famous atrium fountain in western Europe stood before St. Peter's. Its renown derived from its location close to a mighty spiritual center, but also to the technical achievement it represented: the high medieval *Mirabilia* accounts show visitors still marvelled at it long after its construction.⁷⁸ The *pigna*, a large, bronze, pine-cone-shaped, hollow fountain head with numerous perforations whence water dripped into a collection basin, seems to have been the eighth-century successor of simpler late antique fountains. In the 770s Pope Hadrian I thought it worthwhile to repair the conduit supplying the *pigna*, and more restoration occurred a few decades later: Rome could not do without it.⁷⁹ But courtyard fountains were common outside Rome, too. As the Carolingians understood (they copied the pine cone at Aachen), such a *cantharus* refreshed eyes and ears even before its water cleansed those about to enter the sacred precinct of the church. Whether or not these fountains represented the Fountain of Life or the rivers of Paradise, they conformed to Roman ideas of water display as well as being utilitarian structures.⁸⁰ Hence their late antique popularity and the willingness of episcopal patrons to maintain them and their water supplies.

When the *cantharus* received water directly from an aqueduct the water, channelled in lead pipes, would spout higher and tinkle more loudly: Paulinus of Nola, the first writer to note St. Peter's fountain, knew such displays delighted visitors.⁸¹ The *pigna* and its late antique predecessors received water from a derivation off the Trajanic aqueduct built in 109 A.D. Water, under pressure after its descent off the Janiculum hill, lapt from these founts thanks to an inverted siphon. A similar arrangement (but using the Claudian aqueduct) supplied a fifth-century atrium fountain near the Lateran baptistery on the other side of the Tiber, where St. Paul's also had one.⁸²

⁷⁸ Valentini, Zucchetti (1946), 190. The *pigna* still impresses in its current resting place, a Bramantesque courtyard in the Vatican Museums.

⁷⁹ Krautheimer (1980b), 252. On the *pigna*, Krautheimer (1980b), 28, 188, 198. For the dating, see De Blaauw (1994), 465.

⁸⁰ See Potter (1986), 143.

⁸¹ Von Hartel (1894), 279–83.

⁸² De Blaauw (1994), 136, 465. At St. Peter's, in the 4–6th c., there were at least 2 fountains, including one near a public latrine (464–5).

Elsewhere in Italy, fountains at St. Felix's church outside Nola were also fed by a long aqueduct, repaired around 400, producing the desired optical and audible effects, probably thanks to a siphon.⁸³ Ennodius suggests that similar effects could be obtained by fountains fed by rainwater cisterns, as in the fifth-century suburban cathedral of Pavia, but how this worked is obscure.⁸⁴ Another large cistern-fountain of late antique date functioned before St. Apollinare in Classe throughout the early Middle Ages. It had elaborate filtration systems designed to ensure the water's purity, but may not have had the jets of water described elsewhere.⁸⁵ Though there is less evidence for the construction of such water supply systems after the sixth century, many were maintained. They gave prestige to episcopal churches.

Baptisteries in late antique Italy were usually attached to episcopal foundations. A fashion for monumental, free-standing, often octagonal baptisteries swept the Italian peninsula after Constantine and left several such buildings in its wake: they were indispensable components of the dignity of an *episcopium*. They remained a characteristic adjunct of Italian churches even after the rest of Europe had abandoned separate baptisteries. These structures perpetuated Roman refinements like hydraulic cement, siphons, and underground piping, and served as privileged sites for the transfer of ancient hydraulic knowledge to the Middle Ages.⁸⁶

The Constantinian Lateran baptistery in Rome is said by the *Liber Pontificalis* and other sources to have received jets of water from a gold deer and seven silver lambs set on the rim of an octagonal porphyry basin. Early medieval baptisms, in Rome mostly of children, still involved standing in the 45 centimeter-deep basin and being held under the gushing waters (which spouted at about head level) three times. Flowing water, from the Claudian aqueduct called *forma Lateranensis*, was used even in the 770s; this suggests the use of a siphon. The large basin was waterproof, presumably, and had an outflow attached to underground wastewater channels.⁸⁷ Another

⁸³ Von Hartel (1894), 173–85, 279–84.

⁸⁴ Vogel (1885), 134. The spouting lion described by Ennodius was a favourite motif in Italian fountains: Colasanti (1926), x–xiv, 15, 18.

⁸⁵ Cortesi (1980), 47–9.

⁸⁶ Grewe (1991), 19–25.

⁸⁷ For theological reasons, early Christianity preferred “live,” not stagnant, water; this must have produced some odd mixtures of blessed and ordinary water in sewers (Cramer (1993); Fisher (1965)). The Lateran baptistery arose over an earlier

major baptismal font in Rome, inside St. Peter's, apparently employed ground- and spring-water from the hill north of the church, channelled in and gushing loudly into a 6 meter-wide basin. In the early 800s this water spouted from a lamb atop a column in the middle of the basin.⁸⁸ During the fifth century many monumental baptisteries were erected elsewhere in Italy; those of Milan, Albenga in Liguria, and Grado in Friuli are famous. Some had piped water-inflow systems and perhaps siphons, and most had outflow piping.⁸⁹ The Milanese custom of a ritual footwashing after baptism made a further water outlet necessary at episcopal baptisteries. Considering that these waterworks were not used more than a few times per year (Easter and Pentecost, especially), the elaboration of their water systems is extraordinary: the ancient baths, whose hydraulics, decor, and even rituals they copied and sometimes appropriated, had functioned daily.⁹⁰ Baptisteries' sophistication is indicative of the prestige water technologies conferred on bishops and bishoprics.

Yet the earliest baptistery to survive more or less intact, S. Giovanni in fonte at Naples, had no such hydraulic refinements. Its basin was 75 centimeters deep and was filled manually, though it had a drain-way that emptied underground.⁹¹ Similar technological simplicity prevailed in Ravenna's two (one for the Arians) fifth-century baptisteries, and in that on Lake Ceresio at Riva San Vitale. The well-known early medieval font, built around 730 in Cividale, also seems to have relied upon stored, not flowing, water, brought to the 1.26 meter-deep basin by hand.⁹² In these structures gorgeous decorations replaced the technological niceties. Rural baptisteries, such as those in some large southern dioceses, lacked even the marbles and mosaics.⁹³ But builders of all baptisteries retained at least a knowledge of hydraulic cement.

private bath, and may have employed some of its conduits: Krautheimer (1980a), 27. On the liturgical and technological arrangements, see Krautheimer (1980b), 252; De Blaauw (1994), 130–6, 149–55, 180–91; Angenendt (1987), 278–9, 288–90.

⁸⁸ De Blaauw (1994), 488, 580.

⁸⁹ Sciarretta (1966); Lamboglia (1986), 50–61; Apollonj Ghetti (1987), 28, 32–5; Mirabella Roberti (1980); Mirabella Roberti, Paredi (1974).

⁹⁰ See Saxer (1987), 176–201; Cramer (1993), 137–140, 267–271 and, *contra*, Apollonj Ghetti (1987), 25–7.

⁹¹ Maier (1964), 11. It dates to about 400.

⁹² Deichmann (1969), 130–4, 209–12; Kostoff (1967); Cosmi de Fanti (1972), 130–1. This monument has been so altered that not much can be known of its original state. On Riva, see Steinmann-Brodbeck (1941).

⁹³ See Angenendt (1987), 328–9.

The urban fountains of the Italian high Middle Ages were typically either spill fountains or splash fountains. Spill fountains, whatever their architectural elaboration, are hydraulically very simple: on the basis of gravity-flow, water simply discharges into a receptacle. This type of fountain often took the form of a rectangular trough situated below a spout. Some were set in wall niches, while more elaborate examples were vaulted, and might have a series of troughs and multiple spouts. The basic fountain type may derive from antique exemplars. Water was obtained by dipping a vessel in the trough or by holding it below the spout.

A second common type of medieval fountain was a freestanding splash fountain, fed by pressure-pipes in an inverted siphon. Typically a vertical feed-pipe rises up the center of a decorative column or shaft, and discharges its water into a basin. It is not uncommon for fountains of this type to have tiers of basins, with water from an upper basin cascading through spouts into the basin below. In some cases the topmost basin was closed, as in Viterbo's *fontane a fuso*. This basic fountain type had numerous decorative variants (depending on the shapes of the basins, elaboration of the shaft, and sculptural details), and was used for many ecclesiastical, civic, and garden fountains. Water was drawn by either dipping a vessel into the open basin, or by holding it under one of the spouts.

Some medieval lavers and cloister fountains survive in Italian monasteries. The Benedictine cloister fountain at Monreale is decorated in a synthesis of Western, Islamic, and Norman motifs.⁹⁴ At Fossanova, a well-preserved fourteenth-century *lavabo* stands in a square fountain-house, which projects from the south walkway of the cloister in typical Cistercian fashion. A smaller thirteenth-century trough laver stands in a niche in the cloister of the Convento della Trinità in Viterbo, while in 1255 a fountain was made in the convent of S. Francesco in the same city.⁹⁵

Medieval urban fountains were popular with users, who made frequent petitions to expand existing systems, each neighborhood clamoring for its own fountain. This high level of acceptance can be attributed to the fact that the technology did not much alter traditional motor patterns and social interactions; for example, women still washed clothes together at the new fountains, where old water

⁹⁴ Miller (1986), 141.

⁹⁵ Piana Agostinetti (1985), 86, 98–100.

jars, and buckets were still suitable for drawing water. Moreover, most citizens were not asked to pay, at least directly, for the water they used. Civic water systems probably also improved public health, by reducing the incidence of water-borne disease. Fountains provided cities and neighborhoods with comfortable focal points for social interactions and with prestigious symbols of local identity.

Indeed, civic pride was an explicit motive in the construction of some medieval fountains, and fountains played a role in symbolic expressions of civic identity. Decorative fountains associated with core public spaces, such as the Campo fountain in Siena or the Fontana Maggiore in Perugia, were symbols of municipal glory as well as functional amenities: "may the Campo fountain be among the most beautiful, useful, and honorable ornaments of the city of Siena".⁹⁶ Proposals to build new Siennese fountains often stressed considerations of honor and beauty as well as the more mundane justification of utility. A citizens' petition of 1397 linked Siena's fountains to its rivalry with other Tuscan cities:

Your city has always been the most beautiful and the most clean of any in Tuscany and possessed of the most beautiful fountains. For this reason, all the foreigners who visit it want to see the Fonte Branda.⁹⁷

The Campo fountain (Fonte Gaia) was directly associated with Siena's civic patron, the Virgin, to whom the supervisor of waters dedicated candles at public expense.⁹⁸ Rebuilt by Jacopo della Quercia in the early fifteenth century, the new fountain's sculpted decoration deployed civic symbols in a "didactic monument" on the obligations of citizenship.⁹⁹

Water Collection and Storage

The aim of early medieval water storage technologies was the preservation of water in convenient locations for as long as possible without risk of spoilage. Both water conveyed long distances to places of consumption and water gathered in situ (from rooftops or the water

⁹⁶ Bargagli-Petrucci (1903), vol. 2, 377.

⁹⁷ Hook (1979), 156–157; Balestracci (1990), 31.

⁹⁸ Bargagli-Petrucci (1903), vol. 2, 284.

⁹⁹ Hook (1979), 97–100; Hanson (1965).

table) was stored in receptacles designed to prevent the development of cloudiness, or smells and tastes deemed unpleasant. Procopius relates that in the mid-500s Belisarius was unusually skilled at keeping his water free of insect and plant life, using earthenware jars and storage in dark, cool places. Other, humbler people also endeavored to preserve their cooking and drinking water from putrefaction, and were frightened by the growth of organisms in their wells.¹⁰⁰

Both depth in the soil and special construction of the walls helped preserve the water in postclassical rainwater reservoirs. A tenth-century cistern discovered near Brescia was 6.5 meters deep, lined with bricks, and the official price list for masonry construction, from the mid-700s, suggests that cavities some 30 meters deep were imaginable.¹⁰¹ Cost of construction increased with depth, so reaching levels at which water might always remain at or below 4 Celcius was the prerogative of the rich and mighty. Ordinary cisterns were shallower, and few can have had the filtration systems visible at Classe (500s) or S. Giulia in Brescia (700s).¹⁰²

The tenth-century movement towards fortified settlements on hill-tops and other impregnable locations stimulated the construction of reservoirs for the new communities. At Cosa, on the Tuscan coast, a fine barrel-vaulted brick cistern, lined with waterproof cement, made habitation feasible on a rugged outcrop above the sea. Further south on the Tyrrhenian coast similar solid cisterns were built at the site called Caputaquis, inland from ancient Paestum. These examples, which happen to have drawn archaeological attention, show high levels of craftsmanship.¹⁰³

Well shafts occasionally reached the water table or natural, subterranean water sources: inside St. Bartholomew's on the Tiber island of Rome one such well still enables the faithful to draw water, as it has for a millennium. Though early medieval sources (mostly charters) seldom distinguish between wells and cisterns, and probably most *putei* were in fact cisterns, some genuine wells were dug, beyond the special, ritual one in Rome: the Lombard price-list for masons clearly had wells in mind, and in parts of the Adriatic south rain

¹⁰⁰ Procopius *The Wars* 3.13.22–4; Squatriti (1998), 36–43.

¹⁰¹ Perini (1983), 65; Bluhme (1878), 180.

¹⁰² At Classe a private house (active c. 500–700) had ceramic filters and decanters for its cistern waters: Maioli (1983b), 71.

¹⁰³ Delogu (1976), 79–80; Hobart (1995), 572–4, 579.

was too sparse to be trusted. Maintenance and cleaning of wells was less urgent than for rain- or aqueduct-fed cisterns.

Wells and cisterns remained essential components of high medieval rural fortified strongholds. Several examples have been recently excavated. At the castle of Ripafratta near Pisa, a deep well with a brick and masonry shaft apparently proved insufficient as a source of supply, and was supplemented by a rainwater cistern.¹⁰⁴ A masonry well-cistern of the Venetian type (a concentric filtration cistern around the well shaft) was uncovered during excavations of the Rocca di Asolo (Treviso).¹⁰⁵

Wells and rainwater cisterns also remained important sources of urban water after 1000. For many cities they provided the only supplement to river water. By the thirteenth century they were commonly situated in public areas, such as street corners and piazzas. Both neighborhood residents and communal governments built wells and cisterns. Venice built dozens of public *pozzi alla veneziana*.¹⁰⁶ Richer citizens might construct private cisterns or wells: in the better neighborhoods of Florence, up to 39% of households had a private well. Some Florentine buildings had internal well shafts fitted with access doors, so that residents could hoist buckets of water, with the aid of a pulley, to a height of three stories.¹⁰⁷

The rapid demographic expansion of Italian cities in the high Middle Ages created new pressures on traditional urban water sources. A city without a nearby river was especially vulnerable, as the quantity of water supplied by wells and cisterns could prove insufficient to meet rising demand. Orvieto was praised for its "thousand cisterns" in the mid-thirteenth century, but these could not satisfy the growing population, and were soon supplemented by an aqueduct.¹⁰⁸

The adoption of complex, long-distance systems did not eliminate water shortages, however, and water from urban wells and cisterns remained an essential part of a city's total supply. Orvieto's aqueduct was itself supplemented by a large new rainwater cistern, built in 1310 by the Friars Minor to supply themselves and nearby residents.¹⁰⁹ Other cities with public conduits also continued to rely on

¹⁰⁴ Redi, Vanni (1987), 296, 303–304.

¹⁰⁵ Rigoni, Rosada (1989), 212–215.

¹⁰⁶ Costantini (1984), 13–24.

¹⁰⁷ La Roncière (1988), 199–200.

¹⁰⁸ Perali (1912), 247.

¹⁰⁹ Perali (1912), 251, 274.

cisterns and wells to augment their water supply. In Siena, churches were responsible for repairing or rebuilding cisterns and making them available for public use. The civic government called for the construction of wells (fitted with iron chains, buckets, and covers) and cisterns in specific locations throughout the city and *contado*, to supply water not only to residents, but to travelers. The commune also encouraged the construction of additional private wells and cisterns by offering monetary payments and free lime as incentives to those willing to build them.¹¹⁰ Thus, the more complex hydraulic systems did not displace traditional technologies (wells and cisterns), for the simpler structures augmented the water supplied by urban aqueducts and fountains and served as essential emergency back-ups when more complex systems failed.

The supply of water to monastic precincts in the high Middle Ages continued to be provided by wells, cisterns, and occasionally by conduits. Abbot Desiderius of Monte Cassino built a large vaulted cistern beneath the pavement of the atrium, and a bath.¹¹¹

Aqueducts

Early medieval Italians constructed and repaired a surprising number of aqueducts, distinguishing themselves in this way from most other contemporary Europeans. Partly, this was a residue of Roman times, when aqueducts, potent symbols of the Empire, were erected for towns all over the peninsula. Early medieval construction and repair of aqueducts appears motivated by the same considerations that propelled the Romans into this branch of hydraulic engineering, namely glory. Exactly as in Antiquity, when cisterns and wells remained vital for most people's everyday needs, in early medieval Italy aqueducts served privileged communities (ecclesiastical ones) or were a means whereby urban authorities could advertise munificence and competence.¹¹²

¹¹⁰ Zdekauer (1897), Con. 1262, III.230, 240; Archivio di Stato di Siena (1903), Con.1309-10, III.137.

¹¹¹ Lehmann-Brockhaus (1938), no. 2295.

¹¹² Elmhäuser (1992), 2-5 discusses the many usages of the early medieval term "aqueductus". On the uses of Roman aqueducts, see Hill (1996), 30; Trevor Hodge (1992), 5-11, 48-9; Grewe (1992), 18. Cassiodorus (*Variae* 3.53) acknowledged that

Bishops were enthusiastic aqueduct patrons, having the authority and resources such projects required. From Naples to Parma, bishops busied themselves with their cities' aqueducts in Late Antiquity, and even after A.D. 600 episcopal aqueducts continued to function. Like the popes, who strove to maintain Rome's image as "queen of the waters" and made extensive repairs in the 770s and in the 840s on strategic conduits (supplying the Lateran and Vatican), the bishops of Verona patronized aqueducts in the 870s. In this same period urban self-definition still relied upon the technological superiority aqueducts implied.¹¹³ Perhaps for this reason, new towns arising in this period equipped themselves with this expensive and superfluous technology.¹¹⁴

Monasteries were the premier builders of aqueducts in the post-classical world. They had the resources and needs to justify such extravagant systems of water supply. The *Rule of St. Benedict* (ch. 66) instructed monks to secure reliable water sources within the monastic enclosure and avoid distracting excursions outside. Early medieval monastic communities were also big and committed to a specific location enough for aqueducts to make sense. Reliable piped water supplies furnished monastic baths (primarily), cloisters, and kitchens with water for generations, though no Italian houses seem to have used their water supply for industrial occupations (as the famous plan of St. Gall suggests happened north of the Alps).¹¹⁵ Monastic administrators therefore were willing to make the outlays of capital and labor which construction and maintenance of aqueducts dictated. Late medieval Italian monastic institutions remained actively engaged in hydraulic projects. Cistercian houses may have played a particularly prominent role, but there is also evidence for technological

water diviners (capable of discovering hidden springs) found employment in Rome despite its many aqueducts.

¹¹³ For aqueducts at Parma, see Cassiodorus *Variae* 8.29 (also 4.31); on Naples, see Gregory the Great, *Registrum Epistularum* 9.77 and Ward-Perkins (1984), 131. On Rome, see Sagui (1990), 98–100 and Pani Ermini (1992), 500–1. See Pighi (1960), 146 on Milan's self-definition. In 873 the bishop of Verona built an aqueduct to the *episcopium*: Squatriti (1998), 16.

¹¹⁴ Squatriti (1998), 16–8.

¹¹⁵ The use of aqueduct water for baths mirrors Roman allocation. The rich Benedictine abbey of S. Vincenzo al Volturno (flourishing c. 780–850), thoroughly excavated in recent years, apparently had no aqueduct, though it did have workshops needing water: Hodges (1997), 94–101. Evidently the nearby Volturno river sufficed.

expertise among the monks and friars in other orders (such as the members of the Benedictine, Franciscan, and Dominican orders who assisted in the construction of the thirteenth-century aqueduct and fountain at Perugia).¹¹⁶

In the 720s, outside of the southern Lombard capital, Benevento, a monastery dedicated to St. Sophia is the earliest recorded to have an aqueduct. In the course of the eighth century, several other houses likewise built aqueducts. St. Giulia at Brescia may have refurbished an extant one, over which the abbess secured exclusive rights in the 760s, while at Farfa in the Sabine hills the monks built a conduit from scratch, buying the very spring which fed it in 778.¹¹⁷ The Brescian aqueduct replenished a 15 meter-deep cistern of solid brick, with inner and outer walls, purifying the water, much as the ancient settling tanks on Roman aqueducts did, before it was channelled, via lead tubes, to the nuns.

Some monasteries of the high Middle Ages also built complex intake systems. Chiaravalle in Fiastra was supplied by both rainwater cisterns (including a huge one under the cloister) and a spring-fed piped intake system. It also had a subterranean channel below the refectory. The Cistercians of Casamari constructed a masonry aqueduct in 1200, while the monks of Trisulti built a lead pipe system in 1310. Tre Fontane outside Rome also had a spring-fed system of pipes.¹¹⁸

Several Italian communes sponsored long-distance aqueducts. Some cities took advantage of surviving Roman and early medieval aqueducts, incorporating them into new water systems. Examples of such composite aqueducts survive near Narni, Civita Castellana, Spoleto, and in Rome, where renewed papal interest in hydraulic projects created the Mariana aqueduct in 1122, which provided water for the Lateran using part of the Roman and postclassical Aqua Claudia channel, and collecting waters from the ancient Aqua Iulia and Aqua Tepula. The early medieval aqueducts at Salerno were partially rebuilt in the thirteenth or fourteenth century.¹¹⁹ Entirely new long-distance aqueducts were constructed at Sulmona, Perugia, and Orvieto

¹¹⁶ Nicco Fasola (1951), 7–8.

¹¹⁷ Squatriti (1998), 19–21; Brogiolo (1992), 202–6.

¹¹⁸ Tosti-Croce (1993), 47–49; Chiavari (1991), 168, 203; Toubert (1973), vol. 1, 237n.; Schiavo (1935), 74.

¹¹⁹ Schiavo (1935), 33–67; Monacchi (1986), 123–142; Frederiksen, Ward-Perkins (1957), 104; Alloisi (1986), 201; Motta (1986), 204.

in the thirteenth century. Verona, Genoa, and Vietri sul Mare were also endowed with aqueducts in this time.¹²⁰

Aqueducts relied on gravity flow and hence on capable surveying. The captation systems upon which these channels drew are not often described, but clearing a stream of debris, stones, and plants was the first step toward leading water into artificial channels.¹²¹ Dams, associated with some Roman aqueducts, do not appear in the records for medieval conduits.¹²² In the high Middle Ages, water was collected at the conduit-head from springs or aquifers into collection tanks or reservoirs. The *caput aquae* for the Formina aqueduct at Narni consisted of a subterranean vaulted cistern, supplied by a spring-fed intake channel, while a large masonry reservoir stored the spring water which fed Perugia's aqueduct.¹²³ The basins at the conduit-head performed a dual role: they served as an initial collection system and as settling tanks for water purification.

Aqueduct building techniques did not change much after the first centuries of Rome's empire; early medieval repairs to aqueducts suggest that construction methods were stable.¹²⁴ Channels could be cut into living rock, lined with masonry in a trench, or (rarely) carried on masonry superstructures. Stone, brick and cement, as well as lead (usually for short, urban tracts, as in Theodorican Ravenna) were the materials used. Hydraulic cement, used in early medieval cisterns, probably lined the interior of the *specus* in brick segments of aqueducts. The cross-sections of medieval channels were normally either rectangular (cheaper) or trapezoidal (giving less frictional resistance to flow). Often channels were covered with stone slabs, to protect the purity of the water and to reduce losses from evaporation. Segments of the Narni aqueduct exhibit a variety of roofing techniques, including horizontal capstones, pitched flagstones forming steep gables, and masonry vaults.¹²⁵

¹²⁰ Biadego (1891), 351–362; Schiavo (1935), 69–80.

¹²¹ Or so Paulinus of Nola suggests for the period around 400 (Von Hartel (1894), 182).

¹²² Impounding water at aqueducts' sources was a Roman innovation (Hill (1996), 30) but did not interest postclassical writers. See Giorgi, Balzani (1879), 74 for description of abbot Probatas "covering" a spring to increase its flow and prepare to lead its water off to Farfa.

¹²³ Monacchi (1986), 126; Symonds, Duff Gordon (1898), 133.

¹²⁴ E.g. Ravenna (Bermond Montanari (1983), 20); Brescia (Schede (1992), 597); and Rome (Pani Ermini (1992), 500–2).

¹²⁵ Monacchi (1986), 127–128.

Following tradition, aqueduct bridges, tunnels, and occasionally inverted siphons maintained channel gradients across and through topographical irregularities. Like their more famous Roman counterparts, medieval aqueduct bridges carried the channel on top of an open arcade. The arches themselves reflect contemporary architectural styles. At Narni and Civita Castellana, ruined Roman aqueduct bridges were rebuilt and re-used. At Orvieto, an inverted siphon of lead pipes conveyed water across a valley (although the high pressure in the pipes made frequent repairs necessary). Where a channel ran close to the surface of the ground, curves in the conduit-line were employed to keep gradients gentle and constant, although such curves added to the aqueduct's overall length (and cost).¹²⁶

Seepage tunnels, known in antiquity, characterized some medieval systems. These were nearly-horizontal adits that penetrated the hillsides in order to tap subterranean aquifers and bring the water to the surface at the face of the slope. Fountains were built on the spots where these *bottini* entered the hillsides. The floor of the tunnel often had a specially cut and lined channel to carry the water, which percolated in from the sides and roof. An elaborate network of seepage tunnels supplied Siena's public fountains. In the tradition of Etruscan *cuniculi* and Roman tunnels, the Sienese *bottini* had vertical shafts (*smiragli*) along their lengths: these could be used to fix the line of the tunnel, to provide multiple work faces and points where spoil was removed as the tunnel was excavated, as ventilation shafts, and as access points for inspections and repairs.¹²⁷

Some aqueduct engineers presented themselves to likely patrons and solicited work. Siena's Campo system was initiated by the stone mason Jacopo di Vanni Ugolini, who addressed the General Council in 1334, winning approval for the project with him as its master engineer. In the absence of such local expertise, however, the quest for a competent hydraulic engineer could prove exasperating. Perugia's government wrestled with the problem for years: envoys scoured likely Italian towns and inquired among the friaries to see if any trained masters could be recruited. The first master they hired, Bonomo of Orte, inconveniently died, and the search had to begin anew. Among the engineers finally roped into the project were

¹²⁶ Frederiksen, Ward-Perkins (1957), 104–105; Perali (1912), 250–251; Monacchi (1986), 126.

¹²⁷ Bargagli-Petrucci (1903), vol. 1, chap. 3; Balestracci (1984).

Boninsegna of Venice (who had been recruited while working on a fountain in Orvieto), Brother Leonardo of Spoleto, Brother Alberic (a Franciscan), Master Guido of Città di Castello, Master Coppo of Florence, and Brother Bevignate (a Benedictine).¹²⁸

The mix of friars, monks, and laymen at Perugia reflects the social heterogeneity of hydraulic experts. Such men were not affiliated with a single craft, though most were involved in either metalworking or the construction trades: goldsmiths, plumbers, carpenters, and masons all turned their hand to hydraulic engineering. Sieneese civic documents preserve records of tools, materials, and payments to the masters and workmen who dug the *bottini*—workmen (and women) were hired by the day, but the masters tended to be long-term specialists who worked on one particular *bottino*. On occasion men from nearby mining towns were employed—presumably their special expertise was advantageous when difficult strata were encountered.¹²⁹

A sustained commitment was necessary to bring a long-distance water system to completion, and to maintain and administer it afterwards. Perugia had started to build an aqueduct for a public fountain in 1254, but water did not finally flow into the Fontana Maggiore until 1278.¹³⁰ Siena's Campo project overran initial estimates of both cost and time: projected to take three years, it ended up taking ten.¹³¹ Such projects required broad public support to succeed, since the individuals or factions holding office at the start of the endeavor were liable to have been replaced long before water first flowed through the system.

Repairs were an ongoing necessity. In the sixth century extensive reparations were needed on Ravenna's conduit only a few decades after initial restoration.¹³² The restoration of old, like the building of new aqueducts required wealth, skill, and organization. Bridged sections were especially fragile, but as most aqueducts remained subterranean for most of their course, protected from temperature extremes and human activity, root damage was more fearsome. Underground repairs were problematic, and calcium, abundant in much of the water washing out of the Apennines, incrustated the water-bearing cavities,

¹²⁸ Nicco Fasola (1951), 7–11, 55–61.

¹²⁹ Balestracci (1990), 25–27.

¹³⁰ Nicco Fasola (1951), 7, 46.

¹³¹ Bargagli-Petrucchi (1903), vol. 1, 209ff.

¹³² Cassiodorus, *Chronica* A.D. 502 and *Variae* 5.38, and Borman (1888), 8 record major renovations at Ravenna.

and was difficult to remove: in late medieval Siena, axes and special hooked instruments were employed in the battle against *gromma*.¹³³ Descriptions like Paulinus of Nola's of enthusiastic, "grass roots" refurbishing of a Campanian aqueduct (about A.D. 400) are thus unrealistic. The description of works in the biography of St. Marinus, dating from the tenth century, with details of arduous toil and close supervision by the patron, is probably closer to reality.¹³⁴

Medieval aqueducts were also vulnerable to intentional damages inflicted during periods of warfare, with the Gothic War's ravages in Rome and Naples as only the most famous example. The aqueduct supplying Orvieto was devastated during the war between Braccio Fortebraccio and the pope in 1419–20. The city allocated money for urgent repairs in 1420, so that the flow of water into the city would be restored quickly.¹³⁵ Siena fortified some of its extramural fountains, and required that the entrances to the *bottini* be securely locked, not only to protect the water supply itself, but to keep enemies from secretly entering the city by means of the subterranean galleries.¹³⁶ The potential for severance of the water system due to enemy action, coupled with the inevitable periodic disruptions in flow due to technical problems, meant that although Italian cities could reap considerable benefits from sponsoring long-distance aqueducts, they could not afford to become overly dependent on them.

Regardless, aqueducts were not simply for ornament and display; they fed urban distribution networks, which conveyed water to various outlets in the city. These networks might consist of channels, pipes, or a mix of both. The aqueduct at Narni fed a masonry channel, which carried the water to a distribution tank. Here it was divided between three lead pipelines, which conducted the water to two fountains and a *pozzo*. Secondary networks of lead and terracotta pipes fed the public washing basins and supplied water for private use. In Orvieto, both earthenware and lead pipes fed a series of fountains and taps in the thirteenth century, and iron was used in 1362. Wooden pipes were first mentioned in Orvieto in 1480.¹³⁷

The conveyance networks usually fed civic fountains, but their overflow could feed secondary basins, troughs, or pipelines. The water

¹³³ Bargagli-Petrucci (1903), vol. 1, 43; vol. 2, 362.

¹³⁴ Von Hartel (1894), 173–84; Aebischer (1974), 65.

¹³⁵ Perali (1912), 252, 285.

¹³⁶ Bargagli-Petrucci (1903), vol. 1, 58–61; vol. 2, 128–129, 216.

¹³⁷ Monacchi (1986), 134; Perali (1912), 281, 289.

was carried away by means of a waste-pipe, with the mouth set at a level above the bottom of the basin. In some systems the waste-pipe from one fountain became the feed-pipe of the next, as the water flowed from fountain to fountain in a series of inverted siphons.¹³⁸ At Siena the construction of the Campo fountain triggered a flood of petitions for additional fountains to be fed by its overflow, while the overflow from Fonte Branda fed industrial *piscine* and powered the city's mills.¹³⁹

System expansion could overextend distribution networks. Orvieto's pipelines branched out beneath the city streets in subterranean *cunicoli*, supplying fountains throughout the city. By 1300, branch lines fed some twenty fountains, and the city had granted several concessions for private pipes. The private concessions were rescinded, however, and fountains in private homes and courtyards were banned in 1304 (and again in 1323) on the grounds that the flow of water had become insufficient to supply the public fountains. In 1379 the distribution network appears to have been drastically cut back, with the elimination of many fountains and branch pipelines.¹⁴⁰

Like extramural aqueducts, intramural distribution networks required oversight and maintenance. On the eve of a papal visit by Boniface VIII, broken pipes caused Perugia's splendid Fontana Maggiore to dry up, so that the basins had to be hastily filled with buckets. Investigations following a further malfunction in 1300 revealed that someone had pilfered the system's lead pipes.¹⁴¹

Baths

Baths underwent a process of simplification after the collapse of the Roman state, with the relentless advance of ascetic ideals. Huge *thermae* ceased to function as anything more than quarries for building material by the 600s (though a *diaconia* existed in the baths of Caracalla in Rome). Instead, much smaller bath complexes, sometimes without the tripartite articulation traditional in Roman *thermae* (cold, tepid, and hot sections: in parts of north Italy "caldaria" was the early

¹³⁸ Piana Agostinetti (1985).

¹³⁹ Bargagli-Petrucci (1903), vol. 2, 280, 291–293.

¹⁴⁰ Perali (1912).

¹⁴¹ Walther (1992), 886.

medieval term for the whole bath) became the only place of social bathing.¹⁴² After 800 solitary bathing techniques prevailed. Since the function of bathing changed, and the bath became solely a place of corporeal washing (not also a site for recreation), the structures and technologies of the bath also changed.¹⁴³

Few early medieval baths drew on aqueducts for their water. In this respect the monastic baths of the eighth century, St. Peter's "charitable baths," and the papal baths in the Lateran were exceptions.¹⁴⁴ The community at St. Paul's outside Rome was privileged by its proximity to the Tiber and used a *noria* to lift water into the bath around 600, according to an inscription, but this elaborate system has no parallels.¹⁴⁵ Most other known bath complexes replenished their basins with water drawn, by the bucketful, from private reservoirs. Even the Roman monastery at the foot of the Capitoline hill, whose hypocaust-heated bath has been excavated recently and dated to just after A.D. 1000, obtained its water without recourse to aqueducts.¹⁴⁶ Nor did the number of bathers a bath could serve affect the techniques used to supply its water. Larger bath houses, where social bathing continued, in some cases up to the turn of the millennium, lacked aqueducts too.¹⁴⁷ Private, domestic baths, not designed for group washing, increasingly common as time progressed, relied on cisterns and wells in the courtyard of the dwelling they served. Since most "service" rooms were on the ground floor in early medieval houses, procuring water for these baths was easy, either with pipes or buckets.¹⁴⁸

As baths' water-intake systems grew simpler, so did distribution networks inside bath chambers. Most early medieval sources depict bathing taking place in a single room, usually with a single basin. But the classical subdivision into three spaces, for hot, luke-warm,

¹⁴² The sixth-century baths in Brescia's castle area measured 5.7 × 2.1 m (Schede (1992), 596).

¹⁴³ See Ward-Perkins (1984), 125–41 and Sagui (1990), 98–110 for overviews.

¹⁴⁴ No baths have been identified at St. Giulia. Yet hypocausts, lead pipes, and major hydraulic works suggest they existed: Brogiolo (1992), 202–6. On monastic baths, see Squatriti (1998), 59–61 (on Benevento's St. Sophia, see also Rotili (1986), 131–3). No baths have been located at S. Vincenzo al Volturno. For Rome, see Pani Ermini (1992), 501.

¹⁴⁵ Tomassetti (1979), vol. 5, 101–2.

¹⁴⁶ Sagui (1990), 110; (1993), 417.

¹⁴⁷ See the discussion in Squatriti (1998), 44–65.

¹⁴⁸ The domestic bath in Ravenna from about 650 used "fistulae" (Tjader (1982), 176), but other baths in Rieti, Gaeta, Rimini, and Naples apparently did not.

and cold bathing, retained some admirers, for in the late tenth century a bath in Naples was described following Roman schemes. The monastic bath discovered in Rome at Crypta Balbi, dating to the early eleventh century, also was tripartite and classical in plan.¹⁴⁹ Whether in fact water of three different temperatures was available at the same time is uncertain, and it is unclear how this latter bath discharged used water. Regardless, the distribution of water within such baths was complex; furnaces, hypocausts, clay pipes, separate outlets and tanks for heated water would be needed, and reliable outflow systems.¹⁵⁰

Italians of the high Middle Ages continued to bathe at home in hand-filled, wooden tubs, some large enough to accommodate more than one bather. The fourteenth-century fresco in San Gimignano's town hall depicts a couple sitting in such a domestic bath, with a maid in attendance. Their tub is made of upright wooden staves, bound with hoops like a barrel. Elsewhere, public baths were also available, not only for personal hygiene, but for medicinal and recreational purposes. Several communes administered profitable public baths, which provided pleasure for citizens and travelers.

Public baths were supplied by rivers or hot springs. River-fed baths required protection of their water from the common sources of urban pollution. In 1276 Verona's city government ordained that the Masera should be cleaned and repaired, because many persons, both citizens and foreigners, came to bathe in its water "for the health of the body". Verona also prohibited waste disposal in the stretch of the Adige above the bagno di Pezuia.¹⁵¹

In zones with thermal springs, communes might sponsor public spas. Siena appointed commissions to oversee the mineral baths at Petriolo and Macereto. The statutes of 1262 call for the provision of stone seats and stone walls, and for public roads and bridges to provide easy access to the bathing facilities.¹⁵² In Viterbo the commune took a similar interest in sulphurous hot springs in the Piano dei Bagni, where the waters were used for therapeutic baths (as well as the less

¹⁴⁹ Sagui (1990), 110. There are ancient sewers in the area, potentially usable in medieval times (Sagui (1993), 409).

¹⁵⁰ Ward-Perkins (1984), 135–41; Squatriti (1998), 46–8. See Brogiolo (1992), 205; Sagui (1990), 110; Sagui (1993), 109–18; and Bermond-Montanari (1983), 22–5 for archaeological traces.

¹⁵¹ Sancassani (1997), 404; Zupko, Laures (1996), 66.

¹⁵² Zdekauer (1897) Con. 1262, III.263–277.

salubrious activities of flax and hemp retting). The statutes of 1237 and 1251 contain provisions for use of the area, including custodians to the clean the channels and pools. In 1293–4 the commune purchased much of the land in the area, together with its appurtenant *piscine*, *alveos*, *cursus aquarum*, and *balneas*, in an apparent attempt to bring the zone under even closer public control. Orvieto ran the baths of Sovana and Saturnia, which were open in April, May, and June. Although the city retained public control of the baths, it permitted private taverns, food vending, and other commercial activities.¹⁵³

Communal governments kept a close watch over public baths as potential dens of vice and disorder. Siena permitted some recreational activities, such as chess, in the spas, but prohibited gambling. Typically, care was taken to segregate male and female bathers, either by some form of physical barrier, or by providing separate bathing establishments. Orvieto patrolled its baths with soldiers, then enclosed them with a fence, closing and guarding the gates at night. In Viterbo, any crimes committed in the Piano dei Bagni carried a double penalty.¹⁵⁴

By the twelfth century the old Roman baths in the volcanic zone around Pozzuoli were once again becoming popular. According to Benjamin of Tudela, who visited the area in about 1165, “all the afflicted in Lombardy” came to bathe in some twenty curative hot springs during the summer. Visitors to Pozzuoli used the old Roman bath chambers, at least some of which were restored during the Middle Ages. Local lore, combined perhaps with surviving Roman inscriptions, credited each of 35 baths with the power to cure specific diseases. These curative powers were celebrated in Peter of Eboli’s poem *De Balneis Puteolanis*, dedicated to Frederick II and widely copied during the following centuries. The baths maintained their popularity as a health resort throughout the fourteenth and fifteenth centuries.¹⁵⁵

Waste Water

Like late medieval urban legislators, early medieval people too dedicated close attention to the management of water deemed impure

¹⁵³ Riccetti (1992), 154–155.

¹⁵⁴ Waley (1991), 159; Egidi (1930), Stat.1251–52, IV.146; Riccetti (1992), 154–155.

¹⁵⁵ Matthew (1992), 117; Kauffmann (1959), 5–6.

because of the substances it flushed. Two letters of Cassiodorus from the 520s show that the end of imperial administration had not altered rulers' determination to maintain sewers in northern Italy: both open and covered drains were to be cleared and fixed so that water did not stagnate in them. A sixth- and seventh-century ceramic workshop in Classe, near Cassiodorus' adoptive home, was attached to the sewer system, and produced the type of waste water Cassiodorus sought to keep flowing.¹⁵⁶

Toilets appear to have been a speciality of the Byzantine north, and were not always connected to urban canal or sewer systems. However, it is in the Forum of Nerva in Rome that the best example of an early medieval latrine has been excavated. Dating to the ninth century, this latrine in an aristocratic residence emptied into a cesspit.¹⁵⁷ Further south, at Salerno, by 1000 contracts routinely ascribed to owners of houses the right to flush waste water by gutters onto streets.¹⁵⁸ Some residents used pottery tubes to convey their discharges, and one house's toilet emptied into an underground channel ("clavica").¹⁵⁹ Inevitably, different types of waste water mingled in the torrents which sliced through this Campanian city and brimmed over during heavy rains.

In spite of these examples of poor hygienic hydraulics, some governments kept Roman sewer systems in working order throughout the early Middle Ages. Classe's Byzantine administrators maintained the sewers into the 700s. At Pavia the maze of carefully sloped, masonry underground sewer tunnels, flushed by groundwater as well as rain, was the object of civic pride and even appeared in tenth-century chronicles.¹⁶⁰ The good conditions of this Roman system, upheld by the imposition of collective maintenance duties by Carolingian rulers, reflects Pavese awareness of its utility, perhaps because it flushed the city's latrines as it evacuated rainfall. Milan's "cloaca" was also under government supervision in the 950s.¹⁶¹

¹⁵⁶ *Variae* 8.29–30 (also 3.30). See Maioli (1991), 232.

¹⁵⁷ Rooms reserved to bodily functions were called "necessarium" in Ravennan charters. For Rome, see Santangeli Valenziani (1997).

¹⁵⁸ Delogu (1977), 125. Sewage was theoretically excluded.

¹⁵⁹ Delogu (1977), 139.

¹⁶⁰ Becker (1915), 26.

¹⁶¹ Examples of latrines in the Exarchate: Tjäder (1982), 132; Rabotti (1985), 36. Classe's sewers: Maioli (1983b), 70–83. See Paul the Deacon's *History of the Lombards* 5.3 on toilets in Pavia; Ward-Perkins (1984), 133–4 on Carolingian maintenance; and Sickel (1874), 382 on Milan.

The generation of urban waste products increased along with the demographic and industrial expansion of twelfth- and thirteenth-century cities: the more vigorously cities grew, the more acute the problem of urban sanitation became. There were four main sources of pollution: domestic rubbish, animal dung, sewage, and industrial wastes. While they recognized that health and hygiene were linked, medieval Europeans lacked a scientific understanding of the role of water-borne pathogens in the transmission of disease. Foul odors were believed to pose the greatest danger, and attempts at "odor control" lie behind much sanitation legislation. Some of these laws were, indirectly, beneficial in protecting water supplies. Yet the chief methods employed in waste-removal (the containment of wastes in ditches or pits, or their disposal into a body of water) threatened to pollute urban water. Rubbish pits and cess pits were liable to contaminate the ground water, which fed urban wells. Waste disposal in rivers, whether through direct dumping or through pollutants washed in from ditches, streets, and sewers, led to fluvial pollution. Both types of contamination increased the risk of water-borne disease.

Civic statutes contained sanitation measures aimed at keeping streets and squares "clean," and some addressed the question of water pollution directly. Ferrara, for example, prohibited the disposal of human wastes in ditches, streets, or sewers that flowed into the Po, and passed laws protecting the river against industrial wastes. Other cities sought to strike a balance between water quality and industrial needs. Verona protected its watercourses by day, but permitted unrestricted dumping in the swift-flowing Adige by night. Bergamo confined certain industrial activities to the riverbanks, so that the wastes could be removed by the running water. The presumption seems to have been that the river would cleanse itself—or at least that the current would carry the problem downstream. Industries with particularly noxious wastes, such as leather working or flax retting, could be restricted to specified areas within or outside the city.¹⁶²

Drains and sewers used gravity flow. Streets might have open gutters, but some channels were covered, to help contain noxious odors. Siena permitted its dyers to build brick-covered drains, and private citizens were allowed to channel their waste-water under the public

¹⁶² Zupko, Laures (1996), 64–66, 101; Sancassani (1977), 400–404; La Cava (1946); Rocchigiani (1958).

streets.¹⁶³ Drains and sewers were apt to have diurnal and seasonal variations in flow, depending on patterns of use and fluctuations in storm-water runoff. If the velocity of flow was insufficient for self-scouring, they required periodic manual removal of the accumulated sediment and debris. A Ferrara statute called for the regular cleansing of the town's ditches and sewers.¹⁶⁴ In Milan, river water was used to continuously flush the city's sewers.¹⁶⁵

One of the chief difficulties facing the sponsors of civic water systems was protecting fountains against pollution. Originally intended to supply water for domestic consumption, the open basins of Italian fountains invited other types of water-use, like watering animals, bathing, scrubbing clothes, dying cloth, washing entrails, and cleaning the hair out of barbers' basins. Civic statutes, fountain wardens, secret informers, and fines were all weapons employed in the fight against such pollution. Punishments for misuse of a fountain could be severe: fines were heavy, and persistent offenders could be banished from the city. Siena even executed a woman accused of deliberately poisoning the public fountains: the treasury accounts for 1262 carefully itemize the costs of flaying her alive and burning her.¹⁶⁶

In spite of these efforts, inappropriate usage patterns persisted. Civic officials were forced to turn to the more effective solution of adapting the technology to better accommodate users' competing needs. Fountains in some Italian cities, such as Siena and Viterbo, were gradually fitted with multiple specialized basins. The main fountain was reserved for domestic consumption. Its overflow fed a series of troughs: one for watering animals, one for washing clothes, even specialized tiers of troughs for industrial users. Other subsidiary features of fountains also reflect concerns with sanitation. Siena's hill-side fountains were provided with vaults, to protect the water against landslides, and barricades to keep out those notorious agents of pollution, animals and small boys. The surrounding piazze were paved and provided with drains, to keep mud and run-off away from the fountains.¹⁶⁷

¹⁶³ Rocchigiani (1958), 378, 411.

