THE LEGACY OF THE ITALIAN NATURALISTIC HYDRAULICS SCHOOL

CHIARA TOSCANI

Alexandre Koyré defined the 17th century as a transitional historical age – *From the Closed World to the Infinite Universe* – in which scientific disciplines became increasingly more defined in their epistemological structure (Koyré 1957). The birth of modern scientific disciplines prompted an increasing dismissal of the humanistic approach to knowledge which was previously prevalent. Philosophical, ethical, and artistic thought was shunned in favour of disciplinary specialization which could provide an axiomatic model for interpreting natural phenomena. As explained by Stephen Edelston Toulmin, a refusal "of every particular knowledge in favour of the universal one" was articulated, and any kind of unofficial or impure empirical approach slowly came to be overshadowed (Latour 2013, p. 7).

In the hydraulic discipline, and in the work of the protagonists who continue to explore the inherent fragility of the Italian landscape, the beginning of a bifurcation between a purely mathematical approach and broader forms of knowledge can similarly be discerned. The investigations of the first experts, such as Venetian *proti*, Marco Cornaro, Cristoforo Sabbadino, and others, were followed by Benedetto Castelli's *Discourse of the Mensuration of Running Waters* written in 1628. It provided a first understanding of water movement in rivers through a scientific mathematical approach. In this sense, this work cannot only be viewed as the first and foundational Italian hydraulic treatise, but also as the catalyst for this split.

The Italian scenario, however, did not manifest this bifurcation as sharply and definitively. Instead, a tension between closed and infinite worlds was vivid for a long time. Treatises incorporating a broader system of knowledge into a compendium of multitudes of knowledge, empirical interpretations, informal and local practices, and technical solutions regarding water phenomena have continued to be valuable sources of information. Among them, *Della scienza et dell'arte del ben regolare le acque,* written around the same years as Castelli's text by Giovan Battista Aleotti, is considered the first systematic and dedicated Italian attempt into hydraulics and water management.

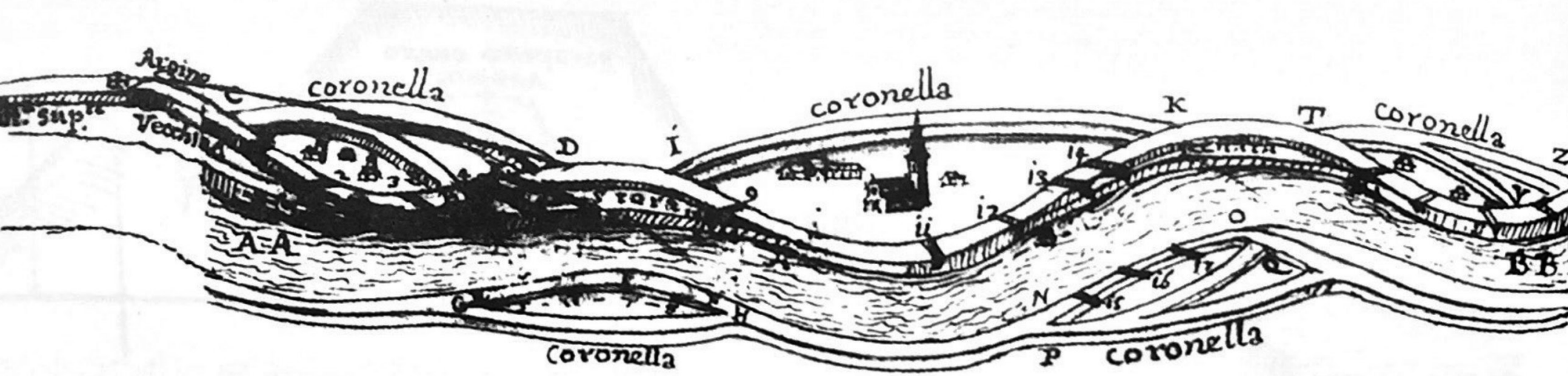
The legacy of the unique approach of Aleotti can be recognized in the particular characteristics of the Italian naturalistic hydraulics school, which was vital until the 19th century, when it was gradually swept away by technological advances and, above all, by French hydraulic school's approach, which was entirely centred on mathematical approaches.

However, according to Giulio De Marchi,

> in addition to hydraulics, which is mathematics but which we prefer to refer to as physics, there is also natural hy-

In this drawing, Giovan Battista Aleotti illustrates the method that was used to design embankments using river soil. The new embankments were not composed of a single element, but rather of a complex structure that included flat parts parallel to rivers. Thanks to this design, a certain amount of water was allowed to overflow in areas called restare; then, forming a secondary embankment further inland, cornelle were constructed to provide additional protection. In addition to reducing flooding, this type of flood control often served the additional purpose of creating new paths and buffer zones, which could be cultivated or reforested by landowners.

