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The Diffusion of Useful and Reliable Knowledge over the centuries of the Great Divergence: Comparative Case Study of Urban Water Supply in Early Modern England and Tokugawa Japan

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RESÜMEE

Dieser Aufsatz untersucht Ähnlichkeiten und Unterschiede in der Herausbildung und Diffusion von Wissen zwischen Japan und Europa vom späten 16. Jh. bis zur Mitte des 19. Jahrhunderts anhand einer Fallstudie zur städtischen Wasserversorgung, welche sich mit Hilfe von Kenntnissen aus benachbarten Felder wie Bewässerungstechnik, Flussregulierung, Bergbau und Schifffahrt entwickelte. Die Analyse fokussiert auf dicht besiedelte Städte in wirtschaftlich fortgeschrittenen Regionen und vergleicht Edo (das heutige Tokio) mit London. Zunächst schildern wir die Wasserversorgungsprobleme, die im 17. Jh. beide Städte charakterisierten, und welche Lösungen erarbeitet wurden. Der zweite Teil des Aufsatzes ist den Ähnlichkeiten und Unterschieden in der Entwicklung von theoretischem und praktischem Wissen und Kompetenzen in den untersuchten Regionen gewidmet. Der dritte Teil beschreibt die unterschiedlichen Pfade, auf denen sich theoretisches hydrologisches Wissen in Japan und Europa entwickelte. Wir schließen mit der Beobachtung, dass, obwohl beide Regionen Fortschritte in der städtischen Wasserversorgung verzeichneten, Europa effizientere und effektivere Institutionen für die Kreation und systematische Diffusion von ‚nützlichem Wissen' schuf.

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1. Introduction

This essay examines the similarities and contrasts in the accumulation and diffusion of knowledge on urban water control in Japan and Europe between c. 1590 and 1850. Knowledge of urban water supply developed by borrowing and applying the skills and knowledge accumulated in related fields, such as irrigation, river control, mining and navigation. This analysis focuses on densely populated cities in economically advanced regions, comparing Edo (today's Tokyo), in Japan, and London. Although the knowledge and skills involved in the management of urban water systems in the two localities were in many respects comparable during the seventeenth and eighteenth centuries, the developments in the following century diverged markedly. This article examines the accumulation and diffusion of artisanal 'how-to' type knowledge and its amalgamation with natural philosophers' 'what is' type knowledge. This approach is most often associated with Joel Mokyr's thesis on how eighteenth-century British social and cultural institutions promoted innovations by marrying propositional and prescriptive knowledge.[2] Karel Davids used the same approach in a comparative case study of river hydrology considering China and Japan. He demonstrated that the more diversified knowledge production systems in Europe (particularly northern Italy and the Netherlands) were more favourable and receptive to new cognitive paradigms concerned with 'theories and regularities' in hydrology than were the more centralized and unified institutions of the Chinese empire.[3] By comparing European urban water control with Tokugawa Japan (1603–1867), the present paper also aims to provide a balanced foundation from which to evaluate the similarities and contrasts in the development of useful and reliable knowledge in Europe and East Asia.

The opening section of this article outlines the problems of urban water supply with which Edo and London had to cope and how people in these cities attempted to solve these problems. The next section analyses the similarities and differences in the development of 'how-to' skills and knowledge in the regions under discussion, while the third section highlights the divergence in the development of propositional knowledge of hydrology between Japan and Europe. We conclude that, although both regions developed prescriptive knowledge, during the centuries under discussion, Europe was establishing more efficient and effective institutions for the creation and systematic diffusion of useful knowledge.

2. Growing Demand

In the seventeenth century, both Japan and many regions in Europe were experiencing rapid urban population growth. Urbanisation began in Japan in the late-sixteenth

2 J. Mokyr, The Gifts of Athena: Historical Origins of the Knowledge Economy, Princeton 2002.

3 K. Davids, River Control and the Evolution of Knowledge: A Comparison between Regions in China and Europe, c. 1400–1850, in: Journal of Global History, 1 (2006) 1, pp. 59-79.

century when many castle towns were built by local warlords (daimyō) and market towns emerged as hubs of commerce and trade. As the locus of the Tokugawa shogunate (1603–1867), Edo rose from its humble origin as a small bay town, to become the country's political and bureaucratic capital, with a peak population of slightly fewer than one million by the early-eighteenth century. England is one of the north-western European countries that experienced rapid urbanization during the same period as Japan. Her largest city, London, saw its population rise from 250,000 in 1600 to 740,000 in 1760, reaching one million in 1801. In Edo as well as London, this rapid growth in urban households soon began to pose constraints on the existing small-scale systems of sourcing drinking water from wells and fountains. Edo's earlier piped waterworks, for instance, supplied fresh water only to the Tokugawa castle and high ranking samurai elite residences, leaving the mass of commoner residences dependent on insufficient water supply from fountains. London sourced its water mainly from the Thames and from relatively small springs in the vicinity of the city, through a system of conduits[4]. London and Edo were facing comparable challenges during the late-sixteenth and early-seventeenth centuries and both embarked on large engineering projects. Canals were constructed that exploited natural watercourses to bring water from springs and rivers into the cities and distribute it through pipes to households. London's New River project was completed in 1613 while Edo's Kanda River water system was initiated in the 1590s and the larger Tama River system in 1653.

3. The provision of water in cities

The expansion of Edo and its infrastructural improvement properly began after the first military general (shōgun) Tokugawa Ieyasu (1543–1616) declared Edo the political and administrative capital in 1603. By 1609 it consisted of the Shogun's Castle, daimyō residences, and the quarters of merchants and craftsmen. The Tokugawa Castle was located on a hillside surrounded by daimyō residences (some of which were later relocated to newly created man-made islands), whereas the quarters for commoners occupied the south and east of the city. Like many other early modern castle towns across Japan, Edo was built on rivers and along a bay in order to take advantage of waterborne transport arteries. In 1603 the Tokugawa government landfilled the river mouth area to extend the eastern part of the city. This posed serious problems for supplies of drinking water in large areas of the city except for the Castle and some daimyō residences.[5] The problems became particularly acute in the eastern parts of the city where the wells were contami-

4 D. Lewis, For the poor to drink and the rich to dress their meat: the first London water conduit, in: Transactions of the London and Middlesex Archaeological Society, 55 (2004), pp. 39-68 and H. W. Dickinson, Water Supply of Greater London, London 1954.

