Water control and useful knowledge: river management and the evolution of knowledge in China, Northern Italy and the Netherlands

Karel Davids

Introduction

'Since European rivers presented few serious control problems, European interest [in hydraulic works], when eventually it arose, centred mainly on transport canals', Joseph Needham many years ago claimed in his magisterial *Science and civilisation in China.* [1] In contrast with China, European countries apparently developed no particular interest, or competence, in the management of water flows in rivers. Anyone who has kept up with the news of the last ten years or so knows that Needham's remark was in fact rather optimistic, to say the least. European rivers nowadays *do* present serious control problems and, the historian may add, they did so in the past as well. Problems of water control, and their solutions, in Europe differed less from those in China than a casual glance might suggest. The history of water control offers a rich field for challenging comparisons between Europa and China.

This paper will look from a Chinese perspective at river management in Europe. The importance in Chinese history of the problem of controlling the Yellow River is, thanks to the work by Needham, Flessel, Elvin. Dodgen and others[2], quite well-known. Comparable problems arose in regions in Europe, notably the coastal

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[11] Needham, Joseph, with Wang Ling and Lu Gwei-djen, *Science and civilization in China*, vol.4.III, *Civil engineering and nautics* (Cambridge 1971) , 376; Needham was nevertheless aware of the emergence of what he calls `post-Renaissance mathematical hydrodynamics', see footnote d on p.231.

[2] Needham *et al*., *Science and civilization*, 229-241, K.Flessel, *Der Huang-ho und die historische Hydrotechnik in China* (Tübingen 1974), Mark Elvin, *The retreat of the elephants. An environmental history of China* (Yale UP 2004), Mark Elvin and T.-J.Liu (eds.), *Sediments of time. Environment and Society in Chinese history* (Cambridge 1998), Mark Elvin, H. Nishioka, K. Tamaru and J. Kwek, *Japanese studies on the history of water control in China: a select bibliography* (Canberra 1994), Randall A.

plains of Northern Italy and the Rhine delta in the Netherlands, which, like the Yellow River basin, were not only densely populated, prosperous and politically prominent, but also quite vulnerable to recurrent calamities caused by the unruly behaviour of rivers forcing their way in from a mountainous hinterland. Like China, these European regions in course of time saw the growth and application of a extensive body of `useful' knowledge intended to make possible a better understanding and, ideally, a more effective approach to the problem of water control. The period between about 1400 and 1800 was in this respect both in China and Europe particularly important.

In this paper, I will analyze the differences, similarities and possible connections in the evolution of `useful' knowledge on river management between the Yellow River basin, the coastal plains of Northern Italy and the Rhine delta in the Netherlands. Although the `base lines' in these three regions around 1400 were in many respects similar, the path of development in the following centuries diverged markedly. Why was that? My argument will concentrate on the evolution of distinct forms of knowledge, the operation of transmission mechanisms within and between these three regions and the paramount role of underlying socio-political structures. Section one discusses the nature of the fluvial problems with which people in the three regions had to cope and compares the development of river management. How did people actually attempt to get unruly rivers under control ? The next section analyzes the differences in the development of knowledge about river hydraulics in the three regions and stresses the epistemic leap that took place in Northern Italy and the Netherlands in the seventeenth and eighteenth centuries. The origins of this transformation in knowledge in these European regions are discussed in section three. The fourth section, finally, seeks to relate

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Dodgen, *Controlling the Dragon. Confucian engineers and the Yellow River in Late Imperial China* (Honolulu 2001).

the differences in the development of knowledge to underlying socio-political structures. The conclusion will briefly address the question what the case of river hydraulics might say about the development of `useful' knowledge in Europe and China in general.

1. Controlling wild rivers

Through the ages the Yellow River has been notorious for the massive amounts of silt which it carries from the loess plateau in Northwest China to the sea, and for the wide seasonal fluctuations in its flow. During its traverse of the upland plain of Shaanxi and Shanxi, the river receives large quantities of yellowish mud, which it partly deposits on its bed in the lowlands of Henan, Hebei, Anhui, Jiangsu and Shandong and partly at its mouths in the gulf of Bohai (or formerly, in the Yellow Sea). The steady rise of the river bed, which in the past has proceeded at a rate of about 3 feet per century[3], frequently causes the river to overflow its banks and sometimes to seek new routes to the sea. In the late twelfth century, the Yellow river switched course to stream south, instead of north, of the Shandong peninsula, and in the mid-nineteenth century it changed back again to flow out in the gulf of Bohai. The troubles caused by the continued, massive sedimentation are aggravated by the sharp variations in the size and speed of the river's flow over the year. Sudden, heavy rainfall during the summer months can turn the sluggish stream overnight into a torrent, which can not easily be contained within its banks. Flooding by the Yellow River has been a regular occurrence throughout most of China's history. The problem of managing this river was since the early fifteenth century further complicated by the reconstruction of the Grand Canal, connecting the southern provinces with the capital Beijing, which crossed the Yellow River and included part of its lower course. The key issue was to find a way both to contain the Yellow River and to keep the junctions with the canal in operation. [4]

Whereas rivers in Northern Italy do not bring down as much silt as the Yellow River in China, nor show such violent fluctuations over the year, sedimentation and torrential flows nevertheless have caused serious problems, too, especially in the plains of the Veneto and the Emilia-Romagna, where numerous larger and smaller streams converge towards the Adriatic Sea. [5] In the lowlands of the Veneto, large amounts of silt carried by the Piave, Brenta, Musone, Sile and other rivers threatened to fill up the lagoon of Venice and its entrances, thus smothering the commercial lifeline of the Republic. The Adige at times conveyed such great quantities of water from the Alps that the river broke its banks and sought new courses in the low-lying lands of the Veneto. In the region to the south of the Po, hydraulic problems grew as the branch of this river called `Po Grande' between the thirteenth and sixteenth centuries received an ever larger share of the water, depriving the branches of the `Po of Ferrara' and the `Po of Primaro' of much of their inflow and thereby speeding up the process of silting. This obstructed the access to the port of Ferrara and made it harder to control the river Reno running from the Apennines along Bologna to the Po.