Aleotti G.B., *Della scienza et dell'arte del ben regolare le acque*, a cura di Mario Rossi, Panini, Modena 2000, p. 322.



draulics, which applies its techniques and is almost entirely dependent on observation and experience. Instead of the logical attitudes that distinguish mathematicians, the second necessitates intuition, which is a trait of naturalists and physicians (Di Fido, C. Gandolfi 2014, p. 59).

In this sense, the Italian naturalistic hydraulics school offered a remarkable and peculiar contribution. This was not just historically, but as a valuable treasure trove that still resonates with contemporary ecological strategies used for strengthening the relationship between humans and the natural environment.

THE ITALIAN NATURALISTIC HYDRAULICS SCHOOL

In addition to all related events, such as the diversion of the Brenta river (1610), the Sile river (1683), the Piave river (1641) and Taglio di Porto Viro (1604), which prevented Venice from draining the Lagoon, the instability of rivers throughout Italy, such as the Reno, the Arno and the Tiber River, kept mathematicians, engineers, and governors engaged over the centuries, trying to find methods to prevent erosion of riverbanks and the rivers' diversions.

The most relevant element of this Italian naturalistic approach was the idea that any solution required in-depth investigation into the state of the health of rivers and their idiosyncratic features. Consequently, a few empirical and informal practices, which belonged to collective memory deeply rooted in local communities, continued to be discussed in treatises as a relevant part of hydraulic science. Among these was *Trattato della direzione de' fiumi*, written in 1664 by Famiano Michelini, an Italian mathematician. The text investigated various theories and methods used in the protection of riverbanks from erosion, such as *paradori, pali, pennelli,* and *pignoni*, which were preferred to the rigid and orthogonal reinforcements of the banks along with forced diversions. Along with Michelini, other scholars can be cited, such as Giovanni Battista Barattieri, an Italian engineer, who wrote *Architettura d'acque* in 1669, which beautifully illustrated the corrosion along rivers.

However, the contribution of Domenico Guglielmini, a doctor, chemist, and hydraulic engineer, was crucial to defining the school theoretical approach. From the works of Barattieri and Michelini, Guglielmini moved towards a more detailed investigation of rivers and an understanding of water movement based on inherited medical-naturalist traditions.

In one of his most significant works, *Della natura dei Fiumi*, a mathematical and physical treatise written in 1739, he defined rivers as a body of water, applying the metaphor of the human

body's circulatory system of blood. Contrary to what one might think, the application of this metaphor, which had its roots in the tradition of 16th-17th century Italian hydraulic studies, such as Sabbadino and Aleotti's works (Sabbadino 1919; Aleotti 2000), did not hinder the effectiveness of scientific investigations.

This was the key to integrating innovative physical-mathematical principles with empirical approaches in order to identify the best interventions to be used to protect the rivers and surrounding areas. According to Cesare Maffioli, Guglielmini had a medical perspective, treating the river as a living organism with its own unique personality, a clinical case, to be investigated (Maffioli 2010, pp. 271-278).

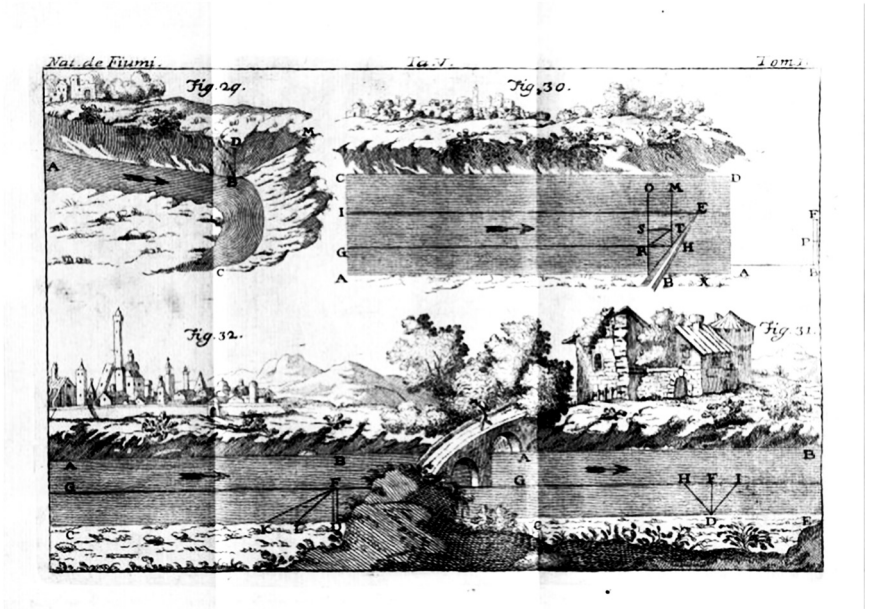
This perspective was essential to finding out the causes of its "illness": those internal, such as its innate morphology, its course of water, its dimensions, the orography of the ground, and the density of sand within it; and those external such as attributable to human interventions, which often complicated the understanding of water motion and its management.