5 These were supplied by the small scale Kanda Waterworks which was built in the 1590s. J. Hatano, 'Edo's water supply,' in: J. L. McClain / J. M. Merriman / K. Ugawa (eds), Edo and Paris: urban life and state in the early modern era, Connecticut 1997, pp. 234-247, here p. 235.

nated with salty water. At the beginning of the seventeenth century Edo lacked a stable supply of drinking water except in the western parts of the city where a number of fountains and wells produced 'sweet' water which was traded commercially.[6]

The Kanda Waterworks was built in the 1590s to provide water to the Castle and some daimyō residences before flowing into the commoners' quarter, north of River Kyobashi. However, it did not supply the south and west of the city; to deal with these areas, the Tamagawa Waterworks was completed in 1653. This waterworks had three main pipelines which provided water to a much wider area of the city: the Castle, the daimyō residences and the commoners' quarter to the south and west of the River Kyobashi. By the middle of the seventeenth century the supply of water to commoners had become a more important concern. After the construction of the Tamagawa Waterworks, four additional but smaller waterworks were constructed, providing water to the newly developed residential areas. However, all of these smaller waterworks were demolished in the early-eighteenth century.[7]

The main technological problems faced by those constructing Edo's waterworks concerned the calculation of gradients.[8] Edo included many hills and valleys, and its water system was designed to exploit natural flows of water down slopes from the highest point in the west to the lowest point at the outlet to the Bay, an altitude of about two–three metres. The beginning of the Kanda Waterworks in Ochanomizu was at an altitude of about five–six metres, while that of the Tamagawa Waterworks was at about 34m, at Yotsuya Gate, so the latter could supply water across the city.[9] Originally, the water flowed along simple ditches, but from the middle of the seventeenth century, these were replaced first by wooden and then by stone pipes. Generally, hill top residences could use the water supplied from the fountains as well as the pipes, while residents in low lands and newly filled lands depended solely on the supplies from pipes because of the problem of saltwater mixing with purer underground water. Advancements in techniques for digging wells occurred in the mid-eighteenth century, and this enabled the construction of deeper wells, particularly in the commoners' quarter, and as a result these parts of Edo became less reliant on pipes.

During the late-sixteenth century the need for a more efficient water supply system was increasingly felt in London, where for centuries water had been taken manually from the Thames, as well as conveyed from springs and streams in the vicinity of the city through a system of conduits. A project to build a 'New River' to channel water from springs in surrounding counties into the city of London was proposed in 1602 by Edmund Colthurst, a gentleman from Bath. In 1609, leadership of the project was taken on by

6 K. Ito, Edo Josui no Rekishi, Tokyo 1996, chapter 1.

7 About the abolition of the four waterworks, see for example, Ibid, pp.101-131.

8 'Josui-ki', the manuscript about the technical and management aspects of the Tamagawa waterworks, was written in 1790, a century and a half after the construction had been completed. For the study of Josui-ki, see for example K. Kanki, Tamagawa Josui no Edo shichu ni okeru Kouzou to Kinou ni kansuru Kisoteki Kenkyu, in: Doboku-shi Kenkyu, 13 (1993), pp. 177-191:

9 Ibid, p. 177.

Hugh Middleton, an entrepreneur of Welsh origins, based in London.[10] The New River was finally completed under Middleton in 1613.[11] The system derived its water from the 'springs of Chadwell and Amwell' and from the River Lea. [12] It flowed to a round pond at New River Head on Islington Hill, where a water house was built.[13] The reservoir (subsequently greatly enlarged) served to store water, ensuring a steady supply to the pipes and allowing sediments to settle. The water was transported from the pond into the city of London through wooden mains pipes, to which single households were connected by brass ferrules and small lead pipes.

Technical challenges posed by the construction of the New River were mostly of two kinds. Firstly, it was important to find the optimum route that would allow for a reliable flow despite the limited difference of altitude between the spring and the city (which resulted in an average gradient of around eight cm/km). Secondly, raised structures were required to take the water across brooks and valleys. These were built at two different points along the route: at Salmon's Brook (at Bush Hill near Edmonton) and at Hackney Brook. A further technical difficulty, which was greatly underestimated at the time, concerned setting up the system of pipes. This aspect of the project does not seem to have been discussed and nobody with relevant knowhow was involved in the project. The greatest problem was dealing with 'altitudes' in different parts of the city, which were not taken into account when the pipes were standardised at a diameter of 0.5". Pressure in the pipes was frequently insufficient and by the beginning of the eighteenth century it had become apparent that parts of the city in the catchment area of the New River Company could not be supplied effectively with water. At this point discussions took place in order to decide if the introduction of pumps might solve the problem.[14]

In contrast to London, Edo enjoyed constant flows of large amounts of water and the outlets for excess water played an important role in the system. The military government constructed two ring moats around its Castle into which excess water was poured from both the Kanda and the Tamagawa waterworks. Surplus water also flowed into a huge reservoir at Akasaka. The Tamagawa Waterworks had fifteen outlets flowing into the moats, the reservoir, and the ponds across the city. Only 15% of the water was used for drinking and other domestic usages in daimyō residences, where water also played an

10 Middleton (1560–1631) was the son of Richard Myddleton (c. 1508–1575), Member of Parliament for Denbigh 1542. He became a member of the goldsmith guild in London and had a successful career. But he also had a number of other financial interests including cloth trade mining, to which we will come back later in the article. He was member of parliament (1603–28) and was made baronet in 1622. His brother Thomas (1550–1631) was alderman and sheriff of London (from 1603) and later became major of London (1613). Encyclopædia Britannica Online Library Edition, s.v. "Myddelton, Sir Hugh, 1st Baronet," accessed February 18, 2013.

11 R. Ward, London's New River, London 2003. and B. Rudden, The New River. A Legal History, Oxford 1985.

12 Which caused disputes with the towns using the river as a waterway; see R. Ward, New River (fn 11), pp. 47-48.

13 The water house served as home for a keeper of the New River and as a counting house. It also contained a reservoir in the basement, in which water coming from the pond was conveyed to the main pipes.

14 See, for example, the opinion expressed by Christopher Wren on the subject. C. Wren, Thoughts of Sir Christopher Wren concerning the distribution of the New River Water…, in: The Gentlemen's Magazine, 1753, pp. 114-6 (text probably written in 1702, see R. Ward, New River (fn 11), p. 235).

important decorative role in the gardens.[15] As much as 75% of water provided to daimyō residences poured out as excess after flowing through the ornamental ponds in the gardens.[16] In contrast, ornamental water was rarely present in London but it was a significant element in representations of power and wealth in other European cities. Rome in particular had a market for the water supplied by aqueducts which had flowed through fountains owned by noble families and this reinforced social hierarchies.[17]

Edo's excess water was employed to maintain the quality of water in the Castle moats. Approximately every sixteen days, the outer moat filled up causing water to flow into the Bay at the eastern end of the city, flushing Edo's large moats free from sewage and debris of all kinds.[18] Kanki has estimated that the total water capacity of Edo's waterworks had the potential to supply a 1.7 million populace,[19] suggesting that it was probably sufficient to cover the city's entire population, which only reached one million at most during this period. However, this is a crude estimate and, in reality, large amounts of water flowed into the fountains of the daimyō residences, while multiple usages of water also need to be taken into account. All the daimyō residences were well supplied with water, although from the mid-eighteenth century some ceased using water from the pipes and preferred to use the newly developed, deeper wells. Some parts of the commoners' residential areas in Fukagawa (eastern Edo) never received water from pipes and their inhabitants purchased water from vendors.