Like the coastal plains in Northern Italy, the Netherlands is at the receiving end of big rivers carrying a mass of water and silt from a mountainous hinterland to the sea. In this case, the usual problems of sedimentation and variations of the water flow over the year were compounded by incursions from the North Sea and by the interference between the rivers Rhine (entering the country from the East) and Meuse

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[3] Needham, *Science and civilisation*, 237.
[4] Flessel, *Der Huang-Ho*, 7-10, Elvin, R*etreat of the elephants,* 23-26*,* 128-132*,* Dodgen, *Controlling the Dragon*, 11-13,
[5] Salvatore Ciriacono, *Acque e agricoltura. Venezia, l'Olanda e la bonifica europea in età moderna* (Milan 1994) 138-139, 162-164, 196-201, C.S. Maffioli, *Out of Galileo. The science of waters 1628-1718* (Rotterdam 1994), 24-42-43, 156-158, 347, 371.

(entering from the South). The destruction of the Grote Waard polder southeast of Dordrecht by a disastrous storm tide about 1420 and the subsequent creation of a large, permanent water-logged area called the Biesbosch, led to an displacement in an upstream direction of the mouth of one of the branches of the Rhine, called the Waal, which increased the Waal's fall and thereby influenced the distribution of the water of the Rhine over its various branches. This distribution was further disturbed by a accidental diversion of the river's course around 1530 near the point where the Rhine entered the Netherlands.[6] During the sixteenth and seventeenth centuries, the distribution of the Rhine's water in fact became more and more skewed, with the effect that by 1700 some 90 % of all the water of the Rhine which entered the territory of the Dutch Republic near the fortress Schenkenschans, flowed into the river Waal, as against only 10 % into the Lek and the IJssel. The consequence of this disproportionate distribution was, that the water level in the Lek and the IJssel became so low (and silting increased to that extent) that shipping traffic was often seriously hindered and the military defenses of the Republic were gravely weakened, whereas the volume of water in the Waal grew so massively as to cause enhanced risks of flooding downriver. An even more complicated situation developed in the area between Gorinchem and Dordrecht, where the Maas first merged with the Waal into the Merwede at Loevestein, and the Merwede subsequently dispersed most of its water over the innumerable creeks of the Biesbosch. This peculiar combination of conditions on the one hand increased the risks of flooding and the formation of ice dams in wintertime

[6] M.K.E. Gottschalk, *Stormvloeden en rivieroverstromingen in Nederland*, vol.II (Assen 1975) 96, 100, vol.III (Assen 1977), 418. G.P. van der Ven, *Aan de wieg van Rijkswaterstaat. Wordingsgeschiedenis van het Pannerdens Kanaal* (Zutphen 1976), 26.

in the region of Gorinchem and on the other hand decreased the navigability of the river Merwede between the Biesbosch and Dordrecht.[7]

To protect lands along the rivers from flooding, a common defensive measure taken in all three regions was the building of levees, dikes or embankments. Levees appeared along the Yellow River from at least the time of the Warring States onwards and emerged in Nothern Italy and the Netherlands in the High or Late Middle Ages. Dredging as a means to combat silting started somewhat later. Mechanical dredgers spread in China from the time of the Song government onwards. Dredging engines cleared the canals of Venice since the sixteenth century. They appeared on the river IJssel in the Netherlands not long thereafter, too.[8]

In each of the three regions, offensive operations to control unruly rivers were undertaken as well. In the Yellow River basin, the most common method of managing the river from the late Song period until the late Ming was to subdivide its flow into various streams, by blocking outlets at some points and allowing it to pass at others. By the mid-1560s, the lower course of the Yellow River was said to consist of no less than sixteen channels.[9] In the late sixteenth century concerted efforts were made to solve the problems of river management in a radically different way, however, namely by re-unifying the river into a single course, and constricting its flow to a narrow channel ranged by a set of embankments, backed up by another set of dikes at some distance behind it (plus a number of spillways) to contain the overflow during periods of extremely high floods. The idea underlying this major

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[7] Van der Ven, *Aan de wieg van Rijkswaterstaat*,. 24-27, G.P.van der *Ven et al*., *Niets is bestendig... De geschiedenis van rivieroverstromingen in Nederland* (Utrecht 1995) 11-24.

[8] Dodgen, *Controlling the Dragon*, 16, Needham, *Science and civilisation*, 336-337, Ciriacono, *Acque e agricoltura*, 216, J. Nanninga Uiterdijk, `Een baggermachine van het jaar 1562', *Bijdragen tot de Geschiedenis van Overijssel*, X (189) 66-73, H. Conradis, *Die Nassbaggerung bis zur Mitte der 19. Jahrhunderts* (Berlin 1940) 24-27.

reconstruction, designed by the Imperial Commissioner for the Yellow River Pan Jixun, was to let the river scour its own bed by increasing the speed of the current. After a brief reversal of policy during the last decades of the Ming, Pan's strategy was resumed in the late seventeenth century and remained the principal model for projects of river control in the Qing period until the middle of the nineteenth century.[10]

River control in the coastal plains of Northern Italy to some extent followed the same pattern as in the basin of the Yellow River. The threat of flooding by the river Adige was in the early modern period met by the making of embankments, the building of overflow structures and the multiplication of the number of channels by which the water could find its way to the sea. Around Venice, major operations were undertaken to divert rivers to outlets outside the lagoon. A new channel for the river Brenta, for example, leading the river to the south of the lagoon, was constructed in the early seventeenth century. The Piave was in the 1640s diverted into the river Livenza and once the disastrous consequences of this project had become clear, in the 1680s redirected to a new mouth at the village of Cortellazo north of the lagoon.[11] To facilitate the reconstruction of the channels of the Po of Ferrara and the Po of Primaro, the river Reno was in 1604 provisionally diverted into a marshy area south of Ferrara. The unintended result was, that the Reno overflowed its banks, a large part of the plain between Ferrara, Bologna and Ravenna changed into a swamp and much agriculturla land seemed to be irretrievably lost. After much discussion and planning, the problem was in