In this sense, the approach that emerged from Guglielmini's text regarding the channelization of the Reno River in response to the incessant flooding that occurred in Bologna and Ferrara's countryside at that time, was enlightening. In fact, although the flooding phenomenon was well-known, no definitive solutions were found due to local governors debating two opposite perspectives, which necessitated different diversion projects; Bologna argued for the diversion of the Reno directly into the Po Grande, contending that this intervention most respected the natural topography of the territory. However, this solution would have caused considerable damage to Ferrara, since the maximum slope of the water pointed directly at the city, which had long since defended itself against flooding by building riverbanks resembling walls. Having already renounced the navigability of the proposed secondary branch of the Po, Ferrara instead proposed the divergence of the river on the east side, towards the sea, which favoured its commercial trade routes. Bologna became the champion of a perspective that promoted the principles of nature only for its own strategic, political, and economic advantages. Ferrara couldn't help but oppose it, evoking, on the contrary, the value of applying art over nature when it was necessary to protect its citizens and territories.

The text is a collection of Guglielmini's evaluations of various proposals that animated the debate around 1693. Despite the variety of arguments and subjects covered in the text, some of which are extremely technical, one cannot fail to notice how it is constellated by an uncountable amount of Guglielmini's

Considerations of water motion in rivers were based on their morphology. The drawings accompanied some geometrical demonstrations, corollaries and prepositions, explained on pages 130 to 136. However, it is important to note that there was still a preference for superimposing geometric figures, derived from the demonstrations, as opposed to beautiful engravings depicting rivers, characterized by their water textures, the varied roughness and topography of their banks, and their surrounding landscapes: the countryside in the foreground and the city in the background. It is, therefore, possible to make a comparison with the following treaties. Calculations and geometrical figures did not leave room for such representations.

Guglielmini D., *Della natura dei Fiumi,* Filippo Parmigiani, Parma 1776, TAV 5.
https://www.byterfly.eu/islandora/object/libria:11295#page/442/mode/2up



observations based on the concept of naturalness as a primary condition, not only to observe, but to define any practical proposal or artificial transformation of rivers. For instance, by answering to those opposed to the diversion of the Reno into the Po Grande, he stated that historically "the Reno River had always strived to unite its current with the Po River by its natural disposition" (Guglielmini 1776, p. 33).

Just as a good doctor who cares for their patients' needs with the primary objective of protecting their health, the care for the management of waters would be based on the adoption of those artistic principles consistent with the nature of the river and its features. A naturalistic approach, therefore, that would cause no fractures between the human and natural realm and no conflict between science, art of water management and nature (Newman 2005, pp. 23-24). Rather, it would be a combination of rationality and empiricism, which was crucial with the complexity of the hydraulic discipline.

In addition to Guglielmini's work, other minor authors of the time also provided important contributions. Among these, Vincenzo Viviani, an Italian mathematician and engineer, wrote two discourses in 1688: one intended to protect Florence from the Arno's floodings, *Discorso intorno al difendersi da'riempimenti e dalle corrosioni de'fiumi, applicato ad Arno in vicinanza della Città di Firenze;* and a second, *Discorso intorno al difendersi da'riempimenti e dalle corrosioni de'fiumi.-Relazione intorno al riparare la città e campagne di Pisa dalle inondazioni*, which focused on the same subject but with Pisa's countryside as a case-study (Viviani 1668).

These texts are extremely relevant, as they demonstrate Viviani's intuitive and empirical approach from the outset, developed from more than just theoretical work. The book was addressed to Cosimo III, the Duke of Florence, who requested suggestions for protecting Florence and its surroundings from the increasing expansion of the Arno.

On the one hand, Viviani realised that the rising water level was already a phenomenon present in the city. Through archaeological findings, he reconstructed how the city changed over time due to this reason: ancient floors and architectural ornaments located at different heights on buildings and blocked-up windows. On the other hand, the rapid increase in the water levels of the Arno was unnatural; therefore, Viviani claimed this could be partially due to the morphology of the river, since the rise in water levels affected the surrounding countryside even before it reached Florence.