¹⁶⁴ Zupko, Laures (1996), 65.

¹⁶⁵ La Cava (1946), 43.

¹⁶⁶ Bargagli-Petrucchi (1903), vol. 1, 73; vol. 2, 122.

¹⁶⁷ Egidi (1930), Stat. 1251-2, I.60, III.59, 200, IV.83; Bargagli-Petrucchi (1903), vol. 1, 63-75, 313-314; vol. 2, 73, 95, 101; Banchi, Polidori (1863-71), vol. 1, 184, 270-72, 355; vol. 2, 321-22.

Guilds and private citizens helped enforce appropriate fountain behavior. The Siennese wool guild and the butchers of Viterbo each had their own written statutes strictly regulating fountain use.¹⁶⁸ Informal social networks and sanctions also played a role in discouraging undesirable practices, and in teaching new urban immigrants appropriate patterns of water use and waste disposal. In 1376 in Viterbo, a member of the papal retinue washed a puppy in a neighborhood fountain, and was scolded by a local woman. As the argument escalated, the woman was killed and the neighborhood rioted against the papal court. Thus, flagrant misuse of a fountain could generate a public outcry, an effective complement to official measures protecting purity. To punish the Viterbesi, however, the pope demolished their fountain.¹⁶⁹

Watermills

Water had many "industrial" applications, from the manufacture of pottery, which in parts of south Italy remained outside of the domestic economy in the early Middle Ages, to that of glass.¹⁷⁰ But little is known of how early medieval people used water in productive processes. This obscurity makes the excavated fish-processing shop in Byzantine Reggio Calabria exceptionally enlightening.¹⁷¹ An installation active from the sixth to the early eighth century, it probably made the Mediterranean delicacy called *garum* (a pungent fish sauce). Located close to a heavily embanked torrent that had an artificial bed designed to slow the current, it used freshwater in the production process, to wash carcasses and flush refuse. Special conduits drew water into basins and back out again, using gravity. Thus, although Italy has produced no evidence for the massive use of water for "industrial" purposes which has been hypothesized for St. Gall, water was artificially led into places of manufacture.¹⁷² Milling grain is the most important and best known "industrial" use of water in the medieval period.

¹⁶⁸ Banchi, Polidori (1863–71), vol. 1, 127–384; vol. 2, 271–336.

¹⁶⁹ Ciampi (1872), 35n, 396–397.

¹⁷⁰ Arthur, Whitehouse (1982), 39–44; Lieciewicz et al. (1977), 144.

¹⁷¹ Spadea (1991), 689–707.

¹⁷² Horn (1975), 241–3. S. Vincenzo al Volturno's baffling river canalizations (Hodges (1993), 36–8) may have had industrial purposes.

Perhaps the most important realization in the past half century of mill studies (since Bloch's famous essay made such studies "mainstream" among medievalists) has been that water-driven mills were quite common in the Roman empire.¹⁷³ Ancient historians have long held this position,¹⁷⁴ but medievalists have only begun to accept it.¹⁷⁵ Both horizontal and vertical mills, it now appears, were familiar technologies in Roman Italy, and the early medieval epoch cannot claim credit for inventing or disseminating these machines along the peninsula's watercourses. A consequence of this "gradualist" picture of mill technologies and their propagation is the parallel realization that different milling techniques coexisted in pre-industrial societies (hand querns, muscle-powered, and different water-powered mills), each having an ecological, social, and economic niche in different regions. Thus, the history of water-driven milling no longer has the teleological narrative of "progress" behind it, as Bloch imagined. Instead the apparently sudden appearance of so many water mills in Italy (and Europe), particularly after A.D. 700, is an example of technological continuity and a result of document survival.

References to Italian mills multiply after 1100. Only in part does this result from the greater abundance of documents; there were also more mills. Most mills were used for grinding grain, and the proliferation of new mills was undoubtedly linked to increased agricultural production, and the increased demand for flour to feed a rising population. Traditional watermill technology was adapted to perform a variety of industrial processes. By the fifteenth century, however, many mills fell into a state of disrepair or went out of use, due to a drop in population in the wake of famine and plague, and the devastations of war.

The term "molendinum" was used for a variety of structures in medieval Italy, and a detailed picture of the mechanical components of watermills in the high Middle Ages remains elusive. References to the internal mechanisms of mills are vague, or expressed in obscure terminology. Charters from the period 700–1000 allow some reconstruction of the use of water to grind grain (there is no evidence of

¹⁷³ Bloch (1935).

¹⁷⁴ E.g. White (1984), 196–201; Wikander (1979), 14–28; Wikander (1981), 101–2; Wikander (1984), 18–26; Hill (1996), 159–63.

¹⁷⁵ E.g. Lohrman (1990), 36–42; Holt (1996), 105–19; Hall (1996), 85–101; Squariti (1997), 125–38. The older view was encouraged by "evolutionary" statements, like those of Isidore of Seville (*Etymologies* 15.6.4).

mills producing anything but meal in this period). The most detailed documents, contracts whereby owners leased mills to millers, come from tenth-century south Italy, but earlier references suggest that techniques of water milling did not change much. The documents present the water works as the most important portion of the mills. Dams, sluices, channels (ponds are not mentioned, but must have existed behind dams) were associated with many mills. The construction of these structures is not explained, but the absence of archaeological evidence implies, perhaps, that stone and brick did not prevail, and less durable wood and dirt did. (An exception to this were the Janiculum mills in Rome, fed by a masonry aqueduct which functioned into the ninth century.)¹⁷⁶ The length of the channels, their drop and design, is likewise not specified. However, these installations, which it was the obligation of millers to clean and repair, secured mills from spates, and regulated inflow. Mastery of them was essential to the miller's craft.¹⁷⁷ Mills' waterworks also changed natural flow enough to awaken enmity: Rothari's *Edict* of 643 expected stream users to want to demolish mill dams, probably because they affected rates of flow.¹⁷⁸

It is not clear what degree of technological change occurred after 1000. The basic features of watermills may have been perfected early and remained unchanged for centuries. Some scholars see innovation in the diffusion of two additional types of mills (the overshot "French" mill and the undershot orbital mill) from northern Europe into Tuscany in the thirteenth century, and in the fourteenth-century combination of the principal mechanisms of the overshot and horizontal mill in the "French horizontal mill". Late fifteenth-century sources contain relatively detailed records of mill components, which seem generally consistent with the occasional technical details (wheels, millstones, axles or shafts, toothed wheels, poles, hammers, various iron fittings, conduits) mentioned in earlier sources, but detailed reconstruction of medieval mill mechanisms based on such late sources remains problematical.¹⁷⁹

¹⁷⁶ Even thereafter, the Claudian aqueduct fed a mill: Hubert (1990), 76.

¹⁷⁷ Elmshauser (1992), 3–4 on mill channels; Squatriti (1998), 128–39.

¹⁷⁸ Bluhme (1868), 35. See Natale (n.d.), 24 for a northern example of a mill dam.

¹⁷⁹ Chiappa Mauri (1984), 152–175; Giuffreda (1981), 220; Lanconelli (1992), 27–28; Balestracci (1981), 133; Muendel (1984).

The mill house itself, containing the millstone and waterwheel, attracted less attention from the redactors of early charters. These buildings, too, seem to have been made of wood solid enough to sustain great weight. Many of their main technical components were wooden, and a rich abbey like Bobbio in the 800s expected carpenters, not masons, to build its mills.¹⁸⁰ The paddle wheel surely was wooden, though there are no early medieval examples in the archaeological record (the spade-shaped paddles of the monumental mill from Roman Venafrò remain exceptional). It was connected to the millstones by wooden axles, and, in the case of vertical-wheeled mills, the "spindle" and other gearing parts were also of wood.¹⁸¹ Nevertheless, southern contracts often refer to the "ferraturia" of mills. This term refers to the iron parts of gearing mechanisms and the iron reinforcements for points of greater stress of the mechanism (the base of the axle, the juncture between rotating axle and millstone, perhaps portions of the "spindle"). Iron was also deployed in the device that regulated fineness, by adjusting the space between the two millstones, sometimes by means of a chain.¹⁸²

The iron reinforcements were sparingly used and worried millers and owners (who had different interests when breakdowns occurred), for they were expensive and difficult to replace.¹⁸³ So were millstones, whose grooving was one of the key skills of millers. Trade in millstones was underdeveloped in the early Middle Ages, and most stones must have been local; yet quarrying them, transporting them to, and calibrating them at mills were arduous tasks even if done nearby.¹⁸⁴

Several different types of mill were in use during the Middle Ages. Floating mills, first mentioned by Procopius, obviated the need for complex water control systems. They were supported on two (or three) ships. In the early centuries, their paddles seem to have lain flat on the water; later examples had vertical wheels which communicated power to millstones by means of interlocking, right-angled gears. The distribution of floating mills was limited to areas with navigable rivers. Since they rose and sank with the water level, flows

¹⁸⁰ Hallinger (1962), 422.

¹⁸¹ Forbes (1957), 597–8.

¹⁸² The evidence is late: Morcaldi (1878), 175–6 (A.D. 1029) and Morcaldi (1887), 250–1 (A.D. 1054). See Comet (1992), 461–2; Beretti, Iacopi (1987), 26 on regulating devices.

¹⁸³ See Del Treppo, Leone (1977), 45–9.

¹⁸⁴ On the stone trade see Williams-Thorpe, Thorpe (1991), 42–5.

did not have to be closely regimented (as in the case of mills with immobile wheels). They were vulnerable to floods, but if river levels fell they could be moved into the deeper parts of the channel.¹⁸⁵ After the sixth century, floating mills are documented in tenth-century Rome, where they belonged to the powerful clerical and secular elites, who secured "parking" rights for them and made sure that users could easily reach them from the Tiber's banks along gangways.¹⁸⁶

Suspension mills (*molendinum pendulum*) may have employed Vitruvian gearing systems or horizontal wheels, whereas many terrestrial mills (*molendinum terraneum*) seem to have had horizontal wheels (*ritrecine*). By the middle of the thirteenth century, Florentines were using both orbital mills with vertical landed undershot waterwheels on the banks of major rivers such as the Arno, and overshot "French" mills (*mulini franceschi*) with Vitruvian vertical wheels along the more erratic torrents of the hills and mountains. Orbital mills seem to have caused a decline in the number of floating mills in Florence, but the overshot "French" mill does not seem to have displaced mills with horizontal wheels. In many cases, the overshot wheel was simply added to a pre-existing *ritrecine* complex. Vertical-wheeled, geared, watermills tended to find favor with great landlords and in places of sustained demand for flour. The fact that they made more efficient use of water power, especially when overshot (receiving water onto the paddle wheel from above) seems not to have affected their popularity, even in hilly and arid zones where their efficiency mattered more.¹⁸⁷ Horizontal-wheeled mills had fewer moving parts and less need for metal reinforcements. They were cheaper to build and fix, though they too required extensive waterworks (and, like any aqueous installation, they needed clear title to use of their lifeblood, water). They also required fast-moving water, as they did not exploit the weight of the water, but only its kinetic energy.¹⁸⁸ By the latter fourteenth century, some sources suggest that the principal components

¹⁸⁵ Bortolami (1988), 292–293; Benedetto (1993), 73–79; Beggio (1977), 549–562; Muendel (1981), 87; Muendel (1984), 224–225.

¹⁸⁶ Lohrman (1991a), 277–86.

¹⁸⁷ It is futile to calculate, in HP or other measures, how much more energy than other mills geared mills harnessed: water flow varies by region and season, and wheel size, a crucial variant, is never known.

¹⁸⁸ Reynolds (1983), 4–14 contrasts vertical and horizontal mills' characteristics. See also Condorelli (1983), 838; Chiappa Mauri (1984), 10–7, 24–5; Amouretti (1987), 14–9; Squatriti (1998), 135–9.

of overshot and horizontal mills had been recombined to create a new type of "French horizontal mill".¹⁸⁹

Some mills were complex structures, with more than one wheel or set of millstones. At Brescia in the 760s a wheel turned two monastic millstones. A fourteenth-century description of Pavia mentions terrestrial mills with two wheels each along the Ticino, while some Milanese mills were equipped with three, even four wheels by the fourteenth century. A mill complex in Padua had eight wheels. The most profitable mills in Pistoia were equipped with more than one set of millstones, and the highest yielding mill had three sets.¹⁹⁰

Italy is too environmentally varied for generalizations about the uses of water power. However, the great majority of water-powered mills were used to grind grain, though as grain mills were the most likely to be taxed, records of other types of mills tend to be sporadic and incidental. In some cases fulling mills or *gualchiere* (which seem to have been by far the most common type of industrial mill) were systematically recorded. Mills were used for crushing olives and hay, grinding chalk and oak-galls (used in tanning leather), honing iron instruments, and sharpening weapons. References to iron mills, saw mills, hemp mills, and paper mills also appear intermittently in the documents. In 1268, Fabriano had seven water-driven paper mills. The same mill could be employed for more than one purpose: in Florentine territory there were combined grain and fulling mills, and mills in the mountains around Pistoia ground chestnuts as well as wheat. It is also possible that individual mills changed function over time, as one process was substituted for another requiring similar mechanisms.¹⁹¹

Little detailed information is available for the inner workings of industrial mills. Some mills certainly had hammers, probably operated by a camshaft. The fulling mills in Florence appear to have had one hammer for each stone basin, implying the usage of a recumbent

¹⁸⁹ Muendel (1981), 87, 103; Muendel (1984), 225–241; Muendel (1992), 84, 92; Chiarlone (1993), 172–173; Lanconelli (1992), 28–30.

¹⁹⁰ Squatriti (1998), 129; Chiappa Mauri (1984), 173–174; Bortolami (1988), 281, 301.

¹⁹¹ Muendel (1972), 44; Muendel (1981), 90, 98, 101–105; Muendel (1992), 90; Balestracci, Piccinni (1977), 163; Chiappa Mauri (1984), 67; Bortolami (1988), 281–282, 310ff.; Varanini (1988), 359, 363; Gimpel (1976), 14; Palmucci Quagliano (1993), 91–106.

hammer rather than a vertical striker, though *gualchiere* with vertical strikers may also have been introduced in the thirteenth century.¹⁹²

Mill locations depended on the characteristics of local watercourses and the type of mill. Floating mills, which could only be situated on navigable rivers, were plentiful on the Arno, Po, and Adige, but absent in areas, such as Sicily, without perennial streams. Suspension mills were also found in great number on the Arno, but terrestrial mills were apt to be located on secondary watercourses. Many mills were situated on artificial canals, such as those along the right bank of the Bisenzio, or in the hinterland of Milan. Artificial channels, derived from the main watercourses and regulated with sluices, were sometimes used to power the mills, so that the mill wheels themselves did not obstruct the main waterways and were safer from seasonal floods. The *clusa* which diverted water into the leats, however, could obstruct watercourses, and frequently became the subject of disputes.¹⁹³

Multiple mills were constructed along favorable stretches of rivers, such as the clusters of mills along the Adige at Verona, or along the river Oretto by Palermo.¹⁹⁴ According to the early fifteenth-century registers, only 27% of Florentine mills were situated on the Arno or its principal tributaries, while 73% were widely dispersed throughout the territory along secondary torrents. In 1350, 53% of Pistoia's mills were to be found on the plain containing the major rivers and canals. A further 29% were located in the zone of middle hills, principally along small torrents, while 18% were in the mountains by the tributaries of the major rivers. The fifteenth-century decline in the number of mills affected all zones, but not equally. The overall percentage of mills in the mountains remained about the same (19%), but those in the middle hills had fallen to 22% of the total, while those in the plains, although declining in total numbers, now represented 59% of the surviving mills.¹⁹⁵

The lack of watercourses within Siena meant that few mills were located inside this hilltop city, exposing Siena's food supply in times of war. The commune responded by fortifying some of the extra-

¹⁹² Muendel (1981), 114n.; Muendel (1984), 236–237.

¹⁹³ Beggio (1977), 549–559; Benedetto (1993), 67–89; Muendel (1981), 86–87; Chiappa Mauri (1984), 16–17, 75; Giuffrida (1981); Chiarlone (1993), 170–171.

¹⁹⁴ Varanini (1988), 342–353; Giuffrida (1981), 206.

¹⁹⁵ Muendel (1981), 99; Muendel (1972), 42–46; Muendel (1984), 218.

mural mills. Severe seasonal water shortages also faced some mills. When river levels dropped in the dry summer months, water-powered mills in places like Siena and Sicily were forced to suspend operations.¹⁹⁶ In some places the lack of a dependable year-round water supply led to the adoption of "dry mills" (*molendina siccha*), powered by animals, hand, or the wind.¹⁹⁷

Mill proprietorship in medieval Italy shows considerable diversity. Ecclesiastical mills may be over-represented in surviving records, but they did make up a significant portion of the total number of mills, especially in rural areas. In addition to the usual grain mills, some monasteries also owned fulling mills. Although feudal lords owned many mills by about 1000, and even thereafter in Sicily and Piedmont, elsewhere their presence as owners declined. Private ownership in common may be linked to inheritance traditions. Co-proprietor included family members and unrelated shareholders, each owning a fractional portion of a mill. Such joint-ownership arrangements seem to have been dynamic and fluid, and shares in a mill could easily be transferred. Communal ownership of mills facilitated control over the urban food supply, and helped civic authorities keep political disorder at bay. Institutions too could practice co-proprietorship. Twelve mills on the Merse river, for example, were jointly owned by the commune of Siena and the Abbazia di Torri. Mill-owners often leased the mill, either perpetually or for a specified number of years, to professional millers. Lease contracts could include detailed provisions for the maintenance and upkeep of the mill and associated watercourses. It is possible that collaboration between Italians and immigrant Germans lies behind the origins of the Italian fulling mill or *gualchiera* (a word with Germanic roots). The practice of co-proprietorship may also have played a roll in the transmission of the landed undershot waterwheel and the "French" overshot mill from France to Tuscany in the thirteenth century.¹⁹⁸

¹⁹⁶ Balestracci (1981), 128; Giuffreda (1981), 207.

¹⁹⁷ Lanconelli (1992), 10n.; Balestracci (1981), 128-129; Alliaud (1993), 47-57.

¹⁹⁸ Muendel (1972), 39, 49-51; Muendel (1981), 85-86, 97-100; Tosti-Croce (1993), 48-51, 77-79, 97-126; Lanconelli (1992), 56-71.



CHAPTER SEVEN

HYDRAULIC SYSTEMS AND TECHNOLOGIES OF ISLAMIC SPAIN: HISTORY AND ARCHAEOLOGY

Thomas F. Glick and Helena Kirchner

Introduction

The study of water use in medieval Spain has enjoyed an unprecedented period of growth over the past twenty-five years. Although the stimuli informing this literature have been complex and multifocal, the two most pertinent are related to broader trends in Spanish “medievalism.” First, the reexamination of feudalism beginning in the 1970s drew attention both to the non-feudal nature of Andalusí society and to the differing ways in which water was appropriated in Latin and Muslim societies, the water mill providing an example that was emblematic of the distinction. Second, the emergence of a dynamic new field of medieval archaeology focused on social organization of rural Islamic Spain (al-Andalus) resulted in the reformulation of the centrality of irrigation in medieval Muslim agriculture.¹ The archaeological results are consistent with the conclusion that virtually all irrigation systems and networks in al-Andalus were built by the initiative of peasants living in clan-based settlements, whose social organization and approach to irrigation agriculture was based in the prior experience of tribal groups in their areas of origin, particularly North Africa.

In the present chapter, we will selectively review medieval hydraulic archaeology—the most innovative sector of Spanish hydraulic studies; we will then survey specific techniques, such as qanats, norias, various kinds of storage and regulatory tanks, and diversion dams,

¹ Below, we use the term “Andalusí” to refer to structures or traits found in Islamic Spain. For bibliography to around 1990, see Glick (1990), 121–153; (1991), 167–192; (1992), 209–232. Interestingly, there has been virtually no interest in these issues among medieval economic historians. For an up-to-date bibliography, see Barceló et al. (1998), 99–106.

particularly as they were integrated into small-scale peasant agriculture. We will then briefly examine the fate of hydraulic systems of Muslim origin under Christian rule.² There are two notes of caution: first, we recognize that it is often difficult to establish any fully systematic congruity between the historical and archaeological "registers,"³ and while we believe that documented social mechanisms of water distribution in tribal societies complement, and to some extent explain, the findings of the archaeological record, we also understand that such congruence, while logical, is inferential. Second, the nature of such a survey does not allow as much distinction to be drawn between the social organization of al-Andalus and Christian Spain as the subject merits. We understand that similar techniques were integrated in the two societies in very different ways.

The vast majority of rural Andalusi hydraulic systems studied are of Muslim foundation. In some places, there was some recycling of physical components of Roman irrigation systems, but the completely different bases of the social distribution of water make Roman irrigation in Hispania irrelevant to the medieval experience.⁴ Moreover, the general retrenchment of population and economic decline in the fifth and sixth centuries render specious any argument for continuity between Roman and Muslim irrigation, including the huertas of La Plana, Valencia, and Orihuela where Romans are known to have irrigated.

Hydraulic Archaeology of Al-Andalus: General Considerations

Research on the irrigated spaces of al-Andalus begun by Barceló in the 1980s has led to the development of specific research procedures whereby original results have been obtained. Although this kind of research can be considered archaeological, the particular artifact studied (agrarian space, its design, and especially the builders and users

² In general, the archaeological sections below are written by H. Kirchner, those on institutions and specific hydraulic techniques by T. Glick.

³ See comments by Barceló (1992), 457–462, esp. 458–459.

⁴ On the debate over the supposedly Roman origins of the huertas of eastern Spain, see discussion by Barceló (1986), 10, 13–15, 17–19; and (1989), xvi–xix, xxiii (the same article has also been published in Barceló et al. (1995), 51–71; and in English in Barceló et al. (1998), 9–22. For an example of the recycling of a Roman canal in the Andalusi city of Siyāsa (Cieza), see Yelo Templado, et al. (1988), 609.

of these spaces) is not congruent with the habitual procedures and objectives of recent archaeology, whose principal object of study has continued to be the residential zone—the misnamed “habitat”—and all that it contains. In the best of cases “extensive” or “spatial” archaeology⁵ has sought to describe the structure of settlement in specific geographical areas and deduce data about social and political organization from settlement maps or from changes in the distribution of settlements over predefined periods. Hydraulic archaeology, by contrast, is based on the supposition that the choice of one form of settlement or another and its emplacement are determined by the particular kind of agricultural work that the group in question practices.

General Principles of Peasant Hydraulics

Any hydraulic system must be designed prior to its construction. Design therefore is the first principle from which all the rest follow. In medieval Iberian archaeology, Barceló first enumerated a set of principles which apply to any kind of traditional hydraulics.⁶ The same principles hold for any kind of traditional hydraulics, but were developed through the study of early Andalusí hydraulic systems in Andalusia and Mallorca⁷ and indeed what we have called “hydraulic archaeology” has been applied mainly to the society of al-Andalus.⁸ By “design” we mean the plan for articulation between the water source, distribution canals, irrigable space, and tanks, mills and any other appurtenances. This articulation depends on the fact that water flows by gravity and therefore its distribution depends on the existence of favorable slopes which can be modified to permit the controlled

⁵ “Extensive archaeology” is understood as survey archaeology whose aim is to propose and resolve problems through studying the siting and geographical distribution of material remains of places of residence and other spaces visible on the surface. In this sense, it is a type of archaeology which offers information different from, or complementary to, the results of excavating a concrete archaeological conglomeration.

⁶ Barceló (1989), vol. 1, xv–xiv.

⁷ Barceló et al. (1998). Although published recently, the field work took place between 1985–1987.

⁸ For a survey of the few examples of hydraulic archaeology applied to feudal society, see Kirchner (1995b), 35–64. More recent studies of feudal hydraulic systems are Kirchner, Oliver, Vea (in press); Batet (1998), 387–395, and Arbués (1998), 463–467.

flow of water through the space of cultivation. A hydraulic lay-out cannot be improvised when planning an irrigated space; rather the route the water is to follow for its effective functioning must be ascertained beforehand.

The role of gravity in water flow supposes that the result of a design will be a space delimited by "lines of rigidity" which result from the establishment of channels for the controlled flow of water. Thus any irrigated space has an upper line of rigidity, described by the main canal or canals for water distribution above which the water cannot flow because the slope is unfavorable. The lower line of rigidity is that established by the lowest slope favorable for water flow—a gully, a river, the floor of a valley—or at least the lowest point at which the debit of water available will permit irrigation. That is, a concrete amount of water will permit the irrigation of some maximum area, dependent also on the type of crops planted and the frequency of irrigation.⁹ In this case, the lower line of rigidity can be less stable and more easily modifiable as a function of changes in irrigation procedure or in the amount of water available.

The need for a design, a concrete plan for the flow of water and the rigidity which results from such a process of planning, causes hydraulic systems to display great stability. The institutions that guarantee the functioning of a hydraulic system are also "ultrastable," insofar as they display "the capacity to maintain their essential variables within a changing natural or social environment."¹⁰ Moreover, the stability of institutions and of modes of water distribution depends in great measure on the maintenance of the irrigated space in the same conditions as those of its foundation. Changes can easily affect the distribution system and require negotiation and the assent of the users. Any modification of a part of the design might provoke the

⁹ The mix of variables in the use of irrigation water has been modeled by Maass, who also studied social relations of water use in eastern Spain, both in successor systems to Muslim ones and others created more recently: Maass, Anderson (1978). These authors have studied the relation between irrigable surface and the volume of available water in the context of the different social and institutional factors that condition it, in various of the great Spanish and North American huertas. The maintenance of an equilibrium between irrigated surface and volume of water is not solely guaranteed by the principles of proportional distribution and equity, virtually universal in norms of social distribution of water. The efficacy of local management of a hydraulic system is especially dependent on the ability of an irrigation community to restrict the expansion of the area under irrigation.

¹⁰ Glick (1988), 165.

disarticulation of the elements composing it and force a new design and the establishment of a new pattern of articulation. It is clear that there are modifications which can require more or less serious changes in the original design: thus the alteration of the slope of a main canal would have greater consequences than the building of a new mill at its tail end, or the introduction of a holding tank which had not been present previously. For this reason, the modifications that turn up in these studies tend to be those which least compromise the original design, typically the introduction of hydraulic appurtenances such as mills or tanks which require no alteration in the gradient or trajectory of the main canal, or else, alterations in the area irrigated owing to the lengthening of the main canal or the addition of new water sources if they are located higher up than the original catchment, permitting the establishment of a new line of rigidity above the former one. In reality, however, tapping a new water source implies a new design and the creation of a new system, with its water delivery grid in some instances linked into the older one (see figure 7.1).

The logic discernable in the hydraulic systems thus far studied displays a tendency towards the preservation of the original design, complicated, to be sure, by extensions and small modifications. The original design, however, is almost always detectable and distinguishable from later changes. Indeed the great majority of modifications or extensions are post-medieval, and most are quite recent.

Nevertheless, stability need not necessarily imply immutability or the indestructible permanence of the original design.¹¹ On occasion designs are remodeled, creating new ones. Permanence would only be guaranteed by the absence of destruction or of substantial modifications made by the irrigators themselves, by the absence of destruction caused by external forces or, in the case of an abandoned system, by the lack of sufficient time to permit the disappearance of traces of its original design. There are enough cases, however, of sufficiently profound changes to suggest the redesign of some hydraulic systems. For example, there are instances of the modification of the slope of a main canal, originally of earth, making it more gentle and compensating for the resulting reduction in the velocity of flow by making the canal impermeable. In such a

¹¹ On the meaning of stability, viewed archaeologically, see Barceló (1996a), 273–292, commenting on Gutiérrez (1996).

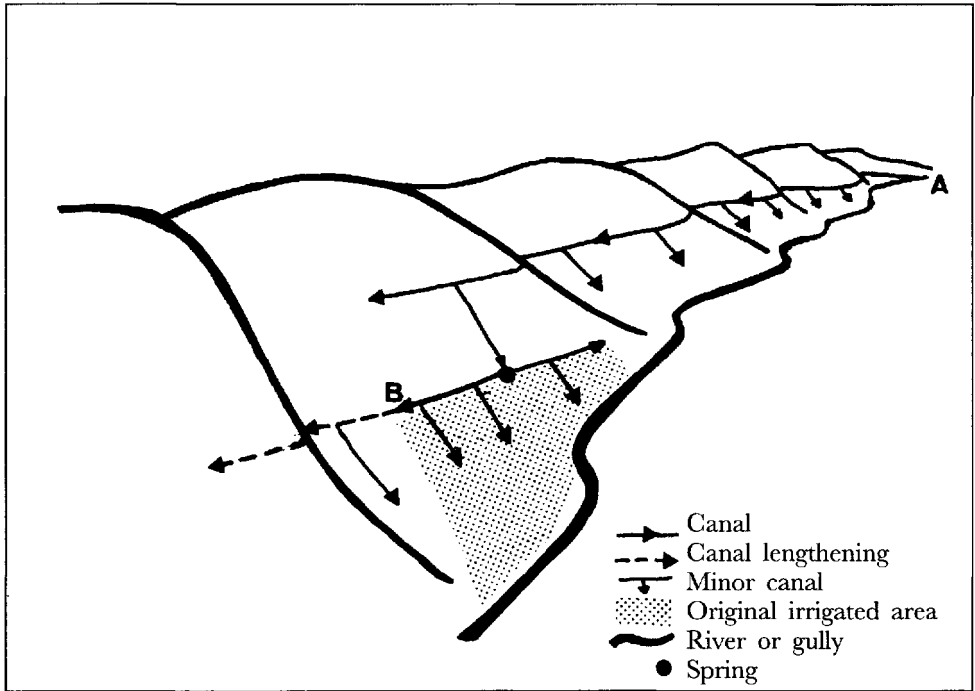


Figure 7.1. Forms of expansion of irrigated space in a hydraulic system; (A) by means of new water tap on a slope higher than the original. The two canal systems can be connected at some point. (B) by extending a main canal.

case, we find the upper line of rigidity raised and, as a result, the irrigable perimeter between it and the lower line of rigidity is increased (figure 7.2). Such an operation would force the redesign of the entire course of circulation of water through the irrigated area, while the case of an increase in irrigable area via the extension of the main canal would only require designing the circulation of water in the new parcels added onto the end of the original space. In other instances, the remodeling of the design has been forced by the need to modify the morphology of the fields. Thus the desire to have parcels of the maximum area possible (to introduce new types of agricultural machinery, for example) can induce an overhaul of the entire system and creation of a new one using the same water source. This circumstance is characteristic of small hydraulic systems (one or two hectares) which in recent times have come into the possession of a sole proprietor or user who can make such modifications without having to consult other users. In such cases, it is virtually

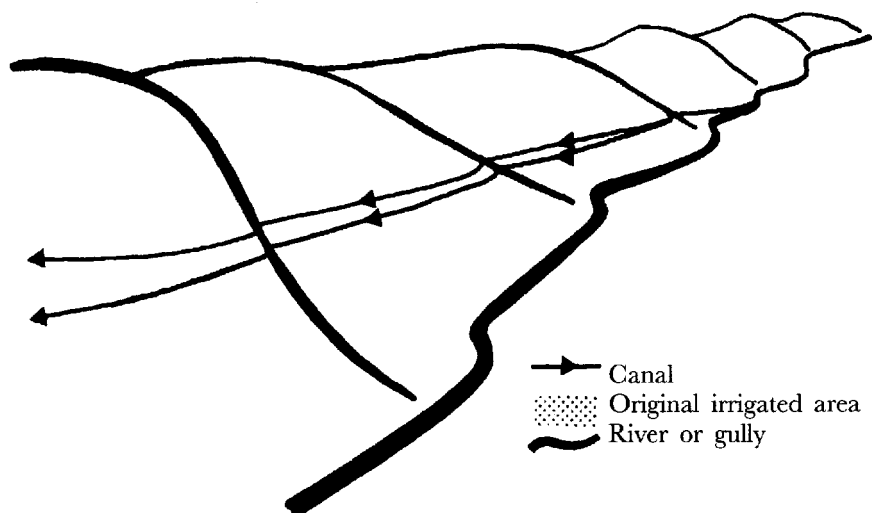


Figure 7.2. Expansion of an irrigated space by modification of the slope of the main canal. This modification is sometimes produced when an earthen channel is surfaced with concrete, permitting a more gradual slope without impeding the flow of water.

impossible to reconstruct the original design, beyond establishing the maximum possible space it might have occupied.¹²

The general principles of peasant hydraulics are identical for small as well as for large irrigated spaces. Spatial dimensions do not alter the requirements imposed by gravity. It has always been supposed that the great urban huertas must have been more hydraulically complex than small peasant systems, when the only physical complication added is the need for a greater profusion of secondary canals to distribute the water. There is no doubt that the intensification of the distribution network requires greater social control, but that does not alter the basic processes of design prior to construction, with well defined lines of rigidity, and the same tendency towards

¹² For examples of these kinds of modifications in Mallorca, see Kirchner (1997a); and (1997b), 139–161.

long-term stability. Likewise, to introduce supposed processes of alluviation which might have altered the original design of a huerta, inevitably leads to confusion. S. Gutiérrez, for example, implies the possibility of the breaching of the principle of the stability of hydraulic systems—and, thus, the method of studying them—owing to processes of alluviation which bury the original design of a huerta beneath meters of sediment. Specifically she mentions the example of a tenth-century well associated with a noria at Santa Fe de Oliva.¹³ There is no research as yet that bears on whether or to what extent alluviation significantly alters hydraulic designs. In the first place, one must establish the existence and extent of the alluviation, not just assume it. Irrigation in itself can be a factor limiting the effects of the deposition of silt, in view of the fact that, historically, natural gullies were canalized precisely to impede their destructive effects on cultivated fields. Neither is it clear to what extent the process of the raising of ground level is owing to natural depositions or caused by irrigation itself. The progressive elevation of ground level requires an equivalent adjustment of the level of the distribution canals, particularly the main one.

As a result, diversion structures which in large huertas usually consist of one or multiple dams diverting water from a river, would also be progressively displaced upstream in order to ensure the flow of water. The slowness of this displacement does not necessarily imply the periodic redesign of the system, nor undermine the principle of long-term stability. On the contrary, the stability principle is reinforced inasmuch as the design can remain unchanged in spite of deposition. A spectacular exemplar of such stability is that of pre-Islamic spaces in Yemen irrigated by floodwaters carried by wadis in monsoon season. The accumulation of silt, suspended in water circulating through secondary canals and deposited on fields through

¹³ This now-famous site is described by Bazzana, Climent, Montemessin (1987). It is not particularly suited for the kind of claims that Gutiérrez makes for it, owing to the conditions under which it was excavated, namely after the upper portion of the well had already been removed by an excavating machine. Calculation of the depth to which the well was buried, as given by the authors, is not that same as that given by Gutiérrez, who seems to inflate it. Again, see Gutiérrez (1996) and Barceló's (1996a) critique. It is also not an appropriate example because the hydraulic space and field systems of the area where this noria once functioned have never been studied. We have no way of knowing whether alluviation, which undoubtedly took place there, whatever its depth might have been, altered the original design, to what degree it did so, or whether it forced the replacement of the original design by a new one.

successive waterings, led to vertical soil deposition of up to 15 meters, accompanied by the progressive displacement of the points of diversion to ever higher altitudes, without producing any abrupt change in design.¹⁴ One cannot condition the stability of a hydraulic design on the assumption that its slope will remain permanently fixed, even though it might well have a physical limit. In some of the Yemeni cases mentioned, the raising of the ground level reached a point where the original design could no longer be maintained, when the catchment level could no longer be raised, having reached the highest point of a stream bed, or because the run-off watershed had become too small. We find such sites abandoned today. J. C. Wilkinson, in his study of the *aflāj* (singular *falāj*) of Oman, illustrates the different scenarios accounting for inoperation of water sources owing to modifications in the level the groundwater tapped or to accumulations of sand and silt deposited by runoff. He adds, however, that the peasant community is organized to clean the galleries and resolve these problems. The silting up of a qanāt might suggest the reason for its abandonment; however, "while the immediate cause is physical, the reason behind it is the failure of the traditional *falāj* maintenance system: so it is not changes in the physical environment but rather in the human organization that have caused disaster."¹⁵

The Methods of Hydraulic Archaeology

Barceló's group began to develop a method which they later named "hydraulic archaeology" in a study of irrigated Andalusí agrarian spaces.¹⁶ The specificity and novelty of the method does not so much consist in the application of any concrete techniques as in a specific approach to the reconstruction and analysis of hydraulic lay-outs. The techniques of hydraulic archaeology, therefore, are not in themselves original with respect to those used in extensive archaeology generally or to the historiography of water, where documentation exists. Inasmuch as the basic objective is to recreate the original design, the state of preservation of a given irrigated site may require analytic techniques of greater or lesser sophistication.

¹⁴ Gentelle (1991), 5–54; Coque-Delhuile, Gentelle (1995), 122–128.

¹⁵ Wilkinson (1977), 91.

¹⁶ Kirchner, Navarro, (1993), 121–150.

The objective of hydraulic archaeology is to reconstruct the original design of the hydraulic system and, in doing so, identify the changes or accretions that it might have undergone. Reconstruction of the original design implies the study of the entire process including the original site-selection criteria for establishing an agrarian space; observation of the relief and hydrographic conditions; plotting the layout of canals from their points of diversion, as well as the size and shape of the cultivated parcels; and localization of appurtenances such as mills, tanks, and structures for the distribution of water. Finally, in the case of al-Andalus, the number of groups participating in the construction of a hydraulic system, the provision of irrigable space necessary to meet the needs of subsistence, and the political weight of each group in relation to demographic strength are all factors which may have influenced the final design. In the case of feudal societies, the social origin of a hydraulic system, whether peasant or noble, can give rise to very different physical results. By the same token, seignorial intervention in an irrigated space of peasant origin may also have physical repercussions in layouts together with obvious repercussions in the social distribution of water in small peasant systems; however, it appears that the new feudal colonists made few physical changes. In Mallorca, for example, after 1229, when Andalusí irrigated spaces were occupied by new feudal colonists, they were the object of a transformation in the organization of the social distribution of water as well as in newly introduced crops, especially grapevines and cereals. These crops could be irrigated under unusual circumstances, in time of drought, for example, but for all practical purposes the areas irrigated by the new colonists were limited to small gardens adjacent to mills. Primacy in water distribution, that is, passed from irrigation to milling.¹⁷

The analytical method of hydraulic archaeology is based on a combination of information of diverse nature. The information used includes place names, still surviving or documented from earlier periods, which permit the identification of the groups that built or used the hydraulic systems. Place names are studied in their physical and social context (for example, to establish patterns of clan migration), rather than just etymologically.

Information from archaeological surveys is used to locate the zones of residence linked to the irrigated spaces studied. The chronology

¹⁷ See Kirchner (1995a), 279–316.

of archeological remains provides a rough chronology for agrarian spaces even when they cannot provide a foundation date, because materials dating from the earliest phases of occupation are not always found on the surface. In traditional extensive archaeology, residential sites have been privileged over workplaces. But without linking the two, one can never explain the siting, or distribution, or size of the former, or its relation to other sites.

A third type of information is the analysis of written documentation, which can provide a variety of data according to each case, including the system's foundation date, the chronology of modifications to it, descriptions of the physical configuration or institutional modalities of water distribution, identification of place names or specific settlements. Such information is not necessarily direct. The foundation date might be deduced from the sudden appearance of irrigated parcels or of a main canal in a homogeneous series of documents.¹⁸ Descriptions of the spaces studied are very rare, however. The most one normally has are post-conquest Christian notarial documentation or land registers which provide some details about parcels and their boundaries, typically in the form of indirect information about the configuration of the irrigated area, its bounds, the number of mills and tanks (or absence of them), passing references to crops, and so forth.

Hydraulic surveys, which establish the planimetric reconstruction of the hydraulic system and help to distinguish the original design from later modifications in the event that the system has been operational until recent times, are also employed. These surveys are done *in situ* with the aid of enlarged aerial photographs. Thus equipped, and with some documentary support, one can identify both Andalusi and feudal systems, beginning with the principle of spatial association between zones of residence, tribal territory (in relevant cases), and irrigated spaces. This kind of survey, resulting in the mapping of the fields and water distribution network, is extremely tedious and too many students of Andalusi irrigation systems have omitted it, relying on the simple observation of aerial photographs. Yet, to understand how these systems functioned, the hydraulic survey is

¹⁸ That does not mean that the "first mention" of an artifact can automatically be considered as a post quem date. The first mention of an irrigated space in feudal documents subsequent to the conquest of al-Andalus records its existence at the time of conquest, not its foundation.

absolutely necessary. It is the secondary feeders that give meaning to the water distribution system, both in its spatial and social dimensions.¹⁹ All of the secondary distribution channels must be identified, turn-out by turn-out, until the water reaches individual parcels. In clan-based irrigation, these patterns of subdivision have obvious social meaning, as scholars from Diaz Cassou in the nineteenth century to Berque in the twentieth have recognized. None of this is immediately perceptible in aerial photographs, no matter how much enlarged. The preparation of a detailed map is the only way to distinguish the original design from later amplifications, if any. The latter present themselves as additions to the initial irrigated space and are clearly differentiated because they owe their existence to new water sources, to extensions of main canals, to alterations in the configuration of secondary canals, or to the modification of the main canal's gradient making it more gradual, thereby including new irrigable space between the new canal and the trajectory of the previous one. All these possibilities depend on favorable, irrigable terrain.²⁰ On the basis of the hydraulic survey and the resulting map, it is possible to establish the relative chronology of successive modifications starting with the nucleus defined by the original design. By comparing the map to such documentary evidence as exists, we can then assign dates for many of these changes. Inasmuch as most of these systems survived the feudal conquest, this procedure is necessary in order to distinguish between the clan-based Muslim system, on the one hand, and the feudal successor, on the other. Most of the amplifications, interestingly enough, have proven to be modern and the remodeling of field systems typically dates to the eighteenth century (when "rationalized" agricultural strategies of the Enlightenment were introduced), or even to the nineteenth. Thus, modifications in the gradients of canals, infrequent as they were, are generally correlated to cementing them, the resulting impermeability of the channels permitting more gradual slopes.

Finally, morphological analysis of parcels through the study of aerial photographs can be used as the primary technique of analysis in cases where the hydraulic system did not survive into modern times. An irrigated zone can be easily identified by its well-defined limits,

¹⁹ For the names of appurtenances of irrigation canals, we follow standardized English terminology as found in Maass, Anderson (1978), and Glick (1970).

²⁰ See, in this regard, Barceló (1989).

by coloration resulting from moisture, and by the morphology of its fields which differs from that of the dry-farmed fields around it. Thus a fossilized irrigated space will leave impressions on the land which can be recognized. On this basis, it is possible to establish the route of the main canal, the point where the source was tapped, and the boundaries of the formerly irrigated space. Such morphological analysis is also useful in determining areas added to the original design or changes in the original layout of fields. In this sense, there is a kind of horizontal, stratigraphic pattern of blocs of parcels differing in morphology or chronology which are added on to one another or which cross-cut each other. In some cases an increment in irrigated area does not imply the creation of new parcels but simply the new irrigation of parcels previously dry-farmed. Another pattern is the superposition of successive field systems in the same space, when the form of the parcels changes over time. This second type is much harder to detect. Sometimes portions of the old field system survive unchanged, while in other cases one finds fossilized traces detectable only in certain aerial photographs.

*Different Technical Solutions in the Construction of Hydraulic Systems:
Types of System*

Although all gravity-flow systems display common features, a variety of techniques or strategies were adopted. Thus the specific nature of the water source and its location, as well as the orography of the terrain deemed suitable for irrigation, the layout of the distribution canals and, finally, differing norms informing the social distribution of water all may be reflected in the morphology of an irrigation system.²¹

Valley-floor systems are irrigated spaces constructed on the floor of a valley, occupying the flattest terrain extant between the margins of a stream or gully and the valley slopes (figure 7.3). The disposition of the slope, whether sharp or gradual, may not have been the crucial determining factor. Rather, the location of the source could have been more determinant, and orography may have influenced the design in some cases. Valley-floor systems always have

²¹ On the morphology of irrigated parcels, see Argemí et al. (1995), 163–189; Kirchner (1997b); and Kirchner (in press a).

