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Leonardo and Water. The Challenge of Representation

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Drawings and texts on hydrology and hydraulic engineering are found among Leonardo's earliest written work. Already in MS A, Leonardo begins planning a *Trattato de l'acqua* (fol. 55v, *c.*1492). Manuscripts entirely or partly devoted to hydrodynamics arise around 1495 (MS H and I), and circa 1508 (Codex Leicester; MS F).[1] Water also plays a significant role in Leonardo's theory of painting: the representation of water was indeed praised by ancient authors as the exclusive domain of painting, which distinguished it from sculpture.

The earliest hydrological texts thematize water from three perspectives, for which Leonardo could sometimes draw upon ancient and medieval sources: water as a life-giving element; the analogy of micro- and macrocosm; and hydraulic engineering. In all three areas, however, Leonardo's focus would soon shift specifically to the forms and dynamics of water in motion. After 1500 in particular, water would become the principal engine of Leonardo's investigations into geography, geology, meteorology, anatomy, and botany, all focused on the study of concrete processes.

In an early text in MS C (fol. 26v; *c.*1490) Leonardo expounds at length under the heading "Che cosa è acqua." He characterizes water as the element that makes life possible the first place ("questa è aumento e omore di tutti i vitali corpi"), a power it loses the longer it remains stagnant ("fermezza la corrompe"). The mobility and various manifestations of water are thereafter thematized consistently in his work. Later, Leonardo would emphasize water's destructive power, the negative opposite of its vitalizing properties – culminating in a catalogue of the various forms of currents, in which vortices, significantly, are absent.

The "Cominciamento del trattato de l'acqua," found in MS A (fol. 55v), starts with an *analogy of the human body and the Earth.* However, the discussion that follows (until fol. 61r) focuses mainly on the hydrological cycle and, increasingly, on how water appears while in movement.

Already in Leonardo's letter of presentation to Ludovico Sforza, of which a copy is preserved (Codex Atlanticus, fol. 1082; *c.*1482), Leonardo promises inventions in four *hydrotechnical* realms: the construction of bridges, ditches, battleships, and canals. Even in Leonardo's autograph list of his works (probably *c.*1482) there are "certi strumenti per navili" and "certi strumenti d'acqua" (Codex Atlanticus, fol. 888r). Leonardo was indeed involved in corresponding projects during his first sojourn in Milan (1482–99).[2] A litany of later, often utopian plans and projects involving water stretches into his final years: damming the Isonzo River to defend against the threat of Turkish invasion; re-routing the Arno; flooding the Val di Chiana to make the Arno navigable by ships; regulating the Adda canals, especially the Naviglio della Martesana; draining the Pontinian swamps dry; and canal building projects in France, particularly in connection with plans for Romorantin (see cat. nos. VIII.9 and VIII.16).

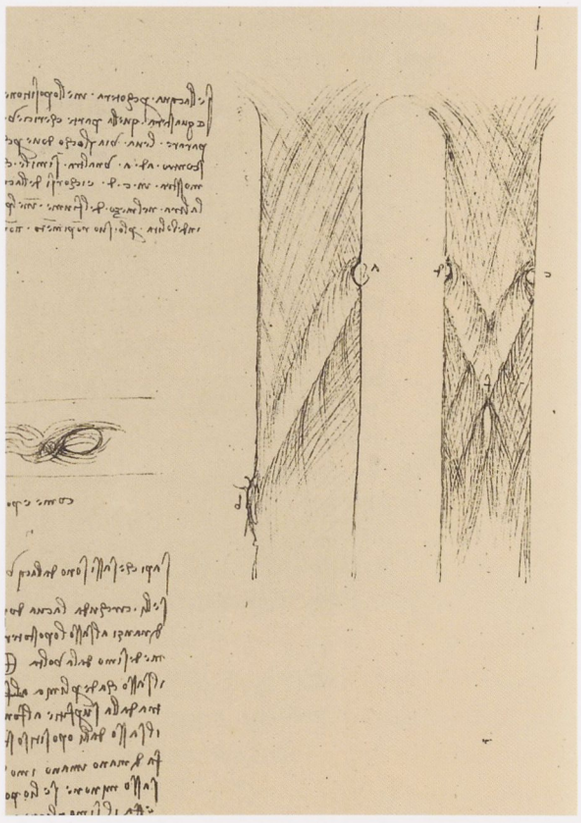
Leonardo's early reflections on the vitality and cosmology of water drew from a rich body of natural philosophical and medical literature. However, the notion a *vis viva* (living force) particular or inherent to water is scarcely thematized further in his writings,[3] where it is soon eclipsed by the analogy of micro- and macrocosm, which Leonardo sceptically works through up until his latest manu-