By widening the investigation's area, he determined that the primary cause of this rapid increase in the flooding phenomenon

in Florence was human-caused deforestation in the surrounding mountainous regions. Deforestation left lands bare and unable to hold back floods, which violently swept through the valleys, carrying stone and other waste materials downstream.

According to Viviani, firstly, in order to prevent flooding, locks would need to be constructed along the tributaries of the Arno to slow their flow. Secondly, he suggested replanting their banks with olive trees. However, he stressed that this process should not be hurried out of greed for acquiring new pastures. Rather, it would be necessary to wait for trees to grow naturally, in order to form compact soil that could withstand floods and retain water.

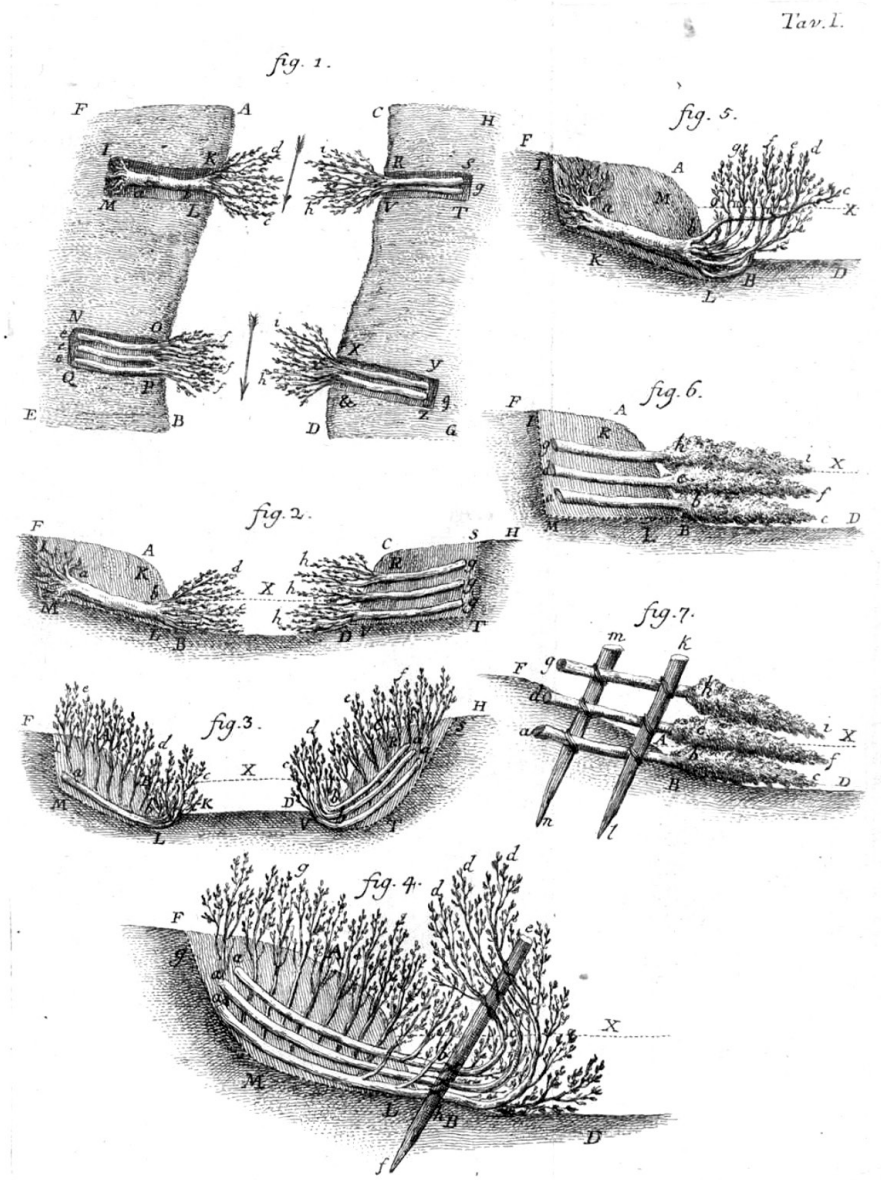
The idea that human greed was primarily responsible for environmental instability was not an original argument. Even before Sabbadino used it to describe one of three enemies of Venice's lagoon in his text on Venice and Aleotti used it to build his accusation against Bologna's government, Alberti had already theorized it in *Theogenius* and vividly repeated it in the tenth book of the *Art of Building in 10 books*. Therefore, like his predecessors, Viviani could only confirm the connection between the inner nature of human beings and the negative impacts on the environment.