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[9] Dodgen, *Controlling the Dragon* , 14, Elvin, *Retreat of the elephants*, 132-135.
[10] Vermeer, E.B. , `P'an Chi-hsün's solutions for the Yellow River problems of the late sixteenth century', *T'oung Pao* lxxiii (1987) 33-67, Dodgen, *Controlling the Dragon* , 18-22, Elvin, *Retreat of the elephants*, 135-140.
[11] Maffioli, *Out of Galileo*, 62, 156-158, 371, Ciriacono, *Acque e agricoltura*, 162-168.

the second half of the eighteenth century eventually solved by redirecting the Reno into the Po of Primaro.[12]

In the Netherlands, extensive works to solve the nagging problem of the distribution of water of the river Rhine over its three major branches Waal, Lek and IJssel were carried out in the eighteenth century. Piecemeal engineering to remedy the situation, which began around 1600, did not result in any durable improvement. In the end the problem was permanently solved by the making of some drastic changes in the river bed between Schenkenschans and Arnhem. The strategy consisted of diverting the course of the river and constricting its flow. The construction of the *Pannerdens Kanaal* (1706-1708), the *Bijlands Kanaal* (1776) and a massive groyne at the point of separation between the Waal and the *Pannerdens Kanaal* (1784) directed a larger flow of water into the Nederrijn instead of into the Waal. The flow from the Nederrijn into the IJssel was increased by the making of an intersection of the Pleij headland between Arnhem and Westervoort in 1773-1775. The net result of these adaptations was, that the distribution of of the water of the Rhine over its three branches by 1790 had changed to the extent that 6/9 of the total volume streamed into the Waal, 2/9 into the Lek and 1/9 into the IJssel.[13] The hydraulic works aimed at improving the navigability of the Merwede near Dordrecht, started in 1736, were discontinued a few years later, however, when the damming of the Biesbosch led, unexpectedly, to such a rise in the river's water level that the island itself on which the city

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[12] Maffioli, *Out of Galileo*, 42-44, idem, `Italian hydraulics and experimental physics in eighteenth-century Holland. From Poleni to Volta', in C.S. Maffioli and L.C. Palm (eds.), *Italian scientists in the Low Countries in the XVIIth and XVIIth centuries* (Amsterdam 1989), 243-275, p.245.

[13] Van der Ven, *Aan de wieg van Rijkswaterstaat,* chapters II, III and VI, A.Bosch and G.P. Van der Ven, `Rivierverbetering', in: H. *Lintsen et al.* (eds.), *Techniek in Nederland. De wording van een moderne samenleving 1800-1890* (Zutphen 1993) , 103-127.

was built ran the risk of being inundated.[14] Wholesale reconstructions of the lower courses of the rivers Waal and Meuse were not carried out until the second half of the nineteenth century.

2. Differences in the development of knowledge about river hydraulics

All these efforts to control the flow of rivers in China and in Europe between c. 1400 and 1800 had in common that they were grounded in a corpus of knowledge about hydraulic phenomena, which was at least partly recorded in manuscript or print. It was in part verbalized or visualized. River management at this time in all three regions thus involved more than `tacit' knowledge. Yet, the path of development of knowledge about water control was significantly different.

To analyze these differences, we can usefully apply some distinctions employed by Joel Mokyr in his *Gifts of Athena* Mokyr distinguishes two types of `useful' knowledge : `propositional' knowledge, referred to as `Ω- knowledge', and `prescriptive' knowledge, denoted as `λ-knowledge'. The first type of knowledge - `what'-knowledge - encompasses all knowledge about natural phenomena and regularities. It can assume two forms, Mokyr explains: one `is the observation, classification, measurement, and cataloguing of natural phenomena', the other is `the establishment of regularities, principles and "natural laws" that govern these phenomena and allow us to make sense of them'. `λ-Knowledge', by contrast, is `how' knowledge: it consists of techniques, i.e. `executable instructions or recipes' for ways to manipulate nature.[15]

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[14] Paul van den Brink, *`In een opslag van het oog'. De Hollandse rivierkartografie en waterstaatszorg in opkomst, 1725-1754* (Alphen aan den Rijn 1998), 42-43, 68-87.

[15] Joel Mokyr, *The Gifts of Athena. Historical origins of the knowledge economy* (Princeton/Oxford 2002), 4-5, 10.

What is most remarkable in the Chinese case, is the predominance of a particular form of `propositional' knowledge up to the nineteenth century. Chinese hydraulic experts could draw on a vast stock of `descriptions, classifications, measurements and catalogues' of phenomena related to the Yellow River which had accumulated over the years. Yet, there seems to have been certain limits to the evolution of this knowledge. As Randall Dodgen pointed out, technical training of these hydraulic experts was approached in a purely `ad hoc' manner. Hydraulic engineers acquired their knowledge `on the job from subordinates or from the writings of their predecessors'. Publication of books on river management was highly valued, to be sure. `Those who wrote knowledgeably were lionized, and their works became the canons of later generations of hydraulic officials' [16]. The first survey of waterways that has survived to the present day has been dated by Needham to the third century AD. The number of books in this field sharply increased from the time of Song dynasty onwards. Half a dozen works wholly or partly devoted to river control are known from the eleventh and twelfth centuries.[17] The great, classic compendia were produced in the late Ming and early Qing dynasties. Pan Jixun's *He Fang Yi Lan* (An overview of river defense), composed in 1590, was still regarded as a `standard guide' in the late eighteenth century. Jin Fu's *Zhi He Fang Lue* (Methods of river control), presented to the court in 1689 but not printed until 1767, `long exerted great authority'. Many more works followed in the eighteenth century. [18] What appears to have been lacking, though, was the development of a kind of abstract reflection on the subject. These writings on river management are usually described as collections of recipes, procedures, regulations and work rules, based on accumulated

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[16] Dodgen, *Controlling the Dragon*, 7-8, 22.
[17] Needham, *Science and civilisation*, 324-325.
[18] Dodgen, *Controlling the Dragon*, 20, 178, Needham, *Science and civilisation*, 325-326.

experience, rather than as theoretical treatises.[19] None of them seems to have presented a general theory on the motion of fluids, which might - in Mokyr's terms - have served as an `epistemic base' for techniques of water control. The second form of propositional knowledge, in short, did not come about.