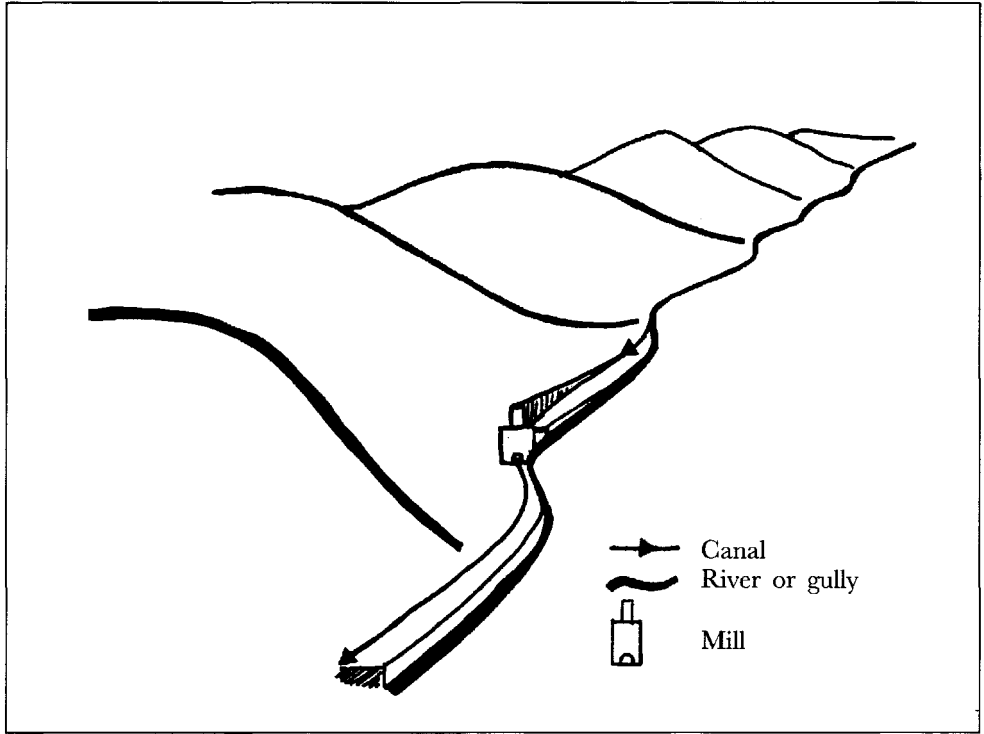


Figure 7.3. Valley bottom irrigated space.

their water source in the same channel as the natural run-off, or near it. We often find diversion dams collecting permanent or seasonal run-off, or springs in a gully bed or to one side of it; or qanats which capture either the underground run-off of a gully or fossilized aquifers formed in debris cones.

On the valley floor, terracing is minimal, often reducing the need to channel the gully or water course to protect the parcels. The main canal extends along the edge of the parcels that irrigate directly from it, without the need for secondary canals. Sometimes the main canal might cross a gully or water course on the valley floor, seeking the bank that best permits the construction of parcels. That side normally would be the inside edge of a meander where, moreover, the predictable accumulation of sediment carried by run-off can be appropriated for the construction of the parcels which, as a result, tend to be shaped like elongated half-moons.

Very often in Andalusi valley-floor systems, wherever the debit of the source permits, there are water-mills installed right on the main canal and located at the end of a zone of irrigated parcels. In the case of a small system, like for example Castelltix (Mallorca) which has only one meander formed by the irrigated area, the mill is located at the end of the system. The irrigated space is confined by the two lines of rigidity defined by the gully (the lower one), and by the route of the canal, the upper one. The area deforested and conditioned for irrigation coincides with the space defined by a meander of the gully. The noria which irrigates a small parcel adjacent to it is most probably a very recent addition. The mill was powered from a canal supplied by the qanat and runoff carried in the gully. A tank situated a bit before the mill served to regulate the head which powered it (figure 7.4).²²

In systems with several mills, these tend to be sited along the entire course of the main canal, closing blocs of parcels, with the blocs defined by each one of the meanders of the natural channel. Mills are located at the point where the main canal has enough drop to permit the construction of a vertical penstock (in Catalan, *cup*; in Castilian, *cubo*).²³ The presence of the mill requires that the canal continue on at the same level, or almost, of the valley floor and be not too distant from the zone of irrigable parcels. Mills were also located at points where the main canal crosses over to the opposite bank of the valley floor.

Various examples of this kind of layout have been studied in the Balearic Islands and in Sharq al-Andalus (the eastern region of Islamic Spain, embracing the present provinces of Valencia, Tarragona, Alicante, Murcia, and Castelló). The systems of Coanegra (Mallorca) and Buscastell (Eivissa) have been particularly well reconstructed thanks to availability of abundant and precise written documentation. It is worth mentioning that in these cases the morphological configuration of the systems, in several blocs of parcels, each one closed by a mill, is congruent with the supposition that these were spaces shared by different clan groups, mainly Berbers, but also some

²² Barceló et al. (1998). In Ibiza (Eivissa), the Xarraca system was also closed by a mill, likewise preceded by a tank permitting regulation of the head. This space was a valley-floor arrangement, even though in this case more than one parcel is found on two levels of terrace; Navarro (1997), 53–64.

²³ This kind of mill is described below.

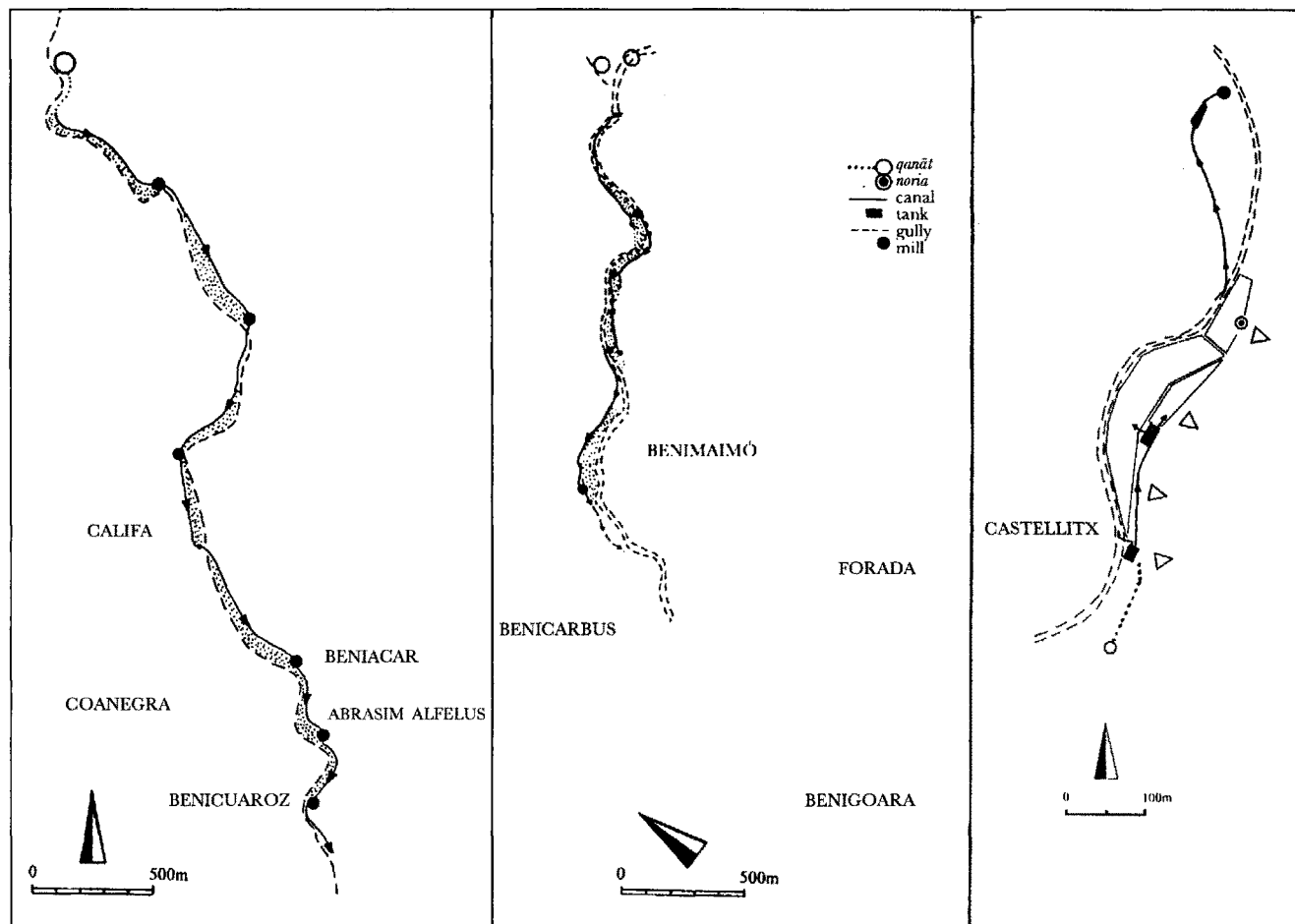


Figure 7.4. Hydraulic systems in the valley of Coanegra (Mallorca) (Kirchner [1997a]), the valley of Buscastell (Ibiza) (Argemí et al. [1997]), and of Castellitx (Mallorca) (Barceló et al. [1998]).

Arabs. This arrangement is clearly consistent with clan organization and with the preference of tribal irrigators for self-monitoring. The irrigated space was shared on the basis of equity (but not necessarily equality) among clans of different sizes which, in the moment of the foundation and construction of the systems must have established the pacts necessary for their use. The size of the groups must have been determinant in such pacts, given the greater capacity for work of the more numerous groups, as well as the unequal subsistence requirements of each one of them (figure 7.4).²⁴

Unlike valley-floor ones, slope systems are built on valley slopes which are terraced to obtain level parcels. According to the placement of the water source, two distinct types can be identified. In a first variety, the water source is located in a valley floor (figure 7.5). From a water source in the bed of a gully or stream (or near one) the main canal runs along a valley slope.²⁵ The light gradient of the canal causes it to depart progressively from the level of the valley floor, and the space between it and the stream bed grows increasingly wider. Thus this type of irrigated system tends to open out in the form of a fan. In cases studied in Mallorca, such as those of Bunyola and Alaró²⁶ (figure 7.6), there are mills all along the main canal, whose course is stepped because the emplacement of vertical penstocks requires a certain drop in the canal. In this kind of system, it is not possible to irrigate all of the terraces directly from the main canal, and a network of secondary feeders is required to distribute the water. The principal branch canals are usually found at the same level as the mills, perpendicular to the main canal. This

²⁴ Balearics: Buscastell, Ibiza: Argemi et al. (1997), 37–51. Mallorca: Coanegra Valley, Kirchner (1997b). A series of hydraulic systems in the gully of Algendar, Menorca: Retamero (1998a), 261–270. El Molinell, Culla, province of Castelló: Barceló (1995a), 25–39. The *insulae* of Girona described by Martí on the basis of feudal documentation were also valley-floor systems, as were feudal hydraulic systems linked to the oldest mills in the Aravó river valley of Cerdanya (documented from the tenth century). Each system was comprised of a canal that irrigated the area between it and the river and which powered a mill at the end of its course. This is a type of hydraulic system characteristic of the organization of irrigated spaces in feudal societies. In such systems, moreover, irrigable space is secondary, with mills the primary organizing feature; Martí (1988b), 111–123; Kirchner, Oliver, Vea (in press).

²⁵ There are also systems with two main canals, one for each slope, rising from the same source or from two different sources. In such cases, two more or less symmetrical irrigated perimeters were constructed.

²⁶ Kirchner (1997a).

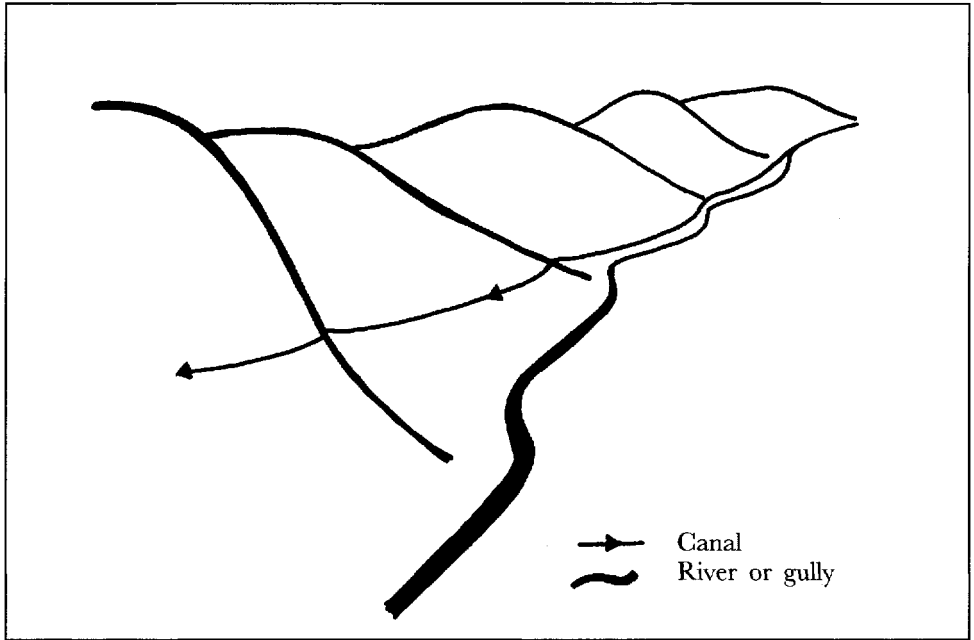


Figure 7.5. Irrigated hillside system with water source on the valley floor.

network of secondary canals, therefore, defines the blocs of parcels watered from the same point. This fact creates regularities in the arrangement of fields determined by the disposition of turn-outs and of secondary canals.

A second type of slope system uses the water source on a valley slope (figures 7.7, 7.8). The set of terraces irrigated is located on the same slope. Depending on the debit of the source there is usually only one main canal (normally following the natural gradient of the valley) or two, running in opposite directions. In this latter case the two main canals embrace the terraced space which tends to describe a circular form or that of a cupola. The length of the two canals depends on the available debit. The space is divided into two morphologically congruent areas determined by the distribution of the water and if there are canal turn-outs and secondary canals along the two main canals, these will define blocs of homogeneous parcels. A good example of this kind of system is that of Guájar Faragüit (Granada), where water from a spring situated in the middle of a slope is collected in a tank and distributed among the terraces from

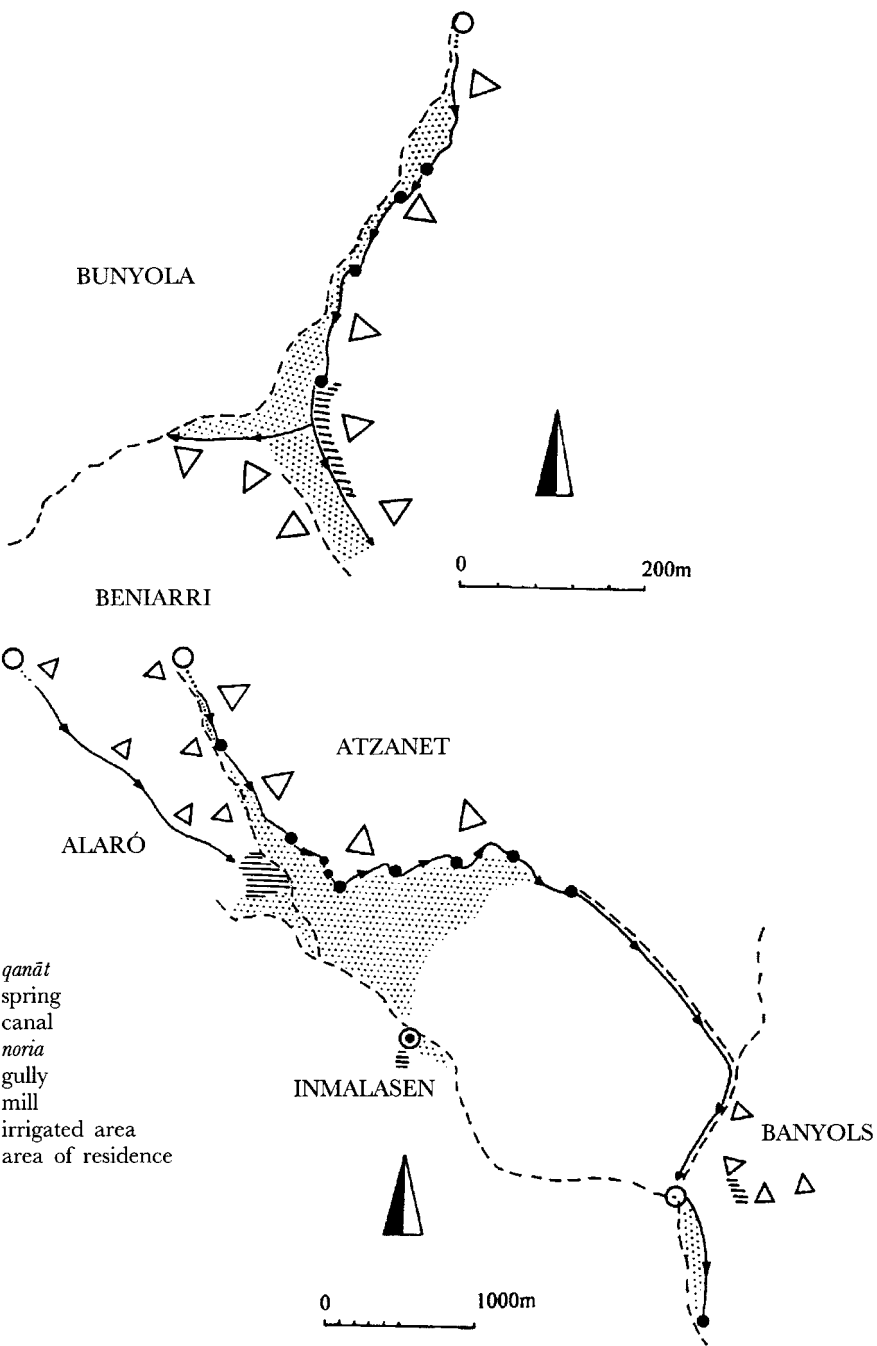


Figure 7.6. Hydraulic systems of Bunyola and Alaró (Mallorca) (Kirchner [1997a]).

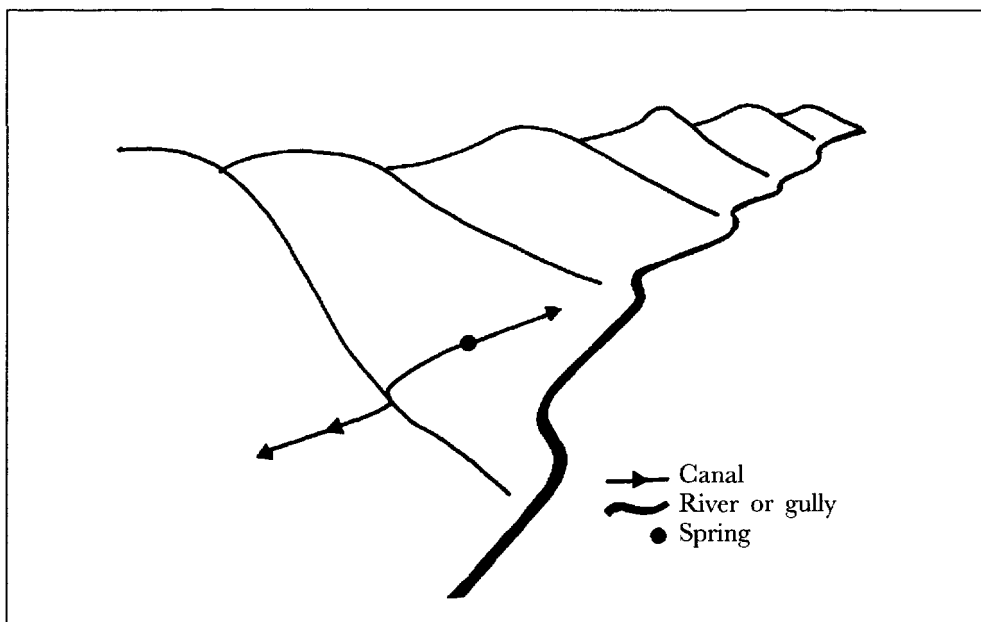


Figure 7.7. Hillside irrigation system with a single source of water.

two main canals flowing in opposite directions, one in the same direction as the gradient of the valley, the other in the opposite direction.²⁷ The space comprised by these two canals has a rounded form. The tank, which serves to regulate the head and the irrigation turns, is not a large tank for accumulating or storing water. The spring does not provide enough water to permit direct circulation through the canal network. Water must therefore be accumulated in a tank to obtain a sufficient volume. It takes approximately twelve hours for the tank to fill, and it voids alternately into each of the two main canals. More recently, the frequency has been increased thanks to the addition of water from a canal probably built in the nineteenth century. This canal carries river water which runs along the valley floor through a canal that begins in a turn-out built a few hundred meters above the original irrigated perimeter. The new line of rigidity established by this canal passes above the spring, thus enveloping the Andalusi irrigated perimeter within the more recent one. Thanks to this new supplement of water, it takes the tank a bit

²⁷ Barceló et al. (1998).

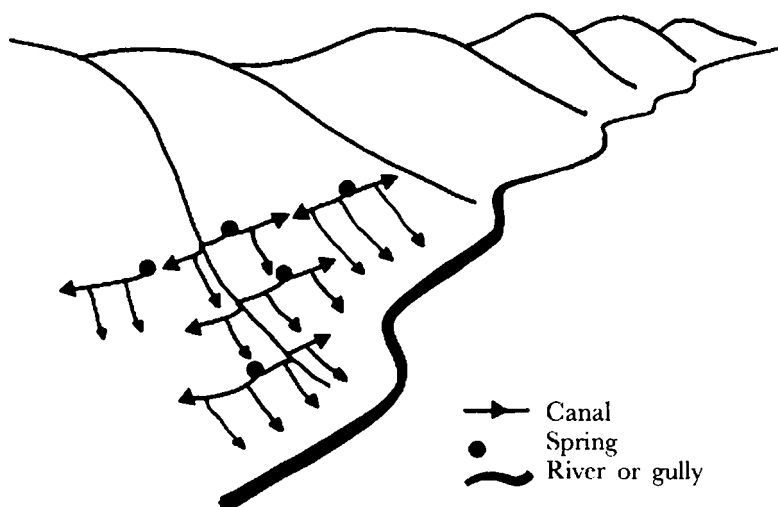


Figure 7.8. Hillside irrigation with multiple sources of water.

more than three hours to fill when it receives the water of the new canal through a turn-out specific to it (figure 7.9). The case of Liétor (Albacete) is similar, except that it has more than one source, each one of them defining an independent irrigated perimeter. Each of the springs is associated with a regulating tank and with distribution turns among the group of users in each zone. The road network internal to the hydraulic system is also congruent with the boundaries of the different zones, permitting access to all of them. The general physiognomy of the irrigated space, built on a slope with a steep gradient (and hence terraced), is very homogenous, in spite of being watered by several hydraulic systems with regular areas. This is indicative of a global design taking all of them into account (figure 7.10).²⁸ In all the cases thus far studied, these blocs of parcels cannot be discerned by aerial photography alone. Each canal must be walked and mapped along with the parcels they irrigate in order to establish the type and to understand the rationale of its morphology.

²⁸ Navarro (1995a), vol. 6, 365–378, and (1998).

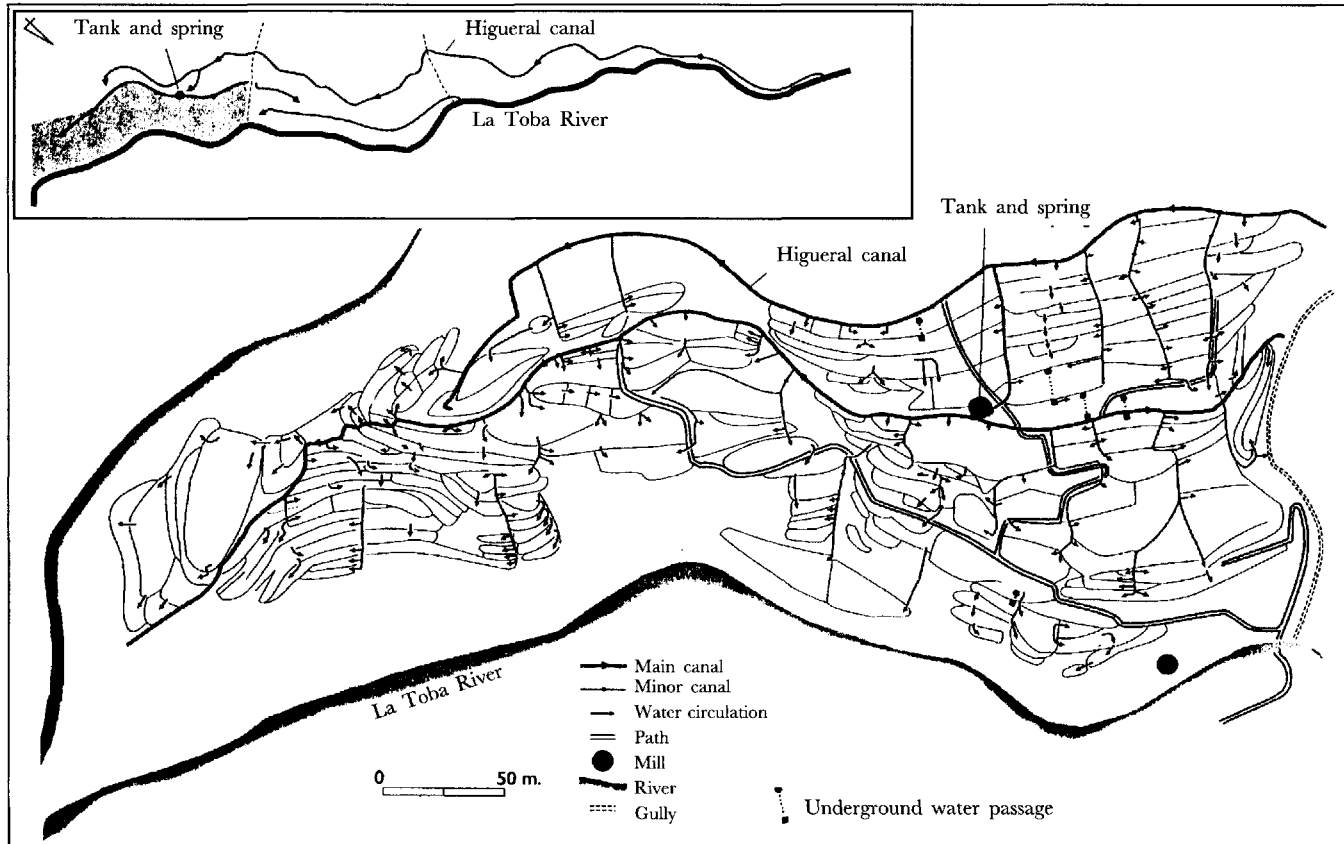


Figure 7.9. Hydraulic system of Guájar Faragüit (Los Guájares, Granada) (Barceló et al. [1998]).

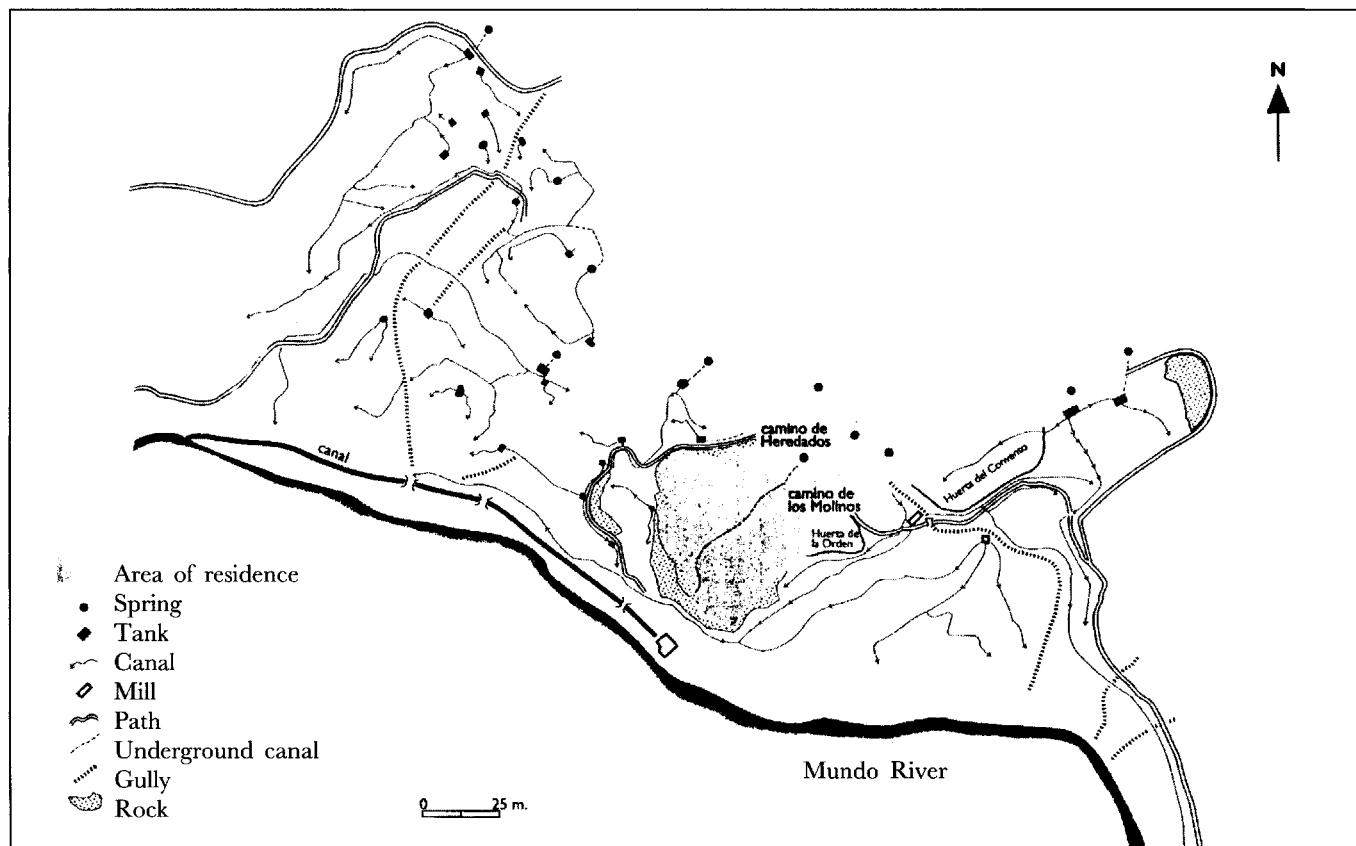


Figure 7.10. Hydraulic system of Liétor (Albacete) (C. Navarro [1995a], [1998]).

These different types of hydraulic system, characterized by their morphology, have been proposed on the basis of many case studies. But there are also numerous examples which, because of idiosyncratic orographic characteristics, cannot be easily assigned to one class or the other. For example the hydraulic system of Felanitx, Mallorca, is technically a slope system with its water source, a natural spring, on the valley floor. But the gradual gradient of the slope creates a field system of the elongated form typical of valley-floor systems.²⁹ The water sources of the systems of Balàfia and Can Rei (Xarraca), in Ibiza, are each located on the edge of a gully with a steep drop, so that the floor of the valley cannot be used for irrigation. Rather the irrigated spaces are sets of terraces on a bank of a gully and tend to have the circular form characteristic of slope systems with a water source on the same slope (figure 7.11).³⁰ Another factor that might create idiosyncratic morphological characteristics is the presence of tanks that regulate the debit of the water source and of the distribution network. Such tanks are found in many systems fed by natural springs or other forms of subterranean sources, such as qanāts, whose debit is insufficient to distribute the water directly to parcels. The tank permits the accumulation of sufficient water to generate an artificial head. These tanks, which function as the core of an hydraulic system, are almost always present in small systems of no more than two hectares in area. The area irrigated bears a proportional relation to the water available. Therefore, where there is scant debit, we find small irrigated spaces in conjunction with regulating tanks. This type of tank is also characteristic of slope systems with the water-source located on the same slope. Here, the source is usually a natural spring.³¹

The morphology of an irrigated field system, therefore, is highly determined by the emplacement of the source and the relief where the fields are established, but precisely the rigidity imposed by gravity flow permits us to distinguish irrigated perimeters from their

²⁹ Barceló, Kirchner (1995).

³⁰ Kirchner (1998b), 351–372.

³¹ This is the case not only of Liétor (Navarro [1995]) but also of Guájar Faragüit (Barceló et al. [1998]). Stable, permanent sources typically provide enough water to preclude regulation tanks. As for qanāts, both options hold. Their debit depends on the quality of the aquifer tapped. Thus there are qanāt-based systems that do not require regulating tanks and others that do. The latter are smaller than the former. See Kirchner (1997a).

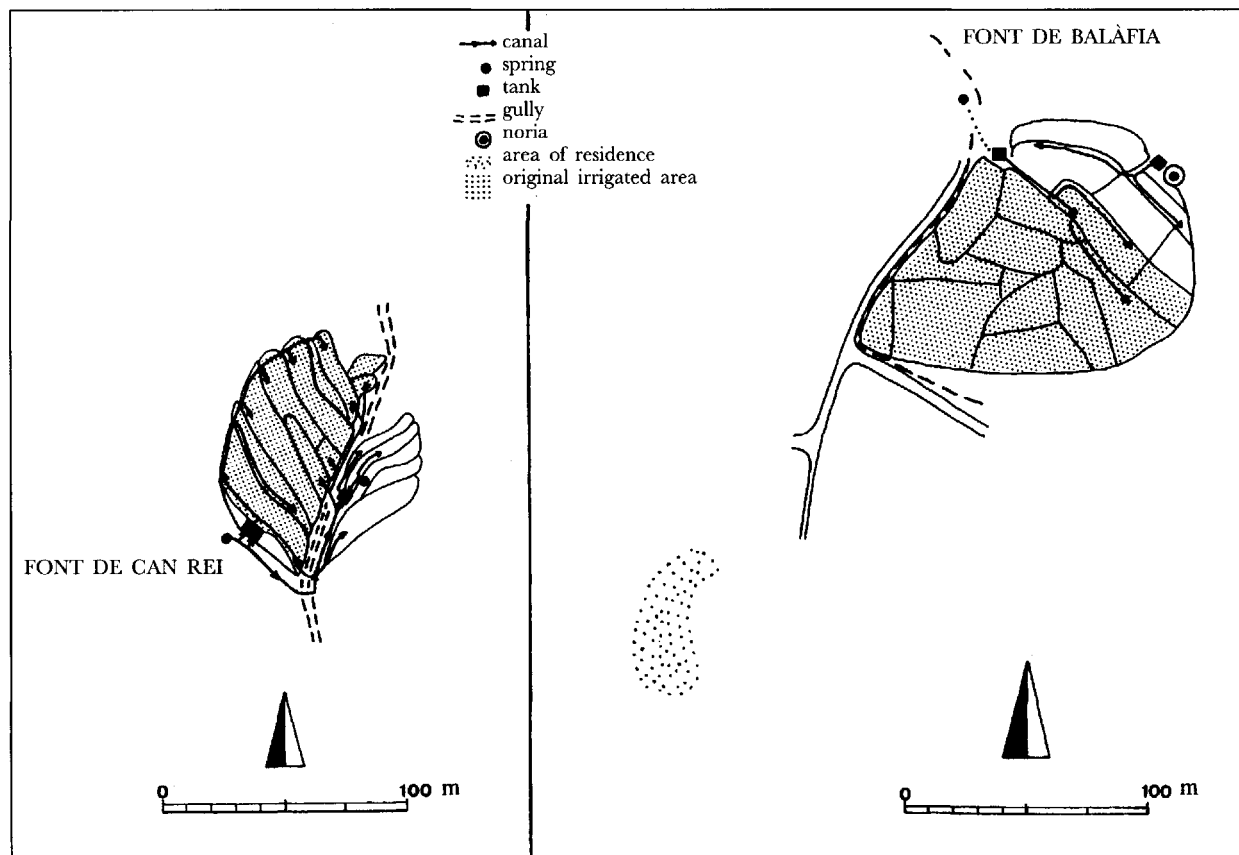


Figure 7.11. Hydraulic systems of Can Rei (Xarraca, Ibiza) (Kirchner [1998b]), and Balàfia (Ibiza) (work in progress in the Hydraulic Archaeology Project, directed by M. Barceló).

surroundings: they have very clear boundaries. Moreover, water flow shapes the internal layout of irrigated field systems in ways that clearly differentiate them from their surroundings. We only find similar layouts in the case of dry-farmed zones later converted to irrigation. In such cases, field morphology is similar to that of the dry-farmed areas bordering them. This situation is typical of zones into which irrigation has been extended when a main canal is lengthened making possible the irrigation of fields previously dry-farmed. An extreme situation, that of an irrigated field system indistinguishable morphologically from the fields bordering it, would likely arise from the construction of a hydraulic system after the fields had been laid out, forcing their adjustment to a different agricultural regime.

Peasant Hydraulic Systems in al-Andalus

The migration of Arabs to the Magrib and al-Andalus was accompanied by the diffusion of Eastern hydraulic techniques, which in turn were intimately associated with the transfer and acclimatization of a series of new cultigens, originating most significantly in India.³² The cultivation of these plants (particularly those originating in Monsoon regions of Asia) required irrigation in the Mediterranean world and hydraulic techniques diffused as a means for permitting their cultivation. However, as Barceló notes, in this historical scenario irrigation was a peasant *option*, not merely the result of a natural constraint like aridity.

In this sense, the original design of a hydraulic system and the area of cultivation which it presupposes are the result of the assessment that a group of peasants makes of its own horizon of subsistence which necessarily includes quotients of work and produce that would ensure the ongoing stability of production. There is obviously a relationship between the size of the group and the area of the cultivated space it establishes.³³ The concrete size of irrigated spaces is

³² See Barceló (1996b), vol. 7, 295–297; Glick (1979), 76–78; Watson (1983). The latter is a now-classic study of the transfer from the Islamic East to the the Magrib of plants either completely new to the region (sorghum, Asiatic rice, hard wheat, sugarcane, cotton, citrus fruits, banana, coconut palm, watermelon, spinach, artichoke, colocasia, eggplant, mango) and others known before but vastly diffused by the processes of conquest and Islamization (fig tree, caper, pomegranate).

³³ Barceló (1995a).

therefore significant. Barceló further links the segmentation of the peasant group with the rigidity that characterizes the irrigated spaces. When the original estimate of its own needs is exceeded by the growth of the group, one part of it must then produce a new space, at greater or lesser remove from its place of origin. The creation of a new settlement typically involves the duplication of the clan name, making possible the reconstruction of the segmentation process through the study of place names.³⁴ In this context, the process whereby sites are selected for settlement acquires great importance. The place of settlement is determined by the possibility of constructing a space of cultivation that responds to the assessment made by the peasant group and which includes inspection of terrain, localization of aquifers capable of being channeled towards a space with favorable gradients, measurement of the debit and of gradients, calculation of the area potentially irrigable with a concrete debit—all these factors determine the choice of a place of settlement. Next to such considerations, the area of residence is decidedly of secondary importance, a lesser decision even though in conventional excavation archaeology it has been portrayed as crucial to the understanding of spatial sequence.³⁵

The now abundant studies of Andalusí irrigation systems have revealed the morphological homogeneity of the principal options for constructing a hydraulic system.³⁶ For Barceló, this homogeneity is the result of a synthesis of techniques probably already in place in al-Andalus by the ninth century, with the consolidation of settlement by migrating Arab and Berber groups, particularly in places where control by the central state was scarcely felt.³⁷ Thanks to their political and social organization based on lineage, these groups impeded the accumulation of wealth in the hands of some of their members. This was a social result which may, in part, have been an unintended consequence of irrigation agriculture, which favored the production of perishable crops that could not be stored. As there was no social class able to dominate the processes of work by demanding rent, we perceive an apparent “slowing down” of historical time in the long-term spatial stability of the organization of peasant work.

³⁴ Barceló (1995a), 28.

³⁵ Kirchner (in press b).

³⁶ Kirchner (1997a); Kirchner (1998b); Barceló (1997a); Navarro (1995a); Argemí (1996), 259–271; Argemí (1998), 373–386; Vea (1995), 302–213; Retamero (1998a).

³⁷ Barceló (1995a), 37–38.

This is particularly true of irrigated space, whose ultra-stability is notorious. It is not at all strange, therefore, that such spatial representations are repetitive.³⁸

It is clear that the repetition of technical and spatial solutions was also determined by the limited range of possibilities available (here, the prior experience of the settling groups mattered), although that in itself does not explain the consistent selection of small spaces. The aggregation of results on a regional level, together with the detailed study of settlements and irrigated spaces associated with them, yields a picture of networks of clan settlements associated with irrigated cultivation of small size, settled by small groups of people. Irrigated spaces just a bit larger were often shared by several groups.³⁹ Both in the Balearics and in certain sites in Sharq al-Andalus modal settlement size varies between one and two hectares per settlement, even sinking below one hectare at times.⁴⁰ It is clear that there are aquifers or sources whose debit does not permit more extensive irrigation, although there are some that permit systems of from four to ten hectares or a bit larger, shared by several groups. Thus it seems that there was a clear preference for keeping populations small.⁴¹ Furthermore, in the majority of cases the irrigated space as originally designed never exhausted the possibilities of the available debit, as is amply demonstrated when, especially in modern times, some of these spaces were doubled or more, before reaching the limits of water available or sometimes over-extending irrigation, threatening their very viability.

Water distribution necessarily requires regulation. To ensure the stability and operation of the hydraulic system, rules are elaborated taking into account the area to be irrigated, the type of plants grown, the seasonality of irrigation, the number of users or of groups involved in the construction of the system, and labor requirements, always in

³⁸ See, in particular, Barceló (1995a), 32.

³⁹ Kirchner (1997a); Argemí et al. (1997); and Argemí (1997).

⁴⁰ For the Balearics, see n. 24, above. For Sharq al-Andalus, we refer to as yet unpublished research directed by Barceló in the Gallinera Valley, and that of Vea in the neighboring valley of Planes (Alicante) (as an example, see Vea [1995]).

⁴¹ We cannot generalize from these study areas to Al-Andalus as a whole. Some fairly large irrigated spaces occupied by one group only have been identified: Yetture (near Liétor), 18 hectares, Letur (Albacete), 28.8 hectares, and Yátor, Granada, 27.6 hectares; Navarro (1998). However, the ratio of area of residence to that of cultivation there is consistent with that found in Mallorca; see Navarro (1995b), 181.

consonance with the values (equality, equity, justice, efficiency, etc.) of the social group(s) in question. Virtually all studies of tribe-based irrigation stress the importance of equity in the elaboration of operating procedures and its significance as a feature enhancing social cohesion.⁴²

It is entirely natural, therefore, that the social distribution of water be spatially represented in the distribution network and field systems. Thus, in systems shared by several groups different blocs of parcels can be distinguished, congruent with the main turn-outs from the main canal, the number of which coincides with the number of peasant groups involved.⁴³ On the other hand, in small systems associated with just one clan, with an area of a few square meters up to one hectare, the field system is not subdivided at all, the organization of water distribution permitting no fragmentation either of space or of water delivery.

Suburban Huertas

No Spanish suburban huerta has been adequately studied, at least with the methods of hydraulic archaeology, the best tested way to establish and explain the original design. The great huertas of eastern Spain, as we see them today, appear to be the result of accumulated expansions and uniformizing of the trajectories of canals which give an appearance of homogeneity indicating little about their formation. Most of what is known of the Muslim huertas of Valencia and Murcia, for example, has been learned or inferred from post-conquest Christian documentation which does not, of course, reveal anything about the historical processes by which those huertas developed.

Somewhat more can be said of the urban huertas of the Balearic Islands. That of *Madīna Mayūrqa* seems, at least in part, to have been the result of a state initiative directed by *ʿIṣām al-Ḥawlānī* after the Arab conquest of Mallorca in 903. The name of the *qanāt* that

⁴² On tribal irrigation, see for example, D. Hart, who (in his introduction to Blanco Izaga [1939, reprinted in Moga Romero, Bravo Nieto 1995], 68) states that in the Rif of Morocco, irrigation turns are on the basis of equal distribution among families. Among Spanish medieval archaeologists, Barceló (1995b), 240–254 has insisted on the distinction between the social and physical logics of water distribution.

⁴³ See the examples of Coanegra (Mallorca) (Kirchner [1997]) and Buscastell (Ibiza) (Argemí et al. [1997]).

provisions the city and its huerta was called 'Ayn al-Amīr.⁴⁴ But the huerta of the *madīna* (city) of Yabisa/Ibiza, on the other hand, appears to have resulted from the synoecism of six peasant settlements, most with Berber clan names: Beniatzara (Banū Ajjār), Beni Pater (Banū B.d.r), Massana (M.S.N), Benissomada (Banū Sumāta), Benialgacil (Banū Agazi), and Alcudeya (*al-qudya*), along with some complementary participation by residents of the city.⁴⁵ All these settlements, including the city, encompassed a space of some 72 hectares of irrigated huerta, and 71.6 of meadow (figure 7.12). This huerta was the result of the drainage—as complex and planned as any irrigated space—of a wet zone. On its lower edge, the huerta is bounded by meadowland, where the drainage works served only to void water from the upper cultivated zone into the sea. Norias were introduced in order to irrigate the upper zone, drained for cultivation, or those immediately adjacent to it. Thus, in the case of Ibiza, a detailed study of the huerta and its field system, with the assistance of written documentation, photo-interpretation, and information yielded by urban excavation, has not only made it possible to describe the original Andalusian nucleus of the urban huerta and its extensions beginning in the seventeenth century, but also to identify the specific builders of the agrarian space, by their clan names, as peasant groups. These were groups identical to those settled on the rest of the island (which have also been studied), not an exclusively urban population.⁴⁶ The city expanded and occupied huerta space, especially beginning in the eleventh century, when numismatic studies permit the hypothesis that the Taifa state had developed some efficiency in the collection of taxes in the Balearics.⁴⁷

The case of Ibiza cannot be generalized to all al-Andalus. Indeed, caution is recommended in those cases where the creation of a sub-urban huerta has been attributed to early medieval urban expansion but where insufficient systemic research has been performed. Based on urban excavations (which typically have not been systematic, but rather in response to legislation requiring “emergency excavation”

⁴⁴ “Spring of the Emir.” In the *Liber Maiolichinus*, which describes the Catalan/Pisan attack of 1115, this qanāt is called *Enelamir*. It also appears repeatedly in different versions of the *Llibre del Repartiment*. Fontanals (1984).

⁴⁵ On these etymologies, see Barceló (1997b), 22–24.

⁴⁶ González Villaesclusa, Kirchner (1997), 90 for norias; Barceló, González, Kirchner (1997), 113–125.