Additionally, it is remarkable to note how ethical arguments were still joined with technical observations in hydraulic treaties, as if they were intrinsically linked. The benefits resulting from this strategy would not just protect the city of Florence and its citizens from flooding, but also meant landowners would see greater results from their crop harvest in the long run: "they would enjoy the goods of those valleys, consolidated and secure from landslides. they would enjoy the goods flowers and fruits from plants, and in due time, oil from the olive groves, timber, and livestock of all sorts and in greater numbers of pastures" (Viviani 1668, p. 36).

However, Viviani presented another argument that transcended the political and economic dimension, introducing an aspect often overlooked in territorial management policy: the aesthetic outcomes of care.

In attempting to demonstrate how the proposed practices would benefit community members and private interests, he asserted that these would provide not only material and economic safety for citizens, but also aesthetic enrichment. According to Viviani, through the restoration of riversides and adjacent areas, the forgotten *amoenus loci* would regain their aesthetics as a result of communal commitments. And, vice-versa, these practices would strengthen the intangible ties between human beings and their natural environment.

This is one of the visual plates that comprise the final part of Bettoni's treatise. Here are some visual explanations of Bettoni's experiments on stabilising and protecting a riverbank via intertwining the branches and roots of plants.
Bettoni C., *Pensieri sul governo de' fiumi,* Pietro Vescovi, Brescia 1782.



To conclude his argument, he invited one to apply this perspective, through transcending political boundaries, as well as temporal ones, and embracing the destiny of future generations: "there is no expenditure the most plausible, nor the most grateful, though very great, then that which is for the benefit of the next generations" (Viviani 1668, p. 37).

Whilst Viviani did not provide any drawings in his text, those contained within the book, *Pensieri sul governo de' fiumi*, written in 1782 by Conte Carlo Bettoni, made up for this lack (Bettoni 1782).Unlike previous authors, Bettoni was an agricultural reformer who, in order to secure his lands, developed an interest in protecting riverbanks. Beyond his words, the most fascinating aspect of his text consisted of a series of explanatory boards of various processes, drawn to illustrate the repair of eroded riverbanks using local plants and as a result of long tests and experimentations. Bettoni described which plants were most appropriate, along with different methods for intertwining their branches so that they could grow deeply rooted in the soil and compact it.

However, it is when reading the beginning of the last chapter of *Corrosioni dei Fiumi* by Francesco B. Ferrari, that one can still find the singular trajectory defined by the Italian naturalistic school in 1792. Referring to the embankments effectively designed by Guglielmini along the Po River near Piacenza, he stated that such a brilliant result "would never have been achieved if only theoretical notions or only practical ones would have been applied" (Ferrari 1792, p. 52). Mathematical calculations and theoretical assumptions should have been combined with careful "eye-observations" of the "quality, nature, and the place where the river is located" (Ferrari 1792, p. 54). In light of that, he dedicated this chapter to describing various local techniques to repair and protect the riverbanks.