In London, the provision of fresh water spread relatively slowly through the city and, by 1616, three years after the completion of the New River, only forty households were connected. By 1619, this number rose to 1500, but still represented less than 3% of the population.[20] With improvements in the delivery capability of the New River system, and the development of a number of private water companies during the eighteenth century, the number of connected households increased dramatically. By 1800, over 80,000 customers were being supplied[21] and, although it is difficult to estimate accurately, it appears that approximately three-quarters of the city's population were supplied with water.[22] Nevertheless, some areas of the metropolis did not have water delivered into

15 H. Goto, Edo no jouge-sui to hori, in: Edo iseki kenkyu-kai (eds), Edo no Josuido to Gesuido, Tokyo 2011, pp.10-40 here p. 36.

16 Ibid, pp. 35-36.

17 W. Rinne, Water: the currency of cardinals in Late Renaissance Rome, in: A. Calzona/D. Lamberini (eds), La civiltà delle acque: tra Medioevo e Rinascimento, Firenze 2010, pp. 367-87. It is well known that in some cases water was circulated in cities (and since the middle ages in monasteries) according to a "hierarchy of uses" from those requiring the purest possible water (e.g. drinking) to those where cleanliness was not paramount (e.g. water as a power source for mills, other industrial usages). This does not seem the case in Edo and in Rome, where the users "down the chain" depended on the received water for all their needs.

18 H. Goto (fn 15), p. 39. This observation is based on an early-20th century remark.

19 K. Kanki/T. Watanabe, Edo suido no kiso-teki kenkyu, in: Nihon doboku-shi kenkyu-kai (eds), Nihon Doboku-shi Kenkyu Happyo Ronbun-shu, Tokyo 1998, pp. 274-281, here p. 279.

20 These numbers do not take into account the households supplied by the London Bridge water works which, in any case, were very few at this time.

21 R. Ward, New River (fn 11), p. 161.

22 This percentage takes into account the customers of the several water companies active in London at the time. One of the difficulties in producing an estimate derives from the fact that the average number of people per

their houses until late in the nineteenth century, and water was taken from the mains to the households by hand.[23] Thus, a figure of about half of the population having water delivered into their houses by around 1800 seems a reliable estimate.[24]

4. Similarities and contrasts in the development of prescriptive knowledge on urban water control

Provided that ecological and environmental conditions are reasonably similar, we can assume that expert knowledge of 'how to' control and manage water would move freely between states, cities, regions or countries facing similar problems. Possible obstacles to the diffusion of knowledge include states or guilds that may choose to protect and monopolise knowledge by prohibiting experts from migrating out of their jurisdictions.[25] State protectionism over useful and reliable knowledge is more likely to be seen amongst 'competing states' than in empires. Early modern Japan and Europe were indeed 'competing states' and the knowledge concerning warfare and territorial security, including the skills for constructing moats to protect the castle and market towns, and for providing water into those towns, bore military and economic importance.

After a century and a half of warfare amongst territorial warlords (daimyō) – the so-called Warring States era (1493–1590) – Japan witnessed unrest and destruction coming to an end with the unification, in 1590, under Toyotomi Hideyoshi (1537–1598), reinforced in 1603 under the first Tokugawa shōgun, Ieyasu. The cessation of warfare marked the beginning of a steady increase in agricultural production, and systematic investment in social and economic infrastructures, which led to a period of economic growth under the Tokugawa government. Daimyō lords were keen on such investments because each of the 270 daimyō had his own fiscal policy over his territory, independent from that of the Tokugawa shōgunate government. Thus, the country was a 'compound state', com-

household in the period was not constant across the city, particularly variations in the number of apprentices and / or servants belonging to the household varied. The average size was around 5.5 persons. See the Project "Families, households and housing in London, 1550–1720", IHR, http://www.history.ac.uk/cmh/pip/pip.html (retrieved in May 2015). In reality the percentages of the population estimated here represent a minimum as more than one household could share one contract, but it is clear that the proportion of citizens connected was at that time still relatively low.

23 In Hampstead, for example, water was still carried in buckets to single households as late as 1851 (J. Timbs, Curiosities of London, London [1855] 1867, p. 610). For the different 'stages' in the development of urban water supply through the centuries in Europe see A. Guillerme, The Age of Water. The Urban Environment in the North of France, A.D. 300–1800, Texas 1983.

24 We are grateful to Dr. Carry van Lieshout for providing us with these estimates. see aslo her dissertation 'London's Changing Waterscapes – the management of water in eighteenth-century London.', submitted at King's College London in 2012 and available on line at https:// kclpure.kcl.ac.uk/portal/files/32139633/2013_Van_Lieshout_Carry_0430811_ethesis.pdf (retrieved in May 2015).

25 For an overview of the role of guilds in fostering or limiting knowledge flow see S. R. Epstein, Craft Guilds, Apprenticeships, and Technological Change in Pre-industrial Europe, in: Journal of Economic History, 58 (1998), 3, pp. 684-713 and S. R. Epstein / M. Prak (eds.), Guilds, Innovation and the European Economy, 1400–1800, Cambridge 2008.

posed of autonomous economic and political units. Daimyō not only used hydrology techniques for military purposes, such as moat building, they also initiated large-scale irrigation and river control projects to improve agricultural productivity and to protect paddy fields from flood damage. When the country was unified and peace was resumed, many daimyōs began investing in land reclamation projects to expand arable lands. Furthermore, in daimyō territories such as Kai and San'in, where underground mineral sources were abundant, mining became a major source of income and hydraulic skills became highly valued in this context. Daimyōs such as Takeda Shingen (1521–1573) and Kato Kiyomasa (1561–1611) were renowned for giving their patronage to experts in hydraulics. They recruited the skilled experts as their feudal retainers and sometimes restricted their travel in order to monopolize their knowledge and skills.[26] Takeda's territory of Kai was located in mountainous land with fast river flows that caused flood damage to rice cultivation; he solved this problem by building embankments and re-diverting rivers away from the paddy fields, using expert knowledge and skills. Kai's economy grew further through the exploitation of the territory's rich gold and silver resources. Thus, skills and knowledge of river control, irrigation and mining were accumulated and retained under the patronage of lords such as Takeda, who prioritised these economically advantageous infrastructure projects. It was during times of peace under the Tokugawa reign (when useful investments in public services for the population were not destroyed by warfare or crowded out by military expenditures) that the accumulated knowledge of various hydraulic fields crystallised in urban waterworks projects.