A similar observation, interestingly, has once been made about the Netherlands around 1770. Inspector-General of the Rivers Christiaan Brunings stated in 1771 that the Dutch possessed an abundance of `practical knowledge' about hydraulics, but that `the reflective part of these sciences' had hardly been cultivated. [20] Although this remark was a bit unfair to the hydraulic expert Cornelis Velsen, who had published a theoretically ambitious treatise about rivers and river management twenty years before[21], it was generally true in so far that nearly all writings on this subject composed before the 1770s were either of the prescriptive sort (instructions how to deal with specific hydraulic problems) or of the propositional category of observations, classifications and measurements of natural phenomena. By the end of the seventeenth century, it had become a normal practice among surveyors or engineers, for instance, to cast proposals to solve the problem of the distribution of water of the Rhine in the form of written memoranda, often accompanied with maps, which were based on rules derived from experience as well as a series of soundings and careful observations of the situation on the spot.[22] From the 1720s onwards, the surveyor Nicolaas Cruquius brought this approach still a major step further, by grounding every proposal, advice or statement about hydraulic matters on an extensive base of

[19] Flessel, *Der Huang-ho*, 1, Needham, *Science and civilisation*, 325-329, Vermeer, `P'an Chi-hsün's', 35.

[20] Quoted in P. van Schaik, *Christiaan Brunings 1736-1805. Waterstaat in opkomst* (Zutphen 1984) 78.

[21] Cornelis Velsen, *Rivierkundige verhandeling, afgeleid uit waterwigt en waterweegkundige grondbeginselen, en toepasselijk gemaakt op de rivieren den Rhijn, de Maas, de Waal, de Merwede en de Lek* (Amsterdam 1749).

measurements of hydraulic variables and making as much use as possible of cartographic aids to record and analyze the resulting data. Other experts soon followed his example. [23]

The difference between the Netherlands and China was, that the corpus of knowledge later also grew to include `propositions' of Mokyr's second form, viz. statements about `regularities, principles and "natural laws". This beginning of this phase almost exactly coincided with Brunings' critical observation about the lack of reflective power in Dutch hydraulic science. Scientific societies began to stimulate thinking about theoretical aspects of hydraulics from the 1770s onwards. The very first volume of transactions published by the *Bataafsch Genootschap der Proefondervindelyke Wijsbegeerte* in 1774, for example, opened with a treatise running to over 200 pages by a medical doctor Lambertus Bicker about the basic principles of river management and their application in the case of the Dutch Republic.[24] There arose a lively public debate on issues related to river control, in which the participants did their best to bolster their positions with theoretical arguments. In contrast with China, education about hydraulic matters did not remain confined to training on the job or to the individual perusal of writings of famous predecessors. Johan Frederik Hennert, professor of mathematics, astronomy and physics at the University of Utrecht, began to offer `public lectures on the course of rivers' from the 1780s onwards. At the University of Leiden, hydraulics was taught by Jan Frederik van Beeck Calkoen, who held the chair of natural philosophy since 1799.[25] Pupils at the privately endowed Fundatie van Renswoude in Delft who chose to become a hydraulic

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[22] Van der Ven, *Aan de wieg van Rijkswaterstaat*, 64-102.
[23] Van den Brink, `*In een opslag van het oog'*, chapters 1 and 4.
[24] L. Bicker, `Rivierkundige grondwaarheden bijzonderlijk toegepast op de rivieren onzes lands tot herstelling derzelven', *Verhandelingen van het Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte*, I (1774) 1-210.
[25] Maffioli, `Italian hydraulics, 250, *Nieuw Nederlandsch Biografisch Woordenboek*, vol.IX, 123-124.

engineer, received at that time both a training `on the job' and a thorough grounding in mathematics and physics from teachers at the institute itself.[26]

Northern Italy preceded the Netherlands by a wide margin, however. The change in the nature of `propositional' knowledge, which became manifest in the Netherlands from the 1770s onwards, began south of the Alps some 150 years earlier. This transformation has been described by Cesare Maffioli as the rise of the `Science of waters'. Like China, Northern Italy - in addition to an oral culture of transmission of knowledge[27] - boasted a long tradition of writings about rivers and river management. Studies about the effects of the outfall of rivers on the lagoon of Venice, for example, started to appear from the mid-fifteenth century onwards. The views of engineer Christoforo Sabbadino, laid down around 1550 in his *Discorsi per la laguna di Venezia* and *Instruzione … circa questa laguna*, acquired the same paradigmatic status with generations of hydraulic experts in the Venetian Republic as the works of Pan Jixun and Jin Fu in China.[28]

The novelty in the Italian case was the emergence of a theory on river hydraulics. This `theoretical turn', which started in the Papal States in the 1620s and reached the Venetian Republic a few decades later, essentially consisted, as Maffioli put it, in reshaping the existing tradition of fluvial hydraulics `in a geometric fashion, around the basic concept of velocity', in order to obtain more reliable knowledge about the motion of waters in rivers.[29] Its founding father was a Benedictine monk who taught mathematics at Pisa and Rome, Benedetto Castelli. Castelli's treatise *Della misura dell'acque correnti* with its companion piece *Demostrazioni*

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[26] E.P. De Booy and J. Engel, *Van erfenis tot studiebeurs. De Fundatie van de vrijvoruwe van Renswoude te Delft* (Delft 1985) , 72-81, 105-112.
[27] Ciriacono, *Acque e agricoltura*,. 142-143.
[28] Ciriacono, *Acque e agricoltura*, 148-153, 163.
[29] Maffioli, *Out of Galileo*, 419-420.