⁴⁷ Retamero (1995).

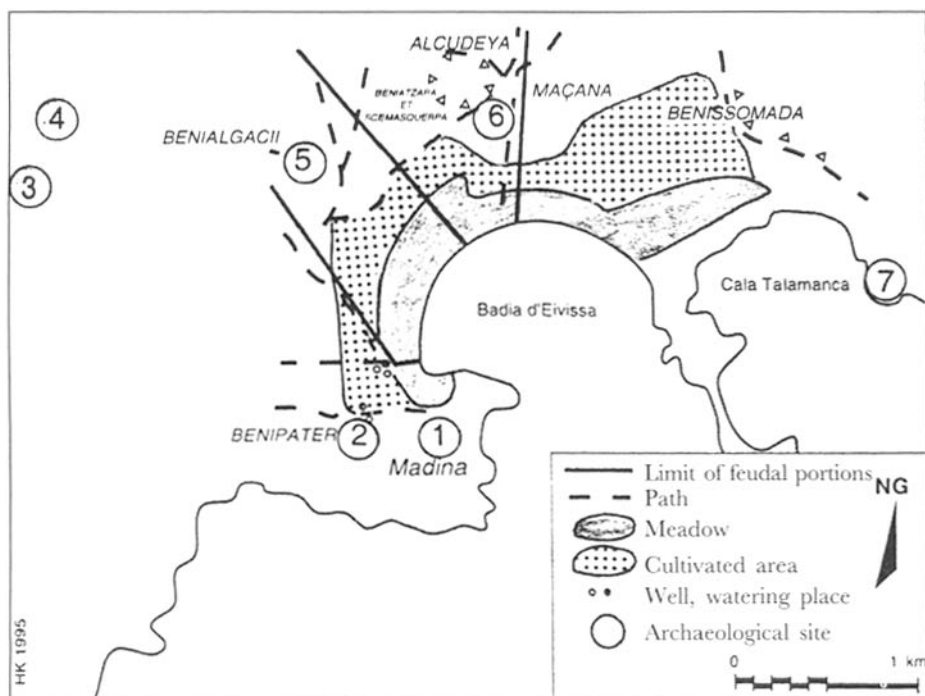


Figure 7.12. Reconstruction of the *hawz* of the *madina* of Yābisa (Ibiza) (González Villaesclusa, Kirchner [1997]; Barceló, González Villaesclusa, Kirchner [1997]).

of building sites), urban expansion in the Andalusi period is datable beginning especially in the eleventh century. However there is at yet no explanation of this process.⁴⁸ What is clear is that dynamic urban growth could only have been possible in the presence of an agrarian space capable of provisioning larger settlements.

We can, however, briefly review the state of research on the sub-urban huertas. The emergence of the great huertas of the eastern peninsula (from north-to-south) Castellón de la Plana, Valencia, Gandia, the Ribera del Júcar, and Murcia-Orihuela (Lower Segura) has been studied from a variety of viewpoints, though none with the rigor of the Balearic surveys just described. Nevertheless, some preliminary findings, taken as a whole, present some common characteristics.

⁴⁸ Bolens (1972), 65 has suggested the importance, in this regard of the "regionalization" of the Andalusi economy in the wake of the dissolution of the Caliphate of Córdoba. For a critique of this economic model, see especially Retamero (1998b), 75–91.

First, early development of littoral marshlands, perhaps as early as the eighth century, with the introduction of norias, first for drainage (to lower the water table), then for irrigation. Second, small scale irrigation in the huerta proper, which both in the Ribera del Júcar and Valencia was originally based on springs, not on rivers. Third, the development of canal-based irrigation, from rivers, producing irrigation systems whose general contours were prefigured by "paleo-canals"—natural channels, running parallel to the river (both in Valencia and Murcia/Orihuela), carved out by flood waters, appropriated by cultivators for permanent irrigation or drainage channels. In certain zones of the huertas of La Plana, Valencia, and Orihuela these channels formed comb-shaped patterns, such that, when they were converted into permanent irrigation canals, they required the imposition of a rotation, which in turn accounts for similar institutions of water distribution. Fourth and last, as the interstices between original small spring-based systems were filled in, and canals extended, small systems were linked together by canals and fused into larger networks of systems.

These stages can be seen as sequential—albeit with considerable overlap—and are illustrative of the process whereby individual systems (taking as a "system" an entity based on one water source) form networks created by the "juxtaposition, agglomeration, or interpenetration of several systems."⁴⁹

In Castelló, Bazzana and Guichard describe a network of old canals around Burriana, certain of which have names corresponding to *alquerias*. However, Burriana, the major town on the flood plain of the Millars (Mijares) River, had only a small irrigation system in the Andalusi period. The older irrigation zones of the plain did not necessarily irrigate from the river as they did after the conquest when new canals were built. J. Mateu suspects that Muslim irrigation there consisted mainly of small systems, irrigating with norias or by canal from springs, rather than any articulated system of canals. Flood plains, as Mateu observes, are rich in springs and aquifers

⁴⁹ Cressier (1995), 267. Cressier believes it deceptive to think of large huertas as "macrosystems," when (with the possible exception of that of Valencia) they are networks comprised of different kinds of systems. Likewise, it is inexact to compare, for example, the vega of Granada (a mosaic of complementary systems) with the Ghūṭa of Damascus (a homogeneous, although large, system with one water source only).

that could have been tapped in the Andalusí period without any overall coordination.⁵⁰

González Villaescusa, comparing the morphology of irrigation in the huerta of Valencia with that of Roman centuriation patterns still visible, concludes that the former was superimposed on the latter and that, for example, the Montcada Canal system does not correspond to any anterior Roman one.⁵¹ The huerta of Valencia evolved slowly through the agglomeration of adjacent spring-fed systems serving individual *alquerías*. Inasmuch as many of these *alquerías* were settled by Berbers, one can posit a primitive huerta organized by clans, as we have noted in other areas.⁵² The Ribera del Júcar, to the south of the city of Valencia is also a flood plain, where the Muslims irrigated not from the Júcar, but rather from smaller affluents or with *norias*.⁵³

With regard to the huerta of Orihuela, Gutiérrez attributes to the city (*madīna*) of Orihuela the creation of the huerta of this city based on the fact that al-ʿUdhri mentions the construction an irrigation canal by its inhabitants. The creation of this huerta would also justify the abandonment of early medieval settlements related to the swampy zone of the lower course of the Segura River.⁵⁴ Without an accurate hydraulic survey such assertions are only suppositions. The building of a canal in the eleventh century does not necessarily imply that there was no organized hydraulic system prior to it.

⁵⁰ Bazzana, Guichard (1981), 138. Mateu Bellés (1989), 171, 180–181. See also Torró (1999), 124.

⁵¹ González Villaescusa (1996), 348. His inference that some Andalusí state entity was responsible for the design of the huerta has been superseded by the conclusions of J. Mateu and J. Marco (work in progress).

⁵² Oliver Asín (1996), 165–175 identifies a number of prominent *alquerías* in the huerta of Valencia with Berber placenames: Mallīla (sub-tribe of the Hawwāra); Godella from Gudāla (a Sanhāja subgroup), Almusafes (Massūfa, a Berber fraction neighboring the Gudāla in the deserts of Mauritania), Benimaclet (Maklata, a branch of the Nafzāwa), Benimamet (a fraction of the Zanāta Banū Tujin), Mestalla (Meshddāla, a Zuwāwa, Kutāma fragment). While Guichard held that the Valencian region (Sharq al-Andalus) was almost wholly Berber from the eighth century, Barceló Torres (1983), 55 and (1984), 134 has argued that the presence of many Arabic place names within a 60 km radius of Valencia city is explained by mixed Arab-Berber settlement in the tenth and eleventh centuries, when Berbers were substantially Arabized; identifiably Berber place names were late, she thinks. She has underestimated the incidence of Berber tribal toponyms. Moreover, Mateu's finding of small, spring-based irrigation systems, associated with Berber clan names, in the primitive huerta of Valencia lends further credence to Guichard's contention.

⁵³ Mateu Bellés (1989), 171.

⁵⁴ Gutiérrez (1995), 87.

Both Gea and Gutiérrez present eighth-century irrigation in the Ribera Baja in the littoral marshes, associated with norias.⁵⁵ Gea describes the emergence of the huerta from channels or paleocanals developed naturally by both the Segura and Guadalentin rivers parallel to their beds to carry off flood water. These were appropriated for use as irrigation and drainage canals and, in the lower sectors of huerta, gave rise to geomorphologically characteristic comb patterning of canals that are found in La Plana as well as in certain sectors of the huerta of Valencia. Gea claims that in the mid-eighth century, Egyptian military contingents (*jundi/s*) settled in the huerta of Orihuela which they farmed as in Egypt, using the periodic flooding of the river, together with run-off from paleocanals. He dates the emergence of the mature huerta to the tenth century, but without any hard data to support that claim.⁵⁶ Pocklington notes, purely on toponymic evidence, that the Murcian irrigation canals with Arab names form a coherent network, while those with Latin names are scattered around, suggesting that the core of the huerta was developed by Arab speakers.⁵⁷

⁵⁵ De Gea Calatayud (1995), 65–70, and (1997), 155–217. Gea's chronology follows Gutiérrez's dating of noria pots. The topography of littoral marshlands gave rise to settlements on hillocks (*cabezos*) rising above the marsh. See also Gutiérrez (1997), who proposes an "indigenous" population identified by their technique of hand- or turntable-built pottery, the heir, in this view, of late Roman techniques. The introduction of noria pots and the norias themselves is ostensibly owing to the settlement of Egyptian army (*jund*) units. According to Gutiérrez, the fact that the form of these pots resembles the recent pots published by Schiøler is congruent with her thesis. Her ethnographic argument is therefore a crude one. Moreover, the settlements described are ex novo creations, without any continuity with late Roman settlements, with the result that the relevant ceramic chronologies display gaps of two, three, and four centuries. Moreover, the diffusion of the noria was not an isolated phenomenon, but was part of a set of agricultural techniques and concepts that only Berber peasant groups could have had. See critiques by Barceló (1996a) and Kirchner (1999).

⁵⁶ De Gea Calatayud assumes that a literary trope comparing the Segura to the Nile reflects the Egyptian organization of the huerta, but there is scant evidence that such was the case. The fact that a *jund* contingent was recruited in Egypt says nothing about the ethnicity of its members. As we will note below, the institutions of the Murcian huerta show a strong Berber imprint which would suggest that the mature huerta emerged as late as the twelfth century.

⁵⁷ Pocklington (1986), 462–473. On the limitations of his analysis (which, in any case, have to be regarded as inferential, absent a proper archaeological survey of the huerta), see Glick (1995), 88.

Urban Hydraulics

A number of studies allude to the determining role of canals in shaping the morphology of various towns of al-Andalus. To understand this logic, the distinction between the supply of domestic water and hydraulic systems related to Andalusí cities of different sizes is important. The urban plans of some Andalusí cities seem in part determined by the need to supply water throughout the urban grid to various mosques, baths, and small intramural gardens, but also private houses, water mills and tanning pits had access. In these cases the network of canals which supplies urban water is that same that permits irrigation in a more or less extensive huerta adjacent to the city.⁵⁸

J. Mateu has shown that the Rovella Canal traversed the *madīna* of Andalusí Valencia at its highest point. It was a prototypical industrial canal, powering six mills.⁵⁹ In the case of Xàtiva, all of the water-using facilities of the Muslim city—the mosque, baths, dyers' establishments, etc.—lay along the line of the main canal, the Sèquia de la Vila, and lay outside of the area encompassed by the Roman city. Clearly, the canal had to be in place *before* the town could be laid out.⁶⁰ A similar, but more complex case is that of Madīna Mayūrqa (Palma de Mallorca) in the tenth century. The main canal, the Sèquia de la Vila, is fed by a spring ('Ayn al-Amīr, or the Emir's Spring) some seven kilometers from the city. As it flows through the city, branch canals diverge to the east and west and, following the topography, form concentric ellipses, the city streets accommodating themselves to that form. The water-consuming public buildings, notably mosques and baths, are sited at the ends of the branch canals. The shape of the eleventh-century city wall was determined by the configuration of the urban canals.⁶¹

⁵⁸ On urban water supply and its relation to huerta canals in Al-Andalus and the Magrib see, among many, on Fès, Madani (in press), and LeTourneau (1949), 232–238; on Granada, Barrios Aguilera (1985). On intramural gardens in Madīna Mayūrqa (now Palma), see Riera Frau (1993).

⁵⁹ See Mateu Bellés (in press). The Christians displaced the channel of the canal to the south and added more mills. On the Rovella Canal as an organizing focus of Christian industrial activity, see Glick (1992), 483–484.

⁶⁰ González Baldoví (1988), 21–31.

⁶¹ Riera Frau (1994), 305–312. See also Fontanals (1984).

Techniques

Andalusi hydrotechnology is best understood from the perspective of peasant work, though the same techniques were available for productive or sumptuary consumption by other sectors of society as well. Technology is a cultural subsystem integrating tools, techniques, and resources in the context of specific social values and norms informing the social relations of production. Our objective in enumerating specific techniques (the technical details of which are in any case well described in the literature) is to indicate, to the extent that current research permits, some of the ways in which these techniques were integrated into peasant irrigation systems.

Dams

Diversion dams combine the functions of two distinct devices: the weir which changes the course of flowing water without affecting its level, and the storage dam, which impounds water. The diversion dam (Arabic *sadd*) raises the water's level so that it can flow into canals whose channel is higher than that of the stream. The ubiquity of such structures in al-Andalus accounts for the wide usage of Arabisms denoting them in Hispanic Romance languages (Castilian *azud*; Valencian *açut*).⁶² Cressier presumes that most were of earth on a wooden armature, as in North Africa. Such dams were either oblique with respect to the river bed, which they only partly traverse; or else they crossed the entire bed at the perpendicular, in which case a canal could be generated on both sides. As Cressier observes, tribal groups use simple construction techniques, even those subject to erosion and which require constant rebuilding, because in a collective agricultural regime the cost of labor is irrelevant.⁶³

Dams are also, as Cressier observes, unique among hydraulic apurtenances because they lend themselves to monumental building projects, of which there are numerous examples in the eastern Islamic

⁶² In Yemen, however, the term *sadd* also refers to Himyarite or pre-Islamic reservoirs.

⁶³ Cressier (1989), vol. 1, li-xcii, and (1995), 256, 274–275. Traditionally *azud*/s of this type were made of mud-covered cane. See Torr , Segura Mart  (1988), 68. In situations with steep gradients and possibility of flash floods, less erosion will result if the weir or dam washes out quickly and the water flows overland rather than eroding canal channels and fields; see Dootlittle (1990), 105–106.

world. The fact that the Umayyads of al-Andalus did not engage in any such projects unrelated to their own palaces is an indirect corroboration of the centering of irrigation activities at the level of the peasant community.⁶⁴ Of the three major eastern hydraulic traditions, the Syrian, the Yemeni, and the Persian, the only notable importation into the peninsula was the Syrian tandem diversion dam/fluvial water wheel complex which the Umayyads used on their estates, most notably, the Munyat al-Na'ūra in Córdoba. Examples are still extant in the Lower Segura, where the dam pools water for lifting to a higher level by the current wheel.⁶⁵

Cisterns and Other Tanks

The common word for cistern, a tank holding drinking water for human or animal use, was *jubb* in Arabic (in Castilian *aljube*, in Catalan *aljub*). Virtually every *ḥiṣn* (fortress) displays one or more cistern, the volume of which can be used to make a gross estimate of the number of people who could seek refuge there. The simplest kinds were rectangular or trapezoidal, sometimes built of the same masonry as the walls of the fortification. Some of these were huge, holding 50–60 cubic meters of water, and some received water through filtering basins.⁶⁶ Andalusí cities had public cisterns (as well as smaller, household ones). In Granada, twenty-eight of these large vaulted structures survive and have been studied. Of these, fourteen were associated with mosques. In the weekly turn of the Ainadamar Canal, water flowed to public and household cisterns every night and all day each Friday.⁶⁷ The mosque of Córdoba had an elaborate system that directed rainwater from the roof and from the Patio of al-Manṣūr through subterranean conduits leading to a cistern beneath the patio.⁶⁸ The water system of the Alhambra was a complex mixture of gravity-flow canals, cisterns, and norias, that supplied not only the buildings and gardens of this Nasrid palace-city, but also irrigated several hectares of intramural agricultural space. The Albercón de las Damas, located above the Generalife gardens, held 401 cubic meters of water.

⁶⁴ Cressier (1996). The cultural specificity of Cressier's scheme is questionable, however, in view of the universality of diversion dams.

⁶⁵ See Diz Ardid, García Menáquez, de Gea Calatayud (1985), 177–179.

⁶⁶ Bazzana (1992), vol. 1, 251–257.

⁶⁷ Orihuela Uzal, Vilches Vilches (1991).

⁶⁸ Pavón Maldonado (1990), 80.

It was originally fed by *noria* from a well, but as the agricultural space grew, the *noria* was discontinued and a canal, the *Acequia del Tercio*, supplied it.⁶⁹ Cisterns in the houses of the affluent were typically located in an interior patio, beneath, or alongside an ornamental pool (*birka*).⁷⁰ There were also rural cisterns, some of them quite large, which collected rain water for cattle.⁷¹

Regulatory or holding tanks were commonly found in conjunction with springs of low output to collect a sufficient volume of water to permit adequate flow through a canal to fields. They were also used in conjunction with *norias* (see below). These were called *birka* or *šahrīj* in Arabic, giving rise to the Castilian *alberca* and the Catalan *safareig*, noted in place names like Alberca, Jaraiz, Zahariche, Safarich, and so forth.⁷²

Recent archaeological findings distinguish between two common types of tank. The first permits the accumulation of water to create an artificial debit at the outlet of the tank. These are typically sited alongside a water source with too little output to distribute directly to fields. The Balearic Islands provide many examples found in small hydraulic systems covering an area of no more than 2 hectares, associated with a settlement of a single peasant clan, of scant population (between two and seven houses in the best documented cases) where the construction and cultivation of the irrigated space is carried out collectively. In such cases, there is no possibility of dividing the space into homogeneous blocs of parcels assigned to different users under an irrigation turn. The management of such spaces is carried out homogeneously. The volume of water accumulated in the tank will be congruent with the irrigable space in such a way that one turn is established for each space.⁷³ Examples at Can Rei, Eivissa (figure 7.11) correspond to this type.

The second kind of tank is used to regulate the distribution of water. It is generally found in conjunction, therefore, with volumetric measurement of water due to each user, with some kind of ruler (Liétor, Guájar). The simplest version is that which uses the volume of the tank itself as a measure of distribution: one complete voiding

⁶⁹ Malpica (1995), 229–233.

⁷⁰ Pavón Maldonado (1990), 13.

⁷¹ Pavón Maldonado (1990), 88–89; and Lamalfa Díaz (1989), vol. 2, 797–811.

⁷² On toponyms, see Torró (1990–91), 56; Garulo (1980), 27–41.

⁷³ Kirchner (1995b); (1997); (1998b).

of the tank corresponds to one turn of water circulating in an irrigation canal. For example, at Guájjar Faragüit, the tank is emptied alternately into one of the two main canals (figure 7.9).⁷⁴ Quite often, the two functions converge and, given the relationship with scant debits, they are typically associated with natural springs, qanāts, and norias.

Of more modest proportions are the irrigated microspaces watered by a spring/basin complex in Albaida, the Vall de Gallinera, the Sierra de Espadán, Mallorca, and other, mainly mountainous, sites. In the mountains of Almería, where water is scarce, there are single *albercas* into which water from permanent streams, runoff, wells and springs feed simultaneously.⁷⁵

Qanāts

The qanāt is a tunnel or gallery that runs through a water table, capturing water by filtration (thus it is referred to as a “filtration gallery”). Qanāts typically have air shafts, spaced evenly along their trajectories, to supply air to workers and to evacuate the rubble excavated during construction. Previous history of this ancient Persian invention concentrated preferentially on monumental qanāts of Kirmān, Tabrīz and other Persian centers or, in al-Andalus, on those—equally impressive—which supplied Madrid with drinking water.⁷⁶ It is the merit of Iberian hydraulic archaeology to have identified a family of modest qanāts, integrated into the small-scale peasant irrigation systems that we have been discussing, qanāts which have proven to be ubiquitous, built with simple construction techniques available to peasant cultivators.⁷⁷

The qanāts of Mallorca, which are the best studied, were built of dry-rock, open to the air and then either vaulted over or covered with stone slabs. The open trench construction style enabled peasants to remove large amounts of earth easily, in contrast to the laborious tunneling procedures of classical Persian galleries. Most of the Mallorcan qanāts, moreover, were excavated from the downstream

⁷⁴ Barceló et al. (1998).

⁷⁵ Torró (1990–1991); Butzer et al. (1985), 497–499; Cressier (1995), 261; Kirchner (1997b), 153.

⁷⁶ Goblot (1979); English (1968), 181; Oliver Asín (1959); Barceló (1983), 3–22; Glick (1970), 182–184.

⁷⁷ On the recent archaeology of Andalusí qanāts, see Barceló et al. (1986); Barceló (1983), 3–22; Barceló (1988a), 217–231.

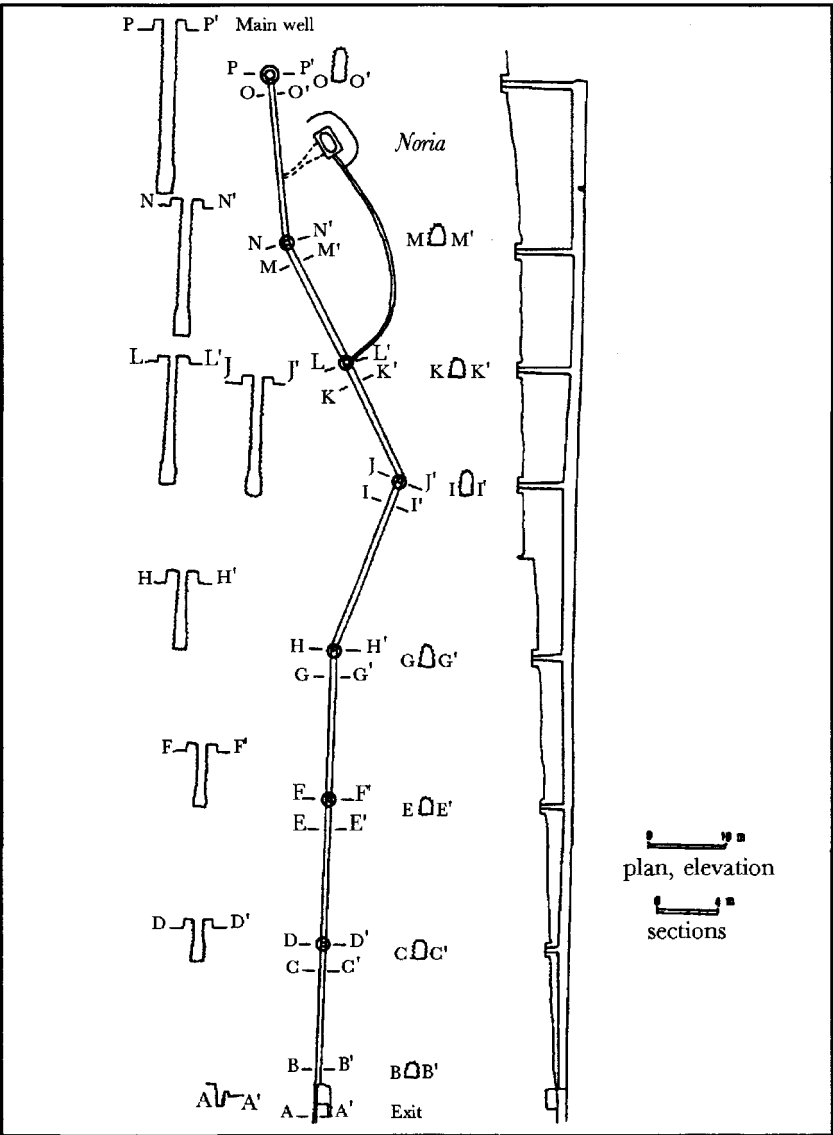


Figure 7.13. The *qanāt* of Rafal Cauhas (En Cabàs, Mallorca) (Kirchner, [1997a]).

end up to the mother well, and the last segments dug—between the first air shaft and the mother well—tend to have steep gradients.⁷⁸ These construction techniques presuppose easy access to the water source. Few Mallorcan mother wells are more than five meters deep. Mountain qanāts are quite short, usually with only one air shaft. To avoid tunneling, the water is tapped upland where the gradient is steep; then a long canal is required to bring the water down to the level of village fields in the slopes and valleys below. In contrast, the typical Persian qanāt was long, dug through rock, and was supplied by a deep mother well. The vast majority of Mallorcan galleries are short (40 meters or less) and none exceeds 300 meters in length.⁷⁹

The modest scale of most qanāt construction described in Mallorca (and elsewhere by medieval archaeologists) suggests the compatibility of the techniques employed with the capacity of peasant labor to make such installations without any need for specialized engineering.

Norias

Norias, or hydraulic wheels, are of two kinds: large, current-driven wheels that raise water from rivers in irrigation canals, or from main canals into secondary ones at a higher level, and the smaller, animal-driven variety.

Current wheels require no gearing; the paddles are either in the form of buckets or else compartments which fill through holes in either side, voiding at the top of the cycle into a chute (Castilian *añaquil*, from the Arabic *naqīl*, “carrier”) leading to an irrigation canal. They are documented in Murcia by a number of medieval Arab writers. Al-Ḥimyarī notes that, other than two great canals originating in qanāts, all irrigation in Murcia was by means of current wheels (*dawlāb*, *sāniya*) and that river water was not used.⁸⁰ The *Repartimiento* of Murcia documents current wheels sited both on the river and on irrigation canals (“açenna del rio,” “açenna que tira agua de la açequia”).⁸¹ Al-Ḥimyarī also describes *dawlāb*/s in Almería

⁷⁸ Martí (1986), 59–60

⁷⁹ Barceló, Carbonero (1986), 43–44. There is a related family of short, vaulted galleries called *alcavons* or *alcavors* (Arabic *qubba*, “vault,” with Romance suffix) in the Alcoià-Comtat region of Valencia, west to Bocairent; see Domènech Domínguez (1991), n.p.

⁸⁰ Lévi-Provençal (1938), 183 for the Arabic text, 220 for translation. On construction techniques, see Córdoba de La Llave (1996), 301–316.

⁸¹ De los Llanos Martínez Carillo, Martínez Martínez (1993), 19.

lifting water to the highest part of the citadel.⁸² 'Abd al-Rahmān III's favorite country residence was the Almunia al-Na'ūra, whose gardens were watered by a wheel from the Guadalquivir. In the twelfth century, al-Idrisī described current wheels on the Tajo at Toledo, including a huge one (90 cubits in diameter) between the Alcántara bridge and the Roman aqueduct.⁸³

The common noria was powered by a donkey or mule trudging on a circular path while hitched to a horizontal wheel whose energy was rendered vertical upon engaging a potgarland wheel (measuring from 1.80 to 2.20 meters in diameter) with its toothed rim.⁸⁴ To the outer surface of the potgarland wheel is attached a double rope to which the pots are tied. When the animal walks, the endless chain of pots descends into the well, scooping up water which it discharges at the top of the cycle into a chute leading to an irrigation canal or, more typically, a small tank or reservoir (*alberca*) which regulates the flow of water from the noria to the field. Tanks were generally made of earth and were oriented towards the fields, in a location intermediate between the noria track and the field to be watered. Tanks could be equipped with several outlets to water fields at different levels.

Recent archeological studies have demonstrated the wide distribution of the noria by documenting the presence of the noria pot (Arabic *qādūs*; Catalan *catúfol*; Castilian *arcaduz*) in numerous medieval sites.⁸⁵ On the Mediterranean coast, south of Valencia, several sites located in or near littoral marshlands have yielded *qādūs* shards, indicating that norias were used there either for irrigation or for drainage. At Les Jovades, near Oliva, no less than 30,000 *qādūs* shards, the earliest dating to the tenth century, were unearthed at one medieval noria site, where the noria well was close to a holding tank. The

⁸² Lévi-Provençal (1938), 184 (text), 221 (translation).

⁸³ Pavón Maldonado (1990), 281.

⁸⁴ The classic in noria research is Schioler (1973).

⁸⁵ Acien Almansa, Martínez Madrid (1989), 132; Acien Almansa, Castillo Galdeano, Martínez Madrid (1990), 159; Azuar Ruiz, Gutiérrez Lloret (1989), 120; Bazzana, (1987), vol. 2, 421–432; Bazzana (1992), vol. 1, 144; Bosch Ferro, Chinchilla Gómez (1987), 497–499; Camino Guertes Santos, González Virseda (1994), vol. 3, 774; Carrasco Martín (1987), 531–535; Castillo Galdeano, Martínez Madrid (1993), 97; Coll Conesa, Martí Oltra, Pascual Pacheco (1988), 107; Gutiérrez (1995), 152–155; Gutiérrez (1996); Lister, Lister (1987), 27–28; Roig i Buxó, Roig i Deulofeu (1994), vol. 3, 749–754; Rosselló Bordoy (1991), 21, 64, 149, 174; Rosselló Bordoy (1993), 32–33; Soler García, (1994), vol. 3, 823. See also Glick (1977), 644–650 and Schioler (1973), 97–109.

numerous wells adjacent to the noria suggest that some of them might have been linked by an underground conduit to the noria well, following a well-known suggestion by the Andalusí agronomist ibn al-ʿAwwām for increasing the supply of water.⁸⁶ In the valley of Pego, a bit to the south of Les Jovades, norias were used not in marshlands but on alluvial fans and in gullies.⁸⁷ In the Balearic Islands, most of the ruins of norias visible now, alongside gullies and on terrain where natural runoff is concentrated, are very recent (most from the eighteenth century or later). There are few well documented cases of Andalusí norias. The clearest case is that of the huerta of Yābisa, described above, where the norias permit the tapping of groundwater at scant depth due to the fact that the huerta is located in a zone of drained swamp. Norias documented in medieval land registers have been found accidentally in the course of urban excavations on the fringes of the drained zone.⁸⁸ The survey of many rural settlements on the same island makes clear that this hydraulic technique was not as common on the medieval island as it has been recently. Only a few noria-pot shards have been found, and these in settlements adjacent to the Santa Eulària River or at St. Antoni de Portmany (probably an old swamp area).⁸⁹

Mills. Their Types

The standard Andalusí mill (Arabic *raha*; plural *arhāʾ*), was a horizontal mill powered by a column of water delivered from a vertical penstock called a *maṣabb* or *aruba* ("funnel;" Catalan, *cup*; Castilian, *cubo*) which was filled from an irrigation canal, by a flume from a river, or from a holding tank.⁹⁰ The shorter the water supply, the taller the penstock (from 7 to 14 meters). The water is delivered to the blades of the water-wheel (Arabic *ruṭīnat* or *dawlāb*; Catalan *rodet*;

⁸⁶ Bazzana, Climent, Montmessin (1987). Ibn al-ʿAwwām said that the volume of well water could be doubled by digging four wells in the same water table, adjacent to each other and with the depth of each stepped, the last three (progressively shallower) supplying water to the main well. Bolens (1972), 71–72 observes that this technique is related to that of qanāts.

⁸⁷ Torró (1998), 452.

⁸⁸ González Villaesclusa, Kirchner (1997).

⁸⁹ Unpublished results of the project directed by M. Barceló in Eivissa, from 1992 on.

⁹⁰ Selma (1993b), 31 and passim. See also García Tapia, Carricajo Carbajo (1990), 207–211, and Glick (1995), 118–119.

Castilian *rodeznos*) at high velocity through a wooden chute. The vast majority of such mills had one millstone only, although they could be rigged to supply two. For more than three millstones, additional penstocks were required.

The geographical distribution of the vertical penstock raises interesting historical issues. It was known in the Near East from the Sassanid period, but was not widespread in Morocco, where oblique penstocks or chutes were preferred.⁹¹ This type of mill was unknown in the Christian kingdoms until the Catalans began to build them after the conquest of Lleida and Tortosa from the Muslims in the twelfth century. In situations where the water supply was both abundant and regular, as in the great suburban huertas watered from rivers, water could be delivered, also at high velocity, through an inclined wooden chute, or ramp.⁹²

The *Libros de Repartimiento* have left at least a partial record of the Muslim human landscape as the recorded by Christian surveyors soon after the conquest. In Mallorca and the Kingdom of Valencia, the mills documented are mainly of peasant origin; only a small percentage appear to have been associated, in urban huertas, with specific offices or individuals.⁹³ There are 257 mentions of mills in the *Repartiment* of Valencia, half of which are generic. On the basis of this data, Selma calculates the total number of Muslim mills in thirteenth-century Valencia at 385, a figure which, although inferential, is probably close to the truth. Twenty-five of these mills were large, that is, they had from three to fourteen millstones; the rest, including all those generically mentioned, are presumed to have been small, with one or two millstones.⁹⁴ Large mills were associated with cities: Valencia had twenty-four mills, with a total of ninety millstones;

⁹¹ Cressier (1995), 278, following Cresswell (1993).

⁹² An Andalusi mill of this type, with two millstones mounted in separate chambers, was discovered in 1997 by archaeologists in Valencia in pristine condition, with the millstones in place. Water was delivered from the Rovella Canal; Martí (1999), 22–23. In traditional Mediterranean mills of this sort, the chute was typically made of hollowed-out logs. The ramp variety runs on the kinetic energy of flowing water, the vertical penstock, on pressure. Vertical penstocks create more torque than chutes; the latter cause friction and turbulence which slow the jets, and form waves, reducing the impact per cm² on the water-wheel blades, according to Cresswell (1993), 195, 200.

⁹³ Barceló first and, later, Selma (following Barceló's research model) have analyzed this type of documentation which contains abundant information on mills: Barceló (1987), 253–262; Selma (1993b).

⁹⁴ Selma (1993b), 76–78.

Xàtiva eleven, with twenty-nine millstones; Alzira five or six, with ten or eleven millstones. The smaller towns of Ontinyent, Onda, and Liria each had four mills.⁹⁵ 162 mills appear in the *Repartiment* of Mallorca, nearly all with one pair of millstones only. In addition to the mills of the city, Madīna Mayūrqa, the large hydraulic systems of the island, those with the largest canals and greatest debits were those which had the greatest concentrations of mills.⁹⁶ These were systems normally associated with several alquerias which shared mills and where those persons from smaller irrigated settlements that had no mill probably went to mill their grain. Concentrations of mills of this type are found, for example, at Artá, Coanegra, Bunyola, and Alaró in Mallorca, and at Buscastell in Eivissa. In general these are mills sited on main canals and which did not require regulation tanks because these were hydraulic systems with abundant water.⁹⁷ In other systems, lacking sufficient debit to power the mills directly, regulatory tanks were needed. In these cases there were only one or two mills, each preceded by a tank. Such is the case with the system of Banyalbufar, Mallorca, where, integrated into the terrace irrigation system, were two mills with vertical penstocks that received water from a regulating tank.⁹⁸

All the mills mentioned in the *Repartimentos* of Valencia and Mallorca are presumed to have been horizontal. And yet vertical mills were surely known in al-Andalus. Al-Razī mentions the repair of mills between the arches of the Roman bridge in Córdoba in 971. These are the famous *arḥāʾ al-qanṭara* (mills of the bridge) driven by vertical, undershot wheels.⁹⁹ Downstream from the bridge was a stone quai (*raṣīf*). Al-Ḥimyarī says that alongside it was a dam (*sudd*) "that supports three mill houses, with four millstones in each."¹⁰⁰ A number of commercial and industrial products such as rice, sugarcane, and paper formed a unified package of Chinese techniques that included processing by means of vertical, trip-hammer mills, wherein hammers attached to the axis of the vertical water-wheel pounded

⁹⁵ Selma (1993b), 103–104.

⁹⁶ Barceló (1987).

⁹⁷ Kirchner (1997a); Argemí (1996), 259–271; Argemí et al. (1997).

⁹⁸ Kirchner et al. (1986), 77–86.

⁹⁹ Cited by González Tascón (1987), 301.

¹⁰⁰ "wa-ʿala al-sudd thalatha buyūt arḥāʾ fī kull bayt min-ha arbaʿa maṭahīn," in Lévi-Provençal (1938), 158 (text); 189 (translation). Lévi-Provençal emends "four pairs of millstones." Two pairs is more likely.

the product to the point where the process could be continued manually.¹⁰¹ Thus paper and sugar-processing diffused simultaneously. Therefore, with regard to the perplexing problem of whether the paper mills of Xàtiva were hydraulic, if it can be determined that there were rice-husking mills in al-Andalus at the time of the Christian conquest, then there is a *prima facie* case for the presence of vertical paper mills: the two machines were, in effect, identical.¹⁰²

Both the origins and precise paths of diffusion of the horizontal and vertical mills are a matter of speculation and there is little consensus on either. The horizontal mill, according to Cresswell, appeared simultaneously "in Scandinavia, the Near East and China sometime during the two hundred years between 100 B.C. and 100 A.D., but also vertical mills with gearing appear at roughly the same time in the Mediterranean, the Middle East, and China."¹⁰³ Although the water-wheels display considerable variety in the form and mounting of the blades, the morphological difference among them is so slight that no logical genealogy can be constructed from them.¹⁰⁴ White's conclusion that the horizontal wheel emerged somewhere to the north and east of the Roman empire is an inference from spatial distribution patterns and cannot be confirmed.¹⁰⁵ More likely is Blaine's notion that the water-powered vertical grain mill was modeled on the *noria*.¹⁰⁶ Such a conclusion is corroborated, at least within the reach of Andalusi culture, by semantic ambiguity in the transmis-

¹⁰¹ Daniels (1996), 30–39. Daniels observes (44) that "the commercial nature of agro-industrial production encouraged transfer of both agricultural and manufacturing skills as a technological package." Goitein (1967), 81 notes the *industrial* nature of both sugar and paper manufacture.

¹⁰² Burns (1985), 167–168 doubts that the paper industry of Andalusi Xàtiva was mechanized. A document of 1261 refers to an "almerxam papiri" in Xàtiva. *Almàsara*, from Arabic *ma'sara*, is an olive press, not a hydraulic machine; Madurell i Marimon (1972), vol. 2, 963. There were, of course, rice mills in thirteenth-century Valencia. Burns (1985), 166, n. 5 cites a document of 1284 referring to a "molendinum picandi arrocium" in the huerta of Valencia in which the owner is authorized to "in eo facere vel hedificare molendina farineria vel draperia". The reference appears to be, then, to a pre-existing vertical rice mill which could easily be converted to a fulling mill because it was already provided with trip hammers.

¹⁰³ Cresswell (1993), 198.

¹⁰⁴ Cresswell (1993), 201–202: "Any one of the forms could logically derive from any other, no logical hierarchization exists."

¹⁰⁵ White (1962), 81. According to Needham (1965), 368 the horizontal mill spread from an unidentified hearth, outward towards the periphery; while the vertical wheel diffused from south to north.

¹⁰⁶ Blaine (1976), 163.

sion of the term *sāniya* to Christian Spain. The term means “vertical water wheel:” in the Catalan-speaking areas of eastern Spain, the Arabism *senia* denotes a noria, while in the Duero valley and other Castilian-speaking areas, the Arabism *aceña* denotes a vertical mill, suggesting that *both* reached Christian Spain from al-Andalus.¹⁰⁷ The *aceñas* of the Duero and Pisuerga rivers were all vertical under-shot grist mills.

The origins of the vertical trip-hammer mill are even more obscure. The machine is the result of mating a water-wheel to a cam (another technique that dates to classical Antiquity), an event which, according to Blaine, most likely occurred in Alpine Europe in the ninth or tenth century.¹⁰⁸

The Siting of Mills

Mills in the Andalusi systems described above were typically sited at the ends of canals, associated with a regulatory tank; or alongside a main canal when the debit was abundant and permitted the mills to function without any need for regulatory tanks.¹⁰⁹ The siting of mills with respect to irrigation systems can be understood at several levels: first, different social groups have different priorities in water use, depending on their values, their social and economic organization, and so forth.¹¹⁰ Second, different groups will address the related

¹⁰⁷ On *aceña* as a vertical water mill, see Glick (1992a), 44–47; Rucquoi (1983), 110–111; Represa Fernández (1998), 186–189, and Represa Fernández (1994), vol. 3, 755–763. Some of the Duero and Pisuerga mills, like the fluvial norias of the Lower Segura, were mounted on dams (see discussion below)—a further indication of diffusion from al-Andalus; see Represa Fernández (1994), vol. 3, 757.

¹⁰⁸ Blaine (1976), 170. Needham (1965), 392, 396, is perplexed: The recumbent hydraulic, trip-hammer mill, invented in China in the second century A.D. or before, may not have reached Europe until the twelfth.

¹⁰⁹ M. Barceló et al. (1988) presented two examples of the integration of mills in a hydraulic system, one Andalusi and one feudal. The mill was subordinate to irrigation in the first case, while in the second it had priority in the distribution of water. Some readers interpreted this discussion as proposing models of integration of mills. Localization of mills depends to a great extent on the head available. For example, Selma (1991), 71, 84, suggested a modification of the tail-end model, based on a reconnaissance of Andalusi layouts in Castellón, where some mills are found at “neuralgic points” of irrigation systems, e.g., after a divisor, or points where there is a significant drop (in which case the mill acts to slow down the current). However, siting after divisors and not on the main canal, is probably due in this case to the need for regulatory tanks before each mill.

¹¹⁰ In the case the Banū Furānik, at Felanitx (Mallorca), for example, there was an irrigated space of 8.1 hectares with no mill. The gradients and the debit of the

problems of monitoring and conflict management in ways appropriate to their values and social organization. Among Berber tribal units practicing irrigation, both the land and water were typically owned collectively. In general, traditional irrigating groups display a preference for self-monitoring. To place a mill downstream from irrigated parcels is a practical way to minimize both its potential to generate conflict with irrigators and the need to monitor it. To place it outside the hydraulic system completely furthers those goals even more.¹¹¹ Locating a mill on the main canal permits milling as long as the irrigation turn has passed on to a sector downstream from the mill. Therefore, those mills which are nearer to the water source will have more opportunities to function, while those at the end will be more dependent on turn arrangements.¹¹²

Feudal hydraulic layouts are considerably less well-studied, but there is evidence that early medieval feudal mills in Catalonia and southern France were placed at the heads of hydraulic systems with parcels irrigated below them, in small gardens, called "subtus rego."¹¹³ When a lord owns or controls the entire system and receives monopoly rents from a mill, irrigation, while important, is secondary to milling, and monitoring is not an issue given the lord's dominance. In Mallorca, the feudal lords subverted the operating procedures of canals by favoring milling over irrigation, reducing the latter to one day per week, while the rest of the days were to be exclusively devoted to milling.¹¹⁴ In suburban huertas, the siting of mills was in part influenced by the provisioning needs of the urban nucleus. The *Repartiment* of Valencia demonstrates the principle for the Muslim huerta just before its conquest by James I. There, mills tended to be massed in the upper stretches of irrigation canals, right below the diversion dam (as in the case of the Mestalla Canal) or on secondary canals entirely dedicated to milling. The rationale however was the same: to minimize the need for monitoring (and make it more efficient) and to avoid conflict between irrigators and millers. Mills are harmless upstream from irrigation because they return the water they use

spring could have allowed for at least one mill, but that would have entailed the loss of approximately one third of the irrigable space. The choice was to privilege the space of cultivation above the need for a mill. See Kirchner (in press b).

¹¹¹ See discussion in Glick (1995), 74.

¹¹² Kirchner (1997a); (1997b).

¹¹³ Martí (1988a), 165-194.

¹¹⁴ Kirchner (1995a).

to the canal, but they are mischievous downstream because even slight adjustments to their intake gates can cause whirlpools and backwashes. If located downstream from divisors—structures that divide water proportionally between two secondary canals—such adjustments can alter the proportions.¹¹⁵ On long canals which had to be heavily monitored because of endemic conflict between upstream and downstream irrigators, mills could be sited at points other than the head or tail, but generally on dedicated side canals.

Social Organization of Peasant Mills

We can presume that the social organization of milling in Andalusí *alquerias* was similar to that prevailing in similar settings in contemporary North Africa. In the High Atlas of Morocco, for example, Berber village mills are “exclusively for domestic production,” and operated mainly by women “who spend an hour or so every four or five days” milling flour for their own use.¹¹⁶ Mills were owned by individuals, by groups of partners, and, according to data preserved in *Repartimientos*, a few by the local government entity (*makhzan*).¹¹⁷

In Mallorca, except for two mills each owned by the state (*makhzan*), pious foundations (*hubus*), and an unidentified *shaykh*, Barceló finds that the rest appear to have been owned by *alquerias* or individuals associated with them. Selma considers nearly 90% of the mills mentioned in the *Repartiment* of Valencia, including most of the small ones, to have been owned by the communities of peasant farmers inhabiting *alquerias*, based on the inference that if one or more mills were conveyed as appurtenances to a Muslim *alqueria*, those structures were communally owned.¹¹⁸ Other evidence, both from Arabic and Latinate documents, suggests, however, that Muslim mills were owned by small groups of partners.¹¹⁹ Although a few Valencian Muslim mills were owned by the state (*makhzan*) or by officials (*wazīr*, *raʿīs*, or *qaʿid*), Selma points out that James I never granted a mill in a Muslim community to any individual as a feudal monopoly, lending substance to the conclusion that mills were regarded as a

¹¹⁵ For examples, see Glick (1970), 88–93.

¹¹⁶ Cresswell (1993), 190–191.

¹¹⁷ Selma (1993b), 131.

¹¹⁸ Selma (1993b), 112.