CONCLUSION

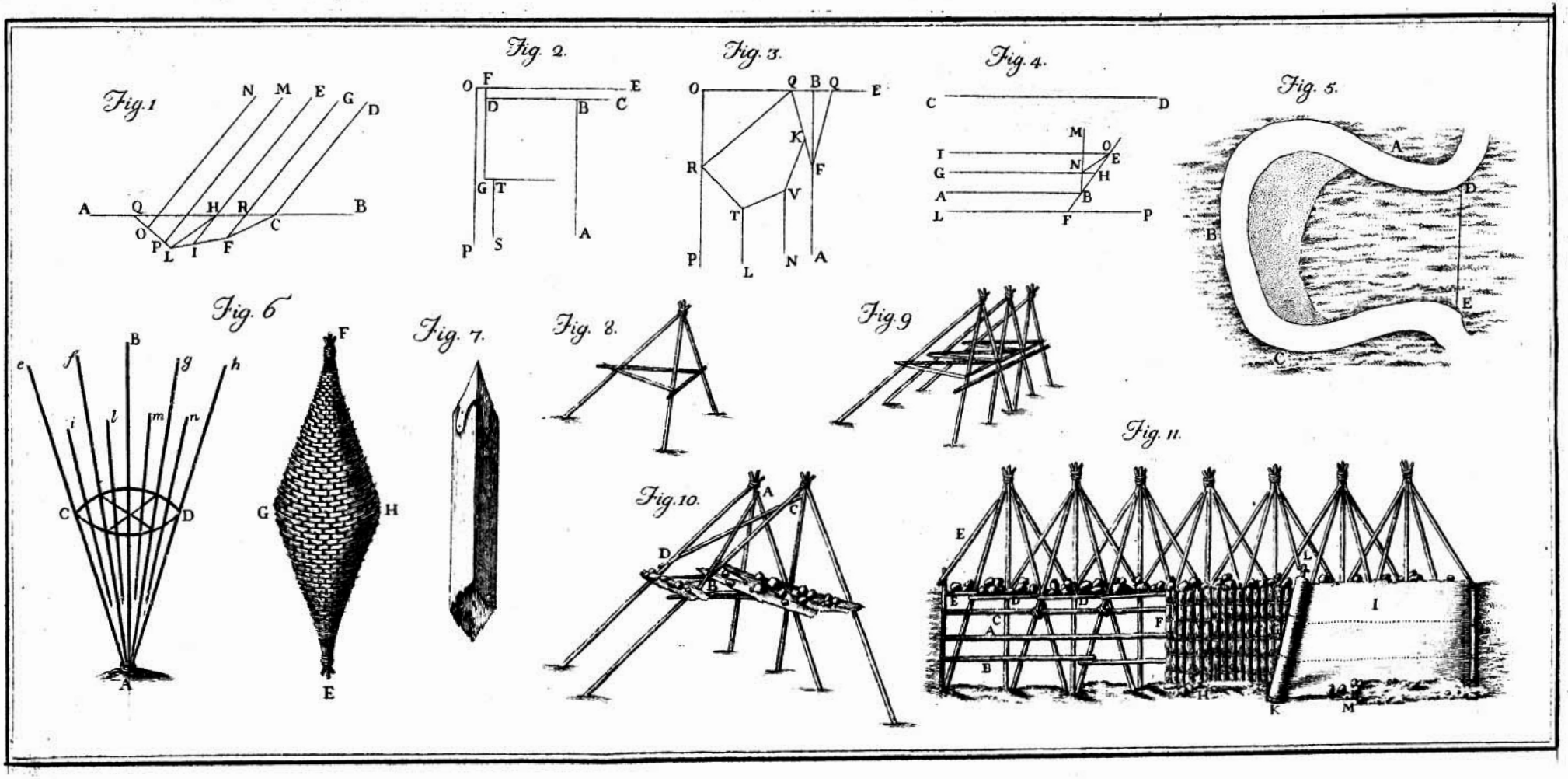
As already said, these contributions were slowly eliminated from the hydraulic discipline and its written scientific production, in favour of a purely theoretical and mathematical approach. Just looking at Bernardino Zendrini 's text, *Leggi e fenomeni, regolazioni ed usi delle acque correnti*, published in 1741, leaves one visually overwhelmed by mathematical calculations and diagram geometric and theorems.

It is important to note, however, that this approach and the comprehensive knowledge contained in these texts are extremely relevant to ecological issues we face today. In addition

to the relevance of hydraulics, which can be interpreted as a discipline regulating one of the first acts of ground transformation, including soil-water reparations, diversions, and ground shaping, the specific approach of the examined treatises also indicates a precedent in the history of land transformations where the bifurcation between nature and culture was not irremediably contemplated. This objective is achieved through the integration of a scientific and technical perspective with nature-based practices, as well as the consideration of ethical, political, economic, and social *concerns* (Latour 2004, p. 232). These visual and written documents perform acts of care, using local materials, multiple techniques, and historical knowledge, characterized by a holistic understanding of soil management and terracing (de la Bellacasa 2017). As a result, they constitute a valuable historical archive for contemporary ecological discourse, contributing to the broadening of its imaginary.

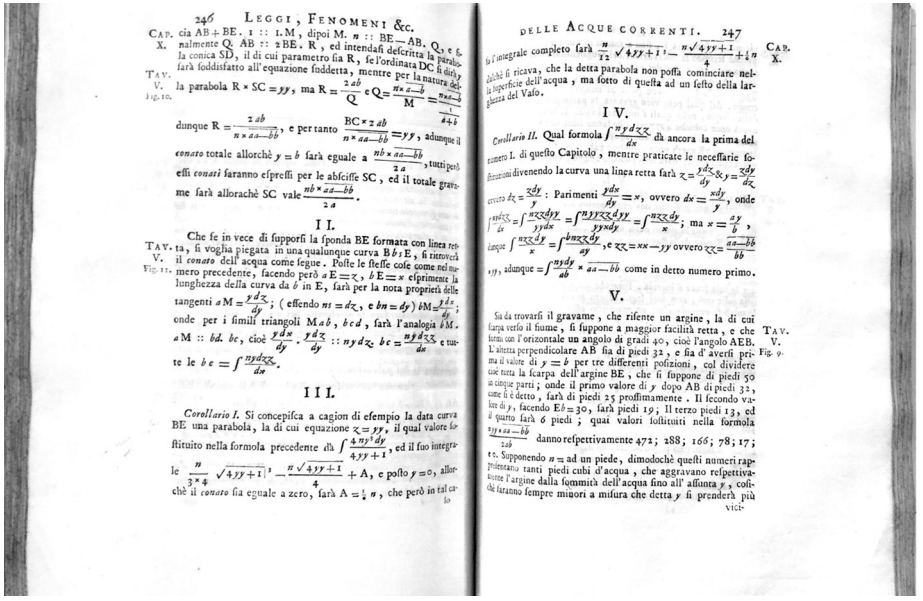
Explanation of tela o cavellotti used to protect the river along the Naviglio Grande and Mussa. Ferrari described this tool as affordable, efficient and safe. They were built using oak and elm timber for the main structure, as well as stones or gravel and cloth to complete the surface. Figures 8, 9, 10, and 11 show how it was constructed.