geometriche della misura dell'acque correnti, published in Rome in 1628, for the first time approached the phenomenon of the behaviour of rivers with the full panoply of definitions, suppositions, propositions and demonstrations, which was known as the 'geometric' way.[30] This 'geometrical' approach of river hydraulics was in the following decades by the combined efforts of a host of other Italian scholars, including Evangelista Torricelli, Geminiano Montanari, Domenico Guglielmini, Guido Grandi, Bernardino Zendrini and Giovani Poleni, extended into an elaborate corpus of general concepts, principles and laws relating to the motion of waters. Maffioli observed that around 1700 many Italian contributions to the European scientific debate `were directly or indirectly related to the science of waters'.[31]

'Science of waters' by then had received recognition as an autonomous academic discipliine by the establishment of a chair of 'hydrometry' at the university of Bologna in 1694. At the university of Padua, `showing a mastery in the subject of waters' was around 1710 `a particularly suitable qualification' for an appointment to the chair of mathematics. At the end of the seventeenth century, hydraulics was included in the teaching of mathematics in several Jesuit colleges in the Po valley, too, and sometimes even special courses on the subject of waters were provided. University-educated mathematicians from about 1680 onwards began to instruct and examine in Venice and Bologna candidates for local offices (*proti* and *periti*) in water control.[32] As in the Dutch Republic a few decades later, teaching about hydraulics was at this time in Northern Italy clearly no longer confined to training on the job.

[30] Maffioli, *Out of Galileo*, 41, 45-51.
[31] Maffioli, *Out of Galileo*, 14, and Tables 1.1. and 1.2.

3. Connections within and between regions

What were the origins of this epistemic leap in river hydraulics ? The Dutch case is simpler than the Italian one. The change in the composition of propositional knowledge about fluvial hydraulics that became manifest in the course of the eighteenth century was the result of a confluence of two developments: increased contacts between the worlds of academic learning and hydraulic engineering and a growing influence from the Italian model.

The increased contacts between the worlds of academic learning and hydraulic engineering in the eighteenth century were exemplified by the fact that all the leading hydraulic experts in this period - Cruquius, Velsen, Melchior Bolstra and Dirk Klinkenberg – did not only receive a training on the job, but also studied for a while at the university of Leiden. Cruquius was matriculated in 1717 as a student in medicine, Velsen in 1727 and Bolstra in 1732 as students in surveying at the *Duytsche mathematicque* (an adjunct of the university, providing vernacular courses for surveyors and engineers), Klinkenberg in 1751 as a student in astronomy and geometry. [33] Leiden professors, on their part, were since the 1720s repeatedly asked by the States of Holland to act as advisors on projects for river improvement. After 1754 this relationship assumed a more institutional form by the appointment of Klinkenberg's Leiden teacher, professor Johan Lulofs, as Inspector-General of the Rivers in Holland. [34] The results of the increased contacts between the worlds of academic learning and hydraulic engineering can be traced in the work of experts such as Cruquius or Velsen. Cruquius's comprehensive, quantitative and highly systematic approach to problems of river

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[32] Maffioli, *Out of Galileo*, 247-249, 276-277, 337, 426.

[33] Karel Davids, `Universiteiten, illustre scholen en de verspreiding van technische kennis in Nederland, eind 16e – begin 19e eeuw ', *Batavia Academica*, VIII (1990) 3-34, p. 19.

[34] Van der Ven, *Aan de wieg van Rijkswaterstaat*, 266-271, Van den Brink, `*In een opslag van het oog',* 32, 51-52, 62-64, 67-69, 73-75, 138-140.

improvement (and other issues in hydraulic technology) was influenced by, among others, the Leiden professors Herman Boerhaave, the guiding star in European medicine in the first half of the eighteenth century, and Willem Jacob 's Gravesande, who after his accession to the chair of mathematics and astronomy in Leiden in 1717 quickly became the foremost champion of Newtonian science on the Continent.[35] Cornelis Velsen's *magnum opus* on river management published in 1749, *Rivierkundige verhandeling*, betrayed not only an extensive knowledge gained from practical experience in grappling with the problems of the Merwede, the Waal and the Lek, but also a thorough acquaintance with general publications on hydrodynamics and with Newtonian science as expounded by 's Gravesande and his colleague Petrus van Musschenbroek. [36] Engineers thus increasingly became carriers of `propositional' knowledge about fluvial hydraulics themselves.

Exchange between academians and engineers became even more intensive in the second half of the eighteenth century as new channels of communications were opened by the rise of scientific societies like the *Hollandsche Maatschappij* in Haarlem and the *Bataafsch Genootschap* in Rotterdam. Membership of these societies were not only recruited from the ranks of academic scholars and amateur-scientists or patrons from the political elite, but also from the group of distinguished or promising experts in various fields of technology, such as – in the domain of hydraulic engineering after 1750 – Dirk Klinkenberg, Jan Noppen, Christiaan Brunings and Jan Blanken Jansz.. Their meetings, prize questions and publication series created even more opportunities for the spread of various forms of propositional knowledge.

The other development that conduced to the transformation of 'Ω'-knowledge in the Netherlands, was the growing influence from the Italian

[35] Van den Brink, *`In een opslag van het oog'*, 13-18, 24-25.
[36] Velsen, *Rivierkundige verhandeling*,16-17, 26-27.

model after about 1720. This influence was transmitted both through the mobility of people and by the spread of knowledge stored in printed works. The Italian engineer and founder of the Institute of Arts and Sciences in Bologna, Luigi Fernando Marsigli, for example, who was a long-time correspondent of Boerhaave, resided for over a year in Holland in 1722 and 1723. During his stay, he made several trips along the hydraulic `sights' in the coastal provinces in the company of Boerhaave and Cruquius. It was the Italian visitor who inspired Cruquius to introduce curves of equal depths in river maps abour 1730, which became a normal feature in the cartography of rivers in the Dutch Republic ever since.[37] Another Italian hydraulic scientist of note, Paolo Frisi, who held the chair of mathematics and philosophy in Milan, kept up enduring contacts with Dutch colleagues after a journey to the Netherlands in 1766.[38] A Dutch translation of a short treatise by Frisi on the division and confluence of rivers, which was partly based on theoretical insights and practical experiences gained by experts in Italy as a result of the long-drawn out debate on the regulation of the river Reno, appeared in the transactions of the *Hollandsche Maatschappij* in 1773.[39] Dutch academians and engineers also learned about advances in hydraulic phenomena in Italy simply by studying their books. 's Gravesande, for instance, was thoroughly acquainted with the work of, among others, Guglielmini, Grandi and Poleni. Theoretical insights and methods developed by Guglielmini and Poleni served as a source of inspiration to Hennert and Brunings in the 1780s.[40] When his regular bookseller failed him, Brunings