In early modern Japan, skills and knowledge concerning water control were accumulated, retained and transmitted through family lineages. A lineage, or 'ryū', to use the Japanese word, was an important institution for learning and transmitting knowledge, and multigenerational lineages were common in Japan, where many occupations were hereditary. Lineages functioned for several centuries, training descendants, passing on secrets and producing institutional memory over generations. An elite occupational lineage might gain the patronage of the shogun or a local daimyō and establish for itself an important place in society. To sustain vitality, lineages were commonly perpetuated through adoption. A successor other than a biological heir, often a favoured student, could be chosen to inherit the lineage headship. Amongst many lineages, the Ina-ryū, Izawa-ryū and Kishū-ryū were celebrated for their hydrologic knowledge. A good example of such knowledge transmission is the lineage of Ina. Its founder, Tadatsugu, is considered to have acquired his hydraulic skills in river control, irrigation and bridge construction through service to Lord Takeda in the Kai region. After the dissolution of the lordship of the Takeda clan, Tadatsugu was recruited by Ieyasu as a special retainer and later appointed as the Regional Governor of Kantō (the area in which Edo was situated), where he was put in charge of various engineering and construction projects for the newly established Tokugawa government. The third head of the Ina lineage, Tadaharu,

26 S. Yajima/ M. Sekino (eds), Nihon Kagaku Gijutsu-shi, Tokyo 1962, pp. 633-635.

and his son, Tadakatsu, oversaw the construction of Edo's Tamagawa River Waterworks as the government's Magistrates in the 1650s. It is clear that water experts' accumulated knowledge of other branches of hydrology, passed down through the Ina lineage, came to fruition in their later waterworks projects. The Ina lineage lasted eight generations as an influential source of hydrology and engineering knowledge in the Kantō region, and the head of the lineage occupied the hereditary position of Regional Governor until 1792.[27] It appears that other lineages of hydraulic knowledge may also have accumulated water control skills and knowledge, then served the local daimyōs who invested in the construction of urban waterworks for castle towns across the country, in the same period as the Ina lineage did. Most of the 43 urban waterworks in Japanese cities and towns were constructed during the final decade of the sixteenth century and the beginning of the seventeenth century.[28]

In many cases in Europe, knowledge related to water control was transmitted over generations through a more open apprenticeship system. In German speaking countries, where the construction of urban water systems was in the hands of 'hydrology-masters', this office was often hereditary, passed down through generations in the same families. Life expectancy was low in the early modern era and cities struggled to find a stable supply of well-trained people, so experts were brought in from other cities. There are several examples of experts being prevented from leaving cities without the consent of local authorities, particularly in times of war, when such knowledge was regarded as a military secret. After periods of war or financial difficulties, masters travelled to other cities to study new techniques.[29]

In general, despite some protectionism, ideas and technical knowledge related to water travelled easily across Europe. Knowledge was often developed, accumulated and diffused across neighbouring fields, such as mining, drainage, surveying and garden architecture (including grotto, fountain and automata design). Such knowledge grew commonplace in central Europe from the fifteenth century onwards and became available to towns dealing with problems of water control.[30]

Many innovations relevant for hydraulic purposes originated in the field of mining. A major example is the reversible waterwheel, which allowed to lift water from a depth of over 200m, compared to older methods that could not deal with depths exceeding 70m. Such wheels began to appear in the 1470s in association with the technician Georg Thurzo, who was active in mines in Slovakia.[31] In time such pumps became more common and were widely used for multiple purposes. In the fifteenth and sixteenth centuries

27 For the lineages of water control, M. Ishizaki, Ina Ichizoku to Izawa Yasobei, in: Y. Yasojima (ed.) Shin-taikei Doboku Kougaku, Tokyo 1994, pp. 93-110.

28 J. Hatano (fn 5), p. 241.

29 A. Hoffmann, Zum Stand der städtischen Wasserversorgung in Mitteleuropa vor dem dreißigjährigen Krieg, in Frontinus Gesellschaft (Hrsg.), Die Wasserversorgung in der Renaissancezeit, Geschichte der Wasserversorgung Bd. 5, Mainz 2000, pp. 99-144, here particularly p. 110.

30 Ibid, p. 117-118.

31 P. Braunstein, Innovations in mining and metal production in Europe in the late Middle Ages, in: Journal of European Economic History, 12 (1983) 3, pp. 573-91, pp. 584-85.

mining expertise was concentrated within the German speaking communities of central Europe, which produced several manuals and books on the subject including the famous texts by Georgius Agricola.[32] In the late 1560s, the English mining industry depended entirely on expertise imported from the Erzgebirge (today's Germany). The banking firm of Haug, Langnauer and Company, from Augsburg (which owned successful copper mines), was asked by the English joint-stock company Mines Royal to provide the know-how (miners and managers) to work copper mines in Cumbria, and was allocated one third of the company's twenty four shares.[33] Knowledge was freely 'traded' and there was no protectionist intervention on the part of the state.[34]

In many respects, and particularly as regards pumps, urban water systems and mining are strongly related to drainage, another branch of technical knowledge that was shared relatively easily across Europe. In this context it is worth noting that Hugh Middleton, one of the main actors in the construction of the New River waterworks in London (1609–1613), was also involved in mining[35] and reclamation works.[36] Drainage know-how was initially developed in Italy, then in Holland, and applied in Germany where it made further advances. Projects were carried out in England in the 1530s and the 1560s, involving experts from Italy, France, Holland and Germany. From the late 1580s, and intensively after the first half of the seventeenth century, large-scale projects were initiated for the drainage of the fens, with massive input (both financial and technological) from Holland. Thus, in terms of knowledge formation, we are looking at a European-wide enterprise that was often financed through private investment, which also attracted the necessary expertise.

Another branch of knowledge worth discussing briefly, because it brings together skills and interests highly relevant to water management, is garden architecture. During the Renaissance, emerging in Italy in the fifteenth century, artists and elites rejuvenated and further developed an ancient tradition of decorative waterworks, bringing about a fashion for elaborate gardens with ornamental water systems, which spread throughout Europe. Water gardens as a symbol of power, wealth and high culture reached England mainly through France[37] thanks to the brothers De Cause, who obtained a prestigious

32 G. Agricola, De Re Metallica, Basilea 1556.

33 E. Ash, Power, Knowledge, and Expertise in Elizabethan England, Baltimore 2004, pp. 19-54, particularly pp. 19-20.

34 It must be noted that Augsburg was a "Reichsfreie Stadt", an independent imperial city, run by an oligarchy of merchants and financiers so that the state was likely to adopt a strategy that would allow for the maximisation of the interests of this group including the commodification of knowledge.

35 At the beginning of his career he made an unsuccessful attempt at coal mining in North Wales. Later he turned to the extraction of copper, gold, silver, and quicksilver and, from 1617, he leased the Cardiganshire mines of the Mines Royal Company. Here he succeeded in obtaining large profits, also thanks to the resolution of draining problems (J. W. Gough, Sir Hugh Myddelton: Entrepreneur and Engineer, Oxford 1964, see also ODNB).

36 From 1620 Middleton participated in a drainage project on the Isle of Wight, which made use of Dutch expertise and imported machinery, see J.W. Gough, Sir Hugh Myddelton (35).

37 King Charles VIII, coming back to France from Naples in 1495, brought with him artists and architects and stimulated the introduction of this new style to France. Thus, in the following century, a French version of the Renaissance garden developed. The brothers Salomon and Isaac De Caus (from Dieppe, in Normandy) were educated in this environment. The earliest English example is probably the garden at Nonsuch Palace, near Cheam in

royal commission at the beginning of the seventeenth century.[38] In 1625, Sir Francis Bacon wrote the essay, 'Of Gardens', in which he stressed the technical challenges related to water features and the importance of technical knowhow: 'the ornaments of images gilt, or of marble, which are in use, do well: but the main matter is so to convey the water, as it never stay, either in the bowls or in the cistern.'[39] At the time the New River was constructed (1613), this kind of useful knowledge in England had not yet found its way from specialized fields, such as garden architecture, into more mundane applications, such as pipe systems to distribute water from the reservoir in Islington to the city of London. However, it did so in the subsequent century, when Britain slowly became one of the leading centres for the advancement of urban water management systems.