F.B. Ferrari, *Corrosioni dei Fiumi*, Giuseppe Galeazzi, Milano 1792, pp. 76-80.



Two pages belonging to Zendrini's treatise. Representations were unnecessary since calculations and geometrical figures were sufficient to describe phenomena.

Zendrini, *Leggi e fenomeni, regolazioni ed usi delle acque correnti, in Raccolta d'autori che trattano del moto dell'acque*, vol. 8, Stamperia S.A.R., Firenze 1741, pp. 246-247.



246 LEGGI, FENOMENI &c.

CAP. X. cia AB + BE. 1 :: 1.M, dipoi M. n :: BE — AB, Q, e fi-
nalmente Q. AB :: 2BE. R, ed intendafi defcritta la parabo-
la conica SD, il di cui parametro fia R, fe l'ordinata DC fi dirà
TAV. V. fara foddisfatto all'equazione fuddetta, mentre per la natura del-
Fig. 10. la parabola R × SC = yy, ma R = $\frac{2ab}{Q}$ e Q = $\frac{n\times a-b}{M}$ = $\frac{n\times a-b}{\sqrt{aa+bb}}$

dunque R = $\frac{2ab}{n\times\sqrt{aa-bb}}$, e per tanto $\frac{BC\times 2ab}{n\times\sqrt{aa-bb}} = yy$, adunque il
conato totale allorchè $y = b$ farà eguale a $\frac{nb\times\sqrt{aa-bb}}{2a}$, tutti però
effi *conati* faranno eſpreſſi per le abſciſſe SC, ed il totale gravа-
me farà allorachè SC vale $\frac{nb\times\sqrt{aa-bb}}{2a}$.

II.

Che fe in vece di fupporfi la ſponda BE formata con linea ret-
TAV. V. ta, fi voglia piegata in una qualunque curva BbıE, fi ritroverà
Fig. 11. il *conato* dell'acqua come ſegue. Poſte le ſteſſe coſe nel nu-
mero precedente, facendo però aE = z, bE = x eſprimente la
lunghezza della curva da b in E, farà per la nota proprietà delle
tangenti $aM = \frac{y\,dz}{dy}$; (effendo $mı = dz$, e $bn = dy$) $bM = \frac{y\,dx}{dy}$;
onde per i ſimili triangoli Mab, bcd, farà l'analogia bM.
aM :: bd. bc, cioè $\frac{y\,dx}{dy}$. $\frac{y\,dz}{dy}$ :: $ny\,dz$. $bc = \frac{ny\,dz\,zz}{dx}$ e tu-
te le $be = \int\frac{ny\,dz\,zz}{dx}$.

III.

Corollario I. Si concepiſca a cagion di eſempio la data curva
BE una parabola, la di cui equazione $z = yy$, il qual valore ſo-
ſtituito nella formola precedente dà $\int\frac{4n^3\,dy}{4yy+1}$, ed il ſuo integra-
le $\frac{n}{3\times 4}\sqrt{4yy+1}^3 - \frac{n\sqrt{4yy+1}}{4} + A$, e poſto $y = 0$, allo-
chè il *conato* ſia eguale a zero, farà $A = \frac{1}{4}n$, che però in tal ca-
ſo

DELLE ACQUE CORRENTI. 247

o l'integrale completo farà $\frac{n}{12}\sqrt{4yy+1}^3 - \frac{n\sqrt{4yy+1}}{4} + \frac{1}{4}n$ CAP. X.
dichè ſi ricava, che la detta parabola non poſſa cominciare nel-
la ſuperficie dell'acqua, ma ſotto di queſta ad un ſeſto della lar-
ghezza del Vaſo.

IV.