[37] Van den Brink, `*In een opslag van het oog'*, 59, A. McConnell, `A profitable visit: Luigi Fernando Marsigli's studies, commerce and friendships in Holland, 1722-23', in Maffioli and Palm (eds.), *Italian scientists*,, 189-207.
[38] Maffioli, `Italian scientists', 257-258.
[39] `Berigt aan de Hollandsche Maatschappij der Weetenschappen van .. Paulo Frisi nopens de verdeeling en zamenloop der rivieren, *Verhandelingen uitgegeeven door de Hollandsche Maatschappij der Wetenschappen*, XIV (1773), 112-130.
[40] Maffioli, `Italian scientists', 238, 252-253, Van Schaik, *Christiaan Brunings*, 12-16, 56-58, Christiaan Brunings, `Antwoord op de vraag..: Is de algemeen grondregel der

did his utmost best to get hold of Italian publications about hydraulics through his connections in the literary world.[41]

The breakthrough in Italy in the second quarter of of the seventeenth was to some extent related to the indigenous tradition of hydraulic engineering that had flourished since the Renaissance. Benedetto Castelli and his followers could build on the accumulated knowledge of generations of hydraulic practitioners. But this was only part of the story – if it had been the whole story, it would be very puzzling indeed why a similar leap was not accomplished in China. Another part of the story was, that the new approach was from the start also clearly contrasted with the tradition of the *periti* and *proti.* Champions of the `science of waters' claimed that their `geometrical way of thinking' would generate more reliable, and therefore more useful, knowledge than the empirical approach of the practical experts. The origin of this theoretical turn should, according to Maffioli, be sought, in the extension of the Galileo's mathematical approach to nature, which was initially developed to study the motion of solid bodies, to the domain of the motion of waters. The `new science' of Galileo thus acquired a wider field of application. And Castelli was in an unique position to forge the link, because he was a hydraulic consultant of the papal court, a mathematics professor as well as one of the closest collaborators of Galileo himself.[42] This does not imply that the new departure in river hydraulics consisted entirely in the transplantation of Galilean concepts and methods. Later generations of scholars made important additional contributions to the field by applying new intellectual tools such as the calculus and refining the use of experiments.[43] The key change, in retrospect, was fusion of insights from

hydrometrie .. insgelyks toepasselyk op de zeeboezems, gelyk het Ye ...', *Verhandelingen uitgegeeven door de Hollandsche Maatschappij der Wetenschappen*, 24 (1787), 1-58.

[41] Van Schaik, *Christiaan Brunings*, 77.

[42] Maffioli, *Out of Galileo*, 37-51, 418-423

[43] Maffioli, *Out of Galileo*, parts III and IV.

two different traditions of knowledge, which provided the field of river hydraulics eventually with a more extended, varied set of propositions about nature than the *proti* and *periti* alone would have been able to muster.

While the change in `propositional' knowledge about river hydraulics in the Netherlands was plainly connected with the previous transformation in Northern Italy, no relationship in this field can be established between the two European regions and China in the period up to 1800. Needham's observation about Linqing's compendium *Hegong Qiju Tushuo* (An illustrated guide to tools used in river work) published in 1836 that it was `very little indebted to Western influences'[44], suggests that the changes in Europa by then still had not exerted any impact on China. Influence in the other direction was apparently non-existent either. True, thanks to the Jesuits and the Dutch East-India Company, Italians and Dutchmen were in the seventeenth century certainly aware of hydraulic achievements in China. But European writers on China generally had a keener eye for transport canals than for river management (as Needham doubtless would have predicted) and they were much more interested in describing artefacts as such than studying the ideas and practices on which the construction of hydraulic works was based. Father Martinus Martinius and merchant Johan Nieuhoff waxed enthusiastic about the Grand Canal and its locks, but they did not write about current techniques for controlling the Yellow River. [45]

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[44] Needham, *Science and civilisation*, 329.

[45] Athanasius Kircher S.J., *China .. illustrata* (Amsterdam 1667) 215, 219, Martinus Martinius S.J., *Novus atlas Sinensis* (Amsterdam s.a..) 84, Johan Nieuhoff, *Beschryving van 't gezantschap der Neêrlandsche Oost-Indische Compagnie aan den Grooten Tartarischen Cham den tegenwoordigen Keizer van China* (Amsterdam 1665) I, 112, II, 94; Nieuhoff, II, 104, only mentioned the redirection of the Yellow River many centuries before.

4. Knowledge and socio-political structures

Finally, we have to address the question how these differences in the development of knowledge about river hydraulics can be explained. Why did China not witness the same epistemic leap as Northern Italy and, later, the Netherlands ? If the theoretical turn in Italy indeed, as Maffioli put it, essentially consisted in reshaping the existing tradition of fluvial hydraulics `in a geometric fashion, around the basic concept of velocity', part of the explanation of its absence in China may lie in the circumstance that `deductive geometry in the Western sense' as such was lacking, too. `Chinese mathematics' after all `rather focused on arithmetical and algebraic procedures'. [46] Yet, there must have been more to the matter than the mere absence of particular intellectual tools. One of the striking features of the Chinese case is that both `prescriptive' and `propositional' knowledge about fluvial hydraulics was apparently entirely produced *within* the central bureaucracy that was concerned with controlling the Yellow River. There were no complementary, or rival, sites of knowledge production and distribution about river hydraulics outside this central institution.