In addition to oral and tacit traditions of knowledge transmission through family lineages and apprenticeships, both early modern Europe and Tokugawa Japan had long histories of codifying in written form the skills and knowledge associated with hydrology.[40] Historical literature on urban water supply overlaps in many respects with books concerned with river control and with more theoretical writings dealing with the velocity and the 'physics' of water. Nevertheless, there is a field that is more focused on urban water management and deals either with instructions on how to set up the water delivery system or with pumping machines. Some of these writings, again, are more prescriptive in nature, but some also reflect the tendency – observed by Davids in the context of river control – to understand and describe regularities and general principles. For example, we can look at literature produced on the subject in Augsburg in the seventeenth and eighteenth centuries, when that city was famous all over Europe for its sophisticated system of urban water supply. The city's position on high ground did not allow for flows of water through simple gravity. Over the centuries more sophisticated techniques for raising and distributing water were developed. By the end of the sixteenth century several Archimedes screws were combined to raise water to high levels and the city was marked by imposing water towers and elegant fountains. Moreover, at that time Augsburg was also one of Europe's most important printing centres. From the middle of the seventeenth century a number of cutting-edge publications in the field of mechanics and architecture were

Surrey, constructed in the 1580s (a garden with grottos inspired particularly by mannerist Italian examples from Florence and Rome), but it seems that it was an isolated case (see T. Knox, ‚Complicated beauties': the artificial grotto in England, c. 1600 to the present day, in: I. L. Ballerini/ L.M. Medri (eds). Artifici D'acque e Giardini, Firenze 1999, pp. 48-75, here p. 48). On English Renaissance Gardens, Strong discusses the predecessors of the extensive Jacobean usage of water in courtly gardens: French jardin de plaisir and the usage of water to stage court entertainment (mostly using existing moats) during the Elizabethan era. R. Strong, The Renaissance Garden in England, London 1929, p. 125.

38 Such as the gardens of the London residence of Queen Anne (Somerset House, 1607) and those for the prince's residence in Richmond (1611).

39 Emphasis added. 'Of Gardens' was the 46th essay in the collection of essays Bacon published in 1625. F. Bacon, Essayes or Counsels, Civill and Morall of Francis Lo. Verulam, Viscount S Alban, London 1625. For a critical consideration of this source see P. Henderson, 'Sir Francis Bacon's Essay 'Of Gardens' in context', in Garden History, 36 (2008) 1, pp. 59-84.

40 The development of European publishing on hydrology has been summarized elsewhere, see, for example, A. K. Biswas, History of Hydrology, Amsterdam/London 1970. For references concerning Japan see later.

printed there, both by Germans and well-known foreigners. Joseph Furtenbach's influential treatise on architecture, which includes a section on water management, appeared in 1662. In 1720, the architect and mathematician Leonhard Christoph Sturm published his Vollständige Anweisung Wasser-Künste, Wasserleitungen, Brunnen und Cisternen.[41] In the same period, the two engineers in charge of Augsburg's waterworks, Caspar Walter senior and junior, published several books on water control. Some of these publications are of a more theoretical nature while others are descriptions of waterworks.[42] Compared to Japan in the same period, we can detect a tendency to publish printed books of a more theoretical nature as well as descriptive works. This tendency reflects Augsburg's participation in the eighteenth-century enterprise of knowledge production on a European scale by technicians who wished to see their work recognised intellectually and to attract patronage.

In the seventeenth and eighteenth centuries in England, very little was published on hydrology. Books dealing with water-related problems were mainly concerned with the properties of water and techniques for rendering seawater sweet[43] as well as with questions of improving internal navigation. One of the earliest publications of a scientific and technical kind is John Bate's, The mysteries of Nature and Art (1634), which presents examples of machines (such as pumps, engines, and vessels with specific properties) and solutions to common problems (for example, how to draw water by a crane or by an engine, how to force water to high places and so on), as well as experiments such as 'forcing water by aire compressed', or 'motions by rarifying aire by fire'. The publication could be described as a 'recipe book' that does not aim at explaining general principles.[44] Another such book is George Atwell's, The faithful surveyor… (1665).[45] Atwell was not a university graduate but a surveyor. Nevertheless, he had made a name for himself in

41 J. Furttenbach, Die nur noch übrige Früe und Spaetstunden: mit liebreichen Delectationen der 3 Arten hochnutzlichen Gebäwen, sampt derselben Mitgliedern in den Freyen Künsten wol anzulegen, Das Wassergebäw … / Durch Joseph Furttenbach den Jüngern, Augsburg 1662; L. C. Sturms, Vollständige Anweisung Wasser-Künste, Wasserleitungen, Brunnen & Cisternen wohl anzugeben, Augsburg 1720.

42 C. Walter, Hydraulica Augustana, das ist: Ausführliche Beschreib- und Auslegung alles dessen was in des Heil. Röm. Reichs-Stadt Augspurg in den daselbst befindlichen drey obern Haupt-Wasser-Thürnen … / beschrieben und herausgegeben von Caspar Walter, Augspurg 1720; C. Walter, Beschreibung Aller höltzernen...Gumber-Werck… von Caspar Walter, Stadt Brunnenmeister, Augsburg1761; C. Walter, Architectura Hydraulica, oder Anleitung zu denen Brunnenkünsten, Augsburg 1765. They also published on other aspects of architecture, such as carpentry (C. Walter, Architectura civilis, Augsburg 1704) and bridges (C. Walter, Brücken-Bau: Oder, Anweisung wie allerley Arten von Brücken, sowohl von Holz…, Augsburg 1766).

43 Following the invention, in the 1680s, of a method to do so by Robert Fitzgerald, publications on the matter were translated into other languages such as Italian and French.

44 It is worth noticing that a second, enlarged edition, as a small, easily portable and not too expensive book, was printed a year later, a testament to its popularity. Also interesting is the fact that the second edition's additional material is found mainly in the section on water works.

45 G. Atwell, The Faithful Surveyor: teaching how to measure all manner of ground exactly, by the chain onely: also, thereby to take distances of a mile space, and the situation of any building. Shewing likewise the making and use of a new instrument, called a pandoron; which supplies the use of the plain-table, theodelite, quadrant, quadrat, circumferentor, and any other observing instrument. As also divers secrets for conveying and clensing of water, flowing and draining of grounds, quenching houses on fire, &c. With an appendix unfolding errours in board and timber-measure: with directions for making a carpenters rule. By George Atwell late teacher of the mathematicks in Cambridge, London 1665.