Corollario II. Qual formola $\int\frac{n\,y\,dz\,zz}{dx}$ dà ancora la prima del
numero I. di queſto Capitolo, mentre praticate le neceſſarie ſo-
ſtituzioni divenendo la curva una linea retta farà $z = \frac{y\,dz}{dy} - x\,y = \frac{z\,dy}{dz}$
ovvero $dz = \frac{z\,dy}{y}$: Parimenti $\frac{y\,dx}{dy} = x$, ovvero $dx = \frac{x\,dy}{y}$, onde
$\int\frac{n\,dz\,zz}{dx} = \int\frac{n\,z\,z\,dyy}{yy\,dx} = \int\frac{n\,yy\,z\,z\,dyy}{yy\,x\,dy} = \int\frac{n\,z\,z\,dy}{x}$; ma $x = \frac{ay}{b}$,
dunque $\int\frac{n\,z\,z\,dy}{x} = \int\frac{b\,n\,z\,z\,dy}{ay}$, e $zz = xx - yy$ ovvero $zz = \frac{aa-bb}{bb}$
yy, adunque $= \int\frac{n\,y\,dy}{ab}\times\sqrt{aa-bb}$ come in detto numero primo.

V.

Sia da trovarſi il gravame, che riſente un argine, la di cui
ſcarpa verſo il fiume, ſi ſuppone a maggior facilità retta, e che TAV. V.
formi con l'orizontale un angolo di gradi 40, cioè l'angolo AEB. Fig. 9.
L'altezza perpendicolare AB ſia di piedi 32, e ſia d'averſi pri-
ma il valore di $y = b$ per tre differenti poſizioni, col dividere
cioè tutta la ſcarpa dell'argine BE, che ſi ſuppone di piedi 50
in cinque parti; onde il primo valore di y dopo AB di piedi 32,
come ſi è detto, farà di piedi 25 proſſimamente. Il ſecondo va-
lore di y, facendo Eb = 30, farà piedi 19; Il terzo piedi 13, ed
il quarto farà 6 piedi; quai valori ſoſtituiti nella formola
$\frac{n\,y\,z\,z\,a-bb}{2ab}$ danno reſpettivamente 472; 288; 166; 78; 17;
ec. Supponendo n = ad un piede, dimodochè queſti numeri rap-
preſentano tanti piedi cubi d'acqua, che aggravano reſpettiva-
mente l'argine dalla ſommità dell'acqua fino all'aſſunta x, coſi-
che ſaranno ſempre minori a miſura che detta y ſi prenderà più
vici-

De Marchi (1890-1972) was a hydraulic engineer and scholar, as well as a professor at the Politecnico of Milan, who published numerous works regarding hydraulics and water motion.

Cristoforo Sabbadino's texts, particularly his sonnet at the beginning of Discorsi per la Laguna di Venezia (1540), testify how the landfill process affected the Lagoon at that time, generating several concerns for Venice's military defense and for the whole functioning of its fragile ecosystem (Escobar 1980, p. 104).

The use of the body metaphor is a result of Neoplatonist conceptions of microcosm and macrocosm. Its impact on culture and ideas is well explained by Philippe Descola in the definition of analogical ontology (Descola 2014, p. 232). On the complexity of the use of this metaphor and its implications, see also (Mills 1982, p. 242).

The expression, "own individuality" is borrowed by Barattieri's text, see page 142.

The concept that nature could be perfected by art without running into an ontological debate was an issue dating back to Aristotle's division between arts. According to William R. Newman, the Mechanics, which was one of the most influential Aristotelian texts during the 15th and 16th centuries, divided the interaction of art with nature into three categories: arts that operated by mimesis, such as painting, sculpture, and architecture; "perfective arts," such as medicine or agriculture; and the art of mechanics, aimed at "conquering nature" by overcoming its obstacles and acting against it. Despite this division, Newman argues that these three perspectives are intrinsically linked. The art of mechanics suggests a principle of naturalness whilst involving two levels of artificiality, in terms of both its products and its effects on nature. The reason for this interlinking can be found in the fact that machines - mainly levers, pulleys, and scales - were conceived as having originated from observations of natural phenomena, or from the movements of animal and human bodies. This was then followed by an imitation and translation of natural processes into functional objects, without deeply changing their matter or the elements they interacted with. The term 'conquer' did not dislocate transformations outside the natural system; nature could be copied, transformed, or conquered, but it was not fundamentally altered, even if these former concepts were the philosophical presupposition of its distortion. As a result of the ambiguity surrounding this term, it was difficult to distinguish between transformations that "bested" nature and those that "replicated" or profoundly modified it (Newman 2005).