River management formed part of the field of activity of the central state in China from a relatively early date, compared to the Netherlands or Northern Italy. A central agency to coordinate efforts to control the Yellow River, the Office of Rivers and Canals, was established already in the middle of the eleventh century, `The centralization of the management of the resources destined for the handling of the river was shown indispensable once hydraulic operations, whose costs could no longer be borne at the local level, appeared as a new charge in the budgets controlled by the central administration', Christian Lamouroux has

[46] H.Floris Cohen, *The Scientific Revolution. A historiographical inquiry* (Chicago 1994) 440, followin Joseph Needham, *The Grand Titration. Science and society in East and West* (London 1969) 44.

observed.[47] In the following centuries the state stepped up the input of resources for the maintenance of the control system of the Yellow River, especially since the management of the river from the 1410s onwards was closely connected to the upkeep of the Grand Canal, which served as the main artery for the supply of foodstuffs and other goods to the capital and army in the North. The north-south route of the Canal namely `included a portion of the lower course of the Yellow River, a fact that complicated both canal transport and river management', according to Dodgen. [48] Because of its vital importance for the preservation of the state itself, the maintenance of the Yellow River and Grand Canal system became one of the principal preoccupations of the imperial bureaucracy. The efforts to keep the control system intact in spite of the growing problems caused by the steady accumulation of silt left by the river, were not abandoned until the middle of the nineteenth century, when the Qing state `could no longer afford to keep (it) operating'. [49] The technical management of the system was undertaken by an ever expanding hydraulic bureaucracy, assisted by provincial officials for the organisation and supervision of maintenance and repair jobs at a local level. The top positions in this bureaucracy were in the Qing period increasingly filled with people who had risen through the ranks and thus had acquired a high degree of specialization in river hydraulics.[50] This elaborate bureaucratic structure did allow the emergence of divergent views about ways to solve the problems of managing the Yellow River - witness the intense debates and dramatic shifts in policy in the time of Pan Jixun at the end of the sixteenth century.[51] But the different evolution in European

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[47] Christian Lamouroux, `From the Yellow River to the Huai. New representations of a river network and the hydraulic crisis of 1128', in: Elvin and.Liu (eds.), *Sediments of time*, 545-584, pp.559-560.
[48] Dodgen, *Controlling the Dragon*, 15.
[49] Dodgen, *Controlling the Dragon*, 159.
[50] Dodgen, *Controlling the Dragon*, 22-24.
[51] See note 10.

regions, which I will discuss below, strongly suggests that the *de facto* monopoly on knowledge about river hydraulics held by the imperial bureaucracy in China may also have hampered the rise of new forms of propositional knowledge.

Centralization of river management in the Netherlands, by contrast, proceeded extremely slow. River defense for a long time rested almost exclusively in the hands of local or regional water boards. It was not until the end of the seventeenth century that provincial governments began to play a more active role in efforts at river control and the degree of cooperation and coordination between individual provinces in this sphere of activity gradually increased. Still, provincial authorities exerted only a limited influence on the technical solutions that were chosen in each particular case. When the interests of the various parties involved diverged too much, and no party possessed a clear ascendancy over the others (financially or otherwise), the result could be a complete stalemate. This was what eventually occurred, for instance, in the case of attempts to control the river Merwede between Gorinchem and Dordrecht in the 1730s. The difference of interest between the cities in Holland that had a stake in the solution of the problem (Gorinchem, Dordrecht, Rotterdam, Schiedam, Delft and Brielle) in the end proved too large to be bridged by some ingenious, laborious compromise.[52] As a result, the development of technical means and devices to cope with the issue in this particular case remained stuck for years as well. The tardiness of active management at a higher level than that of local or regional water boards is also reflected in the fact that the leading province of the Dutch Republic, Holland, did not begin to allocate substantial sums of money for investments in river control on a regular basis until the late 1730s. More than three-quarters of the expenses for the works of redirecting the river Rhine were up till then paid by Gelderland and Utrecht. The largest projects, the construction of the *Bijlands Kanaal* and of the huge groyne at the point of separation between the Waal and the *Pannerdens Kanaal* in 1776 and 1784 respectively, were for more than 70 % financed by the province of Holland, however.[53] A central bureaucracy in river management in the Netherlands did not come into being until the very end of the eighteenth century. The Dutch counterpart of the Office of Rivers and Canals, *Rijkswaterstaat*, was finally established in 1798. [54]

Expertise on river hydraulics in the Netherlands accordingly showed a lower degree of institutional concentration than in China. Producers and distributors of knowledge on this subject could be found at a variety of places. Apart from `independent scholars' such as Christiaan Huygens and Johannes Hudde, who were in the 1670s and 1680s occasionally asked for advice by the provincial government of Holland, the array of experts also included small groups of surveyors or engineers employed by provincial administrations, regional water boards or urban governments and a number of professors at the universities of Leiden and Utrecht. The relative lateness of centralization in river management, plus this diversity in the social and institutional basis of knowledge on fluvial hydraulics, allowed a smooth adoption of the `Italian model' after about 1720, There was not some countervailing power from a rival tradition of knowledge. The timing of this shift in knowledge itself was largely determined by the growing interference of the provincial government of Holland and the powerful water board of Rijnland with the field of river management, and by the increased interest among scholars at institutes

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[52] Van den Brink, *`In een opslag van het oog'*, chapter 3.

[53] W.Fritschy and R.Liesker (eds*.), Gewestelijke financiën ten tijde van de Republiek der Verenigde Nederlanden, vol. IV Holland (1572-1795)* (The Hague 2004) 454-455, Van der Veen, *Aan de wieg van Rijkswaterstaat*, 363.