¹¹⁹ On mill partnerships (*shirkāt*), see Lagardère (1991), 115. On the survival of mills owned by Muslim partners in Christian Spain, see Glick (1995), 163.

public service by Muslims, whatever the details of ownership may have been.¹²⁰

Institutions of Water Allocation and Distribution

In traditional societies, irrigation institutions—arrangements by which water is distributed to irrigators—all derive from a basic principle of proportionality: that is, water is distributed in rough proportion to the area irrigated. Where water is distributed by time unit, we find some variation of a twelve-base system wherein a unit of water corresponds to an hour or a portion thereof. Specific operating procedures, such as the rules governing turns or rotations; priorities in water use, or special drought regimes, are the result of a complex mixture of social values, factors of climate and topography, and techniques of tapping water sources and measurement.¹²¹ Such arrangements and the terminology used to describe them are useful in establishing the history of irrigation systems and, in the case of those described archaeologically, confirming the social organization of irrigation suggested by specific hydraulic layouts.

Documentation of water distribution procedures in Al-Andalus is scant. Some can be inferred from Islamic law (e.g., upstream users have priority over downstream users on the same stream to water their fields to an ankle's depth, although some preferment may also be given to rights based on time priority) or from Berber customary law (absolute priority of upstream users).¹²² Turns within a system proceed by lineage groups, specific details being set by informal or written agreements among the different clans. In general, canal rotations run from head to tail or from head to tail and tail to head, alternately.¹²³ The logic of Berber custom can be appreciated from specific hydraulic layouts. In Coanegra (Mallorca) and Buscatell (Eivissa), for example, a long irrigation canal is divided into clearly marked

¹²⁰ On mill ownership, see Selma (1993b), 111–118; Barceló (1987), 256–258.

¹²¹ Irrigation operating procedures may also be viewed, broadly, as technology inasmuch as they are instrumentalities of resource use and maintenance. Moreover, they were packaged along with information about hardware and transmitted simultaneously with it.

¹²² On absolute upstream priority in Berber customary law, see Hezenni (1995), 405; Blanco Izaga (1939), 104; Glick (1995–1996), vol. 2, 200–201.

¹²³ Blanco Izaga (1939), 103, 108.

units, each one serving a different clan-based *alqueria*, and each closed by a mill.¹²⁴ In such a case, the alternate turn procedure might be expected.

The operating procedures of Andalusí irrigation systems can be recreated wherever Christian settlers adopted them in a literal fashion. After the conquest, newly arriving Christians learned the operating procedures already in force from Muslim irrigators, sometimes through public inquests such as the one conducted by the feudal magnate Peregrín de Atrosillo in Gandia in 1244.¹²⁵ As J. Torr   has observed, the rationale for such inquests (and, indeed, for the extremely literal way in which Christians appropriated and continued Muslim operating procedures) was that the logic of distribution by lineage groups (the normal modality of distribution in tribal irrigation where both land and water were owned collectively), rather than by individual parcel owners, made no sense to the Christians and had to be decoded for them so that privatized parcels, superimposed on collectively owned ones, could continue irrigating under the operating procedures then in force.¹²⁶ The result was that Muslim institutions, appropriated literally, can be read as a fossilized record of pre-conquest arrangements and then matched with related or antecedent systems elsewhere in the Islamic world.¹²⁷

Thirty years ago, it seemed that Andalusí irrigation institutions fell into two modal types, a Syrian type characteristic of *huertas* with large canals derived from rivers, and a Yemeni type, with oasis-style

¹²⁴ In the case of Coanegra, the four *alquer  as* all have names relatable to Berber segments: Kirchner (1997a). In Buscastell also, four Berber clans shared the hydraulic system; Argem   et al (1997). The pattern of a long canal divided into clan-based sectors is also clear in the case of the Alquibla Canal in the huerta of Murcia which changes names four times along its course, the last two sectors being Benicot   and Benicomay, toponyms indicative of tribal segments: Torres Fontes (1971), 21.

¹²⁵ Roque Chabas (1898) with an English translation in Glick (1970), 233–234. Although there are references to inquests in the *Repartimiento* literature (Glick [1995], 151–153), the Gandia document is the most complete surviving record of one. Its survival is not adventitious because the Gandia irrigation network, with many canals with Beni-names and complex water quotients whose rationale is not apparent, is a quintessential example of allocation by lineage. For a concrete example of how rotation by lineage works in practice, see Blanco Izaga (1939), 118; see also B  doucha (1993), 77–107, esp. 91.

¹²⁶ Torr   (1999), 144. New Christian landowners must have quickly realized that, in practical terms, the water rights adscripted to their parcels were encoded in Muslim operating procedures.

¹²⁷ Glick (1988), 165–171. We have already noted that clan groups, after a process of segmentation and migration, built hydraulic systems virtually identical to those of the parent group, not only morphologically but institutionally as well.

systems where water was distributed in time units.¹²⁸ This typology was simply a culturally-specific adaptation of the long familiar dichotomy proposed by J. Brunhes for North Africa and Spain, based on the distinction between operating procedures in systems where water was relatively abundant (water adscripted to land) and relatively scarce (water not adscripted to land and distributed in time-measured units).¹²⁹ The cultural specificity proved to be confusing in practice and not sensitive enough to the geographical and social variation of irrigation practices in the hearth areas: Yemen, for example, has both mountain and oasis-type systems, with different allocation procedures.¹³⁰ The match between the distribution of water of the Barada river among the canals of Ghūṭa of Damascus and that of the Guadalaviar (now, Turia) among the canals of the Valencia huerta suggested importation to Iberia of the Syrian "type." Indeed, the Barada scheme is highly idiosyncratic, the number of units of water in the river not decreasing with each subtraction, but rather reconstituting itself as 24 full units at each stage of diversion (by contrast, in the division of the Vernisa River in Gandia, where many of the canals have Beni-names, the stream is reckoned to have a total of 60 *filas*, the numbering diminishing with each subtraction.) The repetition of the scheme in Valencia is reminiscent of Damascus, but twelve-base allocation systems are so common that, absent concrete documentation, association between the two is speculative.¹³¹ The Yemeni "type" was based on one system only which, indeed, is similar that those of Elche, Novelda and other "oasis" type systems in Eastern Spain.¹³² Whatever Yemeni inspiration there may have been, however, the proximate origin of such distribution measurement formats are more likely to be found in North African oases.¹³³

A few examples of operating procedures duplicated in al-Andalus

¹²⁸ Glick (1970), 214–215.

¹²⁹ Brunhes (1902); Glick (1970), 368, n. 1.

¹³⁰ See the comments in Hunt, Hunt (1976), 389–411, both for misinterpretations of Glick's typology, as well as Glick's own modification of it (400–401). Perhaps unconsciously, the Syria/Yemen dichotomy has appeared recently, e.g., in Cressier's (1996) typology of dams.

¹³¹ Glick (1970), 209–213, with the Barada document on 264–265. In Los Vélez, Málaga, the canalized water of four springs, divided in three successive divisors, is reckoned at 24 *hilas* at each stage; Cara Barrionuevo (1992), 18.

¹³² Rossi (1953), 349–360; Glick (1970), 215.

¹³³ On Yemeni influence in the Magrib, particularly among Sanhaja Berbers, see Norris (1962), 317–322.

and North Africa illuminate this discussion. The most distinctive feature of irrigation in Murcia is that parcels were described both in measures of area (*tahullas*) and coordinately in measures of value (*alfabas*), both terms being Arabisms from *ṭahwila* ("field") and *ḥabba* ("grain"), respectively. The *ḥabba/alfaba* has an interesting history, closely associated with Zanāta Berbers. Analysis of how the Zanāta conceptualize water and productive value in oases in Algeria, shows irrigation is by qanāt and distribution basin (*foggara* and *mājin*) and the unit of measurement is the *ḥabba*, a measure of outflow through an orifice conventionally the diameter of a finger, but which also represents one grain of barley (the literal meaning of *ḥabba*).¹³⁴ Multiples of the *ḥabba* are expressed duodecimally (12, 36, 60, 84 . . .), yielding what Marouf calls an "hydraulic accounting" which is used as a money of account for all financial transactions. The *dirham* coin (as a unit of exchange) is likewise conceptualized in terms of grains of barley (72 per unit, according to Ibn Khaldūn).

This system arose in the oases because of commercial exchanges with northern centers, the Zanāta trading dates for wheat. (Later, they cultivated wheat in the oases themselves.) So, with regard to the measurement of water, the *ḥabba* has both a geometrical, technical sense and a symbolic, monetary one. Where land valuation is concerned, however, the cereal reference is double.¹³⁵ Irrigated fields are measured by their area and by their productive capacity. Here *ḥabba* yields a different, possibly older, reading representing a *ḥabba/mājin* transposition, where the *ḥabba* is defined as the water filling a *mājin* in a period of 24 hours. The *mājin* is a module measured in hydraulic "space-time": its absolute size and that of the area it waters vary according to the debit. The different registers of measurement are transposable into one other: 24 hours of water = 24 *gammun* of wheat. That is, one *ḥabba* permits the filling of a *mājin* in 24 hours which furnishes the water supply for 24 *gammun* of land, which represent a wheat harvest of the equivalent of 120 kg. A *gammun* is a measure of productive capacity (in yield of wheat), not of area. Now it is

¹³⁴ Marouf (1980), 125–165. The orifice in question is that of a water clock (clepsydra) used to measure irrigation time. See Glick (1969), 424–428; and Bouderbala et al. (1984), 246. This meaning of *ḥabba* is reflected in the usage, *grano* ("grain") in Almería, where one *hila* of water is divided into three *arobas*, and each *aroba* into eight grains; Cara Barrionuevo (1992), 19. The *hila* is a proportional unit in a 12-base measurement system. *Arroba* is from the Arabic *rubʿ*, "one-quarter."

¹³⁵ Marouf (1980), 160–161.

clear that this is the same concept underlying the *alfaba* of Murcia which Steiger correctly identified with the *habba* and which has been recognized by later authors as a unit of valuation, not of area, and which Torres Fontes identified as a rent valuation unit.¹³⁶ The huerta of Murcia was a site of Zanāta settlement, as reflected in the Acequia and alqueria of Zeneta.¹³⁷ The *alfaba* of the *Repartimiento*, according to Torres Fontes had a constant relation to the *tahulla* (the unit of areal measurement), and "its differentiation was owing almost completely to the variability of terrain."¹³⁸ However it is the rationale informing the variability that is crucial. The Murcian *alfaba* was applied to both irrigated and non-irrigated land; its possible connection with wheat has not been explored.¹³⁹

The *alfaba* was the standard unit of valuation of irrigated land for the tithe (*almagram*, *'ushr*) throughout the post-conquest Muslim communities of the mountain valleys in the Alicante hinterland.¹⁴⁰ One might then ask to what extent this represented a peculiarly Zanāta *modus operandi*.

Further to the north, the Vall d'Abaida contains several dozen irrigation systems, each with distinctive institutions, permitting them to be grouped according to type. One of these is characterized by semi-adscripted water rights (whereby water is alienable within a branch canal, not outside of it, suggesting the possession of such channels by tribal segments holding water rights collectively), distribution by time units, and the use of clepsydras to measure water flow, found in Adzeneta d'Albaida, whose name recalls the Zanāta Berbers who settled there. There were, in fact, two Zanāta settlements in the Vall d'Albaida, the second representing a segmentary migration from the first. Both places have the same water distribution system, as does another Atzeneta quite a bit further to the north in the Vall d'Uixó.¹⁴¹

¹³⁶ Torres Fontes (1971), 53–64; and (1959), *passim*.

¹³⁷ Asín Palacios (1944), 103, s.v. "Ceneta", derives the toponym from Zanāta. Pocklington (1990), 236–237 derives it from *sanad*, "slope." However, the association of the *alfaba* with Zanāta Berbers suggests that Asín was correct.

¹³⁸ Torres Fontes (1971), 63. In Zeneta, interestingly enough, the double *tahulla/alfaba* system was not used, parcels being described in *alfabas* only: Torres Fontes (1959), 13.

¹³⁹ In the *Repartimiento* of Murcia, *alfaba* is also applied to houses and other objects, besides land. This is unsurprising because among the Zanāta the *habba*, besides being a measure, was also a unit of monetary account. *Habba* can also refer to the size of the orifice of a clepsydra or a water measurement unit.

¹⁴⁰ Torró (1999), 209–210. See also Bazzana, Guichard (1981), 124, 130.

¹⁴¹ Soler (1995), 82–84. On Zanāta settlement in Valencia and Mallorca, see

The clepsydra (*ampolla*) time measurement system of Adzaneta d'Albaida is conceptually similar to the *alfaba* system, inasmuch as it involves the multiplication of a unit of time by a water-right, expressed in *filas* (literally, "threads"), which represents an aliquot portion of the entire debit according to the area watered. The same is true of Vall d'Uixó where the measure of water is volumetric (*arroba*)¹⁴² and the measure of land, a time measure (*cànter*, which like *ampolla* is both the clepsydra and the time-unit it measures), which only makes sense if the two are compounded together—Marouf's "space-time."¹⁴³

In Adzaneta, the irrigation turn is based on a periodization of 24 hours, while everywhere else in the Vall d'Albaida, 12-hour periods are the rule. The duodecimal basis of Zanāta measurement systems is documented by Marouf. The basic unit of water measurement in Albaida is the *ampolla*, originally measured by a clepsydra with a value of 20 minutes. But the water right is also expressed in *filas*, one *fila* to each irrigator, with each *fila* theoretically equally to one *ampolla*. If a given canal holds four *filas*, one for each of four irrigators, and if one of these irrigators has a right to two *ampollas*, instead of receiving 40 minutes, he receives 4 by 2 *ampollas*, or two hours and 40 minutes.¹⁴⁴ This system is functionally similar to the *alfaba* system because it makes it possible to assign water according to the differing valuation of parcels equal in size. The same is true in Vall d'Uixó.¹⁴⁵

Torró (1990–1991), 58, where he notes that Guichard dates Zanāta settlement in Albaida to the Almoravid occupation of the twelfth century. Barceló (1997a), 24, however, asserts there is no evidence for the migration of Berber *peasant groups* after the eleventh century.

¹⁴² Vélez Blanco, where tank water is measured by a combination of *granos* (*habba/s*) and *arobas*, may well be another Zanāta irrigation system. Steiger, cited by Torres Fontes (1971), 62, n. 15.

¹⁴³ Peñarroja Torrejón (1984), vol. 2, 509–520. In North Africa, the orifice of an outflow clepsydra is conventionally one *habba*. Whether the Adzaneta/Uixó systems are exactly the same as the *habba/alfaba* system, remains to be seen: if so, the size of parcels of equal numbers of *canters/ampolles* should vary in hectares.

¹⁴⁴ That is, the *fila* is an aliquot share of water representing the area of land to which the right to it attains. So in this operation, the time unit (*ampolla*) is multiplied by the unit reflecting space (*fila*), yielding Marouf's "space-time" unit of valuation.

¹⁴⁵ Soler (1995), 54. It is important to bear in mind that the Moriscos may have lost the original rationale of the measurement system, that the Christian successors almost certainly did not understand the rationale, and in the cases considered above, as elsewhere, there was an attempt made between the sixteenth and nineteenth centuries to establish hard numerical values for proportional measures. The Andalusi Zanāta systems must be restudied in order to ascertain how much of the logic described by Marouf can be identified.

Furthermore, canal rotations in virtually all irrigation systems of the Vall d'Albaida proceed, in Berber fashion, from head to tail.¹⁴⁶

Irrigation systems in the Huecha River valley of Aragón, present two common features of Berber irrigation, documented from Morocco to Lybia. The first is that irrigation turns were measured by the interval between Muslim canonical prayers. In a settlement charter granted by the Monastery of Veruela in 1238 to Alcalá de Moncayo, an *alqueria* associated with a *ḥiṣn*, whose original irrigated space was located on alluvium next to the bed of the river, a time period in an irrigation turn on the river is called an *azaira* (in other documents, *zaiara*), a term hitherto unexplained.¹⁴⁷ This is an Arabism from *'asr*, the canonical afternoon prayer, which in the oasis of El Guettar, near Gafsa, Tunisia, has been converted into a measure of irrigation water four hours in length, with six *'a'sar* in a period of twenty-four hours.¹⁴⁸ Irrigation time is measured in Morocco by the canonical prayer intervals following the position of the sun, but the generalization of *'asr* to mean any such interval appears to be specifically Tunisian.¹⁴⁹

The second feature is the determination of the interval by shadows. The four daytime *a'sar* in El Guettar are determined by the shadow cast by a man, the first from sunrise until the shadow reaches a length of 12 feet to the west, the second from the 12-foot shadow until midday, when the sun is at the vertical, etc. Shadow measurements are pretty much universal in North Africa, in Tunisia, as well as Morocco.¹⁵⁰

Shadow measurement was also used in some of Veruela's possessions on the Huecha, with the same values as in the case of El Guettar—e.g., a turn described (in 1199) as extending "twelve feet of that water . . . till midday."¹⁵¹ Shadow measurement, expressed in

¹⁴⁶ Soler (1995), 42, 44, 72.

¹⁴⁷ Ledesma Rubio (1991), 222.

¹⁴⁸ Nouailhac (n.d.), 30; Bédoucha (1993), 91, 98–99.

¹⁴⁹ Bouderbala et al. (1984), 247; Blanco Izaga (1939), 108 Prayer-interval timing is apparent in many Spanish successor systems; see, e.g., Cara Barrionuevo (1992), 21. Cara Barrionuevo (25) believes the irrigation systems of Los Vélez to be similar to those of Touzer, a Tunisian oasis.

¹⁵⁰ Bouderbala et al. (1984), 249; Bédoucha (1993), 91.

¹⁵¹ "xii pedes de illa aqua . . . usque ad medium diem." Archivo Histórico Nacional, Madrid, Codex 995B, fol. 49: Agreement between the Monastery of Veruela and Farag de Alhazin and his brothers. We are grateful to Simonne Teixeira for this reference. The precise time value of an *'asr* measured by shadows would vary by

feet (*peus*) also appears in Albaida, in an irrigation turn between Atzeneta and El Rafalet.¹⁵²

Measuring irrigation time by prayer intervals determined by shadow measurement was common throughout the Islamic world, in Berber North Africa as well in the Yemen. Similar measurement systems elsewhere in Spain are bound to be identified in the future. These practices do not appear by chance, but were put in place by immigrants who brought concepts of water allocation from their places of origin.

Post-Conquest Christian Reorganization

As Christians conquered areas of al-Andalus they were able to channel settlement there by peasants and others dispossessed by primogeniture rules, many of whom had fought in the armies of conquest and were rewarded with agrarian parcels. *Repartimiento* allotments typically mixed land uses, each settler receiving some irrigated parcels, some unirrigated (wheat for feudal rents could be grown on both), and some for vineyards. As Torr  indicates, the result was not a simple reconfiguration of Andalusian agricultural spaces, but a global transformation of production in those places, together with the incorporation of newly cultivated land.¹⁵³

Two features of Christian settlement and administration destroyed the social fabric of Muslim agrarian organization, except in those *alquerias* (none in Mallorca, quite a few in Valencia) left to function as autonomous Muslim communities. The first was the new specializations of agrarian space, in particular the increased cultivation of cereals and grapevines. The second was the imposition of norms of private property, for example, surveying and marking the previously unsurveyed bounds of *alquerias*, and subdividing formerly communal fields into private parcels, with measured and recorded metes and bounds.¹⁵⁴

latitude and, over the course of a year, the declination of the sun. See King (1917), 361–362. Dakhla is an oasis in eastern Libya.

¹⁵² Soler (1995), 87–90.

¹⁵³ The same point was made before by Kirchner, with respect to Mallorca, with the difference that there the creation of new cultivated space did not appear immediately after the conquest but begins to be visible in documents towards the end of the thirteenth century: Kirchner (1995a); (1997a).

¹⁵⁴ Torr  (1999), 141–142; Torr  (1990), 81–86; Glick (1995), 135.

Changes induced in Andalusi Hydraulic Systems

In Mallorca, the design of rural, previously clan-based irrigation systems was minimally changed, but the pattern of water use shifted dramatically. For the valleys of Coanegra and Alaró, the texts of ordinances for the distribution of water made by the new feudal occupants have been preserved. In both cases, irrigation was restricted to one day a week. While mills do not consume water, inasmuch as they are located on the main canals, if all run at the same time, as the ordinances provide, they monopolize the water because, from one mill to the next, if water is diverted for irrigation it would leave those mills downstream without water. This preference for milling was associated with a change in crops. Grapevines were introduced within the irrigated perimeter, and garden crops and trees were restricted to small gardens adjacent to the mills. We also find mentions of cereals within the irrigated perimeters. Neither grapevines nor cereals would be irrigated save in case of drought, and it seems clear that the water requirements of these crops were in any case less than the old Andalusi crops. The latter, of course, also included grapevines, grown for their fruit or for raisins, as well as cereals; but these were not the predominant crops that they came to be with the feudal colonists. Beyond the irrigated perimeters there were no dry-farmed crops documented at the moment of the Catalan conquest. Thus quite a few years were to pass after the conquest (1229) before we start to find, at the end of the thirteenth century, the first references to the new dry-farming areas or to small extensions of irrigible space. Insofar as the latter are concerned, in the valley of Coanegra the changes consisted in extending the main canal and in building an additional mill. The extension of irrigated space, however, was secondary to the increment in milling, as feudal lords aimed to install mills and irrigate small parcels adjacent to them. At the same time a significant portion of the previously irrigated space was not irrigated by the Catalan conquerors, who invested instead in vineyards.¹⁵⁵

In Palma, James I (who at this time seems not to have under-

¹⁵⁵ Kirchner (1995a). See also Argemí (1996). The expansion of cereal cultivation, in response to a feudal rent system where payment was demanded in kind, not only required more mills, but also more grinding surface, which requires more water power and less of the interruption that irrigation entails. The water power requirements provided an incentive for building mills with vertical penstocks: Cresswell (1993), 208.

stood the principle of proportionality in the allotment of water) usurped the water rights of the Séquia de la Vila in Palma, freely granting new water rights to magnates and the Church and authorizing the construction of new mills, thus causing chronic conflict over water that was litigated for centuries to come.¹⁵⁶

Huertas, such as that of Valencia, were enlarged by extending the length of existing canals. On conquering Valencia, James I found eight canals of similar size. Those on the northern bank of the river subsequently expanded northward across the Gully of Carraixet, creating a wholly new sector of the huerta in consequence of the king's policy of expanding irrigation to lure new settlers.¹⁵⁷ In the later middle ages upstream communities, particular those on the Montcada Canal (a canal that James kept under royal jurisdiction and whose extension he ordered) alleged in litigation that they held a right from the "time of the Moors" superior to that of those downstream whose rights dated from the 1260s or 1270s.¹⁵⁸ Canals in littoral huertas, such as that of Valencia, were also extended into marginally productive areas which were then endowed with secondary irrigation rights, for example to the use of excess water only (*sobrantes*).¹⁵⁹

By the time the King organized the kingdom of Valencia, he made no attempt to feudalize water, establishing in the *Furs*, the law code of the new kingdom, the principle that irrigation systems were to continue functioning as they had "in the time of the Saracens," with water rights of Muslim landholders secured and passing intact to Christian successors. Irrigation communities were established under royal patrimony or municipal control, with the tribal administrative

¹⁵⁶ Fontanals (1984); Glick (1995), 159–160.

¹⁵⁷ The expansion of the Valencian huerta created long canals whose new downstream irrigators were disadvantaged with respect to the upstreamers in the old Muslim-built sector, creating endemic upstream-downstream conflict; Glick (1970), 74–85.

¹⁵⁸ The double-rights structure in the Montcada Canal system can be seen in a 1431 document, where the irrigators of Vinalesa, a village north of the Gully assert an irrigation right from the time "since the kingdom has been Christian." The upstream irrigators opposed them, on the grounds that Vinalesa's claim interfered with a rotation established "from the time of the Saracens." That is, the communities above the Gully held that their rights dated from the before the conquest, those below the Gully claimed rights established by James I (at the time he extended the canal). Arxiu del Regne de València, Governació, Plets, 2244, 15th hand, fol. 5r; 16th hand, fol. 37v (October 13, 1431).

¹⁵⁹ See Cressier (1995) 272; Maass, Anderson (1978), 20 (Valencia), 74 (Lower Segura).

model replaced by one modeled on the organization of urban craft guilds. In *alquerias* under seigniorial control, the handsome returns of irrigation agriculture induced lords to let communities of irrigators (even when these crossed jurisdictional boundaries) operate autonomously.¹⁶⁰

That operating procedures were in general not subjected to feudal rules does not mean that feudalization failed to change the balance between irrigation and other agricultural sectors radically, particularly in Mallorca.¹⁶¹

Notoriously, mills were feudalized. At the time of the conquest of most of al-Andalus (in the twelfth and thirteenth centuries) the feudal rent system was geared to grain payments in kind. Therefore seigniorial agriculture was a machine designed to produce, above all, wheat. Wheat production, in turn, was integrated into a vertical system of royal monopolies, including not only mills but public ovens.¹⁶² In Mallorca a single feudal lord, Nunyo Sanç, held forty-two mills. In Valencia, where feudal custom was less rigidly applied, James I retained some mills and granted others out. Regalian mills he controlled tightly because of their value as a revenue-source. His successor, Peter III, however, substantially modified the practice in 1283 when he decreed that "whosoever might want to mill wheat, olives, henna, linen, rice or anything else, may do so where he wishes."¹⁶³ So long as the king received a share of the income, it was in the royal interest to promote the free expansion of milling. Seigniorial mills, at least at first, tended to be banal (local peasants were obliged to bring their grain there to be ground). Valencian royal mills were not banal and, by the end of the thirteenth century, had begun a slow transition to a commercial model of milling. In Valencia, there arose a kind of institutionally hybrid mill, halfway between a feudal mill and a commercial one. In some cases, the "lord" of a mill had

¹⁶⁰ Glick (1970), 234–254, and (1995), 161; Glick, Martínez (in press).

¹⁶¹ The same may have been true in the north of the kingdom of Valencia, but not in the southern areas where aridity was an inducement both to extend irrigation and to irrigate wheat. In Catalan Roussillon, by contrast, the canals themselves were built and controlled by feudal lords who opposed efforts by the Crown to impose the norms of Roman Law with respect to the public nature of water. See, in this regard, Caucanas (1992), 59–109.

¹⁶² See Barceló (1988b), 195–274; also, Selma (1993a), 333–355.

¹⁶³ *Aureum opus regaliū privilegiorū civitatū et regni Valentie* (1515), cited by Martínez (1992), 130–131, n. 52.

no benefice whatever except for the mill itself. In Catalonia feudal control of mills was far more strict.

*Conclusion: Knowledge Intensity and Social Values in
Peasant Irrigation*

Peasant work is knowledge intensive. That is, it gains its efficiency by reason of intimate understanding of the local physical environment to which peasant labor is harnessed by virtue of the collective archive of techniques and norms. "The greater local peasant knowledge is," Barceló has observed, "the more conditioned its diffusion will be . . . this local character stimulates the variety of plants, procedures, and work schedules" that peasants employ.¹⁶⁴ This is particularly true of peasant irrigation, which involves not only a variety of techniques, but also modalities of water distribution which are both practical (how to arrange distribution physically) and normative (how rights and priorities are assigned, both within and between communities). Settlement was not improvised; immigrating groups of peasants knew what they were looking for, based on prior experience in their places of origin and on that acquired during their migration. They arrived with knowledge of techniques that permitted a choice among alternative approaches which they could select and adapt to the conditions offered by the terrain chosen as a settlement site. They knew how to tap water in various ways, from a range of sources. Therefore the place of work determined site selection, the nature of local aquifers being the key variable.¹⁶⁵

Social (and cultural) values are represented in settlement, in the organization of space, in the organization of hydraulic spaces, and in the allocation and distribution of water. No two groups organize space in precisely the same way.

Law in general, and customary law (Arabic *'urf*) in particular, constitute forms of local knowledge, "local not just as to place, time, class and variety of issue, but as to accent—vernacular characterizations of what happens connect to vernacular imaginings of what can."¹⁶⁶ For obvious reasons water law is particularly sensitive to

¹⁶⁴ Barceló (1998b), 32.

¹⁶⁵ Kirchner (1998a), 455.

¹⁶⁶ Geertz (1983), 215.

locale. Water rights are a reflection of a given social or cultural group's assessment of the optimal use of water. Such optimality comes not necessarily in terms of efficiency, but rather in terms of a specific set of values. The social relations of production channel it in ways that are congruent with group values, which may well act to inhibit the maximum production potential of a given set of resources. Therefore Maass and Anderson observe that a specific group of irrigators may well trade off one value, such as efficiency, in order to optimize or promote another, such as equity or justice.¹⁶⁷ With regard to small-scale Andalusí irrigation, Cressier understands that economics (certainly in the present-day sense of economic efficiency) lost out in the trade-off with equity and equality,¹⁶⁸ and Barceló's school invokes the principle of equity of tribal irrigation in a general way in order to provide an explanatory context for their data. In this view, conditions for the use of shared systems result from pacts among the participating groups in function of the work invested in construction of the system, which in turn is tightly linked to the demographic weight of each group. In the case of systems not shared, but operated by one clan group only (systems generally not larger than one hectare) farming is communal, in the sense of a homogeneous kinship group, small in number. In those cases where the kinship group was large, as in the case of the Yetturer Berbers in Liétor, for example, relations of equity were established among the various extended families integrated into the larger community.

In historical context, however, equity in tribal irrigation does not have to be induced from culturally "mute" archaeological evidence: we know pretty well what Berber and Arab clan organization was, and is, like and how such organization relates to the allocation of water. The vernacular nature of customary legal norms to which Geertz alludes provides the rationale for establishing the routes of diffusion of discrete packages of tools. As Netting put it, "[t]he critical elements in the process of intensification are knowledge of the local environment and the specific requirements of domesticated plant and animal species, combined with a tool kit of practices for soil manipulation, water control, nutrient conservation and restoration, and the protection of cultigens that act to increase and sustain bio-

¹⁶⁷ See, for example, Maass, Anderson (1978), 6-7 (equity), 395-297 (justice).

¹⁶⁸ Cressier (1995), 275.

logical production."¹⁶⁹ The tool kit's practical array of information, stored collectively in the minds of the settlers, contains information sufficiently varied to permit a finely-tuned adaptation to a new environment: peasants "meet similar ecological/economic problems with a multiplicity of means and understandings."¹⁷⁰ Technology alone is not the crucial factor in organizing an agro-ecosystem: knowledge, experience and the social organization of work are. In applying their prior experience, peasants not only implant what they know, but are able to experiment with novelties (contrary to all-too-frequent clichés about the static nature of traditional agriculture): "Conscious experimentation with new crops or interplanting techniques in specific locations contributes to practical ecological knowledge, which is supplemented by the recollection of past yields under a variety of seasonal conditions."¹⁷¹ The reception of the package of Indian/Persian cultigens in al-Andalus is inexplicable except in terms of peasant know-how and receptivity to innovation.

¹⁶⁹ Netting (1993), 56.

¹⁷⁰ Netting (1993), 57.

¹⁷¹ Netting (1993), 63.

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CHAPTER EIGHT

MEDIEVAL FISHING

Richard Hoffmann

Fresh and salt waters all around medieval Europe harboured many life forms. Europeans then classed all aquatic animals, “everything that swims” in the words of eleventh-century monk Ekkehard IV of St. Gall—molluscs, crustaceans, cartilaginous and bony fishes, amphibians, reptiles, mammals—as “fishes” (*pisces*). These creatures provided important natural resources for human food, obtained from wild and, later, also domesticated fish populations by medieval fishers using carefully-selected traditional technologies. Most techniques had long been known to Europeans, but as medieval fisheries—where human material and symbolic culture intersected with aquatic nature—evolved in response to economic and environmental changes, so did the importance and scale of chosen technologies. The inland, estuarine, and inshore coastal fisheries of medieval Latin Christendom were technical systems which both used and influenced Europe’s hydrology.

Knowledge of Medieval Fisheries

Inland and coastal (shoreline) waters and fisheries were common but *local* everywhere in medieval Europe. This condition distinguishes medieval fisheries from the industrial-scale commercial marine fisheries of modern times, which have shaped the regional and national form of most modern historiography and so deformed that of the Middle Ages. Anachronism may prevail because most overviews of fishing in history, including medieval European fishing, have been compiled by one-time fishers or fisheries managers without historical training. Popular surveys, especially those in the English language, exhibit strong Anglo-centrism, recreational bias, and low critical sense. On the other hand, learned historians ignorant of basic fish biology, distributions, and behaviour can err as badly.

Early printed overviews of European fishing are useful primary

sources for early modern conditions. S. B. J. Noël de la Morinière, an experienced administrator in Revolutionary and Napoleonic France, published his *Histoire général des pêches anciennes et modernes* in 1815; the medieval chapters remain a valuable survey and collection of medieval documents. Not until the mid-twentieth century did works of comparable scope—if less historical awareness—come from fisheries authorities.¹ On the other hand, important overall cultural perspectives on medieval fisheries exist.²

Some of the better syntheses are national or regional in scope, though not all are recent and few authors recognize parallels outside their boundaries. A thorough chapter on fishing in Grand and Delatouche's 1950 *L'Agriculture au moyen âge* in effect only covers greater France; additional information on early medieval sources and on maritime fishing is available.³ Another fisheries administrator and scientist, Wilhelm Koch, assembled the one synthesis for central (German-speaking) Europe in the 1920s. He discovered much interesting manuscript material from late medieval southern Germany but integrated little from the several relevant articles which had appeared in the now-defunct *Zeitschrift für Fischergeschichte* (vols. 1–9, 1913–17). Sketches of early medieval verbal and archeological evidence are now in the encyclopedic *Reallexikon der Germanischen Altertumskunde*. Scholarship for Italy is legally-oriented, while Iberian fisheries still await their historian.⁴ Until very recently marine and recreational biases have especially distorted the history of medieval fishing in the British Isles.⁵ Fisheries of medieval east-central Europe have been briefly surveyed, though illustration sometimes outweighs documentation in these studies.⁶

Ethnographers and archeologists provide interpretive and comparative perspectives. One model might be the comparison of prehistoric, historic, and modern fishing gear from northwestern Europe.⁷ Fish-catching methods from more European regions have been analyzed,

¹ Thomazi (1947), Cutting (1955), and Cushing (1988).

² Zug Tucci (1985) and Mane (1991).

³ Verdon (1979); and, on maritime fishing, Hocquet (1987).

⁴ Mira (1937).

⁵ Littler's unpublished 1979 Swansea dissertation, *The Fisheries Industry in Medieval England down to the Reformation*, gave only a few pages to inland waters, but the archeologists and historians who contributed to Aston's (1988) volumes show how to fill the lacunae.

⁶ Górczyński (1964) is a synthetic pamphlet, prepared for the Polish fishing association. Andreska (1987) and (1997) deal with the Czech evidence cursorily.

⁷ Brinkhuizen (1983).

but less systematically.⁸ Less historical but extremely well-organized, even authoritative, comparative views are applied by von Brandt (3d ed., 1984). Before such conceptual tools can help construct a modern understanding of medieval fisheries, however, the principal contribution must continue to be made by local students who combine close familiarity with their waters and ecosystems and the skill to handle written and material remains from their past.

As for primary sources, for most of the European Middle Ages next to no one attempted to report how fish were caught or to describe the technologies used to do so. No self-conscious manuals or handbooks on fishing are known before about 1305, when the Bolognese lawyer Pier de' Crescenzi gave the subject four chapters in a trail-blazing treatise on estate management; on fishing he even overcame his normal reliance on ancient Roman agronomy.⁹ De Crescenzi's Latin text was translated into Italian, French, and German by about 1400, and then printed several times by the early sixteenth century. The text underwent informative revisions in both manuscript and printed versions. But already by the late fourteenth century, quite independently of the Italian precedent, manuscript instructions on how to catch fish, first short, then longer, were multiplying in the European vernaculars. Two independent German oral and textual traditions resulted in a collection of recipes assembled between 1440 and 1470 near the western Bodensee,¹⁰ and in a longer grouping of information on angling, pot gear, and their uses which was originally oral but came to be written down in the cellarer's office of the Bavarian abbey of Tegernsee between 1498 and about 1506. In 1493 Heidelberg publisher Jacob Köbel put yet another set of local traditions into the first printed book on fishing. English fish-catching advice was first welded into coherent tracts on the use of trap nets, on dyeing horsehair lines, and, sometime after 1413, into a recreationally-oriented *Treatyse of fysshynge wythe an Angle*, known from a fragmentary mid-century manuscript of unknown provenance and from a different, later redaction which Wynkyn de Worde printed in 1496 as part of the second *Boke of St. Albans*, a compilation on

⁸ Especially by the several contributors to Gunda (1984).

⁹ Crescenzi (1995–2000). Much of what follows is from Hoffmann (1997).

¹⁰ Now Donaueschingen Schlossbibliothek Codex 792. For an edition, see Hoffmeister (1968).

elite pastimes.¹¹ All these works are anonymous. Their Spanish counterpart, however, a *Dialogue between a Hunter and a Fisher* printed at Zaragoza in 1539, was written by a retired soldier and local literary figure, Fernando Basurto, in honour of a noble patron.

By the early sixteenth century medieval experience with fisheries had also emerged into new manuals on estate management. This included the well-known essay on artificial fish culture, the *De piscinis* of Moravian prelate Jan Skaly z Dubravka (Jan Dubravius), composed in the late 1530s at the request of financier Anton Fugger and printed at Wrocław in 1547. Earlier manuscript tracts on this topic are only now being discovered in central European collections. The genre also conveyed what may be the oldest surviving original fishing instructions from France in sections of Charles Estienne's *L'agriculture et maison rustique* (Paris, 1565).

Earlier traces of technical information on fishing occur in writings of thirteenth-century encyclopedists and natural historians—notably Albert the Great, Vincent of Beauvais, and Thomas of Cantimpré—and more copiously in the sixteenth-century works of their intellectual heirs, the first scientific ichthyologists. Books on fishes published by Pierre Belon, Guillaume Rondelet, Ippolite Salviani, and Conrad Gessner often note how certain species were caught.

Before the fourteenth century extended discourses on fishing were rare and literary, not didactic, in substance. Bordeaux's poet Ausonius (310–394) devoted some 64 lines of his *Mosella* to the fishes and fishing he saw while travelling the river to Trier. Late tenth-century schoolmaster Aelfric of Eynsham thought to teach Latin to his Saxon pupils with social vignettes on, for instance, a hard-working fisherman. A youthful Gui de Bazoches, canon of Chalons-sur-Marne in the mid-1100s, described in polished rhetoric how he and companions “played” at fishing on a country estate near the Ardennes. A pseudo-Ovidian poem of thirteenth-century Parisian origin, *De vetula*, proposed to forget love by fishing in rivers and the sea with seines, pot gear, or hook and line. These texts are not devoid of technical interest.

Legal and regulatory sources provide less coherent or aesthetically crafted, but far more abundant, information on medieval fisheries. Many charters and diplomas, hence most chartularies, identify fishing

¹¹ The manuscript is now Yale University Beinecke Library MS 171. McDonald (1963) contains facsimiles of both versions and Brackman (1980) more context and analysis.

rights at certain sites, often with terms suggesting the techniques there employed. Later privileges can be detailed. That granted Saalfeld in Prussia in 1320, for instance, allowed citizens to fish "with dip nets, with cast hooks, and with seines which are no more than six fathoms long, as far from town as one can throw a stone of a quarter-pound weight."¹² Generally not predating the 1200s but multiplying thereafter are the very specific—and often equally cryptic—fisheries regulations issued by public or private authorities or by organized craft guilds. Philip IV of France banned a dozen named sorts of nets and barrier traps and set strong seasonal restrictions on two more in his general fisheries ordinance of 1289.¹³ The city government at Pistoia was legislating against fish poisons by 1296 and that in Madrid imposed rules in 1507 to prohibit netted enclosures and regulate digging holding tanks in municipal watercourses.¹⁴ In 1442 the corporation of fishers at Auenheim on the Rhine collectively determined measures to protect small fishes and the permitted seasons for fishing on open water, through the ice, with barrier traps, and in flooded side channels.¹⁵

Managerial records and accounts from owners and operators of fisheries are surprisingly often available and richly informative about equipment and its operation. Charlemagne famously instructed stewards on royal estates to retain skilled fishers and netmakers, construct and maintain ponds, dispose of surplus fish, stock more, and report annually on the yields.¹⁶ When Gotahelm left the cellarer's office at Tegernsee abbey in 1023 he inventoried three seines, 34 basket traps, seven panel nets for whitefish, six "stillwater nets", one drive net, a dock, six boats, 16 lines, and "enough rope."¹⁷ Clerks for thirteenth-century bishops of Winchester, for fourteenth-century Dukes of Burgundy, and for sixteenth-century archbishops of Gniezno alike kept track of the small fish set into their lord's ponds, the large fish harvested, and the work done to maintain and improve these

¹² Benecke (1880), 301: "mit hamen, mit wurfangeln und mit waten, dy an deme lengisten sechs clafter lang sind, alzo verre alz man von dem stade mit eyne steine gewerfen mag, de an dem gewichte eynes virdungs swer sy."

¹³ Duplès-Agier (1852), 49–53.

¹⁴ Zdekauer (1888), 131; Puñal Fernández (1992), 178–179.

¹⁵ Mone (1853), 72–89.

¹⁶ The 794 Capitulary "de villis": Boretius (1883), no. 32.

¹⁷ Steinmeyer, Sievers (1879–1922), vol. 3, 657, and vol. 4, 562–563, disassembled the Latin text and German glosses of BSB Clm 18181, fol. 118v.

constructions.¹⁸ The Benedictine kitchener at Selby in Yorkshire spent money on replacement timber, rope, a boat, and day labourers to refurbish a fish weir at Rosscarrs on the Ouse in 1416–17.¹⁹

As Gotahelm's inventory suggests, most fishing was done with perishable organic materials, but surviving and recovered artifacts and structures are important sources of knowledge. Archaeologists have found stone, ceramic, and metal weights and hooks for fishing at many sites in several countries. Waterlogged conditions can even preserve wooden and wicker gear.²⁰ Posts or postholes in abandoned or still active stream beds mark sites of weirs and fish fences, sometimes datable to the medieval period. Earthen mounds, ditches, and walls can on occasion be recognized as remains of medieval fishponds. Excavation cannot always clarify the precise form and use of these devices, but some of these same structures remain in use today. Archeozoologists study the remains of fishes (commonly in kitchen refuse) from medieval sites and have learned to draw critical inferences not only about fish varieties and their availability but also about seasons and techniques of capture.²¹ Systematic inventories and typological comparisons of archaeological materials related to fishing or, indeed, of medieval illustrations of fishing and its equipment,²² are still in their infancy.

Culture, Ecology, and Economy

Medieval fishing activity depended on well-defined cultural motives for eating fish and familiarity with the particular aquatic ecosystems accessible to European exploitation.

Fish flesh offers high quality protein to its eaters of whatever biological class or religious affiliation, but for medieval Christians the eating of fish was no simple matter of nutrition. Christian culture shaped demand for this food, notably through a taboo on eating the meat of terrestrial quadrupeds ("animals"). Since late Roman times the taboo applied permanently to professed ascetics, and imitation

¹⁸ Roberts (1986); Hoffmann (1995); Topolski (1957).

¹⁹ Tillotson (1988), 170–171.

²⁰ Steane, Foreman (1991).

²¹ Wheeler, Jones (1989) is a methodological overview.

²² Mane (1991).

of their practices made it an intermittent rule for everyone else. Consumption of animal flesh was banned on every Friday, the day before important religious feasts, for some weeks of Advent in the late fall, and the forty days of Lent in late winter and early spring. The total, varying from diocese to diocese, came to 130–150 days. There were pronounced but not exclusive seasonal features. Observance, especially of the Friday and Lenten “fasts,” was a generally recognized sign of personal membership in Christian society. Charlemagne’s 785 Capitulary of Paderborn demanded that forcibly converted Saxons fast on pain of death.²³

Fish were just as generally accepted as the substitute for forbidden meat. As all aquatic animals were “fish,” the clear distinction between “flesh day” and “fish day” was a central element of medieval dietary culture. For Charlemagne, fish were the quintessential “Lenten food.” Much later Thomas Aquinas summarized four main rationales for Christian behavior, traceable back to Isidore of Seville or Benedict of Nursia.²⁴ Fish was less “fleshy” and so thought to incite sexual passions less. Fishes plainly did not copulate, so were thought not to reproduce by seed (a sexual act) in the manner of humans, terrestrial animals, and birds. Avoiding the meat of animals was a penitential reminder of the Edenic state of sinlessness and peace between humans and beasts. And, finally, fish provided a practical alternative for meat.

Still, doing without meat did not dictate eating fish. Fish were expensive and of low caloric value compared to grain. An impoverished widow likely put no more fish in her Friday gruel than she did bacon on Thursday. But, notably for the well-to-do, expensive fish on the table were an ostentatious mark of religious observance and social rank. As a German proverb succinctly put it, “game and fish belong on the table of lords.”²⁵

With motives of protein, penance, and prestige, therefore, all sorts of medieval Europeans did eat fish and, *ipso facto*, create an effective demand for this food. Examples of such demand in the earlier written sources pertain only to ascetics like St. Gall, whose *Vita* claims

²³ Boretius (1883), no. 27.

²⁴ *Summa theologica*, IIa, IIae, q. 147.