Cambridge as a tutor in mathematics and had developed good relationships with Trinity College. Atwell's publication followed the printing in English of a treatise by Isaac de Caus (1590-1648), Nouvelle invention de lever l'eau, translated into English by John Leak and published in 1644 as New and rare inventions of water-works shewing the easiest waies to raise water higher then the spring.[46] Another book explicitly devoted to water works is Sir Samuel Morland's (1670–1716) Hydrostaticks, published by his son John in 1697.[47] Morland's book can be seen in the tradition of the 'teatri di machine', but it contains mathematical tables and has 'scientific' aspirations. More publications appeared in the eighteenth century but, in general, between 1650 and 1750 very few books on hydrology were published in England. This reflects a deficiency of indigenous expertise in disciplines contributing to the stock of useful knowledge for the management of water systems. This is a field in which Britain will catch up in the course of the eighteenth century, during which time it will reach a leading position.[48]

In Tokugawa Japan, men in the office in charge of urban waterworks, irrigation and river control were also able to draw on a large body of texts containing hydraulic knowledge. It is probable that these early hydraulic texts came from China. In the fifteenth and sixteenth centuries a large number of Chinese books were imported through official and illicit trade and, although the majority of them were Buddhist treatise, Confucian texts, and Chinese histories, many titles concerned useful and reliable knowledge. There is no doubt that some titles contained hydraulic content, evidenced by Tokugawa intellectuals' repeated references to an Early-Han-period treatise on the Yanzi River.[49] However, in the mid-seventeenth century Tokugawa hydraulic experts began producing their own texts, a genre called jikata-sho, often written by hydraulic experts and administrative officials for their fellow experts. They were published as technical and administrative manuals recording the knowledge and skills gained through direct experience on water control projects. Content ranged from the techniques and methods of land surveying, to budgetary calculations, construction materials and labour management.[50] One example of these jikata-sho manuals is the eleven volume manuscript, Jōsui-ki (Chronicle of the [Tama River] Waterworks), written in 1791 by the Waterworks Magistrate, Ishino Hiromichi. The manual records the history of the construction and administration, the de-

46 I. De Caus, New and Rare Inventions of Water-works shewing the easiest waies to raise water higher then the spring, London 1659 (translated into English by John Leak), based on a work by his brother Salomon: Salomon De Caus, Les raisons des forces mouvantes avec diverses machines, Frankfurt 1615.

47 S. Morland [Edited by John Morland.], Hydrostaticks, or Instructions concerning Waterworks, collected out of the papers of Sir Sir Samuel Morland. Containing the Method which he made use of in this Curious Art, London 1697.

48 S. Ciriacono (ed.), Land Drainage and Irrigation, Aldershot 1998; E. H. Winant, The Hydraulics revolution: science and technical design of urban water supply in the Enlightenment, Virginia University dissertation, 1996. On the shift between Italy and the Netherlands as European centers of knowledge about hydraulics, before Britain took the lead, see S. Ciriacono ibid. and S. Ciriacono, Building on Water: Venice, Holland and the Construction of the European Landscape in Early Modern Times, Oxford 2006.

49 K. Kanki, Muro Kyuso "Mizu ha Shita yori Osamuru" ni mirareru Kyoho-ki no Chisui Shiso, in: Doboku-shi Kenkyu, 22 (2002), pp. 41-47.

50 K. Yamamoto, Kadou Keikaku no Gijutsu-shi, Tokyo 1999, p. 38.

tails of the water supply systems, and the administration of fee collection. Agronomical manuals are another genre of hydraulic text and were published in large numbers in the seventeenth and eighteenth centuries. These were written by educated farmers or heads of villages as well as by agronomists. In Tokugawa agrarian villages, knowledge transmission via agronomical manuals became important largely because the Tokugawa village heads were literate.[51] They recorded locally accumulated knowledge to be transmitted to future generations and consulted such manuals on floods. Learned agronomists drew on the existing books and manuscripts to make a synthesis of practical knowledge related to water control.[52]

Knowledge about water control may have become more easily available in printed form in Tokugawa Japan because an infrastructure for publishing developed rapidly during this period, which in turn might have lead to a better circulation of ideas between different social and professional groups. Printing in Japan began in the 1590s, and the eighteenth century saw a significant increase in the publication of printed books; 22,000 titles were published in Japan as a whole between the 1720s and 1815.[53] Publishers in three commercial and cultural capitals, Edo, Osaka and Kyoto, produced many titles including educational and entertaining texts as well as practical, technical and scientific manuals.[54] However, despite improvements to printing technology, the circulation of knowledge in the form of manuscripts continued until the mid-nineteenth century; one estimate shows that nearly 40% of all publications in the early modern period were in manuscript form.[55] The figure may be even higher in the case of hydraulic titles. For example, a search of the text of all titles on the Kokusho Sou-mokuroku database (Catalogue of early Japanese books) returns fifty-two titles containing hydraulic skills and knowledge but many of them are copied manuscripts. These manuscripts, predominantly jikata-sho and agronomical manuals, were records of phenomena related to water controls in rural and urban sites across the country, accumulated over the years by village heads, engineering officials, hydraulic experts and agronomists. For recording descriptions and measurements of hydraulic phenomena, manuscript proved to be a superior form of publication for its speed of production, local circulation, and ease of revision. On the other hand, the printed titles tend to contain greater classification and cataloguing of hydraulic techniques, so it appears that each form of publication had a different

51 For cultural and economic village elites in rural Tokugawa Japan, see for example, P. Kornicki, The Book in Japan: A Cultural History from the Beginning to the Nineteenth Century, Leiden 2001.

52 For example Shin'en Sato, the educated agronomist, published a title on river hydraulics in the early 1800s. K. Yamamoto (fn 50), Gijutsu-shi, p. 40.

53 In Japan, printing took place on a significant scale from the 1590s and by the end of the 17th century, books printed by woodblock had become a familiar commodity in towns, although the production also increased throughout the Tokugawa period. P. Kornicki, Book in Japan (fn 51), p. 175, and P. Kornicki, 'Manuscripts, Not Print: Scribal Culture in the Edo Period,' in: Journal of Japanese Studies, 32 (2006) 1, pp. 23-52.

54 These publishers in three capitals produced some 400 titles from 1727–1731 and 600 from 1750–1754. J. L. Van Zanden, The Long Road to the Industrial Revolution: The European Economy in a Global Perspective, 1000–1800, Leiden 2009, p 189.

55 P. Kornicki, Manuscripts (fn 53); K. Hashiguchi, Edo no Hon'ya to Hon Dukuri: Zoku Wahon Nyumon, Tokyo 2007.

role in the recording and dissemination of knowledge. It is likely that Tokugawa hydraulic officials consulted the writings of their predecessors to learn specific information about local urban waterworks and rivers, while printed books were consulted to gain broader understanding and knowledge of a wide range of techniques. It is interesting, however, that what Davids observed in the context of Chinese hydrology publications did not seem to occur in Tokugawa Japan. Davids argued that, in China, those books on river management written by knowledgeable court officials became canonized, and were used for centuries by later generations of hydraulic officials.[56] Tokugawa jikata-sho and agronomical texts made frequent references to one another but no particular titles appear to have been canonized.