[54] A. Bosch and W. van der Ham, *Twee eeuwen Rijkswaterstaat 1798-1998* (Zaltbommel 1998).

of higher learning, which became manifest in the second quarter of the eighteenth century, in studying practical, technical problems. [55]

The unique feature of the North Italian case, I would suggest, was a combination of a relative precocity in the bureaucratic organisation of river management with a high diversity in social and institutional basis of knowledge on fluvial hydraulics. Hydraulic administrators appeared relatively early, but the production and distribution of knowledge on the subject was fairly dispersed. A monopoly in this field did not exist. This special combination of elements effected on the one hand that a novel form of `Ω'-knowledge could emerge earlier in Northern Italy than in the Netherlands, but implied on the other hand that there was a greater need for reasoned (or rhetorical) justification of this new approach to old problems.

Hydraulic offices could be found at an early date in several states and cities in Northern Italy. In Venice, for instance, a magistracy for the supervision of canals was instituted in 1224. A *Magistrato all' Acqua,* responsible for handling all hydraulic problems, was established in 1501.[56] Another office, charged with taking care of the river Adige, was erected in 1677, with branch offices in Verona and Padua. The managers of these boards, who were members of the Venetian patriciate, could call on a small staff of technical experts, called *proti*.[57] Bologna had a hydraulic board, too, called the *Assunti* to the waters, who were recruited from the Senate. These *Assunti* likewise received assistance from a staff of practical experts, the *periti*. Another post, superintendent of the waters around the city, was established in 1686. [58] Knowledge on river hydraulics did not remain confined to these special offices concerned with water

[55] Davids, `Universiteiten', 11-23.
[56] Ciriacono, *Acque e agricoltura*, 140, Frederic C. Lane, *Venice. A maritime republic* (Baltimore 1973), 16
[57] Maffioli, *Out of Galileo*, 276-277.
[58] Maffioli, *Out of Galileo*, 172, 181-182.

control, however. Other sites of knowledge production and transmission in the seventeenth century arose at Jesuit colleges and universities. It was at these institutes for higher learning, which were not dependent on the old-established hydraulic offices, that the `theoretical turn' in fluvial hydraulics first occurred. *Proti* and *periti* were naturally neither overjoyed by its appearance nor quickly convinced of its use.

This rise of these rival centres of knowledge was apparently the outcome of three parallel developments. One of the driving forces was the growing competition for students between the university of Bologna and Jesuit colleges as well as other institutes of higher learning in the Papal States. Faced with a serious crisis caused by the diminishing attractiveness of the local university to foreign students and the local nobility, the municipal government of Bologna (as supervisor of this institution) actively welcomed innovation in the curriculum in the later seventeenth century. At the same time, the new approach in hydraulics could also make headway at the state university of the Venetian Republic in Padua, thanks to the support of the Venetian patricians, who set great store on the knowledge of the newly risen `scientists of the waters' as an alternative source of expertise to the traditional lore of technical practitioners.[59] For scholars themselves, employment at a university became more attractive as an avenue to make a career in science, as opportunities for patronage from princely courts declined. In that sense, too, Italian scholars after Galileo struck out into a new direction.[60]

Conclusion

This paper has compared the development of knowledge on river hydraulics in three regions in Asia and Europe: the Yellow River basin,

[59] Maffioli, *Out of Galileo*, 132-135, 243-249, 274-277
[60] Maffioli, *Out of Galileo*, chapter six and 422-428.

the coastal plains of Northern Italy and the Rhine delta in the Netherlands. The clusters of knowledge on this subject were not related to any sort of industrial activity. None of the three regions was in the forefront of the technological advance that made possible the rise of modern industry. Disparities in the evolution of knowledge on this subject between the three regions do not explain the coming of the Great Industrial Breakthrough, or the lack of it. Yet, tehse disparities are nevertheless relevant for the understanding of the Great Divergence between China and Europe because they point to differences in the process of knowledge creation and transmission itself and because they relate to a field of knowledge that in the eyes of contemporaries - witness the growing input of money, manpower and materials - was obviously eminently `useful'. Knowledge on river hydraulics was in each of these three regions considered to be highly important for the protection of society against natural disasters and threats from external human enemies, for the maintenance of wealth and for the preservation of state institutions and political power.

This comparison between the three regions has showed that the evolution of the corpus of knowledge was, up to a point, quite similar. All three regions saw the emergence of sets of both prescriptive and propositional knowledge which on the one hand formed the basis for technical manipulations of the natural environment and on the other hand, through feedback mechanisms, grew by the incorporation of observations and experiences accumulated in the actual practice of water control. But the developments diverged in the nature of the propositional knowledge that was created and transmitted. Whereas Northern Italy and later the twitnessed an epistemic leap from `observations, classifications, measurement and cataloguing of natural phenomena' to another form of propositional knowledge, namely `the establishment of regularities, principles and “natural laws”', China did not experience a corresponding theoretical turn in river hydraulics.

This variation in development between the Yellow River basin and the two European regions is for three reasons significant for the comparison between China and Europe at large. First of all, it points to a vital difference in the way that knowledge creation and transmission worked at a cognitive level. The `epistemic leap' in the European regions had its origins in the grafting of a mathematical (`Galilean') approach to nature onto an existing tradition of engineering. An existing corpus of knowledge was reinterpreted from a new angle of vision. The combination of `new science' with `old practice' thus transformed the nature of `useful' knowledge. The pattern of geographical diffusion of this transformation moreover shows that cognitive innovations, once achieved in one region, thanks to existing cross-border cultural networks, could fairly easily and at low cost be transmitted to other parts in Europe (when the local conditions for their reception were in place). Finally, there was a political dimension to this transformation in knowledge. The cognitive innovation in the regions in Europe discussed in this paper was made possible by the circumstance that the creation and transmission of knowledge was not confined to a niche of technical practitioners in a bureaucratic organization, but was spread over a variety of sites, which could serve as a base for different, and sometimes competing, groups of experts. These alternative sites for the production and distribution of knowledge included – but not necessarily coincided with – universities. Both in Northern Italy and in the Netherlands universities were during much of the seventeenth and eighteenth centuries important centres for the creation and transmission of `useful' knowledge at large – not just knowledge in natural philosophy, medicine or law. And the impetus for the growing interest in the field of river hydraulics at institutes for higher learning, I have pointed out, came both from scholars themselves and from the demand exerted by public authorities.