²⁵ Schreiner (1982), 109. The sentiment is echoed in fifteenth-century poet Heinrich Wittenwiler’s comic epic *Ring*: “Vier ist ein Herrenspeis” (lines 2905–6). Wiessner (1936), 119, gives a long list of parallel literary references. Dyer (1988), 28–31, confirms like English practice.

he caught his fish from a tributary of the Bodensee, or St. Anselm, whose fishers and opportune miracles brought him trout and sturgeon from Norman waters, according to his biographer Eadmer. By the twelfth century Alan of Lille could report in *The Plaint of Nature* that herring "relieved the hunger of the poor" at Paris. Then swelling financial records generalize this information. People who found accommodation at the papal almshouse in Rome were served fish on 117 days during the accounting year 1285–86.²⁶ By then (and on into the 1430s), fish provided 3–5% of the calories given to Norfolk peasants who were fed for compulsory harvest work.²⁷ At the other social extreme, one leading burgher of late fourteenth-century Köln, Hermann Goch, spent on fish as much as he did for meat, up to one fifth of his household's outlay on food.²⁸ Budget planners for English king Edward IV in the 1470s projected fish as taking 10% of the annual maintenance costs for knights of the household.²⁹

Remains of human food from numerous well-excavated archaeological sites confirm the written record of significant and various fish consumption.³⁰ Three very different communities have large collections of discarded fish remains of mainly tenth and eleventh century date: in the 13,842 identified fishbones from the Viking entrepot at Haithabu, herring, perch, and pike are most common; at the Slavic-Magyar village of Zalavár in a swamp near Lake Balaton people ate catfish, carp, and pike-perch; late Saxon Hamwic, the seaport precursor of Southampton, consumed mainly coastal marine fishes, notably herring, flatfishes, and eel.³¹ Inhabitants of the Castello di Manzano, a fortified village built in northwestern Italy shortly before 1014 and abandoned in 1243, included tench, chub, and perch in their diet.³² By the late fifteenth century, wealthy households at Paris, with their pick of the best varieties from fresh and salt water, chose chiefly cods, herring, and carp.³³

²⁶ Cortonesi (1981), 203–204.

²⁷ Dyer (1989), 158. Harvest workers got fish in Portugal and Catalonia, too: da Cruz Coelho (1983), 98–99; Altisent (1972), 33–34.

²⁸ Irsigler (1972).

²⁹ Myers (1959), 108–110.

³⁰ Differential survival and recovery rates of fish and mammalian remains prevent measured comparisons in archaeological contexts.

³¹ Lepiksaar, Heinrich (1985); Bökönyi (1963); Coy (1989).

³² Bedini (1992).

³³ Desse, Desse-Berset (1992); Sternberg (1992).

The fishes consumed in such numbers by medieval Europeans came from the naturally simple aquatic ecologies and distinct hydrological regimes of northern and Mediterranean watersheds, as well as rich northern and relatively infertile Mediterranean coastal waters. The peninsular situation and Pleistocene glaciation of Europe left the continent with a limited freshwater fauna; the number of its native fish species declines down a northwestern gradient from the Balkan refugium to which the glaciers had confined all but the most cold- or salt-tolerant varieties. Europe is, by and large, a territory dominated by rivers, more commonly short and fast ones in the steep terrain of the Mediterranean basin and long, slower, ones in the flatter north. Natural lakes occur in limited areas around the Alps, some other mountain ranges, and morainic belts, and in side channels of lowland rivers. Current speed is a prime determinant of fish habitat, so European waters naturally provide more living space for fast-water than for stillwater fishes.

In drainages from the Baltic to the Bay of Biscay the relatively few native freshwater species display important biomass adaptations to marine access and cool running waters. Fish like salmon, eel, barbel, and pike were familiar inland; the former two species along with sturgeon, flatfishes, and some inshore-spawning populations of herring frequented coastal areas. Cold, nutrient-rich seawater supports large populations of relatively few fish species. Salmon, trout, shad, and sturgeon migrate as adults from the sea into estuarine and even upland freshwater streams to reproduce. Eel, on the other hand, grow from larvae to adults in brackish and fresh water, then migrate downstream and out into the Atlantic to spawn. The warm, clear, Mediterranean housed a greater variety of inshore marine taxa, each in smaller number, but above the estuaries the typically high-gradient streams of this basin provided fewer sorts, and numbers too, of freshwater fishes. Eel, shad, and sturgeon are naturally present, but not sea-migrant salmonids. Extending halfway across the heart of Europe is its only major east-flowing watershed, the Danube, which has a distinctive native fish fauna: lacking eel and sea-run salmonids, it included several different salmonid and sturgeon species and, especially in its lower reaches, many more warmwater cyprinids, including the common carp itself.

Throughout the Middle Ages freshwater fish had dietary importance unfamiliar today. Undependable transportation facilities and limited techniques to preserve easily-spoilt fish set close limits on access to

fresh fish. Since at latest about 1200, a prodigious effort of fast horse relays raced to deliver dubiously fresh fish from the Norman coast to wealthy Paris. If that 150 kilometers marked a practical maximum for shipment, even over easy terrain and in cool seasons, most Europeans had to make do with preserved marine fish, deemed less tasty, or the fresh output of their local waters. (See figure 8.1)

Environmental effects of growing human numbers and economic activity somewhat affected human dependence on the productivity of natural aquatic ecosystems, though this varied by region during the Middle Ages.³⁴ Agricultural clearances, mill dams, drainage, diking, and human or industrial waste evidently damaged fish habitat on lower-order streams and locally in some rivers and estuaries. Human demand for fish prompted overfishing and, by the later Middle Ages, depletion of certain traditionally favoured varieties and populations. After about 1200, continued high levels of demand drove development of new production systems to catch and preserve offshore marine species and to rear fish artificially in the European interior.

In consequence of Europe's well-watered state, fishing activity was nearly as ubiquitous during the Middle Ages as was fish eating. All fisheries depended on good local ecological knowledge, especially of seasonal concentrations where fishes were capturable. Those who would capture creatures like salmon, or eels, or tuna, must know when and where they were present in useful numbers, on a day to day and seasonal basis.

The economic activity of fishing, inserted in its social contexts, was variously subsistence, commercial, and recreational in purpose. Subsistence fishing produces fish for eating by the fisher's household or that of his (since most recorded medieval fishers were male) lord or employer. Medieval peasants occasionally used direct subsistence fishing as a primary strategy: it is, for example, marked in the Slavic place-name *rybyjady*, "fish eaters," beside rivers and Pomeranian lakes. More often, however, fishing for household consumption was a seasonal and part-time activity for cereal producers seeking supplemental dietary protein. The right of full-time agriculturalists to fish "for their own table" was assured for instance, in thirteenth-century charters for Prussian villages and in the 1342 customal of Alrewas, Staffordshire.³⁵

³⁴ Hoffmann (1996).

³⁵ Willam (1961); Dyer (1989), 157.

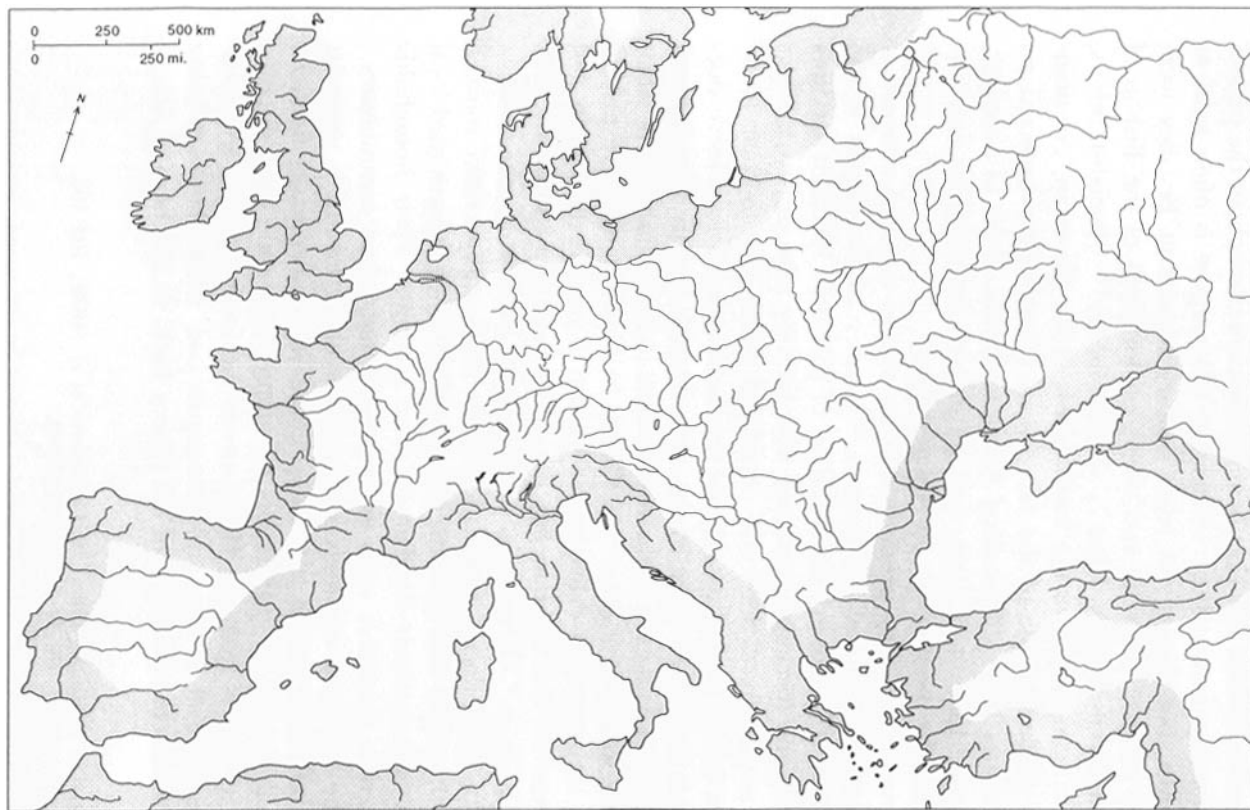


Figure 8.1. Shaded area is within 150 km of salt water. Medieval and early modern transport could not normally move fresh marine fish farther inland without spoilage. Map by Cartographic Drafting Office, Department of Geography, York University.

On the other hand indirect subsistence fishing had general importance for supplying lords' consumption needs during the early Middle Ages and in certain well-documented instances throughout the period. Occasional peasant labour service for this purpose is often hard to pin down, but during the tenth century tenants at Bewdley were obliged to erect fishweirs and others on lordships of the Bishop of Verona owed "weekly labor . . . in the fishery"³⁶ Specialist fishers, servitors comparable to the lord's smith or his plowman, are ubiquitous. Skilled people of the sort whom Charlemagne expected on royal estates were still working full time for the Duke of Leicester, Simon de Montfort, in 1265, and, throughout the eighth to sixteenth centuries, for monasteries on Alpine lakes.³⁷

Commercial fishing produces fish for sale to eventual consumers. An important part of the famous "Commercial Revolution of the Middle Ages" involved the evolution of part-time specialist servitors into full-time specialized artisans, who lived by sales in new markets while paying fixed dues and occasional ritual gifts to their lords. Market fishers ranked among the first such artisans to achieve documentary record. At Pavia by the early eleventh century sixty licenced fishing boats paid cash to the royal palace in lieu of fish except when the king was in residence.³⁸ At Worms in 1106 twenty-three named fishers contracted to deliver three salmon a year to the bishop and the count for the right to fish the Rhine and monopolize the sale of fish in town.³⁹ Commercial production by Parisian "pecheurs de la Seine" is richly documented in legislative, fiscal, and narrative sources, of the thirteenth through sixteenth centuries.⁴⁰ Such artisans used local waters and methods familiar to some peasants. Their households operated as economic units in both rural and urban communities.

Some medieval commercial fisheries evolved toward a capitalist scale and organization. One step came when merchants financed seasonal catches by part-timers to supply large-scale long distance trade, as traders from the Hansa towns did from the thirteenth century for Danish herring and Norwegian cod. More thorough-going changes affected the form of the fishery itself. In the herring fishery

³⁶ Cited in Salisbury (1991), 76; Castagnetti et al. (1979), 102–108.

³⁷ Turner (1841), 16, 39; Hoffmann (1994).

³⁸ Brühl, Violante (1983), 20–23.

³⁹ Boos (1886), I: 50 (compare the discussion in Epstein (1991), 53–54).

⁴⁰ Lespinasse, Bonnardot (1879), 212–214; Lespinasse (1886), 465–472; Laurière (1723–1849), vol. 2, 583–586; vol. 5, 207–208; Géraud (1837), 531, 608.

of the North Sea the Dutch are credited with the fourteenth-century development of salting the catch at sea, which required (and made possible) larger boats and crews, investment in salt and barrels, and the formation of a complex production team no longer financed or controlled by ship masters and crewmen. In Sicily tuna traps spread in place of beach seines from the thirteenth century. Elaborate structures called for an expert team to pen and spear whole schools of 25–50 kilos fish, then transport them to a rendering, pickling, and packing facility on shore. Urban capital hired specialist salaried workers and shipped the product to distant city consumers.

Recreational fishing entertains its practitioners, whether or not the catch is also eaten. From late Gallo-Roman aristocrats like bishop Sidonius Apollinaris (423–87) to Emperor Maximilian (1459–1519), well-known high-ranking people fished as sport throughout the Middle Ages.⁴¹ Very occasional records hint at like pleasures for late medieval townsfolk. But to date medieval sources do not allow us to distinguish peasant recreation from a subsistence activity, or to identify lower class people fishing for fun.

Generally medieval European fishing responded and adapted to specific local ecological conditions, as well as to economic purposes. Its history was, therefore, one of adaptation more than of invention. In fact almost all the techniques for catching fish employed before 1900 were known to medieval Europeans, so artificial flies, rod and line, nets and traps, and crew-served equipment were deployed according to particular situations of water, fish variety, fish behavior, consumer wants, and the potential for distribution of the fish, fresh or preserved. In the area of artificial fish culture, however, medieval innovations played an important role. What follows examines the main recorded technologies, from hand-operated gear of single individuals through crew-served devices to permanent capital structures.

Fishing with Simple Moveable Gear

Several kinds of fishing methods could be handled by one person or perhaps with a single helper. The simplest called for no actual equipment at all, for fish can be caught by hand, with or without concoctions

⁴¹ Sidonius's crowing over a splendid night's catch (poem 21) is not treated in Hoffmann (1986), but many other sport fishers are.

to stun them. Along tidal shorelines, sessile or slow-moving invertebrates (mussels, urchins, etc.) were simply picked up; and an unaided but quick hand and eye could take frogs and crayfish from freshwater. Conrad Gessner's mid-sixteenth century ichthyology reported skillful and stealthy grabbling or "tickling" of individual fish near the bank as an especially English trick, but such fishing by hand is illustrated in German woodcuts and earlier French manuscript illuminations.⁴² (See figure 8.2) This situation was plainly anticipated in recipes for salves using, for instance, extracts of heron for magic powers to draw fishes within human reach.

Fish are easily picked up after being stunned en masse with a poison or narcotic which does not impair their use as food. Classical writers such as Pliny and Oppian had mentioned several herbs with piscicidal properties.⁴³ Ethnographic sources describe use of these methods, especially by women and children, for instance in the early modern Balkans. Regardless of the active ingredient, piscicides work best when low and warm summer streams concentrate fish in deep pools.⁴⁴ Among medieval records, the use for this purpose of extract of "taxus" (yew, *Taxus* spp., or Great mullein, *Verbascum thapsus*, called "tassus") was expressly banned by Frederick II in his "Constitutions of Melfi" (1231), and then in a long run of Florentine, Siennese, and Spanish laws. Thirteenth-century Genoese, however, contracted to use it for commercial capture of marine fishes.⁴⁵ In the mid-eleventh century a literary description of catching fish with powered extract of *Anchusa officinalis* (Common Alkanet, called "Ochsenzunge" and "Buglossa") appeared in the fairy tale *Ruodlieb*, a work with narrowly Bavarian circulation. It is the first sign of a poison later widely mentioned in Latin and German manuscripts.⁴⁶ Other recipes took active narcotic ingredients from nettle, henbane, and spurge (*Euphorbia*), the last of which Sardinian law expressly forbade.⁴⁷ Shortly after 1500 the highly effective *Anamirta cocculus* of south Asian origin, quickly replaced native European ingredients.

Pliny reported some herbal piscicides with powdered lime (CaCO_3) as a dispersal agent, but the first records of poisoning fish with caustic

⁴² Manc (1991), 236; Hoffmann (1997).

⁴³ Zaunick (1928).

⁴⁴ Gunda (1984b).

⁴⁵ Book 3, cap. 72: see Powell (1971), 144; Balleto (1983).

⁴⁶ *Ruodlieb*, Fragment II, lines 1–26 and Fragment X, lines 1–58.

⁴⁷ Fois (1984), 189.



Figure 8.2. "Die schicklihait und pesserung aller fürstlichen lust und nutz der vischerey." Several medieval techniques are shown in this anonymous woodcut, made c. 1515 for Maximilian's personal copy of his autobiographical *Weisskunig* (Österreichische Nationalbibliothek, Cod. Vind. 3033, fol. 169v). Maximilian angles at center, to his right fishers empty a basket trap into a portable storage tank and fish by hand, while in the distance two boats set out a boat seine.

quicklime (anhydrous calcium oxide, CaO) are medieval: de' Crescenzi recommended it, but late thirteenth-century Pistoiese law prohibited it. Fish-catching manuals and other evidence since the fifteenth century confirm this practice in many European popular cultures.⁴⁸ Effects comparable to piscicides were also gained by stunning fish with the shock wave of underwater explosives. Pyrotechnics fired by quicklime (which heats rapidly on contact with water), were described by the early fifteenth century and suggested for fishing before 1500.

Other techniques require specially made equipment actively manipulated by the fisher. Medieval sources give good information on use of fish spears and angling with both straight gorges and bent fishhooks. Spearing or shooting targets individual, normally quite large, specimens visibly present in clear water—pike, salmon, sturgeon, tuna, whales—or fish which take cover in holes or soft mud, such as eel or flounder. Visual spearing requires the skill to find the fish and compensate in aim for the diffraction of the water (the fish appears to be higher and further away). Multi-pronged, often barbed, fish spears (leisters) of varying design and type are well-known archaeologically and in medieval representations. (figure 8.3) A thirteenth-century French poet thought them common equipment in peasant households and de' Crescenzi described their use.⁴⁹ The right to spear salmon was specified in thirteenth-century charters along tributaries of the upper Rhine while illegal nighttime activity, using artificial lighting, remained a concern on Black Forest streams of the sixteenth century and the Dordogne in the seventeenth.⁵⁰ Disputes broke out over peasants spearing pike in fifteenth-century Prussia.⁵¹ Long, narrow eel are caught by jabbing blindly into places they concentrate, so eel spears have many sharp, close-set tines or flattened blunt ones with serrated edges to wedge and lift the prey. In 1381 an agreement set a quota on spearing eel in one Prussian estuary.⁵²

Even more widely familiar was fishing with hook and line. The baited hook was a common literary conceit and visual representation of fishing, but such references rarely identify important partic-

⁴⁸ Zdenkauer (1888), 131; Gunda (1984b), 212–214; Trexler (1974). What at first look like anti-pollution ordinances, as those from fifteenth-century Florence, may instead be efforts to curb such intentional use of piscicides.

⁴⁹ Nyström (1940), 57; de' Crescenzi (1995–2000), 10:30; vol. 3, 209.

⁵⁰ Amacher (1996), 71; Nauwerck (1986); Cocula-Vaillières (1981), 134.

⁵¹ Burleigh (1984), 98–99, and sources there cited.

⁵² Seligo (1902), 12.



Figure 8.3. Eleventh-century iron fish spears and wooden net floats from Lake Paladru (Isère), now in the Musée Dauphinois, Grenoble. Photo from Colardelle, Vendel (1993), 39.

ulars of hooking techniques, which show many special adaptations in the Middle Ages (see figure 8.2 and figure 8.4).

Fishhooks themselves can be curved or straight.⁵³ The straight hook or gorge is a short double-pointed cylinder bound to the line at its midpoint and concealed in a bait. After a fish swallows the bait a pull on the line brings the gorge perpendicular to the line, and stuck transversely in the throat of the fish. Predatory species such as pike and zander, which swallow their prey whole, and also fish-eating waterfowl, are well-suited for gorge fishing. Wood, horn, and bone gorges 3 to 10cm long have been recovered from, for instance, ninth-through twelfth-century strata at Wolin on the Polish Baltic coast.

Curved hooks have three distinctive elements: the hook shank or shaft; the bend, and the point, which may or may not be barbed. The gap measures the perpendicular distance between point and shaft. A curved hook is attached opposite the bend by binding the line behind a swollen or flattened area (spade) or threading the line through a hole or loop in the hook material. Archaeologists have recovered medieval European fishhooks made from wood, iron, and

⁵³ Hurum (1977) is too untidy for incautious use on medieval topics.



Figure 8.4. St. Peter as a successful angler in an Anglo-Saxon Gospel lectionary illuminated c. 1000 in the Canterbury school style. J. Paul Getty Museum, Malibu, CA., ms 9 (85. MS. 79), fol. 2v. Used by permission.

bronze; less durable materials may also have been used. (figure 8.5) Most metal hooks were forged or shaped from square-sectioned wire, but bronze hooks from Slavic sites of early and high medieval central Europe have distinctive twisted wire shanks.⁵⁴ The English *Treatyse* teaches how to make hooks by detempering, bending, and then rehardening sewing needles, a method most applicable to relatively small hooks for freshwater and coastal species. Bronze hooks from the eleventh-century village on Lac Paladru in Dauphiné measure only 2.2–3.5 centimeters shank length. Other specimens from especially marine locations run larger: 3.2–7.5 centimeters iron hooks from late medieval London; 5–6 centimeters wooden hooks from tenth-century Wolin; iron and bronze hooks of about 5–7 centimeters from eleventh-twelfth century Szczecin and Great Yarmouth; and one of 12.2 centimeters also from Yarmouth.⁵⁵

Most medieval fishing line was probably hemp or linen. It decomposed quickly and, even if found in an excavation, is simply a twine of all but indistinguishable purpose. A line braided from white hairs of a horsetail was common in inland settings, recommended by de' Crescenzi and the English *Treatyse* and mentioned in a fourteenth-century ordinance from Vercelli. By the 1400s both English and German fish-catching instructions called for a wire [-wrapped?] line at the hook for taking the sharp-toothed pike.

Hook and line fishing may need no further equipment, though a weight of stone, ceramic, or metal to take the bait down is often a time-saver and essential in deep water. Handline fishing with a single baited hook was the classic and essential method for taking northern cod and southern hake. Sailors on the ill-fated English flagship *Mary Rose*, sunk off Portsmouth in 1545, could opportunely vary their hardtack and salt beef rations with fish taken by hand lines mounted on wooden winding frames built to the same prototype as the one the Norse god Thor uses on a carved stone from the Anglo-Saxon church at Gosworth, Cumbria.⁵⁶ Poor fishers used single-hooked hand lines from the French shore of the Channel in the 1100s and so, apparently, did a person fishing in the moat of Hartmannsberg Castle near Salzburg.⁵⁷

⁵⁴ Górzyński (1964), 37; Heindel (1982); Schmidt (1984), fig. 34; Rulewicz (1994), 99–127; but compare the nicely twisted shank of a hook from a twelfth-century French manuscript: Mane (1991), fig. 2.

⁵⁵ Rulewicz (1994); Steane, Foreman (1988); Colardelle, Vedel (1990), 208; Hutchinson (1994), 130–135.

⁵⁶ Wheeler, Jones (1989), 171.

⁵⁷ Hocquet (1987), 75–76; Noichl (1978), Tafel VIII, Abb. 3.

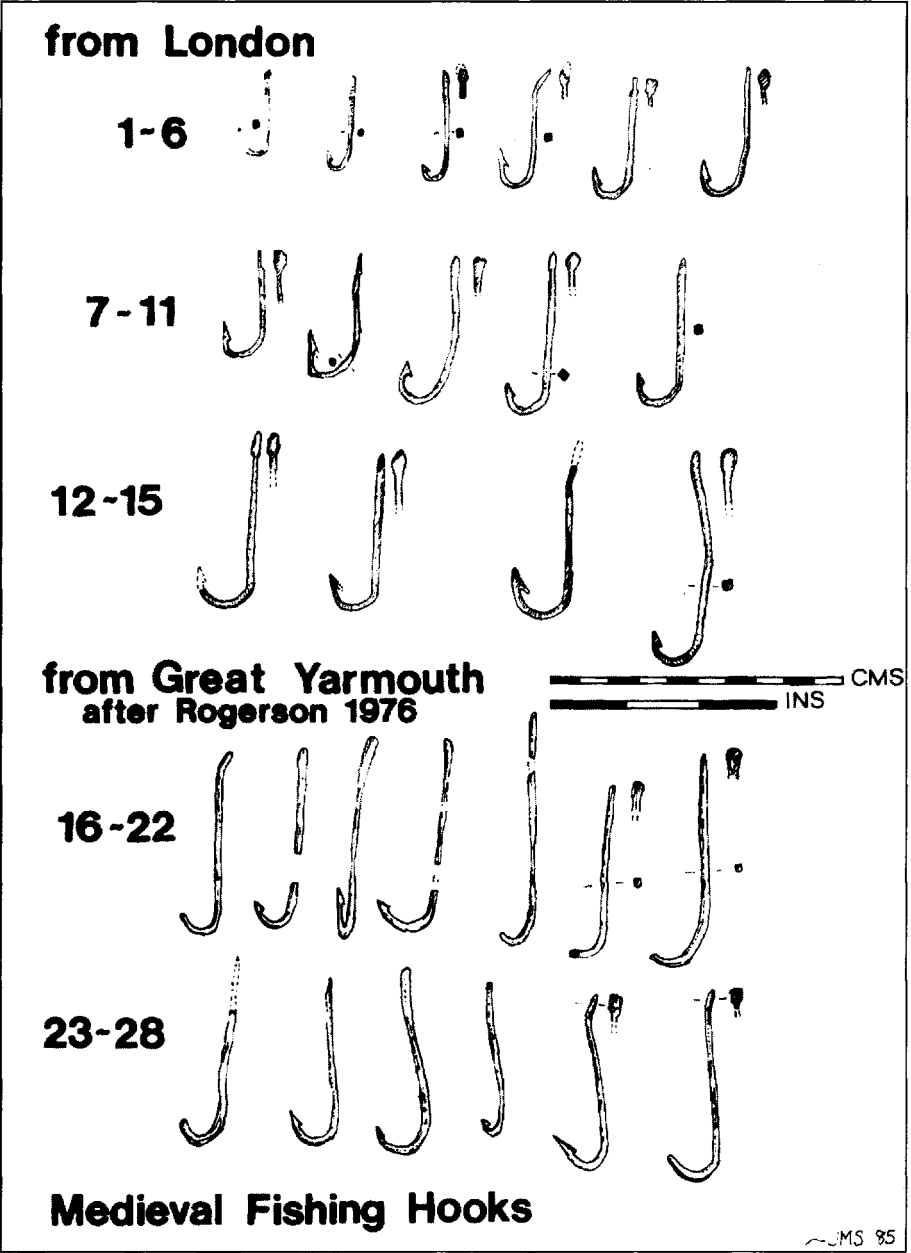


Figure 8.5. Medieval iron fish hooks from Great Yarmouth and London. Drawing from Steane, Foreman (1988), 147.

Some fisheries, especially seeking dispersed or moving fishes, spread many hooks, each on a short dropper line (snood, branch), all along a main line. In the Zürichsee hooks on a long line suspended between two floats were baited for pike and those anchored to the bottom meant to take eel and perch. Sicilian fishers called this technique "palmagastu," and used it to take a variety of inshore marine fishes as, it seems, did shore-based fishers on early medieval Iona. A poachers' tactic, the "zugangl," was prohibited by ordinance on the Traun in 1418, but Prussian village charters expressly allowed the shore-based "wurfangel," anchored to a rock thrown into the water.⁵⁸ A specialized form of long line with unbaited hooks was used in estuaries to take sturgeon; though the main line was set on the bottom, floats lifted the side lines so that the passing fish might brush against them and be held by the unbaited hooks.

The angling technique with line attached to a hand-held pole of about the same length is well documented and well-nigh ubiquitous throughout the Middle Ages (Figures 8.2 and 8.4). Indeed this was the only form of fishing permitted to peasants on lands of Czarnowanz abbey in thirteenth-century Silesia and in some Tirolian lordships of the fifteenth century.⁵⁹ For most of the medieval period all genres of visual representation depict fishing rods no taller and sometimes shorter than the people who use them, so about one to two meters long.⁶⁰ This was also the convention in Greco-Roman art. No formal written descriptions treat such short rods. On the other hand, late medieval instructional writings describe fishing poles at or considerably greater than human height, and this larger dimension (2–5 meters) also then appears in illustrations. Fishing rods were made from various woods (alder, hazel, fir) and other organic materials like reeds or whalebone (baleen). They could be in both one- and multi-piece designs. A reel to secure extra line is nowhere evident in medieval Europe,⁶¹ so rod and line together gave anglers an effective working range of perhaps five to ten meters. Various sources indicate baited hooks fixed to the bottom with weights on the line, drifting under a float, or worked at the water's surface.

⁵⁸ Amacher (1996); Bresc (1985); Wheeler (1981); Scheiber (1930), 152; Willam (1961), 145.

⁵⁹ Wattenbach (1857), no. 9; Stolz (1936), 353, 366.

⁶⁰ Mane (1991), 236–238.

⁶¹ Although reel-like devices are illustrated in ancient Egyptian, Chinese, and possible Byzantine works of art, the first western record of a fishing reel dates to the seventeenth century.

Like Sidonius Apollinaris, Aelfric of Eynsham, and the mining promotor Georgius Agricola (1494–1555), medieval fishers in literature baited their hooks. Practical handbooks chose baits according to the fishes sought, the waters, and the season. Their advice was in tune with de' Crescenzi, who advised opening the stomach of a caught fish and putting on the hook whatever it had been eating.⁶² Lists thus begin with natural organisms: fishes, frogs, crayfish, insects, worms, other invertebrates. They extend to various preparations of flavourful vegetable or animal origin: cooked grain, pulverized leeches, grapes, lard, beaver gall, human blood, etc., worked up into a paste or dough.⁶³ Prepared baits especially took many kinds of herbivorous cyprinids. Fully artificial lures were also important throughout. Early medieval sites in Poland have produced several fish-shaped wobblers or jigs of lead, tin, or bronze, well-designed to attract pike, zander, or inshore cod (Figure 8.6).⁶⁴ Fishing with feathers bound to the hook in imitation of the insects which trouts, grayling, and several fast-water cyprinids eat is well-recorded in Germany since the thirteenth century, England since the fifteenth century, and Spain by the early sixteenth century, where Fernando Basurto called them “moscas artificiales.” They were employed singly by rod anglers and also on long lines trailed behind a moving boat. Plainly, medieval Europeans thought many different kinds of attractions could induce a fish to bite a hook.

Passive entrapment gear depends on a fish voluntarily entering a device which holds it until removed by the fisher. Some important passive technologies were usable by individuals. As ubiquitous as hooks and lines in medieval Europe were small traps or pot gear, called variously “retia,” “retz,” “Reussen,” “netz,” “weels,” “charpagne,” and “verveaux.” These rounded baskets, bags, or cones of wicker, rushes, framed netting, or other materials had funnelled openings allowing entry to fish but no easy exit. Some types relied on a narrow neck, others included a one-way valve with backwards-pointing frames (see figure 8.2).⁶⁵ Pier de' Crescenzi distinguished a wide form for fish attracted by an enclosed bait and a narrow one for vari-

⁶² de Crescenzi (1995–2000), 10:30; vol. 3, 208: “Sed hoc scire potest, qui captorum viscera scindit et inspicit, qualem escam communiter assecuntur, vel si diuerses escas, modo unam modo alteram, in hamo ponit.”

⁶³ Hoffmeister (1968), Braekman (1980), and Hoffmann (1997) are full of examples

⁶⁴ Rulewicz (1994), figs. 21, 25, and 26.

⁶⁵ Brinkhuizen (1983), 38–50.

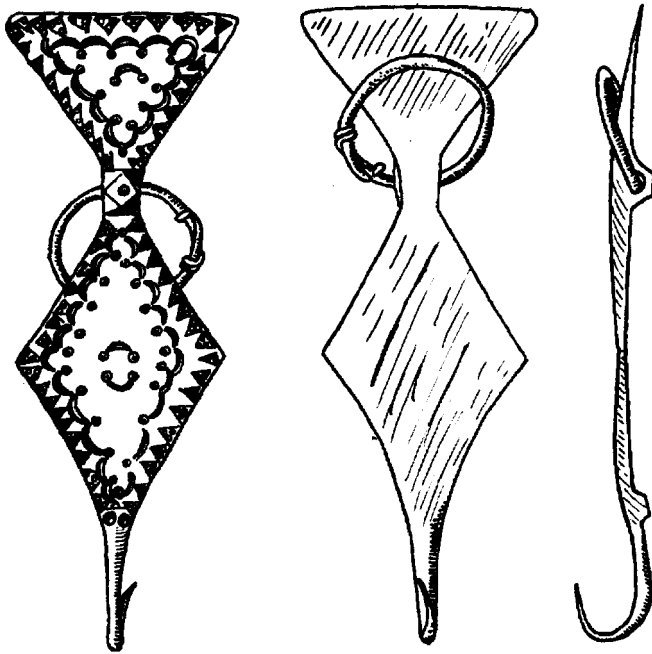


Figure 8.6. Bronze artificial fishing lure. 8.5 cm long, with integral hook. Excavated from eleventh-century layers at Wolin, Poland. Drawing from Rulewicz (1994), 129.

eties seeking to hide.⁶⁶ Recommended baits were those used for angling or, since these fish need not actually bite, visually attractive objects such as mercury, live bees, or naturally phosphorescent rotted wood in a stoppered glass vial. Stone anchors or posts driven into the substrate held traps in place. By varying design, bait, location, and season the pot gear offered high potential for selective fishing; unintended catches could be returned to the water. Small pot gear took eels and other inshore fishes: the early fourteenth century Luttrell psalter from eastern England shows two pots and an eel above the mill dam (see bookjacket illustration). Large models—

⁶⁶ de' Crescenzi (1995–2000), 10:29; vol. 3, 207–208: “Sed duarum formarum sunt; una forma est, quod sit interius multum ampla rotunda, in cuius fundo ponitur creta mollis et grana ei annexa, atque intrant quaedam genera piscium causa cibi et inde exire nesciunt. Alia forma est tota stricta et longa, sed in introitu modiciter aperta et in medio valde stricta, deinde lata et in cauda strictissima; in quam intrant non causa cibi, sed ut ibi occulte morentur. Nec de ipsa, sicut nec de prima, exire sciunt.”

the verveaux used in salt lagoons of Languedoc and also along the upper Saône—were made from netting on wooden hoops as tall as a man.⁶⁷

These devices were deployed alone or as elements in more complex sluices, weirs, and barrier traps. Riparian landowners on the Zschopau in upper Saxony quarrelled for more than a century (1293–1393) over “what is called a ‘rise’ in the vernacular” at a one mill dam.⁶⁸ In the British Isles distinctive funneled “weels,” “kidells,” or “putts” were set to catch salmon and eel at openings in weirs. Good archeological remains of medieval date have been recovered from flood plain gravels along the lower Trent (Figure 8.11 left).⁶⁹ In such situations even small fish traps could affect hydrology and navigation, so a Prussian ordinance of 1406, for instance, barred them from the main river channel. But early sixth-century Ostrogothic legislation judged them less hazardous than full-scale weirs, according to Cassiodorus (*Variae* 5.20).⁷⁰

Early medieval records highlight the basket traps of lords’ and landowners’ indirect subsistence fisheries. While Germanic law codes protected this form of property, eleventh-century Tegernsee abbey had 34 in its equipment inventory, and twelfth-century subjects of Reichenau (on the Bodensee) were obliged to deliver cartloads of willow rods to make “reussen” and stakes to anchor them.⁷¹ Later sources confirm peasant use of the technique, whether as a licit customary means of exploiting commons in thirteenth-fourteenth century Lorraine and early fifteenth-century Prussia⁷² or as a favoured and forbidden tool for poaching in the lord’s private waters. John Thurston and John Newman, fined for illegal fishing with “baskets” (“lepes”) at Upwood, Huntingdonshire, in 1411, would have been just as criminal under the late medieval custom of Stams in Tirol or the laws of Moravia.⁷³ Artisanal commercial fishers continued to find pot gear an effective way to catch certain species in marketable quantities. Already about 1200 “marguil” traps for eels were lucrative appar-

⁶⁷ Hocquet (1987), 63; Kempf (1974), 44.

⁶⁸ Beyer (1855), nos. 216, 510, and 518.

⁶⁹ Steane, Foreman (1988), 170–178; Salisbury (1991); Jenkins (1984); Carville (1971); Winchester (1987), 108–110.

⁷⁰ Benecke (1888), 307.

⁷¹ Drew (1973), ch. 299; Drew (1991), ch. 27; BSB Clm 18181, fol. 118v (see note 17 above); Rösener (1991), 223–227.

⁷² Collin (1971), 43; Benecke (1880), 307; see also Blary (1989), 95–99.

⁷³ Olson (1996), 20, 183–184; Linder (1959), 146; Jeřábek, (1963).

tenances to mills on the Garonne at Toulouse and on the Scarpe and Somme in Picardy.⁷⁴ The 1418 regulations for the Traun (in the eel-free Danube basin) restricted use of baited wicker and basket traps to master fishers with full rights.⁷⁵

More aggressive forms of small entrapment gear were scoops or dip nets, whether of webbing or grillwork. A bewildering variety existed, and de' Crescenzi describes several.⁷⁶ It is, however, difficult to link local dialect names with specific designs found in medieval illustrations or archaeological sites. What various texts called "hamum," "truble," or "pern" was a net bag hung from a rigid circular frame on a single handle a meter or so long. With this device a fisher could scrape fishes or crustaceans from the bottom or pursue individuals or schools flushed from cover.⁷⁷ A rectangular panel with poles as handles on opposite sides, called by de' Crescenzi "riuale" and in German "Stangengarn," could likewise search or block a larger area. The same netting, framed all around and rigged to be lifted vertically, could be laid on a flat bottom frequented by fish and hoisted at the opportune moment. This was one way to fish deep holes where migratory salmon, shad, or sturgeon were known to rest.

Woven mesh was certainly an ancient, familiar, and effective tool for capturing fish. Besides many verbal and visual allusions, actual fragments of hempen twine, netting, and net-making tools survive from several northern continental sites. Some such scraps, descriptions, and representations have a plain purpose, but for others it is no longer discernable. This is true also of pictures where people in a boat haul a net over the side. (figure 8.7) Medieval writers and artists often lacked awareness of the components and operation of complex fish-catching devices. Special skills for making nets were remarked in the Capitulary "de villis" (ch. 45) of the 790s and in a survey of personnel at Indersdorf abbey, Bavaria, from the 1490s.⁷⁸ Many net-fishing methods used a head line of floats and/or a weighted bottom line. As contrasted with the rare bits of mesh, whose precise function is rarely self-evident, both floats (wood, bark) and weights (stone, brick, lead) are so often recovered from medieval shoreline

⁷⁴ Sicard (1953), 119–123; Lohrmann (1995).

⁷⁵ Scheiber (1930), 33 and 152.

⁷⁶ de' Crescenzi (1995–2000), 10:28; vol. 3, 205.

⁷⁷ Scheiber (1930), 142; Mane (1991), 244–246; Steane, Foreman (1988), 178.

⁷⁸ Boretius (1883), no. 32; BHSA KL Indersdorf 185, fol. 157 (courtesy of Michael Toch).

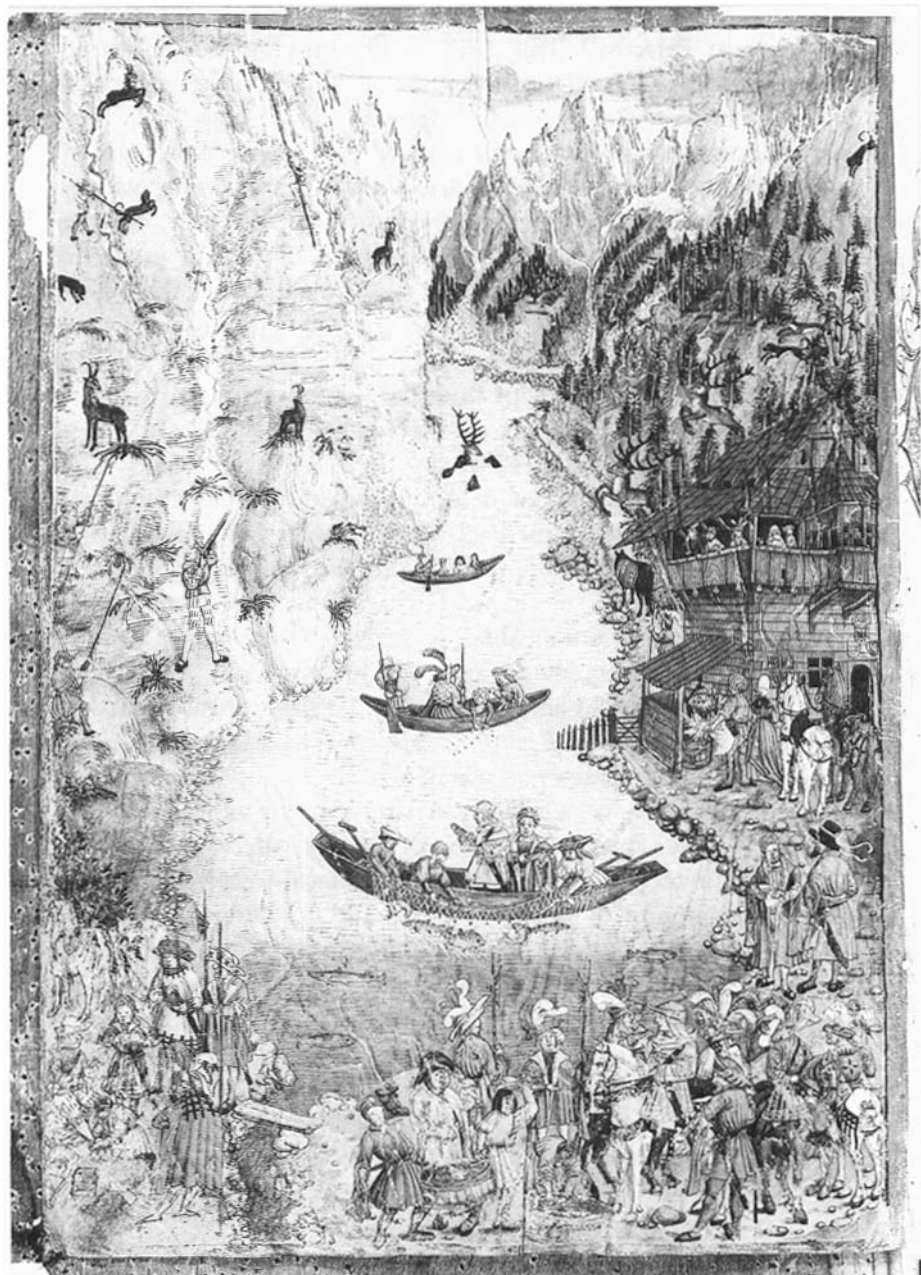


Figure 8.7. Tirolean fishers for Maximilian I haul nets from small boats, perhaps in the Achensee. The emperor sits amidships holding a fish, courtiers observe from the shore, a hunter pursues chamoix in nearby mountains. From Maximilian's *Fischereibuch* of 1504 (Österreichische Nationalbibliothek, Cod. vind. 7962, fol. 3v). Used by permission.

sites that both English and Polish archaeologists have established regional typologies and inferred netting techniques from them.⁷⁹ (See figure 8.8; compare figure 8.3)

Compared to small individual tackle, even simple mobile gear, if large, required greater investment and a team of fishers. It is again useful to distinguish between nets set passively in the water for fish to enter and those actively manipulated through the water to capture fish. Set nets could be fixed to poles or frames or suspended between floats and anchors. Generic "stoknetz," literally "staked nets," on poles in Baltic estuaries were mentioned in 1282, in a treaty between the Teutonic Knights and Duke Mestwin of Pomerania. Perhaps they were the same as the 30 by 4 meter "störlanken" later placed in groups of twenty off the mouths of the Vistula for sturgeon. Contemporaries used nets on posts to take salmon from both Cumbrian and Basque estuaries. Less clear texts report overnight settings of a net called "ricza" and "a spidoni" for sardines in Sicily and similar items in the tidal lagoons and estuaries of Mediterranean France.⁸⁰ It is uncertain whether these devices enclosed or entangled the prey.

The trammel net ("tremaille," or "tramallia") is a distinctive entangling technique with a long medieval record, beginning with the sixth-century Frankish Salic code.⁸¹ Three sheets of mesh hung in close, parallel, vertical curtains. The middle sheet was loose and had fine netting, the outer two, held taut, were of much larger mesh. Fish passed through the first outer panel, then pushed the inner panel through a gap in the third, so forming an inescapable pocket. Besides generic descriptions, use of the trammel net is documented on the medieval Lago di Bientina near Lucca and in the fisheries ordinances of Vercelli.⁸²

The gill nets essential to the large-scale late medieval herring fishery of the North Sea were also used for and seasonally important in whitefish catches in Alpine lakes. They are special entangling gear for schooling fishes of closely similar size. A correct gauge of mesh allows passage forward for the head and gill covers of a normal fish but not its thicker body; fish swim poorly in reverse and

⁷⁹ Steane, Foreman (1988), 162–170 and 178–180; Rulewicz (1994), 240–273.

⁸⁰ Łęga (1949), 29; Willam (1961), 142–144; Winchester (1987), 109; Arizaga-Bolumburu (1984), 202–204; Amargier (1971); Bresc (1985a), 209–211.

⁸¹ Drew (1991), 91.

⁸² de' Crescenzi 10:28; vol. 3, 205 uses the name "transversaria"; Onori (1984), 60–61; Nada Patrone (1981), 325.