5. Differences in the development of propositional knowledge relating to water control

Knowledge about water control had long been generated through numerous trial and error procedures, and accumulated in the form of 'instructions and recipes' that Mokyr describes as prescriptive knowledge. Mokyr distinguished this type of knowledge from propositional or epistemological knowledge, which itself has two parts: the knowledge of 'observation, classification, measurement and catalogue', on one hand, and the establishment of 'regularties, principles and natural laws that govern [natural] phenomena', on the other.[57] Davids' study concluded that, in the evolution of Chinese hydraulic knowledge, the first form of propositional knowledge was highly valued, while the second form failed to become established.[58] The evolution of Tokugawa Japanese hydraulic knowledge appears to follow the same course. An important element of hydraulic engineering involved applied mathematics. In Tokugawa Japan, the application of Japanese mathematics, known as 'Wasan', focussed primarily on land surveying to measure gradients of terrains and water levels. It is generally agreed that Tokugawa hydraulic experts failed to develop the concept of velocity to calculate volumes of water flowing per unit of time.[59] However, land surveying, particularly the accurate measurement of gradients, was crucially important for the design and construction of urban waterworks, which is clear from the design of Edo's Tama River waterworks system. The Tama Waterworks supplied sufficient water fairly successfully to roughly one-third of the city's residential areas. This would have been practically impossible without the application of highly developed surveying mathematics because the waterworks design almost entirely relied on the gradient of land between the highest point, on the western side of Edo city, to the lowest, on the eastern side, which flowed into Edo Bay. As well as the gradient measurements, Wasan mathematics provided solutions to the management and control of the volume of water

56 K. Davids, River control (fn 3), pp. 67-8.
57 J. Mokyr, Gift of Athena (fn 2), pp. 4-5 and 10.
58 K. Davids, River control (fn 3), pp. 67-8.
59 K. Kanki et al. (eds.) Edo-josui no Gijutsu to Keiri, Tokyo 2006, p. 75 ; K. Yamamoto, Gijutsu-shi (fn 50), pp. 44-46.

supplied through the water pipes in the city. Water experts were able to calculate levels and mass of water in order to regulate the supply volume, which otherwise would have caused floods.

Knowledge of applying mathematics to water control was developed largely 'on the job'. Tokugawa Wasan and hydraulic experts developed their expertise by participating in projects involving water control and surveying. Yoshida Mitsuyoshi (1598–1672), the author of a widely circulated mathematical text, Jinkō-ki, came from a family of wealthy merchants in Kyoto who also invested in large-scale canal constructions and river controls near Kyoto region. Yoshida himself participated in many construction projects through which he accumulated and generated the useful application of mathematics to hydraulic problems.[60] Yoshida's Jinkō-ki (first edition in 1629) contained many useful applications of mathematics to calculate slopes and levels.[61] In chapter twenty-one, for instance, Yoshida deals with 'river controls' and the 'building of moats', while other chapters deal with such issues as measuring areas of fields, estimating height and distance, and calculating square and cubic roots.[62] There are many such examples of Tokugawa mathematicians developing their applied mathematical knowledge through their office holding in positions such as accountants or constructors. Yamada Masashige's Kaisan-ki, published in the early-seventeenth century, is another early Tokugawa mathematical compendia in many editions which details the construction of bridges. Mathematical applications for surveying were called chōken-jutsu and practitioners developed various surveying instrument.[63] These were illustrated, for example, in Sanpou-buttankai, which was published in 1673 by Murase Yoshimasu, and also featured a depiction of a spirit level. The early-eighteenth century marks the beginning of a steady increase in jikata-sho titles and publications concerned with surveying; between 1700 and 1856 seventeen titles were published on applied mathematics and many titles included chapters on hydrology. The practical, 'on the job' manner of hydraulic training and knowledge transmission in Tokugawa resembles that of China where, according to Davids, hydraulic experts on the Yellow River acquired their knowledge in a 'purely "ad hoc" manner'.[64]

This is not to say that Tokugawa hydraulic experts and Wasan mathematicians received no formal training at institutions for higher education. Many daimyō lords founded state academies and encouraged their retainers' learning. Although the curricula of these academies reflected the feudal order, instilled the virtues of Neo-Confucian studies and concentrated more on learning the Humanities, some academies were keen to introduce more practical subjects such as Wasan mathematics, medicine and astronomy.[65] Nev-

60 Yoshida's maternal family came from Kyoto's merchant lineage, Suminokura, who traded as far as Vietnam before the Tokugawa government banned foreign trade in the 1630s. The family had a large investment in Takakura in Kyoto.

61 T. Matsuzaki, Edo-jidai no Sokuryou Jutsu, Tokyo 1979, pp. 99-115, 160-173.

62 M. Yoshida, Jinko-ki, [translated by Shin'ichi Oya] Tokyo, 1977.

63 T. Matsuzaki, Sokuryou Jutsu (fn 61), pp. 100-101.

64 K. Davids, River control (fn 3), p. 67.

65 Some academies taught more advanced pure mathematics beyond practical use. See K. Sato, Kinsei Sugaku-shi: Seki Takakazu no Jitsuzou wo motomete, Tokyo 2005.

ertheless, mathematics was considered to be a lower subject in the curriculum, to be learnt by the merchant class and lowly ranked samurai. The lack of formal education and training of hydraulic experts and officials in applied mathematics was likely to be compensated by knowledge transmission within lineages. As well as hydraulic lineages, there were several lineages of mathematics and each of them formed a strong band of expert knowledge holders. The literal meaning of 'ryū' is 'river' – a flow of knowledge from a learned person to students or disciples. The transmission of knowledge was carried out in a personal, vertical manner, suggesting a familial or intellectual 'line of descent' from a single master. A ryū refers to generations of followers under a founding master and there were many distinguished multigenerational ryū in early modern Japan. In these networks, skills and knowledge were transmitted through an oral tradition rather than through written texts. Private tuition by these masters and tutors was widely available in the seventeenth and eighteenth centuries and compensated for the lack of formal training in practical and technical knowledge in formal institutions for higher education. Many Tokugawa water experts and urban planners were mathematically trained and well qualified in surveying and designing waterworks and it is highly likely that private tutoring by notable ryū masters was the basis for their education.

Although there was a lack of expertise in the field of hydrology in England at the time of the New River project, surveyors and surveying techniques were available and successfully employed in its construction. Most of the challenges faced in the construction of the New River were related to measuring the lie of the land. Colthurst had originally conducted a survey of the land to determine the route himself, but when Middleton took over the project he hired Edward Wright (1561–1615), a mathematician, cartographer and designer of mathematical instruments, to handle this aspect of the project.[66] Wright had been educated in Cambridge, was fellow of Gonville and Caius College, and tutor to the Royal family. During Elizabeth I's reign he was involved in the politically and economically significant problem of developing accurate maps for navigation and expansion. He was the author of Certaine Errors in Navigation (1599; 2nd ed. 1610), in which he presented the correct mathematical basis for the Mercator projection and for more accurate maps. Wright was also involved in mathematical theory and had translated John Napier's Mirifici Logarithmorum Canonis Descriptio (Description of the Wonderful Rule of Logarithms) into English in 1616, only two years after its original publication in Latin. High-ranking mathematicians did not disdain applying their knowledge to the solutions of practical problems and becoming involved with engineers and investors. From 1611, Wright's position on the New River project was taken up by John Blagrave, a mathematician who had devoted himself particularly to dialling and the development of surveying and astronomical instruments. Furthermore, we can consider the career of

66 He was a mathematician involved in cutting-edge mathematical advancements of the time, having also translated John Napier's Mirifici Logarithmorum Canonis Descriptio (Description of the Wonderful Rule of Logarithms) into English only two years after its original publication in Latin (respectively 1616 and 1614). In the New River project, he was paid a weekly salary of £2, which was nine times the amount paid to a labourer. R. Ward, New River (fn 11), p. 29.