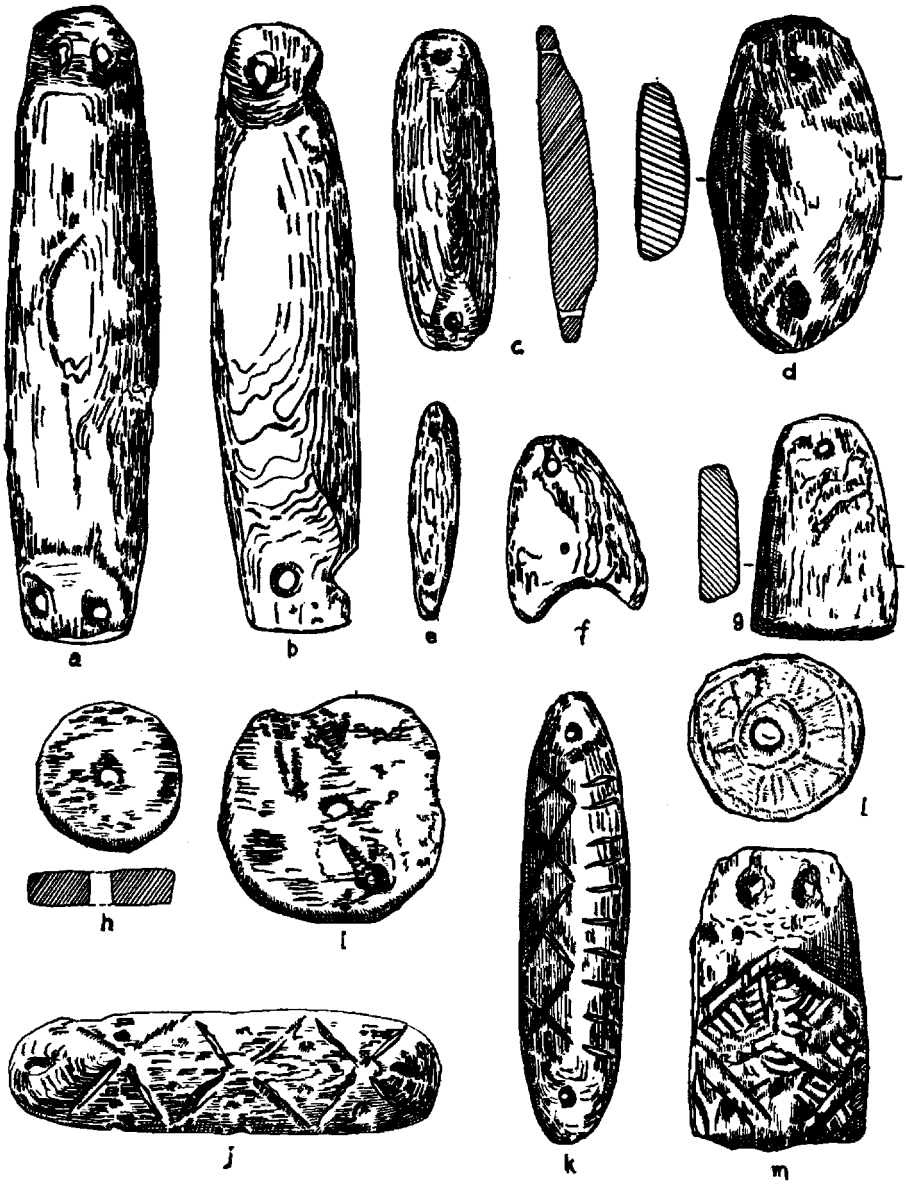


Figure 8.8. Archaeologically recovered wooden floats for fishing nets from twelfth- and thirteenth-century Gdańsk. Drawing from Rulewicz (1994), 242.

the flared gill covers are caught in the mesh. Both the 48-fathom "renkenklebernetz" in the fifteenth-century Tegernsee and North Sea herring nets were drifted as vertical walls close to the surface at night, when these pelagic plankton-eaters ascend with their food, but gill nets can also be fixed anywhere in the water column across routes of moving fish. Herring gill nets may have been a medieval invention, perhaps through modification of a beach seine. Specialized whitefish nets were present in the Tegernsee inventory of 1023 and Sidonius Apollinaris described setting nets at night in lakes of fifth-century Gaul.⁸³

Contrasting with these nets are those used actively, moved through the water to surround and extract fish. In medieval settings the power could be provided by human or animal muscle either ashore, in shallows, or on a frozen surface. In deeper water boats served. The two principal large-scale active technologies, seines and trawls, differ greatly in their construction and operation, though sources often obscure essential features of large mobile nets, rendering ambiguous their actual operation. What analysts now call seines are long nets comprised of two wings and no (or small) bag, not necessarily centered, which are set around an area thought to contain fish and then hauled in to a set place (boat or shore). Trawls are large centred bags with no (or small) wings. They are set closed-end first, dragged open through the water as long and far as desired to scoop out fish, and then hauled up. Seines surround fish in the water; trawls filter fish from the water.⁸⁴ (figure 8.9)

Medieval "sagenae" ("saine," "Segen," or seine) are plainly seines. Pier de' Crescenzi described a shore seine, which he called a "scorticaria," to near perfection: for use on flat seashores, this very long net had one side weighted with lead and the other equipped with floats to hold it upright in the water. While one end of the net was held on the beach, a boat carried the other end seaward and let the panel hang vertically while curving its length in an arc back to shore, where one fisher leapt out to hold that end. The boatman turned back outside the net to keep fish from jumping over the float

⁸³ The medieval invention of herring gill nets is held especially by Steane, Foreman (1988), 159; see also Hoffmann (1994), 310; Brandt (1984), 358; Sidonius, letter 2.2. Storå (1988), 77–78, describes traditional Finnish gill nets for Baltic herring. Compare Höfling (1987), 53–58.

⁸⁴ Brandt (1984), 284–285 et passim.

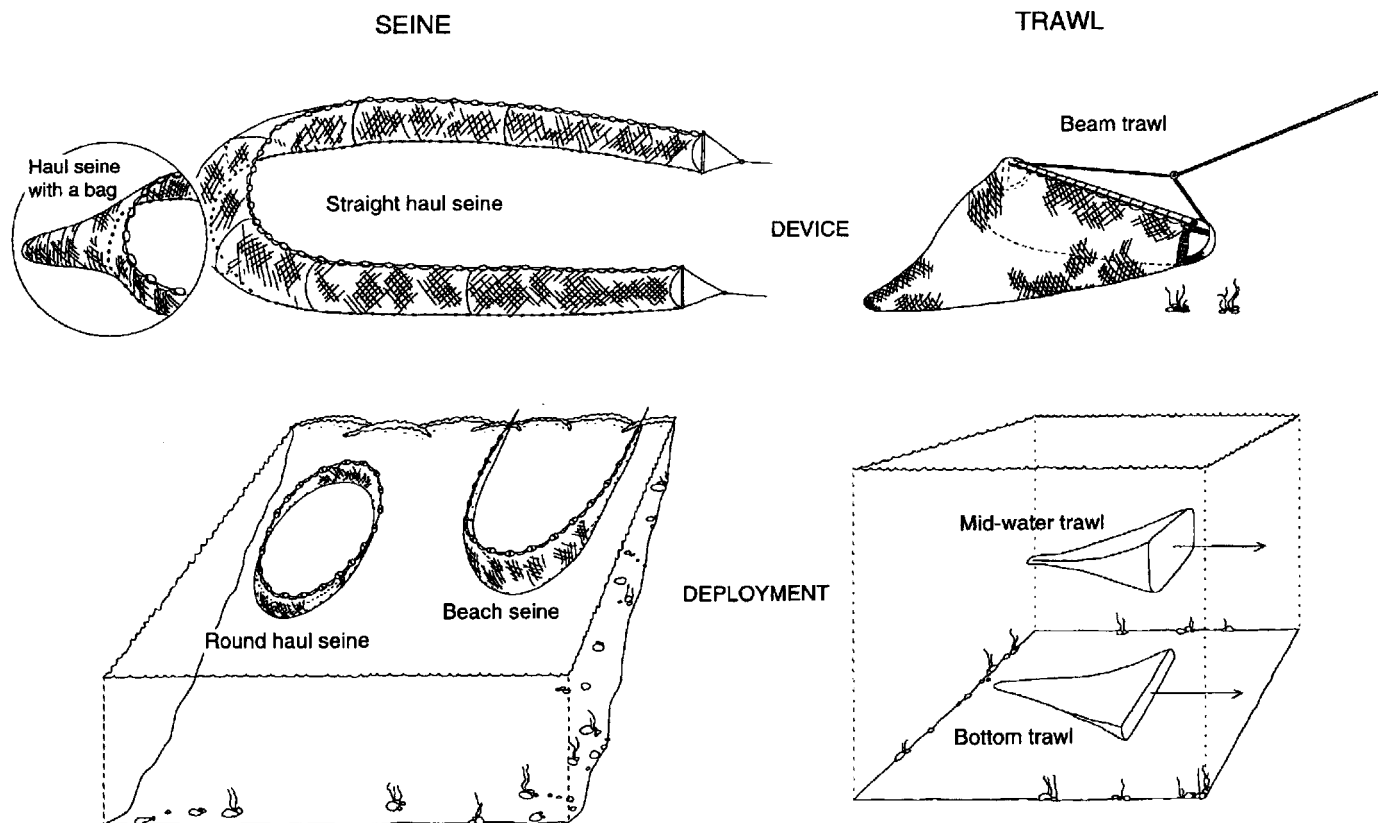


Figure 8.9. Schematic representation of seine and trawl technologies. Drawing by Cartographic Drafting Office, Department of Geography, York University.

line as his fellows on the beach drew in the net and its catch.⁸⁵ Many late medieval illustrations show the circled seine being hauled ashore (see figure 8.2 and figure 8.10). In marine settings precisely this technique described the Sicilian “xabica” or “sciabica” and the Provençal “bourgin” or “bulichi.” Beach seines took salmon and shad at fixed and named hauling sites in estuaries of the Dordogne and the Thames, mullet and flounder from the bay of the Somme, and in-shore schools of herring along the Pomeranian coast in twelfth and thirteenth centuries.⁸⁶ In fresh water the method is evident in the “sagena” set by one boat and the “regfaut” set by two on the upper Saône granted in a charter of 1211 to Cherlieu abbey and in the legally recognized seine sites (“the places for ‘sagenas’ are called ‘wyz’”) of the Hungarian “Tripartitum” law code, dated 1514. In the mid-thirteenth century circling seines harvested bream from artificial ponds of the bishop of Winchester and wild trout and charr from waters of the Lake District belonging to the abbey of Furness, among others. During the 1400s fishers from Preetz convent in Holstein used seines to fish beneath the ice of frozen lakes.⁸⁷

Seine technique was deployed vertically by fishers on deep Alpine lakes who used the “schöpfen” (perhaps known at Tegernsee by 1023) and, later, on both the Bodensee and Chiemsee, the more evolved “klusgarn.” One end of an extremely long net—Tegernsee’s “schöpfen” measured 40 fathoms in the early sixteenth century—was held in the boat and the other, weighted end was first dropped, then pulled up by means of separate long cables; this formed a vertical loop of netting which, the fishers hoped, surrounded a school

⁸⁵ de’ Crescenzi 10:28; vol. 3, 204–205: “In mari iuxta planam litus capiuntur praecipue multi pisces cum reti, quod multi scorticariam vocant. Hoc rete est ualde longum et satis amplum et spissum, habens cordam unius lateris plumbatam et alteram lebiatam, ut in aquis rectum et extensum permaneat. Hoc rete cum navicula infra mare defertur uno capite in terra relicto, ut in aliquae particula eius continuo descendat in aquam, cum nautae fuerint infra mare, quantum rete protenditur. Et tunc arcualiter cum illo capite revertuntur ad litus, et quibusdam ex eis in terram cum capite retis descendentibus unus in naviculam revertitur extra rete ad medium eius ad hoc, ut pisces infra rete comprehensi videntes se ad terram trahi non prosiliant extra rete. Duo autem piscatores ab utroque capite in terra existentes, trahunt cum piscibus totum rete ad litus. Qui saepe multos trahunt parvos et magnos, plerumque paucos aut etiam nullos, cum in eo loco non erant.”

⁸⁶ Bresc (1985a), 209–211; Cocula-Vaillières (1981), 129; Rogers (1866), vol. 1, 606–617; Clavel (1997), 200–202; Górzyński (1964), 37 and 57.

⁸⁷ Kempf (1974), 44; Werböczy (1990), vol. 1, t. 133.42; Roberts (1986), 130–135; Winchester (1987), 110; Bertheau (1917), 113.

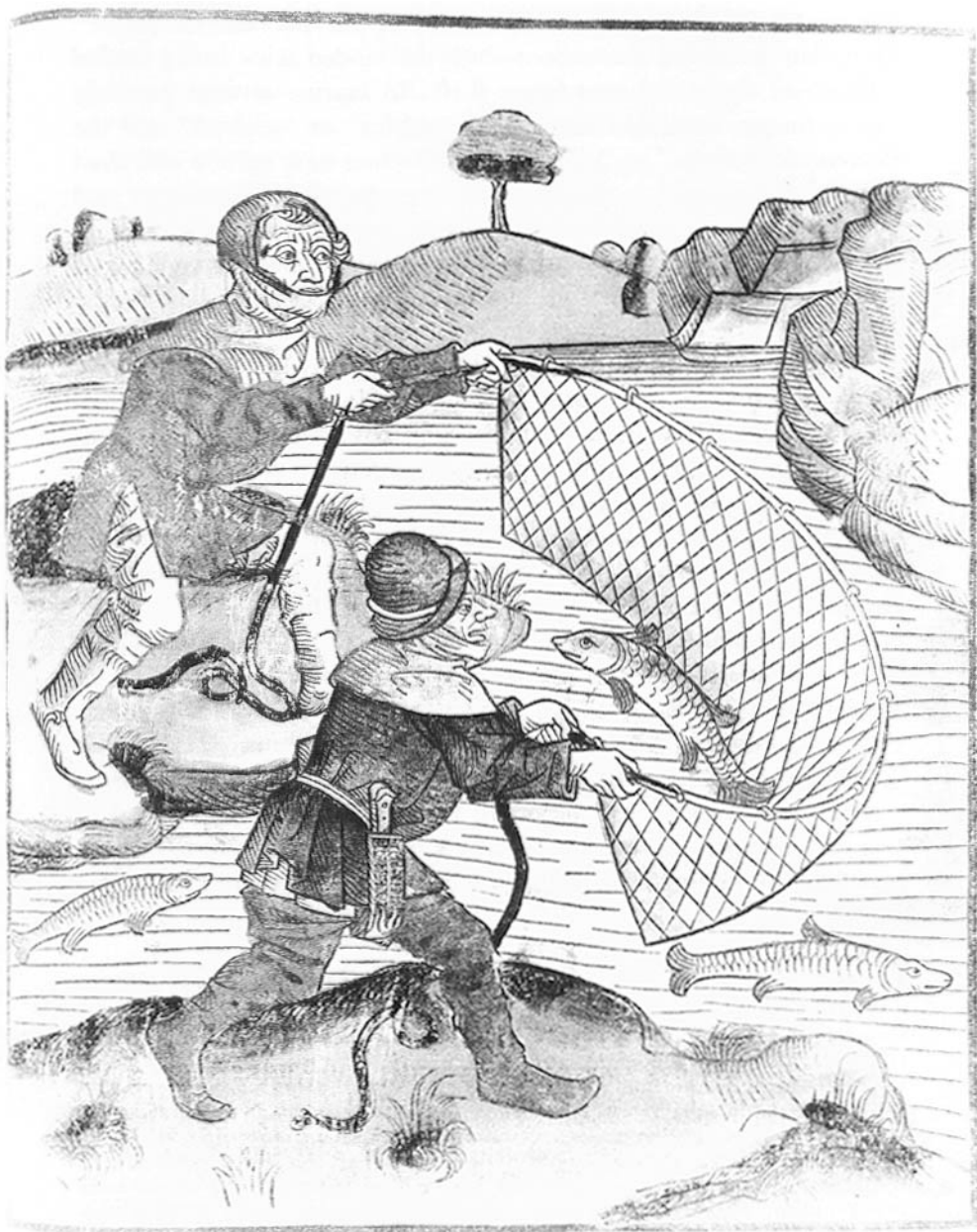


Figure 8.10. Small shore seine, drawn by hand in a fish pond. Woodcut from Bidpai, *Buch der Weisheit* (Ulm, 1483), in the Newberry Library, Chicago. Reproduced by permission.

of whitefish suspended in the depths. Lifting from both ends brought the catch to the surface.⁸⁸

The "lampara" is a special-purpose seine of Mediterranean origin, whose slipper or dustpan shape encircles fish at the water's surface while preventing underwater escape. The name further identifies the device's traditional association with use of artificial lights to attract the quarry. In 1303 fishers from Frejus, Provence, taking brushwood from shore to fuel "fishing to lights" came into conflict with the bishop of Lerins and in the 1380s the bishop of Antibes entered a three-year contract to provide fuel for the light fishing of sardines in return for half the catch. Around Sicily this method was criticised for frightening the valuable migratory tuna, and, possibly for similar reasons, by 1502 only four boats in Provence were licenced to fish with the "lampara." The inland netting technique called "frugnavolo" in nearby Piedmont may have been similar.⁸⁹

A widely-documented "sagena magna" of the medieval south and east Baltic was known in indigenous Balto-Slavic vernaculars as the "niewód." It was already regulated in charters from thirteenth-century Pomerania and later a repeated object of both conservation- and rights-inspired legislation from the Teutonic Order in Prussia. The "niewód" was important in the native artisanal fishery since the late eleventh century, as suggested by extensive finds of locally standardized net weights and floats from most urban sites along the Polish coast. Many records and studies describe its use as "tractus" or "dragged," but at designated sites. In actual descriptions like that by the Order's Grand Master in 1406, it is a net with wings 77.5 by 13 meters and a bag another 13 meters deep, so, indeed, a form of seine. The "niewód" was used in the Vistula, the many large morainic and estuarine lakes of the region, bays, lagoons, and the open sea. Its effectiveness was legendary: one draw in Lake Piannica purportedly gave twenty tonnes of fish. This caused the sovereign Order to claim exclusive rights to use it.⁹⁰

⁸⁸ Hoffmann (1995) and sources there cited; Höfling (1987), 47–50.

⁸⁹ Hocquet (1987), 65–66; Bresc (1985a), 110; Nada Patrone (1981), 326; Amargier (1984), 319–320.

⁹⁰ Seligo (1902), 17–19; Łęga (1949), 28–35; Górczyński (1964), 37; Dąbrowski (1970), 101–102; Kisch (1978), 180–183; Rulewicz (1994), 252–277. The design and proportions of a nineteenth-century Russian "niewód" reproduced in Moszyński (1967), 109, could have been taken from the 1406 specifications.

Not elongated but bag-like in form, true trawls have rigid frames or weights and floats meant to keep the mouth open while dragged through the water. The dragging motion which moves the entire net as a unit is central to the idea of trawling and said to be reflected in medieval terms like “gangui” in the Mediterranean and “tractus,” “Tracht,” or “Gänge” in the north. Toward the end of the Middle Ages a device called “trayn despachat” was pulled through the Gulf of Cannes to catch schools of small tunas.⁹¹ Some argue that trawls evolved from simpler seines given a more concave character for dragging over the sea bed to shore; others derive them from expanding the rigid box used to dredge oysters from the bottom. Among the oldest known trawls was (probably) the “wondrychoun” against which the English parliamentary commons complained in 1376–77, describing a purportedly recent invention resembling an over-large oyster dredge with a net attached which some greedy fishers hauled across the sea bed to take many small fish while disturbing the bottom and harming other creatures on it.⁹² The curious name recalls comparable devices used in Dutch tidal waters. But the precise method of operating the so-called “drag nets” being used by fishers on Yorkshire beaches since at latest about 1229, or the “keutel” (“bag”) for which the Teutonic Order later issued special licences to its subjects, is unknown⁹³

⁹¹ Bresc (1985a), 21.

⁹² *Rotuli parliamentorum*, 2:369 “... que come en plusours lieux deinz vstre dite Roialme, en Crekys & havenes de la Mier, ou soleyt devant ces heures bone & plenteuouse Pecherie estre, a grant profit de la Roialme, laquele en poy est destruit & nientys pur long temps a venir, par ascuns Peschours qi ont a ore a sept ans passez de novel sutiement controve une manere de Instrument que entre eux est appelle Wondrychoun, faite en la maniere d’une drag pur oistres, lequele est outre mesure long: Sur quel Instrument est attache une Ree, si espesse que nulle manere de Pesson, ja soit si petit noun, que entre dedeins ne poet outre passer, einz covient demurrer & estre pris. Et outre ce, le seer grant & long du dit Wondrychoun voet si owelment & durement desur la terre ent peschant, q’il destruit la flym crascete & flurs de la terre desouz la cawe illeoques; et auxint le spat des oistres, musklys, & d’autres Pessons, per ount les grantz Pessons soleient vivre & illeoques estre nurriz.”

Later texts refer to a beam securing the upper part of the net and a heavily weighted cable its lower margin, making a device later familiar as the “beam trawl.” Steane, Foreman (1988), 159–160, and references there cited.

⁹³ Lancaster (1915), vol. 1, 295, conveys a fishery at Eston near Guisborough, Yorks.; Willam (1961), 141.

Semi-permanent and Permanent Fisheries Installations

Fixed structures to block and hold migrating fishes were very important during the Middle Ages. They should be recognized in most of the "fisheries" ("piscaturae," "piscariae," also often "piscinae")⁹⁴ conveyed as appurtenant to landed property. Capital invested in construction, upkeep, and annual operation produced rich seasonal yields of favoured fishes, notably salmon, sturgeon, shad, lamprey, eel, mullet, and herring. Medieval records do not consistently distinguish between barrier devices (generic "weirs") which concentrated fish and actual large enclosure traps which prevented their escape.

Fish naturally congregate at falls, rapids, or constrictions to the flow of tides or floods, as they look for passage or exploit a concentration of food. Fish-eaters, humans among them, learned to use this bounty. It is a small step from fishing at natural barriers to doing it at artificial ones and not much more to make barriers for the express purpose of catching fish. While late medieval Romans set traps in archways beneath the Ponte Sisto, villagers beside Hungary's great rivers maintained openings for floods to fill oxbow lakes and abandoned channels, and as water levels fell, they put in wooden grills to hold large and release small fish.⁹⁵

The most widespread sort of barrier fishing in medieval Europe occurred at mill dams—and so multiplied greatly with water mills during the central medieval centuries. The downstream migration of adult eel gave each miller a lucrative seasonal opportunity to put basket traps or a lift net in his sluice. Mills and eel were closely joined in the English Domesday Book of the 1080s, in twelfth-century conveyances of shares in milling partnerships on the Garonne at Toulouse, and in contracts enjoyed by millers in sixteenth-century Lorraine. Two mills on a tiny Baltic coastal stream together paid 500 eels annually to Preetz convent.⁹⁶ Mill fisheries for upstream migratory salmonids may have had comparable importance. By the 1200s mills had become primary sites in the Norman salmon fishery and for taking lake-run trout from rivers in Tirol. A litany of medieval

⁹⁴ Domesday Book, for instance, does not limit this term to "fish pond" (Darby (1977), 279). "Piscatio," on the other hand, normally denotes a right to fish by any means.

⁹⁵ Brinkhuizen (1983), 15–17; Vendittelli (1992), 392–393; Mákkai (1985), 28–31.

⁹⁶ Darby (1977), 279–280; Sicard (1953), 118–128; Cabourdin (1977), 676–677; Bertheau (1917), 101.

Scottish statutes monitored millers for both their catch of adult salmon and their interception of fry and smolts on the downstream journey.⁹⁷

Fish weirs across streams, rivers, or tidal channels, whether permanently built of stone and timber or seasonal barriers of hurdles and wattle, could concentrate and funnel migratory fishes to other trapping devices or just to a place where they could easily be scooped or speared.⁹⁸ Under a wide variety of temporally or territorially different names, weir fisheries had both economic and hydrological importance long before the thirteenth-century introduction of power and navigational weirs on large European rivers.⁹⁹ Early in the medieval period Cassiodorus denounced fishing with "saepes" for endangering shipping in the Mincio, Ollio, Serchio, Tiber, and Arno rivers. The Frankish *Pactus legis Salica* (27:28) set compensation for damage to a "vertevolum," and a "venna" at a royal estate in the Ardennes is documented in a charter from 644, while another on the Weser can be traced in Corvey's possession from 832 until after 1158.¹⁰⁰ On the Severn just those weirs where monasteries had rights numbered thirty-five and from the rivers of Gdańsk Pomerania thirty-one active sites are recorded during the twelfth and thirteenth centuries alone. In the latter region weirs on the minor river Kacza paid a ducal licence of 300 salmon each year.¹⁰¹

Most of the records marked what the early twelfth-century Czech chronicler Cosmas of Prague called a "wooden structure for fishing." The many "vennae" of Prüm's ninth-century estate survey were glossed by retired abbot Caesarius in 1222 as "an expensive instrument quite useful to seize fish; we call it 'wer' or 'steyle.'" The same document elsewhere refers to villagers providing stakes, poles, or "large rods" for building weirs ("ad vennam," "quibus venna paratur").¹⁰²

Corroborating the verbal record are archaeological traces of medieval fish weirs recovered from French and English rivers. (figure 8.11)

⁹⁷ Halard (1983), 175; Stolz (1936), 346–347; Skene (1774), 288.

⁹⁸ General regional coverages are provided in Lampen (1996); Salisbury (1991); Steane, Foreman (1988), 170–176; Went (1984); Jenkins (1984); Willem (1961), 138–140.

⁹⁹ Remains of structures dating to the Neolithic, Bronze, and early Iron Age have been found on the British Isles and the European continent. Among medieval terms for weirs are "gorges," "vertevolum," "venna," "banna" "obstacula," "captura," "clausura," "fach," "wehr," "paxeria," "jazy."

¹⁰⁰ Cassiodorus, *Variae* 5. 20; Drew (1991), 91; Halkin, Roland (1909), vol. 1, no. 1.

¹⁰¹ Bond (1988), 87–89; tēga (1949), 19–24.

¹⁰² Graus (1953), 97–98; Schwab (1983), 176, 250–255, and 183.

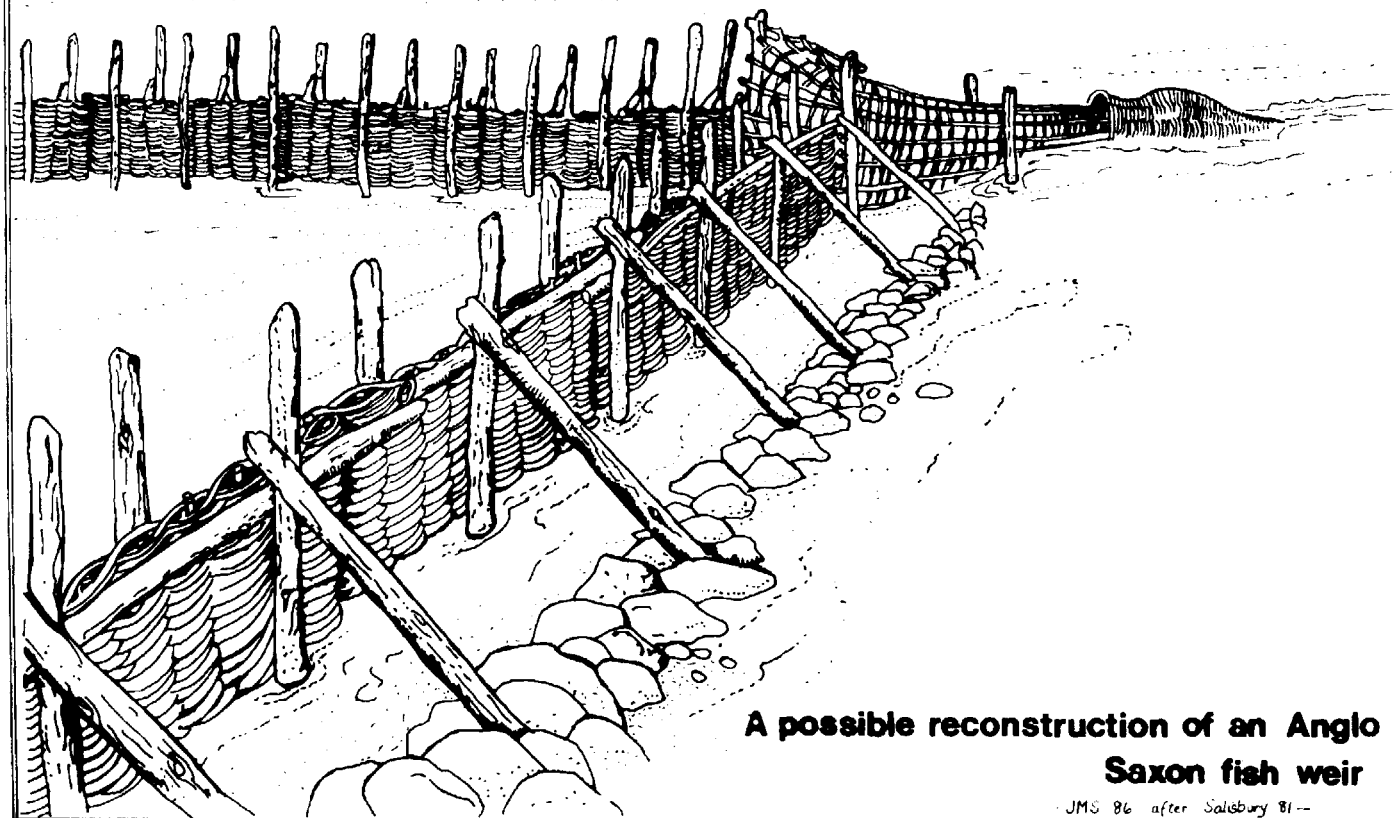


Figure 8.11. Artist's reconstruction of the Anglo-Saxon fish weir excavated in a former channel of the Trent, near Colwick, Notts. The "V" shape pointed downstream. From Steane, Foreman (1988), 171. Drawing by C. Salisbury.

Gravel mining in the flood plain of the Trent near Colwick uncovered a 14-meter double row of oak and holly posts set vertically into the river bed about a meter deep and a half meter apart, braced on the downstream side with oblique posts, and filled with woven wicker panels (wattle hurdles) of hazel. Dendrochronology and radiocarbon studies establish construction during one growing season and maintenance for another thirty or so years during the period ca. 810–880. One wing (the other is lost) of this Anglo-Saxon device probably ran diagonally across the river for some 35 meters. Not far away a similar structure with radiocarbon dates of ca. 1070–1200 had one long wing and two perpendicular short ones oriented at 45 degrees to the current, so forming a funnel or “V” shape pointing downstream.¹⁰³ At sites in the French rivers broken stubs of posts and limestone blocks spanned up to 150 meters in a “W” shape; two of the apexes funnelled downstream migrants and the third channelled fish trying to move upstream.¹⁰⁴ Both have early modern and even nineteenth-century analogs throughout Atlantic Europe. These forms probably used a conical wicker basket trap at the lower apex to capture eels and some kind of box, cage, or lift nets at the upstream end when salmon were expected.

Less is known of the weirs constructed from stone and wattles for salmon and eels in Brittany, or of the perhaps similar “stenwere” (stone weir) which Tewkesbury abbey owned on the Severn since before 1292.¹⁰⁵ Structures to take mullet in channels along the French Biscayan coast had to be of stone to withstand strong tidal currents, but the lesser tides of Languedoc permitted stakes to support brush bundles or nets for the same purpose.¹⁰⁶

Successive weirs up a watercourse aroused competition among human owners and destroyed the fish population. Cumulatively successful blocking of ascending or descending migrants deprived the last reach of water of fish, and, later, of reproduction. A petition from the abbot of Altenberg to the duke of Cleves in 1470 was crisp and blunt: a three-year-old weir further down the Dhünn, a Rhine tributary, meant “neither salmon nor fish can come up.”¹⁰⁷ Conflicts

¹⁰³ Losco-Bradley, Salisbury (1979) and (1988).

¹⁰⁴ Nowacki-Breczewski (1989).

¹⁰⁵ Touchard (1967), 38; Bond (1988), 87–89.

¹⁰⁶ Hocquet (1987), 62–63; Boucard (1983).

¹⁰⁷ “dar enkan noch laeis noch vjsch up gegayn” in Mosler (1955), vol. 2, 209–210.

among weir fishers might be epitomized in an episode from 1313; two Swedish Cistercian houses, one of monks and one of nuns, mutually smashed rival installations.¹⁰⁸ An intent to conserve fish stocks justified public action against weir fisheries. An English ordinance of 1285, reiterated in 1389 and 1393, penalized their use to catch young salmon in springtime; four west-country abbots were prosecuted in 1394–96 for doing this on the Severn.¹⁰⁹ A Scottish statute of 1214, later repeated, forbade weirs blocking the whole of a stream and required a gap large enough “that ane swine of the age of three zears, well feed, may turn himself within the streame, round about, swa that his snowt nor taill sall not touch the bank of the water.”¹¹⁰

Fishing weirs angered other users of a watercourse. Downstream communities in interior Provence complained that the walls erected by Carthusian monks to fish in mountain rivers broke and caused flash floods.¹¹¹ But shippers were the main antagonists from early on: shipping was why Cassiodorus forbade weirs on north Italian rivers. That concern recurs in thirteenth-century charters from Picard and Poitevan estuaries and in the 1418 fisheries ordinance for the Traun. In 979 emperor Otto II settled a dispute between two abbeys over a fish weir on the River Hörsel by ordering an opening big enough for two vessels to pass without touching. Legislation in the Basque province of Guipuzcoa required weirs to leave one third of the stream bed open.¹¹² An English statute of 1351/52 ordered removal of all “wears, mills, stanks and kiddles” impeding boats on the large rivers Thames, Severn, Ouse, and Trent. As the law was reiterated nine times before 1495, its effect may have been sight.¹¹³ In part this was because medieval weir fishers learned to comply by cutting a navigational channel around the weir on the landward side, leaving a small island at the base of the weir.¹¹⁴ Nevertheless, navigational attacks on fish weirs began the process which eventually turned most

¹⁰⁸ McGuire (1982), 193. For the general situation in England and a particular case see Petts (1989), 7–10 and Kowaleski (1995), 311–312.

¹⁰⁹ Bond (1988), 86–87; Wright (1996), 91.

¹¹⁰ Skene (1774), 335.

¹¹¹ Amargier (1984), 316–317.

¹¹² Cassiodorus *Variae* 5. 20; Sickel (1888), no. 209; Coopland (1914), 59 note; Brien (1954), 107 and document XXII; Scheiber (1930), 152; Arizaga-Bolumburu (1984), 202–204.

¹¹³ Bond (1988), 87.

¹¹⁴ Pannett's (1988) identification of medieval weirs on the Severn by tracing the surviving islands (“eyots”) deserves imitation in other jurisdictions.

major European rivers from natural fish habitat into sterile transportation corridors.

As distinct from barriers with associated catching devices or activities, large-scale fish traps actually diverted and guided fish into an enclosure whence they could not escape. Fishers at the village of Kotowice on the Oder in Silesia in 1203 used "an enclosure to capture fish" to supply their lord several times a week. The phrase echoes in eleventh and twelfth-century charters from Poland's other great river, the Vistula.¹¹⁵ Records from this and other regions of medieval Europe illustrate four types of big fish-catching enclosures: foreshore traps, "fish ditches," "fish fences," and tuna traps.

Along flat marine shorelines simple horseshoe-shaped walls of stone or pilings set in the intertidal zone with the open end oriented toward the beach formed temporary pools which held the fish to be picked up as the water receded. These foreshore traps were common along certain French, English, and Welsh coasts with, for instance, thirty-six counted on Île de Rê in 1408.¹¹⁶ In Domesday Book such a "sea hedge" on the Suffolk coast was partly owned by Bury St. Edmunds abbey and under the name "gamboa" or "camboa" they were the oldest structures built for fishing in Galicia. Breton counterparts served local subsistence needs before 1200, when they began to supply nearby towns, and eventually became objects of mercantile investment.¹¹⁷

Other situations called for riverside excavations into which water and fish could be diverted and then closed off. In 1210 the Benedictines of St.-Bertin complained that their Cistercian neighbours at Clairmarais had built a structure commonly called a "verra" at a disputed site "so constructed that fishes could enter that ditch but were not able to get out."¹¹⁸ Earlier tenth and eleventh-century charters from the lower reaches of Seine and Loire refer plainly to "sluices" ("clusa," "sclusa") and "ditches" ("fossatis piscatoriis") as means for catching fish. Specially dug diversions for fishing are later mentioned along

¹¹⁵ Appelt, Irgang (1963), vol. 1, no. 83; Górzyński (1964), 21, and sources there cited.

¹¹⁶ Hocquet (1987), 62; Hutchinson (1994), 135–137.

¹¹⁷ Darby (1977), 285; Bond (1988), 78; Ferreira-Priegue (1988), 132; Mollat (1993), 143.

¹¹⁸ Coopland (1914), 59 note: "apparatus fecerunt qui vulgo verrea dicuntur in terra illa ita dispositos quod pisces intrare possint fossatum illud sed exire non possint."

the Po, in municipal ordinances from fifteenth-century Madrid, and in Olaus Magnus's mid-sixteenth-century Nordic ethnography.¹¹⁹ A German royal rescript from 1300 may describe the typical arrangement; it divided salmon fishing rights at Beuggen bei Rheinfelden. The local commandery of Teutonic Knights received the "pools or ponds which are called 'salmen wege' in the vernacular, built on the Rhine" even though salmon do not live in "ponds;" the local community got the "channel of the riverbank which flows" between two named riparian sites.¹²⁰

Modern ethnographers like to think of close-set poles, so-called "fish fences," as elaborating simple barrier weirs into funnels or labyrinths which prevent escape. Western Mediterranean forms like the Provençal "bourdigol" were associated with estuarine fisheries for sturgeon, shad, lamprey, and some brackish-water fishes like mullets. Complex enclosures of embankments, wooden sheeting, and wood or reed grillwork blocked the Tiber at Rome and the mouths of coastal ponds further south in Lazio, offering sustenance for Romans and fishers and valued incomes to great churchmen since at least the tenth century. Two specialist workers contracted in 1303 to build a "bourdigol" of poles and brushwood at Agens and operate it four years on a share of the catch; nothing seems to distinguish that device from the one at the salt pond of Marignane where St. Victor of Marseilles obtained tithe rights in about 1025.¹²¹ Estuarine salmon traps in Normandy predated the watermill fishery there.¹²² At the mouth of the Schlei, a Baltic estuary, paired "herring fences" extend parallel to the channel for hundreds of meters, gradually narrowing and with angled interior baffles, so the inshore spawning schools come finally into an enclosure where they can be dipped. The structure still present at Kappeln dates at latest to the later Middle Ages, but its forerunners were probably a millennium older, or more.¹²³

¹¹⁹ Examples are available in Brien (1954), 4–5; Verdon (1979), 346 note; and Fauroux (1961), no. 34 (with thanks to Helmuth Irle). Compare Montanari (1979), 284; Puñal-Fernandez (1992), 175–180; Magnus (1555), bk. 20, ch. 12.

¹²⁰ Mone (1854), 73–74. The former Cistercian house at Bukowo, Prussia, possessed what were described in the mid-sixteenth century as "ponds" for catching salmon on the river Grabowa: Popielas-Szultka (1980), 190–191.

¹²¹ Vendittelli (1990), 116–121; Vendittelli (1992), 392–399. Hocquet (1987), 98; Bresc (1985a), 209–211; Amargier (1984), 313–315.

¹²² Halard (1983), 174–175.

¹²³ Radke (1977).

Fish fences of different design were probably also used on inland still waters. In Scandinavia, the east Baltic, the Alps and Balkans, Rhine and Po deltas, ethnographers discovered fishers arranging wooden laths, willow branches, reeds, or nets on poles as a diversion barrier across fishes' routes, leading to rounded chambers at each end.¹²⁴ Deployed along Mediterranean shorelines as a linear net running out from shore and slowly curling into a spiral at its outer end, this same essential form becomes the "cienche," an early trap for migratory tuna.

The "cienche" was likely an ancestor and antecedent of the most sophisticated and capital-intensive of medieval fish traps, the tuna fishery called "tonnara," "madrague," or "almadraba." Of Greek and Arab origin, the technique was revived or gained economic significance along the north coast of Sicily in the thirteenth century, proliferated there, and then in the fifteenth century spread to Provence and some sites in the Maghreb and southern Spain (if the latter was no independent development).¹²⁵ Again a long fence of anchored net panels was extended seaward several hundred meters from a carefully-chosen site where tuna schools passed close to shore. Encountering this long "tail" ("rizza"), the school turned outward and was gradually coaxed into three-sided chambers whose external meshes at first were large and unthreatening in size, then progressively smaller and tighter. Finally the tuna packed into the "camera della morte," where the crew lifted a netted floor to bring all to the surface for slaughter. Financed by merchants from Sicilian and mainland towns and operated by specialized workers under well-proven local leaders with the Arabic title "rais," about thirty "tonnara" used about forty sites in late medieval Sicily, some in biennial rotation. A Sicilian "tonnara" captured about a thousand fish each spring, and this two or three month season yielded about the same number of barrels (some forty tonnes) of brined tuna meat for markets all around the western Mediterranean. In the Byzantine straits similar techniques exploited different seasonally migratory schools. Since ninth-century emperors adjusted maritime law to account for the peculiarity of such privately-owned structures on the public seabed, this Byzantine technology may have been introduced or perfected at that time.¹²⁶

¹²⁴ Brinkhuizen (1983), 17–19; Höfling (1987), 67–73.

¹²⁵ Bresc (1985a), 210–211; Bresc (1985b), 169–173; Bresc (1986), 264–270; Hocquet (1987), 65. Compare Brandt (1984), 161–162.

¹²⁶ Dagron (1995), 60–63.

Facilities for Storing Live Fish

In a culture without refrigeration and canning techniques, yet ill-disposed toward dried, salted, or smoked fishes, the preferred way to keep fresh fish to hand was to keep them alive until mealtime. One consequence was the occasional blurring of distinctions between fish traps, live storage facilities, and fish culture. Moveable and fixed structures for holding fish in water are reminders that even today there is no firm boundary between tank, pool, and pond.

Given sufficient demand, freshwater fish can be transported in water to important consumption sites. Emperor Maximilian claimed in the autobiographical *Weisskunig* to have invented a special overland fish carrier, perhaps a pack barrel or tanker wagon, where trout and grayling stayed fresh and well-flavoured (see figure 8.2). But two centuries earlier his predecessors as dukes of Tirol were having live specimens of these fragile fishes moved for storage and use at their castle high above Merano.¹²⁷ For transport by water, boats were constructed with a perforated compartments (now called "live wells") so new water circulated around the living cargo. Dutch "waterschip" are first recorded in 1339 and hulks of ten medieval examples have turned up in fields once under the IJsselmeer (Zuidersee). A like craft ferried fish from well-endowed Burgundy down the Saône and Rhone to papal Avignon, but was so normal that at Chalon such vessels paid a special toll.

Structures of wood or netting could keep fish, accessible to consumers, for some time. Some large institutional households used wooden tanks for this purpose. At the castle of the counts of Forez in St. Etienne chests fitted with grills were built into the bank of the Loire. A comparable timber structure found beside the Ill in Strasbourg measured 10 by 20 by 3 meters deep; built after 1475, it stored fish for the convent of St. Magdalena. Rein abbey in Styria set wooden tanks with iron gratings into watercourses at four nearby sites.¹²⁸ Temporary cages of netting served the same function in a section of the moat at Dijon and, under the name "rivagiis," along Piedmont's rivers.¹²⁹

¹²⁷ Maximilian (1956), 234–235; de Rachewiltz (1995), 264; Hutchinson (1994), 142–143; Richard (1983), 191–192; Richard (1989), 40–44; Egbert (1974), 41.

¹²⁸ Fremenville (1893), 18; "Chronique" (1991), 335–336; Jaritz (1976), 185.

¹²⁹ Richard (1983), 190–191; Nada Patrone (1981), 320–321.

Permanent fixed structures for keeping live fish a season or more go back to the start of the Middle Ages. In the mid-500s Cassiodorus described his family estate-turned monastery of Vivarium, on Italy's Ionian coast. In a part of his *Institutes* little read during the Middle Ages he told about the site's namesake "vivaria," natural rock coves improved for the storage of marine fish. The three now still recognizable measure roughly 10–12 by 4–5 meters and just over a meter deep.¹³⁰ Charlemagne's capitulary "de villis" (ch. 65) urged sale of surplus fish and regular restocking of "wiwariis" so a fresh supply was always available. A generation later an estate survey noted stocked ponds inside the garden enclosure at three of four (unnamed) royal estates.¹³¹ Tenth-century reformers Olpert of Gembloux and St. Odo of Cluny each reportedly arranged a pond beside the monastery so monks' grudging acquiescence in dietary abstinence could be reinforced with a constant supply of fresh fish.¹³² Twelfth-century texts also mention fish stored in natural bodies of water as well as artificial millponds and moats.¹³³

Without positive evidence to the contrary, one or a few small artificial ponds close to a consumption site should be understood as storage facilities, not artificial fish culture. Storage demanded no special design features and, where winter freezing posed no danger, depths of less than a meter made it easier to remove fish as needed and to clean the basin.¹³⁴ In later medieval centuries urban fishmongers operated extensive store ponds. Those for London, called "stews" since at least the 1360s, stretched along the Thames in suburban Southwark. At Kraków, another town with a busy royal court and ponds along its riverbank, the 1364 market ordinance expected local merchants to carry live fish over from one week's fish day to the next. Contemporary Romans traded the contents of comparable Tiberside eel tanks ("vivaria anguillarum").¹³⁵

¹³⁰ Cassiodorus (1937), 1.29.1; O'Donnell (1979), 194–196 and 244–246. Shallow coastal tanks for keeping captured marine and euryhaline fishes were the predominant Roman and Byzantine form of "fishpond" ("vivarium"). Higginbotham (1997); Beckh (1895), 511–529; Dagron (1995), 59–60.

¹³¹ For the *Brevium Exemplum* survey, see Boretius, (1883), no. 128.

¹³² See Migne (1881), cols. 80, 83 for Sigebert, *Gesta*, ch. 33; Sitwell (1958), 78–81.

¹³³ McDonnell (1981), 14–15; Tock (1991), no. 155.

¹³⁴ Chambers, Gray (1988), 122.

¹³⁵ Currie (1991), 100, and sources there cited; Piekosiński (1879), no. 262 (later details may be found in Piekosiński, Krzyżanowski (1885), no. 564); Lanconelli (1985), 113.

Structures of this kind had long been favoured at the residences of large elite households. England's king Henry III (1216–72) had ponds for fish improved or made at York (the Foss Pool) and in his park at Windsor. English royal records then seem to designate store-ponds as “servatoria,” as distinct from “stagna” or “vivaria.” Henry's continental contemporaries built and used like structures. Count Amadeus VI of Savoy put what his clerks called a “vivier” at Chambry castle and another midway between Chambry and Montmélian, both meant for regular access by his chefs.¹³⁶ Boccaccio, writing his *Decameron* during the 1350s, remarked in passing that prosperous townspeople might construct ponds in their gardens, with clear chest-deep water over gravel bottoms to reveal the stocked fish; one of these, which he called a “fishpond in the Florentine style,” provided its owner with social recreation and food.¹³⁷ In the decades around 1400 Władysław Jagiełło, king of Poland, had fish-filled ponds at several favoured estates: when the royal household came to stay they ate “the king's own fish” until the supply ran out, then turned to the market; after the king departed, the local steward restocked the pond.¹³⁸

Secular prelates like the thirteenth-century bishops of Winchester or fourteenth-century popes at Avignon had household supply requirements, and store ponds, much like lay lords.¹³⁹ The larger and more consistent demand of religious communities for fish, however, made storage facilities a notable element at monastic sites. Those at Cluny, which reared no fish during its eleventh-century apogee, were set along the Grosne river across from the abbey but easily accessible to the fish kitchen.¹⁴⁰ Features of monastic store ponds are visible in

¹³⁶ McDonnell (1981), 20–23; Steane (1988), 39–40. Savoyard store ponds are discussed in Nada Patrone (1981), 320–321, and Lambert (1992), 222. Parallel distinctions and activities on estates of the Count of Champagne in the early thirteenth century are detectable in Bourquelot (1863), 67 and 71–73; those of the Duke of Burgundy in the early fourteenth century—who stored fish for current use in the mid-thirteenth-century pond at Argilly castle—are reconstructed in Hoffmann (1995).

¹³⁷ Boccaccio, *Decameron*, Day 6 conclusion and Day 10, story 6.

¹³⁸ Piekosiński (1896), 61, 101, 289, 378–85, 545–548, and 551–552.

¹³⁹ Winchester records also differentiate between “servatoria” and the “vivaria” used to rear fish: Roberts (1986), 133–135. The papal “vivier” or “piscarium” at Avignon, discussed by Girard (1953), was at least symbolically depicted in a fresco done at the New Palace in 1343: a stone-rimmed rectangular tank approximately 3 by 15 meters lacks visible inlet or outlet for its waters, which are so clear as to reveal several fishes, including pike: Bond (1988b); this was a species which papal purchasing agents were then bringing down from Burgundy.

¹⁴⁰ Evans (1931), 72–73; Ulrich III.18 (Migne (1882), vol. 149, 760–62).

numerous well-excavated and well-documented sites. Cistercians at Obazine on the hilly edge of the Massif Central included a 60-meter long fishpond beside the kitchen and refectory in their elaborate late-twelfth century water system. A few generations later their brethren at Vauclair in a damp valley of the northern Seine basin, installed a new guest house complex at the entrance to the monastic close: this included a rectangular masonry pond 25 by 15.5 meters, which received its water from the abbey drains.¹⁴¹ English Augustinians at Taunton put such a clay-lined structure with staked walls beside their priory about 1200; Benedictines at Battle abbey, set high on a ridge, put three rectangular ponds, each about fifty by twenty meters, down the hill some 250 meters away.¹⁴²

None of these covered a hectare. They required a special location but no elaborate management. They were quite different from fish farms, for storage tanks neither enlarged fish production nor made natural populations easier to catch; they only extended the usefulness of what people already knew how to obtain. For instance, Heilsbronn, which operated extensive wild and artificial fisheries elsewhere, had its warehouse manager ("Speicherverwalter"), not the pond master, see to the "fish container" ("Fischbehalter") at the abbey.¹⁴³ However, "a single stew stocked from a natural source . . . is . . . [the] type of pond to which most [English] documents generally refer before the fourteenth century."¹⁴⁴ The same held on the medieval continent. In historical context store ponds were an intermediary between technologies for the capture and consumption of wild fish and for the reproduction of domesticates.

Fish Culture Facilities

Medieval Europeans reared small captive fishes to consumable size and eventually worked out how to manage the reproduction and growth of certain freshwater species. Because these were the labori-

¹⁴¹ Barrière (1982), 188–192; Courtois (1982), 328–329.

¹⁴² Bond (1993), 71–72; Greene (1994), 11–12, 124–125. Gilchrist (1994), 77–82, suggests small fishponds were almost a diagnostic feature of English nunneries. German and Polish examples are in Kosch (1991), 110–112, 117–118; Grodecki (1949), 364–365; Grüger (1978), 129–131.

¹⁴³ Heidacher (1955), 118–119.

¹⁴⁴ Chambers, Gray (1988), 115.

ous activities and mundane skills of illiterate fishers and peasants, who left no records, we can only infer an evolution from catching and keeping fish to growing caught fish and eventually to selective rearing of domestic stock. In the process people selected fish species with habits amenable to knowing manipulation, largely through purposeful control of water and fish in artificial ponds built and managed with that intent. Medieval aquaculture depended on careful application of techniques for controlling water by means of channels, conduits, dams, and sluiceways.

Modern knowledge of medieval European fish culture stems from the advanced form practiced at the end of the Middle Ages in East Central Europe.¹⁴⁵ Unique contemporary instructions, both published and privately compiled in manuscript, set out the "state of the art" management and techniques used by Czech, Polish, and Austrian fish farmers.¹⁴⁶ What the didactic literature advanced as normal and best practice is corroborated by managerial records of actual enterprises at the time.¹⁴⁷ All these sources show the same procedures for an integrated production system.

At the end of the Middle Ages the best-reputed fish farmers in Europe reared mainly common carp, with a side-crop of pike and sometimes a few bream or crucian carp. These animals like warm, quiet waters and tolerate low levels of dissolved oxygen. Cold-water fishes such as trout and grayling were less common. Continual output required coordinated management through each stage in the production cycle of many ponds, each equipped to adjust the inflow, outflow, and level of water, without unintended entry or exit of fish.

The fish were bred from selected brood stock, though not by artificial means,¹⁴⁸ and moved as a uniform age group (year class, cohort) through a sequence of special-purpose ponds. As the water

¹⁴⁵ Overviews include: Andreska (1977); Andreska (1984); Andreska (1987), 32-51; Andreska (1997), 57-106; Knittler (1989), 146-181; Brzozowski, Tobiasz (1964), 11-37; Górzyński (1964), 41-50 and 59-60; Hurt (1960), vol. 1, 53-219; Nyrek (1966), 89-154; Szczygielski (1965); Szczygielski (1969). Compare Roberts (1968).

¹⁴⁶ Dubravius (1547) and Strumieński (1573), with commentary in Inglot, Nyrek (1960).

¹⁴⁷ Małecki (1962-1964), vol. 2, 225-226, *passim*; Rybarski (1931), 56-84; Šusta (1898), 1-29; Knittler (1989), 146-181; Topolski (1957), 179-197; Cnopf (1926).

¹⁴⁸ Unlike trout or salmon, for instance, cyprinids do not naturally pair up and make nests for their eggs, but groups of ripe females and males gather in vegetated shallows and emit eggs and milt simultaneously, with much splashing and mixing, after which the adults leave the shallow nursery habitat.

in a small, shallow, and vegetated spawning or fry pond warmed in spring the pond master introduced chosen ripe adult carp to emit and fertilize eggs in the natural way, then removed the parents. A summer in the protected and warm fry pond grew the carp larvae into tiny fish by the time they were moved en masse to deeper waters for the winter. The young carp went for another year or two to a growth pond where they would reach "stocker" size of a hand's span, before being set into a much larger, recently re-filled, and otherwise uninhabited fattening pond to get big enough to harvest.

Carp eat mainly small invertebrates they find on water plants or grub out of the bottom sediment. Nutrient-rich waters offer more food, so managers promoted growth by adding manure or channeling runoff from animal or human wastes into their ponds. They also knew to concentrate the carp biomass into harvestable adults by introducing piscivorous pike to eat any fry bred by precociously mature members of the class. Depending on local temperature and climatic conditions, the carp reached table size of 40–60cm and about a kilogram by the fourth, fifth, or sixth year. By 1550 Polish records suggest two distinctive quick-growing domestic races of carp existed, "mirror carp" with a few large scales and entirely scaleless "leather carp."

Harvest came either in weekly stages during Lent when demand reached a yearly peak, sometimes even where this meant breaking ice to get nets into the pond, or in a single push in the fall, when fish not wanted for Advent were put in live storage for the lenten season. In cool weather carp survive some days wrapped in damp cloths or straw for overland transport; portable tanks and boats with live wells were also sometimes available. Water in the fattening pond, which had been designed with large warm, shallow, biologically productive areas at the periphery and a much smaller deep central channel, was lowered to concentrate the fish. After all fish were removed, the flow of water was, if possible, entirely diverted and the pond site left to dry. Best practice called for the bottom to be plowed up, seeded with oats or barley, and that grain used to pasture livestock for a summer. This fallow season or year readied the fattening pond for another cohort of young carp.

Productive operation of a late medieval aquacultural enterprise thus called for integrated management of dozens of ponds covering a hundred or more hectares and a half-dozen year classes of carp, exclusive of breeding stock. In early 1500s these methods sustained,

for instance, annual shipments of some 1500 tonnes of live fish from the ponds of Upper Silesia to Kraków.¹⁴⁹ But the integrated system was unknown in East Central Europe before the mid-fourteenth century and remained rare until enterprises using it proliferated in southern Bohemia, Moravia, and Poland during the late fifteenth century. Earlier development of the mature system's characteristic multiple ponds, water control, and selected breeding and year classes took place further west. Introduction of the exotic carp then capped evolution of practices first worked out with pond fishes native to Atlantic drainages.

The essential technical features of medieval aquaculture arose in the region between Rhine and Loire during the eleventh, twelfth, and thirteenth centuries. No known discursive texts treat the development, but charters and account books first show hydraulic works and water levels being managed for fish production there.¹⁵⁰

Disputes over water rights and flooding reveal the construction and rhythmic operation of pond systems. Dams and excavations for multi-pond projects were undertaken about 1080 by St. Vincent of Mans and other lay and religious lordships in Maine and Poitou, such as the lords of Laval at Marennes.¹⁵¹ Monks at Ronceray complained in 1141 to Count Geoffrey IV of Anjou and canons of Bourges in 1160 to Count Étienne of Sancerre because the counts' new ponds had flooded their properties.¹⁵² Complex pond systems were begun by Cistercians at Chaalis in the Valois after 1160 and by Burgundian nobles and monasteries between 1184 and 1206.¹⁵³ Some charters hint how these facilities were run. A pond built by St.-Père of Chartres flooded land of a neighbour named Aucher: sometime between 1101 and 1129 they came to agree that when the pond was filled, water and fish belonged to the abbey, but when it was dry, land and crop were Aucher's. Because some ponds on a Norman watercourse belonged to a knight, Robert de Buat, and

¹⁴⁹ Nyrek (1966), 29–38, thinks the Polish capital thus received about 50–90% of Upper Silesian output.

¹⁵⁰ Generally see Benoit, Wabont (1991), 189–196, and Gislain (1984), 89. Writers on ponds and fish culture in medieval France commonly neglect their counterparts in late medieval and early modern east central Europe.

¹⁵¹ Delatouche (1969), 174–175, and works there cited; Sanfaçon (1967), 26 and 85–89; Beech (1964), 38 and 106.

¹⁵² Gislain (1984), 95, note; Devailly (1973), 298, and compare 295–296.

¹⁵³ Blary (1989), 31–40; Richard (1983), 181–197; Richard (1986), 99.

others to the monks of La Trappe, in 1215 they arranged to co-ordinate the draining and later refilling.¹⁵⁴ By 1263 ponds owned by the knight Pierre de Palluau at Ograis in Berry were being drained and dried every three years, while new constructions along the eastern edge of the Paris basin in Champagne came equipped with a full set of sluice-gates and drains.¹⁵⁵

Some of the same kind of landowners were also handling fish with forethought. William of Normandy and St.-Benoit-sur-Loire agreed in 1067 to share the fish taken at regular intervals from one of the ponds at St.-Jacques de Beuvron.¹⁵⁶ A financial account kept for the Count of Champagne in 1217 indicates systematic stocking of his ponds, and the 1235 ordinance on fiefs of King Louis IX assumed that fishponds had a five-year production cycle.¹⁵⁷ Those fish were probably bream, the variety then most consumed by Cluniac monks at La Charité-sur-Loire.¹⁵⁸ In England, after 1066, the new elite built and managed pond systems like those on the Continent. The king's own fishponds commonly supplied "fat mother bream" ("bremas matrices et grassas") and pike for stocking his other ponds and those of his favourites.¹⁵⁹ A late thirteenth-century guide to estate management, *Fleta* (2:73), advised putting bream and perch in ponds.¹⁶⁰

Hence fish farming had developed in the region between Rhine and Loire before Balkan native carp reached those watersheds. This exotic fish likely arrived around 1200 and was spreading through central France during the mid-late thirteenth century.¹⁶¹ Indeed in 1289 ponds of the count of Namur held carp chosen as breeding stock.¹⁶² By 1300 carp were already recognized as the typical pond fish and all central elements of the aquaculture system were present in the west.

Integrated aquaculture (multiple ponds used in rotation to rear chiefly carp) subsequently spread from northern France into other

¹⁵⁴ Grand, Delatouche (1950), 541.

¹⁵⁵ Devailly (1973), 556–557; Maas (1944), 74–75.

¹⁵⁶ Gislain (1984), p. 95 n. 6.

¹⁵⁷ Bourquelot (1863), 66–68; de Laurière et al. (1723), vol. 1, 55–56.

¹⁵⁸ Audoin (1986), 147.

¹⁵⁹ Steane (1988), 39–68 and notably 45; McDonnell (1981), 9–12; Roberts (1986), 125–138.

¹⁶⁰ *Fleta* (1955), 247. Despite Grand, Delatouche (1950), 544, *Fleta* mentions no carp, which would not reach Britain for another century.

¹⁶¹ Hoffmann (1994a) assembles the evidence.

¹⁶² Brouwers (1911), vol. 2.2, 433–434; compare Balon (1941).

parts of transalpine Europe.¹⁶³ In the Franche-Comté all the familiar features were imported from ducal Burgundy and occur in production accounts dating 1338–1383.¹⁶⁴ Burgundian techniques also traveled down the Saône (or up the Loire) into Forez and Dombes. A wave of pond building came in the late 1200s. Another followed the 1350s, when large-scale market-oriented carp production helped sustain regional prosperity.¹⁶⁵ Movement northward from French- to Flemish-speaking Low Countries, in contrast, is more visible in the fourteenth-century appearance of carp among customs schedules and food remains.¹⁶⁶

Some well-studied sites mark the passage of fish farming eastward into central Europe. Heilsbronn, a Cistercian monastery not far from Nürnberg in the Main-Rhine drainage, stands surrogate for an aquaculture belt in Upper Franconia and the Upper Palatinate. During the 1260s this century-old house began acquiring first natural, then artificial ponds. By the 1340s the monks were buying and rearing stocker carp for a multipond enterprise which extended to more than 30km from the convent and still served mainly domestic needs. In the late fifteenth and sixteenth centuries, however, and eventually as a state managed foundation, Heilsbronn's large output supplied urban consumers, especially in prosperous Nürnberg.¹⁶⁷

Pond construction for aquaculture in the Czech lands first surged under the auspices of Emperor Charles IV (1347–78), well-connected in France. Charles is even reputed to have urged pond building on grounds the country needed abundance of fish and humidity ("so that our kingdom may abound in fish and vapors"). Dwarfing all known earlier hydraulic works there, 87 new projects can be documented before the Hussite revolt in 1418.¹⁶⁸ Though late fourteenth-century Czech pond masters favoured hill country, which made for

¹⁶³ Carp culture came to Italy and Spain, where it never achieved great importance, only in the fifteenth and sixteenth centuries.

¹⁶⁴ Gresser, Hintzy (1978).

¹⁶⁵ Perceveaux (1962); Perceveaux (1967); Egloff (1937), 84–94; Durand (1889); Fréminville (1893); Fournial (1967), 687–690. See also chapter 5 above.

¹⁶⁶ Mieris, (1753–56), vol. 2, 656; Brinkhuizen (1979); Brinkhuizen (1983a); Eryvynck, Van Neer (1994), 304; Seeman (1989).

¹⁶⁷ Findings of Heidacher (1955), 118–119, are to be modified from charters in Schuhmann, Hirschmann (1957), and with managerial records from 1338–74 in Staatsarchiv Nürnberg, Klosterverwalteramt Heilsbronn, Rechnungen, Bd. 1. Cnopf (1926), 26–82, treats a later period.

¹⁶⁸ Graus (1953–1957), vol. 2, 32–35, 345–346, 483–486; Šusta (1898), 2.

cheaper short dams but less productive deep ponds, some of them built the oldest big ponds (100 ha and more) which still survive; they also installed elaborate sluices and valves, populated ponds with age-class stockers, and selected fish for breeding. Output fed towns in Bohemia, Germany, and Austria.¹⁶⁹ Calmer politics after 1450 restored opportunity for large engineering works in both southern Bohemia and the flat lands of the upper Labe (Elbe) basin of the east. The Pernštejns, for instance, improved their Hluboka estate with the 400-hectare Bezdrev pond.¹⁷⁰ (figure 8.12)

Fish culture facilities were being built in central Silesia, then a dependency of the Czech crown, even during the unsettled 1430s and 40s, and by the 1450s others were operating in the principalities of Oświęcim-Zator, at the low divide between the upper Oder and Vistula basins where Bohemian and Polish influence intersected. Carp from here supplied Kraków in the early sixteenth century. That territory also probably transmitted aquaculture techniques further northeast in Poland to zones between Kraków and Sandomierz and around Kalisz and Sieradz, where production grew after 1550.¹⁷¹

While focusing on aquaculture's "hard" structures of modified and wholly artificial waters, we should remember that many single standing waters ("piscinae") of medieval origin may have had nothing to do with fish. Thirteenth-century encyclopedist Bartholomaeus Anglicus caught a basic truth (in the words of his fourteenth-century translator John of Trevisa): "A ponde hat piscina and is water ygadrede to fedynge of fysshe, thogh ofte gaderynge of water withoute fisse be yclepid 'piscina' contrarye menyng, as Isider seith."¹⁷² A medieval "piscina" is no more a sign of fish than is a modern French "piscine."

Even with fish, simple ponds are not evidence of aquaculture and its special manipulation of animals and water. Most such water bodies were at best transitional or marginal to fish farming. In medieval Yorkshire the earliest artificial fisheries were a secondary use of moats and millponds.¹⁷³ Such arrangements were just as common elsewhere,

¹⁶⁹ General accounts by Andreska (1977, 1984, 1987, 1997) and Kalny (1978) are balanced with particulars in Charvátova (1987), 133; Neumann (1926), 130–133; Šusta (1909), 34; and Hemmerle (1967), 139 and 154.

¹⁷⁰ The chronology in Lower Austria paralleled Bohemia's: Knittler (1989), 152–158.

¹⁷¹ Hoffmann (1989), 365–367; Szczygielski (1965), 21–23; Brzozowski and Tobiasz (1964), 12–15.

¹⁷² John of Trevisa (1975), vol. 1, 661–662.

¹⁷³ McDonnell (1981), 14–16. Compare the moat fishery at Salem abbey in Staiger (1863), 95.

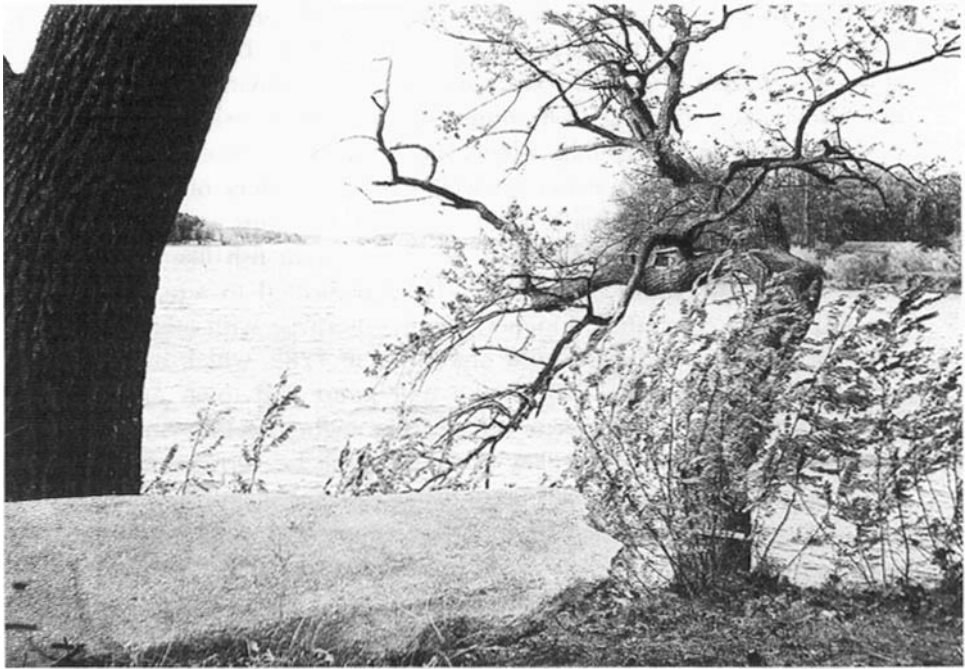


Figure 8.12. Bezdrev pond near Hluboka nad Vltavou still covers 393.5 hectares behind the dam built about 1490 for Czech baron Vilem z Pernštejn. Photo by R. Hoffmann, 1998.

but almost always a compromise: neither the barrier of permanent deep water, nor the energy of running water was wholly compatible with keeping a basin full (to rear) and occasionally draining it (to harvest). Ponds without proper sluices and drains had to be “broken” to take the fish. In a 1282 contract between a miller and Rauden abbey (Silesia), when the monks would “break the pond” each five years to fish it, the miller bore the expense of repairs; were the interval shorter, abbey and miller shared the cost.¹⁷⁴ A local consortium at Cryfield, Warwickshire could “break the millpond to fish” in 1384, but their expected catch of roach, perch, bream, tench, and pike suggests a natural population.¹⁷⁵

Another transitional use of natural or even “improved” waters

¹⁷⁴ Wattenbach (1859), nos. 18, 29. Kempf (1975), 104, has the breaking and repair of a mill dam in Franche Comté from 1306.

¹⁷⁵ Hilton (1960), 220–221.

involved transfer of small fish taken in the wild and kept in hope of growth and recapture. Baby eel, for instance, had long been stocked in Italian lakes and coastal ponds.¹⁷⁶ The activity shaped Pier de' Crescenzi's thinking "On ponds and confined fishes."¹⁷⁷ This practice could imperceptibly arise, even by accident, from live storage. From a legal perspective as well, artificial waters of any kind were private, not commons or public domain, and thus an important step toward the private ownership needed to treat fish like a crop.

At best, single water bodies not wholly dedicated to aquaculture could handle a compatible function for an enterprise with other facilities. On the estate of the Count of Namur in 1289, which included at least twelve managed ponds, the mill pond and town moat at Flavion together held one year class.¹⁷⁸ The eighty-hectare St. Seine pond in a marshy tributary valley of the Saône at La-Perrière received small fish from the Duke of Burgundy's castle moat and also ran a mill. Ducal officials drained the pond and took tens of thousands of carp in 1339, 1345, and 1350. Mature fish fed the ducal household or were sold; fry went, from time to time, to six other ducal ponds. When a single dry year followed, the miller had to find other work; two dry years to repair the dam in 1351–52 gave him a one-year indemnity.¹⁷⁹ A little-known Czech abbey, Svante Pole, used the moat or ditch at its Očelice grange for its breeding stock of carp.¹⁸⁰

Ponds built for fish culture had distinctive generic features. The simple store or growth ponds known to de' Crescenzi needed no more than a reliable water supply and capacity to hold water.¹⁸¹ Pond builders in the Dombes favoured swampy spots called "leschieres," which marked a subsoil of impermeable clay. Dubravius devoted his entire second book to siting and construction. A steady water supply was best assured by a lake or stream, which could be used to flood nearby depressions or flat ground while avoiding dependence on overland drainage. Dubravius expected to rear and fatten fish, so argued that ground now holding fertile fields was the best. In the event, major pond regions across medieval Europe commonly had

¹⁷⁶ Bresc (1986), 261; Scialoja (1910), 814 note.

¹⁷⁷ de' Crescenzi (1995–2000), 9.31; vol. 3, 125–127: "De piscinis et piscibus includendis."

¹⁷⁸ Brouwers (1910/26), 433–434.

¹⁷⁹ Hoffmann (1995).

¹⁸⁰ Neumann (1926), 130–133.

¹⁸¹ de' Crescenzi (1995–2000), 9.31; vol. 3, 125–126.

impermeable soils, and as early as the fourteenth century pond builders in Sologne, for instance, knew to avoid spring water which was too cold for carp.¹⁸²

Provincial codes in central France contained a "right to flood" which let a pond owner flood neighbouring lands first and compensate for damages after. Lords in early modern east-central Europe could suppress peasant resistance to losses of meadows or arable, but even there and more so elsewhere pond construction often agitated local communities. Once the legalities had been settled, at the chosen site builders like Dubravius used a "dioptera," a form of primitive theodolite or sighting device, to set the desired height of the water and survey the outer bounds of the proposed pond. Archaeological field surveys of whole English counties for traces of medieval ponds—surely not all meant to rear fish—argue that forms and bottom profiles vary with local topography.¹⁸³ Czech researchers note a shift from fourteenth-century ponds in hill country with short dams and deep basins to later emphasis on former lowlands or wetlands where longer dams produced large shallow basins and only a confined deeper zone where carp could find refuge from winter cold and fishers, by lowering the water level, concentrate the carp for easy harvest.

Few if any important medieval fishponds were dug out. Instead, earthen dams blocked the flow or spread of water to flood an area upstream. Dubravius called for the crest of the dam to rise a half or one meter ("1–2 cubits") above the desired height of water with a width at the top equal to its height from the original ground. The foundation, he advised, would be three times the height.¹⁸⁴ Everywhere from thirteenth-century Burgundy to sixteenth-century Poland actual construction was handled by specialist work teams, afforded with local wage or servile labour. The best work began, the Moravian prelate stressed, with a trench set into the natural soil perpendicular to the flow of the old channel, then filled and rammed, layer by layer with impervious clay and loam. A revetment protected the upstream side of the dam. In well-wooded country like Bohemia vertical posts driven along the face supported either lattice work or a

¹⁸² Guérin 1960, 133.

¹⁸³ Steane (1970); Aston, Rowley (1974), 152; Royal Commission (1979); Cantor (1982), 78, and works there cited; Steane (1985), 171–172; Aston (1988) *passim*.

¹⁸⁴ Dubravius (1953), bk. 2.3–6.

back-fill packed with logs and brush. Account books and other records from France to Styria and Poland list the earth, poles, and bundled brush used for this purpose. Repair of the Molchesaux pond at Apremont, Franche-Comté, in 1358 used 17,000 faggots.¹⁸⁵ It is hard to tell whether English sites reporting heavy timbers inside medieval dams are such surface protection or internal framing. Some English dams also anticipated Dubravius's advice that, where reasonably available, stone facing lasted longer.¹⁸⁶

Adjustable sluices and by-pass channels are essential to regulate the water level in a pond without losing or accidentally introducing fish. Dubravius called for a reinforced spillway at the top or side of the dam. He recommended oak or fir for sluicegates and drains but said nothing about their design.¹⁸⁷ Two centuries earlier the Duke of Burgundy's bookkeepers paid for a new wooden gate or "stopper," outlet trough, and grillwork at the St. Seine pond and for clearing an earthen bypass channel, all expenditures with which their counterparts among English royal clerks were familiar a hundred years before.¹⁸⁸ In 1320, however, builders of the Messilleux pond for the count of Forez installed a masonry sluice, and at some time stone replaced a wood drain in Thelsford priory pond.¹⁸⁹

Wooden parts of hydraulic systems are difficult to verify archaeologically. So, in fact, are the precise medieval conditions of specialized fishponds, for those used into modern times were often modified, then drained and destroyed. Medieval fishponds rank low among archaeological priorities. Hence hardly any systematic excavations of medieval fishponds have been undertaken by workers aware of the historical record and comparative issues.

Two good studies of thirteenth-century sites offer some bench marks. Oldstead grange pond, now dry, was built by Cistercians of Byland abbey, Yorkshire, about 1240 and probably used into the fourteenth century. Their earthen dam extended about 400 meters across a nearly dry and probably wooded valley barely two kilometers from

¹⁸⁵ Hoffmann (1995); Mercier (1993), 77–80; Gresser, Hintzy (1978), 136; Purkarthofer (1965), 97–99.

¹⁸⁶ Aston, Rowley (1974), 152; Hurst (1979); McDonnell (1981), 34 and works there cited; Steane (1988), 40–41.

¹⁸⁷ Dubravius (1953), bk. 2.7–8.

¹⁸⁸ Hoffmann (1995); Steane (1988), 41. Rybarski (1931), 63–64, found the same in Polish royal accounts.

¹⁸⁹ Fournial (1967), 691; Chambers, Gray (1988), 127 and 132.

the abbey close. The 75 meter-thick base now crests at eight meters, lower than Dubravius later expected, and once flooded about twenty hectares to make the largest of Byland's ponds. There is no sign of a full sluice, just a spillway at the side.¹⁹⁰ Three dams were examined in rescue excavations in the communes of Vallenay, Farges-Allichamps, Nozières, and Orcenais, about 30 kilometers south of Bourges in Berry, a region of many ponds. These sites are probably associated with the Cistercian abbey of Noirlac on the other side of the river Cher. Their earthen berms measure 100–150 meters, 10–20 meters wide at the base, and are now between two and three meters high. Each was trenched into the natural substrate and then built up of layers of compacted sand and clay. Dry-laid stone protected the upstream face and a cut or mortared stone vault formed the sluice with notch for a wooden valve or gate.¹⁹¹ (figure 8.13)

Oldstead pond and the ponds of Noirlac had the features needed for use in medieval fish culture, but single ponds were not enough for continual production. Multipond systems and special-purpose ponds were essential. Waldsassen in the Hartz had waters designed for spawning, for yearlings, and to grow fish three years to market size. The fifteenth-century priory of Loups, at St.-Michel-en-Brenne, used separate fry and growth ponds. At least by the sixteenth century Polish peasants found a niche in the landowner-dominated aquaculture sector by raising fry in small ponds for sale.¹⁹²

In many instances several ponds were designed and built simultaneously along a watercourse. A staircase of ponds coming down a valley is well-known from Maulbronn in the Black Forest, Henryków in Silesia, and Maubuisson in the Val-de-Oise. At the latter four ponds, three equipped with bypass channels, filled the valley above the convent with perhaps thirty hectares of water.¹⁹³ Lowland sites better allowed a web or patchwork of water, separated by embankments and linked with controllable sluices. At Bordesley in Worcestershire the main stream of the river Arrow was pushed to one side and the entire valley filled with two parallel rows of ponds.¹⁹⁴ Increased

¹⁹⁰ McDonnell (1981), 24–27.

¹⁹¹ Barbé (1990).

¹⁹² Muggenthaler (1924), 129–131; Coulon (1983), 15; Guérin (1960), 131–135; Brzozowski, Tobiasz (1964), 18.

¹⁹³ Benoit, Wabont (1991), 212–216 and fig. 25. See similar structural complexes in Seidenspinner (1989); Grewe (1991), 45–48; and Grüger (1978), 129–131.

¹⁹⁴ Bond (1988), 101; Aston, Munton (1976).

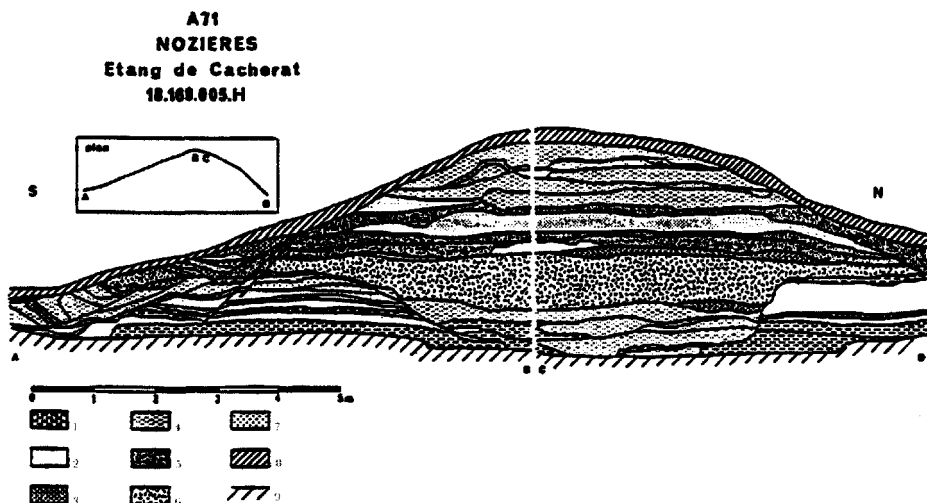


Figure 8.13. Stratigraphy of the dam at the “Étang de Cacherrat” near Nozières, Dep. Cher, probably constructed during the late thirteenth century for Cistercians at Noirlac. Key: 1-compacted clay; 2-sand; 3-sandy clay; 4-sand with clay; 5-clay and sand in heterogeneous mix; 6-clay and sand in homogeneous mix; 7-gravel with fossils; 8-humus overburden; 9-limit of excavation. Drawing from Barbé (1990), 45.

opportunities for large water surfaces made this form more common among large late medieval production ponds.

More important for fish culture than unitary engineering was managerial coordination. Large estates had pond masters in charge of waters over a considerable area. In 1320 the master fisher for the count of Bar was buying fry from one pond to put in another.¹⁹⁵ Heilsbronn, with more than ninety ponds in the early 1500s, based its general manager at the abbey and chief subordinates at three other centres fifteen to twenty-five kilometers away.¹⁹⁶

The area of ponds near an abbey or residence does not allow calculation of an upper limit for the output for a whole fish culture enterprise. The scale and operations in different economic and institutional settings is revealed by using accounts and inventories of all components of three well-documented enterprises. In 1136 the French

¹⁹⁵ Collin (1971), 64–65.

¹⁹⁶ Cnopf (1926), 30.

king Louis VI replaced Benedictines with Cistercians at Châalis on the Launette river in Valois, forty kilometers north of Paris. A fourteenth-century visitor saw a close web of man-made watercourses on the damp bottomland site and eighteenth-century maps and views confirm that aspect of the then-moribund abbey. A thorough field and documentary survey identified ten one-time ponds, some pre-dating 1161.¹⁹⁷ Three, not necessarily the largest, now total more than twenty hectares. In 1146 Châalis acquired land for a grange at Charlepont, 6.4 kilometers to the southwest on the river Thève, now site of the Étang de l'Épin. The first pond in that place was also built by 1161, and later an earthen dam with wooden piles and stone facing flooded more than 8 hectares of former marsh. Further west on the Thève, 13.2 kilometers from the abbey, the monks had by century's end assembled land for another grange, Commelles. When they began an on-stream pond in 1204/08 the Count of Beaumont complained of harm to water for his own older ponds downstream. Between 1250 and 1255 the Cistercians enlarged Commelles pond and, in the fourteenth century, when most granges were being leased out, divided it in two with a dam and fish-control structure which still worked in 1533. Managerial records or accounts are missing, but while at its peak the Châalis fish farm used more than forty hectares of large ponds at three different locations to help feed the monastic community.¹⁹⁸ The fishery deteriorated and was abandoned in the seventeenth century.

A second example of the productivity of medieval fisheries is English. Annual pipe roll accounts supplant charters in a reconstruction of aquaculture on the medieval estate of the Bishop of Winchester.¹⁹⁹ Something more than a dozen ponds were built near the bishop's residential manors, mainly in Hampshire, between about 1150 and 1208. Probably Bishop Henry de Blois (1129–71), king Stephen's brother, initiated this activity; his immediate successors continued the investment and later ones enjoyed its fruits into at least the early fifteenth century. Besides small "servatoria," individual ponds ranged

¹⁹⁷ Blary (1989), 31–40, 46–71, 87–94.

¹⁹⁸ Châalis also used a wild fishery at a watermill lower down the Launette, but its other granges lacked fisheries resources. The 25 by 40 meter pond in the middle of the yard at Vaulerent grange could only provide water for livestock and the household and, perhaps, a place to store fish: Blary (1989), 105–123.

¹⁹⁹ Roberts (1986).

to almost forty hectares and totalled around 150 hectares of ponded surface. The larger ponds were placed near the top of local watersheds where they could be fed by small streams and had room for bypass channels and, perhaps, adjustable sluices. Under supervision of the bishop's master fisher (a Master Nicholas, for instance, served from 1244 to 1262) the mature stock of bream and other pond fishes (no carp) were harvested with the seine and stored for fresh consumption by the bishop and his associates during Advent and Lent. Every five years workmen "broke" and drained each pond for a dry year. Passed into other hands and no longer managed collectively, eight ponds survived into the twentieth century.

Třeboň (German Wittingau), was a great carp-rearing estate of the Rožmberks, barons of legendary wealth and power in southern Bohemia until they died out in the 1600s.²⁰⁰ Clay, loam, and sandy soils along the upper Lužnica, an Elbe tributary, underlay naturally swampy terrain near the Austrian border, where the family had gained lordships by about 1300. A survey of the estate conducted about 1380 expected 15 percent of incomes (96 percent of those from the small town of Třeboň) to come from the fishery, which already included the Bošilecký pond of 190 hectares and the Zábłotský pond of 305. Large ponds for rearing carp on a five-six year cycle had been spreading in Bohemia for a generation. The Rožmberk's lesser neighbour, the lord at Lomnice ten kilometers away, built the Dvořistě pond (337 ha) in 1367; his successors sold out to the Rožmberk in 1437. In 1450 the three large ponds of the Třeboň estate covered more than 700 hectares and were supported by 17 smaller ones.

Successive generations completed the transition to full segregation by year class and raised levels of annual production, both by more sophisticated management and by an aggressive policy of expansion begun in 1491 and lasting into the mid-sixteenth century. Professional pond masters led the enterprise. Želízko, active in the 1470s and famous enough to go advise Bavarian princes on their fisheries, was followed by Kunát Dobřenský the younger of Dobřenic, Štěpánek Netolický (1516–30, d. 1538), and a continuing line. In 1524, when

²⁰⁰ Andreska (1984); Andreska (1987); Andreska (1997), 89–90; Henningsen (1989); Kalny (1978); Šusta (1898), 1–15. After repeated description by scholars of fish culture, Třeboň deserves close study from historians of technology, environment, and the economy.

contract pond masters could not earn a thousand "grošy" a year, Netolický drew a salary of 2400; in retirement he consulted for the Archbishop of Salzburg and the Count of Salm. Třeboň's managers kept precise account of stocking small fish from their own production or subcontractors and eventual sale of adults, but not those consumed internally. This estate was run for market production and shipment of prime carp to Prague, other Czech and Moravian towns, and south into the Austrian lands.

Using dams and sluices like those later described by Dubravius, Rožmberk's managers built three large new ponds in the 1490s, culminating that campaign with Velký Tisý (317 ha) in 1503–5, the first on which Netolický had an active role. When he took over as pond master in 1516, the Třeboň estate contained 37 small fry and yearling ponds (each to 40 ha) and 14 large ones. Work had already begun on the key to further expansion, a 47-kilometer diversion of the Lužnica called the Zlata Stoka ("Golden Ditch"), which when completed in 1518 fed the six more big (150–415 ha) ponds prepared in the interim. (figure 8.14) Netolický's plans for continued system growth carried on into mid-century. A region of some 400 square kilometers around Třeboň is mostly under water in ponds made to grow carp at the end of the Middle Ages and still growing carp today.

Aquaculture provided fresh fish to medieval elites, whether directly or through the market. Especially with their construction on a large scale, artificial fishponds always threatened widespread change to local environments and social relations. Pond building spread a special kind of aquatic habitat, warm and still water, across a subcontinent where it had been rare. Organisms needing cold and running water lost living space to those with other preferences, carp in particular but also malaria-bearing mosquitos. Where fish farming became popular regional impacts were large. The order of magnitude is impressive: 25,000 ponds in Bohemia and 22,000 in upper Franconia, 25,000 hectares of ponded surface in upper Silesia and 40,000 hectares in central France.²⁰¹ With ample evidence for modern drainage of medieval ponds in areas as far apart as France and Poland, few would dispute Robert Delatouche's estimate that the historic province of Maine, for instance, contained at the end of the Middle Ages

²⁰¹ Andreska (1984); Nyrek (1966), 42–43; Bautier (1971), 198–199; Cnopf (1926), 22.



Figure 8.14. Kanov pond was built in 1515 under the supervision of the manager Netolický. When filled it covers 152 hectares. Today, traditional management still lowers water levels for carp harvests. Photo by E. Hoffmann, 1998.

twenty-five times as many ponds as it did five hundred years later.²⁰² In those regions and in others where fish farms were fewer or short-lived, characteristic conflicts over water supplies and flooding pitted pond owners against their neighbours, while struggles over labour services and poaching set peasants against their lords. Likely no other medieval fisheries technology had such deep direct consequences. (figure 8.15)

Few are now aware of the impact of medieval aquaculture because it barely lasted into modern times. English pond systems went largely derelict by the end of the Middle Ages, their product supplanted by enlarged and accessible marine fisheries. Elaborate Czech and Polish enterprises dissolved during crises of the seventeenth century. French ponds were drained in the Enlightenment and nineteenth century. Except in a few regions, European elites and others decided that “muddy” carp and other pond fish no longer fit their refined taste.

²⁰² Delatouche (1969), 173–175; Szczygielski (1965), 19.

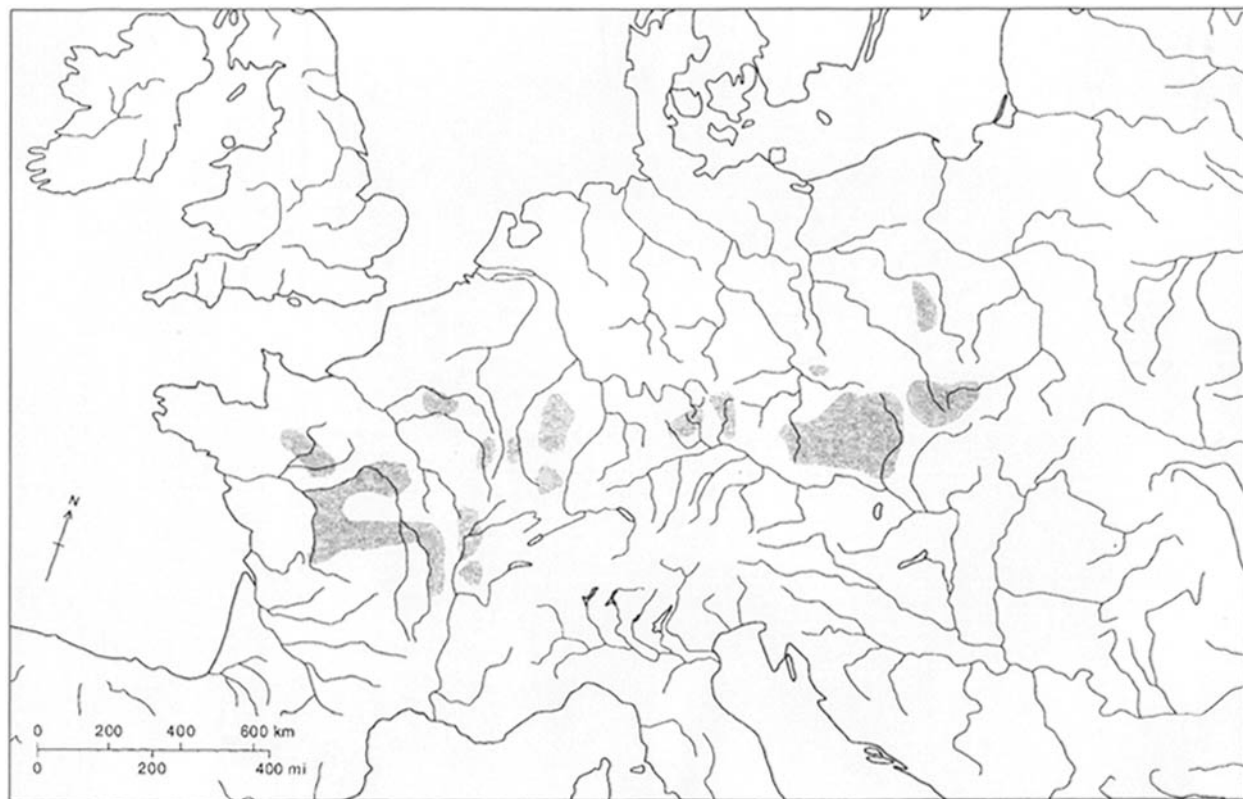


Figure 8.15. Major regions of artificial fish culture in late medieval and sixteenth-century Europe. Map by Cartographic Drafting Office, Department of Geography, York University.

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ISSN 1385-920X