Robert Hooke as an instance of a leading natural philosopher intensively involved in water-related technical problems. For example, in the 1670s Hooke devoted his time to the canalisation of the Fleet river.[67] The interest of intellectual elites in water-related problems is also attested by the activities of the Royal Society, which debated the issue on several occasions. For example, the Mechanical Committee considered the problem of quickening the flow of water to Islington[68] in 1664 and 1665; and in 1733, in the context of the aforementioned discussion of the possible use of pumps to improve supply, the committee considered a model of a new engine presented by its inventor, a Walter Churchman.[69]

The participation of European mathematicians in urban water control can, however, be best illustrated with a case from Bologna, Italy, which marked the beginning of the 'scientification of water-related knowledge', a process that, with time, would spread across Europe and influence the British Isles. In Bologna, the position of University Chair of mathematics had, since the fifteenth century, been given explicitly to a scholar placed in charge of managing the city's water supply. Mathematicians in the Jesuit College at Ferrara were also consulted to solve technical problems of water management for Bologna, and included such celebrated scholars as Scipione del Ferro (1465–1526) and Girolamo Cardano (1501–1576). In the course of the seventeenth century, Italian mathematicians contributed to the theoretical understanding of the 'behaviour' of water, including calculations of its velocity. This would help, in time, to solve problems of flooding and the management of the distribution of water to different users (particularly for agriculture, but also for households in cities). Mathematicians who participated in water control projects were at the same time candidates in public mathematics competitions to secure the nobles' patronage. Both Girolamo Cardano (1501–1576) and Benedetto Castelli (1578?–1643) were winners of such competitions. The latter is particularly well known as the author of influential texts on fluids in motion, Mensuration of Running Water (1628), and Geometrical Demonstrations of the Measure of Running Waters (1639).[70]

Between the seventeenth and the early-eighteenth centuries, significant changes occurred

67 For a description of Hooke's activities see M. Espinasse, Robert Hooke, London 1956. For a discussion of Hooke's interactions with practitioners and his employment in the solution of practical problems see R. Iliffe, Material doubts: Hooke, artisan culture and the exchange of information in 1670s London, in: The British Journal for the History of Science, 28 (1995) 3, pp. 285-318.

68 "Dr Wilkins was desired to propose to those, that are interested in the work of bringing the water of Islington river to London, whether in case any persons can quicken the course of the water, they will consider them for it." Transactions of the Mechanicall Committee, 14 November 1664, 12 May 1665. Quote from 14th November, manuscript collection, Royal Society.

69 W. Churchman, "An Account of a New Engine for Raising Water, in Which Horses or Other Animals Draw without Any Loss of Power (Which Has Never Yet Been Practised) and How the Strokes of the Pistons May Be Made of Any Length, to Prevent the Loss of Water, by the Too Frequent Opening of Valves, with Many Other Advantages Altogether New; the Model of Which Was Shewn to the Royal Society on the 28th of November, by Walter Churchman, the Inventor of It", in: Philosophical Transactions 1733, vol. 38, 402-404. A full account of the diverse interests of the Royal Society in water related technical and scientific problems cannot be given here and will be presented in a separate paper.

70 B. Castelli, Della Misura dell'Acque Correnti, Roma 1628; B. Castelli, Dimostrazioni Geometriche della Misura delle acque correnti, Roma 1639.

in Italy for the organisation of institutions devoted to water control. The involvement of mathematicians active at university level changed the professional profile and the training of personnel engaged in the 'hands on' management of water. From the late-seventeenth century, in Northern Italy, examinations were introduced that would verify the mathematical proficiency of candidates and their understanding of the theoretical principles underlying the 'behaviour of water.'[71]

6. Concluding remarks

In both Japan and Europe the formation of knowledge about water responded to favourable conditions for its accumulation, including relatively free migration, state patronage, and the circulation in different forms of knowledge related to water management, even in times of war. In the seventeenth and eighteenth centuries in Europe, the dissemination of publications on water increased, and experts with positions in universities and high profile 'scientifically minded' individuals and institutions participated in urban projects or in the processes aimed at the solution of technical problems. In Tokugawa Japan, although publications on hydrology also increased, the status of the discipline did not rise to become a subject of higher education until the mid-nineteenth century. Reciprocal comparisons in this essay have highlighted many similarities in knowledge creation and diffusion systems in these cases. However, we have identified important contrasts, including variations in the openness of knowledge transmission systems and the inclusion of these systems in higher educational settings concerned with mathematical subjects. Another point of contrast is the circulation of knowledge primarily through printed books in Europe as opposed to manuscripts in Japan. Although in Europe, as in Japan, the production of manuscripts continued well beyond the invention and entrenchment of print,[72] the wider employment of print in Europe remains a significant point of difference between the two cultures, enabling, in Europe, a wider, more 'standardized' diffusion of technical language, concepts and applications. We suggest that the mechanisms of knowledge formation and diffusion developed in Europe may have been better suited to the systematic analysis of technical problems and their understanding in terms of universal laws and generally applicable solutions. Furthermore, the comparison of Japan and Europe has led us to argue, although tentatively, that the status accorded to intellectuals and experts within European institutions for higher education, to enhance the knowledge pertaining to urban and other problems of water control, represents an-

71 See C. S. Maffioli, Out of Galileo: The Science of Waters, 1628–1718, Rotterdam 1994, pp. 247-9, 276-7, 337, 426 and C. S. Maffioli, La Via delle Acque (1550–1700): Appropriazione delle Arti e Trasformazione delle Mathematiche, Firenze 2010.

72 Not much has been written on the matter in terms of publications with technical contents but for a good overview of the practice of scribal publication see H. Love, Scribal Publication in Seventeenth-Century England, Oxford 1993. and A. Johns, The Nature of the Book: Print and Knowledge in the Making, Chicago/London 1998. See also P. Beal, In Praise of Scribes: Manuscripts and Their Makers in Seventeenth-century England, Oxford 1998.

other contrast between the two regions, which can be dated back to the sixteenth and seventeenth centuries. The accumulation of embodied and disembodied useful and reliable knowledge in Japan largely took place in the multigenerational lineages of experts in hydrology and mathematics. Although the practice functioned well enough to produce a succession of competent water engineers and officials, we are inclined to argue that Japan's system for the accumulation of knowledge only offered limited spill-over effects, and only partially contributed to the substantial increase in the stock of useful and reliable knowledge, and the subsequent development of new trajectories of knowledge.