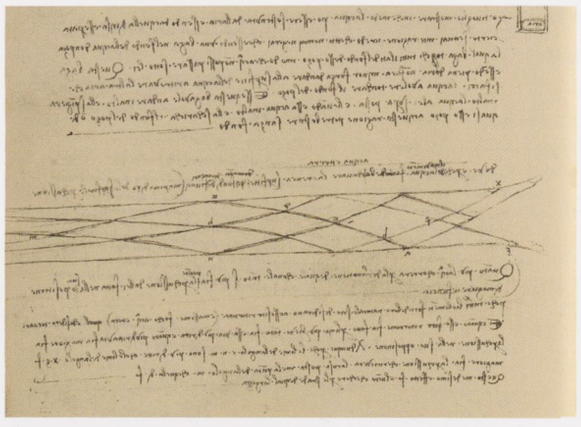
Leonardo da Vinci,
Studies of Flowing Water,
The Royal Collection / HM Queen Elizabeth II, no. 12660v
(detail of fig. 8)

scripts.[4] As a technician, Leonardo could draw upon the work of fifteenth-century predecessors, such as the Sienese engineers Mariano Taccola and Francesco di Giorgio Martini.[5] In contrast to this and to most of his fields of scientific research, Leonardo's work on fluid dynamics is highly original and not dependent on traditional knowledge. Ancient hydrostatics, from Heron to Archimedes, had not found a reception in the Middle Ages.[6] Leonardo seems to have been the first to undertake a detailed exploration of water's dynamic properties, combining observations, thought experiments, and concrete experimental procedures by turn.[7]

Until the mid-1490s Leonardo shows growing interest in rectilinear currents and how they rebound or penetrate, in analogy to optical phenomena and the percussion mechanics of solid bodies. Vortices and helices, which in the architectural treatises of Leon Battista Alberti[8] and Francesco di Giorgio[9] are studied for both their hydrotechnical applications and their destructive potential, play a distinctly marginal role in his writings in the late 1480s and early 1490s. In these early representations, water moves in a predominantly straight, linear fashion. Upon impact or collision, water obeys the law of reflection at equal angles; its currents are able to interpenetrate without any impediment (figs. 1, 2). We might thus speak of an early, "vectoral" hydrology in Leonardo, which conceptualizes water as flowing light.

Beginning in the early 1490s, however, Leonardo's writings show an emerging interest in swirling movements (*retrosi*) and erosion. The motions of water begin to be conceptualized less as one-dimensional, interpenetrating vectors than as extending *masses* filled with solid components. Leonardo increasingly depicts water moving in curved formations, for instance in MS H ("Tutti li superiori liniamenti fatti dal moto dell'acqua fien curvi," fol. 69r). Within a stream, reflexive shocks (*balzi*) of water metamorphose in continual, three-dimensional curved forms.[10] In this way, a helix arises: a spiralling motion that winds around the axis of the direction of flow. Leonardo's primary interest in these years is the tendency of rivers to self-stabilize, restraining their own destructive power through meandering formations and the material differentiations of their beds.[11]





1. Leonardo da Vinci, *Movement of Water,* Paris, Bibliothèque de l'Institut de France, MS C, fol. 24v, detail

2. Leonardo da Vinci, *Movement of Water,* Paris, Bibliothèque de l'Institut de France, MS C, fol. 26v, detail

After 1500 Leonardo focuses increasingly on hydrodynamic *antagonisms* – particularly the relationship between stronger and weaker currents, and between moving water and its material boundaries (erosion).[12] This finds a parallel in his simultaneous activities in military technology and the Florentine civic commission for a monumental painted battle scene (the *Battle of Anghiari*). The erosive effects of water are increasingly studied in a geological framework. Leonardo's late manuscripts show a clear scepticism towards simplistic models. Following the Aristotelian concept of the arrangement of the four elements, Leonardo believes that water always strives spherically to cover the Earth,[13]

with catastrophic results for the existence of terrestrial organisms; however, he ultimately leaves open the question of whether water, because of the influence of the sun, will some day *permanently* flood the entire Earth (see cat. X.9; MS F fol. 70v; Codex Leicester fol. 15A:22r [8]). After 1510, he also begins to radically question the analogy between the water cycle and the flow of blood within an organism.

Leonardo's texts on water range from concise, rule-like theorems to narrative descriptions of water's movements.[14] Often the latter results in spectacular sound-mimetic evocations of flowing water through onomatopoeia, alliteration, or rhyme.[15] His rhetorical tone swings confidently between pragmatism and pathos. This strategy finds its monumental expression in the "deluge" texts of Windsor RL 12665. While the recto contains a pragmatic, hydrological "Descritione del Diluvio", the verso is a literary evocation of the mortal terror of humans and animals that try desperately to flee. In both texts, Leonardo makes use of characteristic "hydro-narrative" stylistic devices such as parataxis, extended period sentences, and complex participial and relative clause constructions.

Representing water in motion was a challenge that allowed Leonardo to hone not only his linguistic skills, but also his skills as a draughtsman. Ernst H. Gombrich argued in 1969 that Leonardo's drawn studies of water were based not on observation but on theory: water's forms of movement are "a matter of thought rather than of sight; it is something that Leonardo reasoned out, not something he can have observed and measured."[16] For Gombrich, rather than straightforward representations, Leonardo's drawings of water are a diagrammatic "visualization of forces".[17] Likewise, as Martin Kemp aptly summarizes: "Leonardo was in effect drawing lines of force. [...] The vortex was a form of dynamic geometry across space and time."[18]

That Leonardo's visual analyses of water currents are not merely notations of visible phenomena is also apparent to hydrologists, who affirm that these drawings, in all their detailed exactitude, are also "rather schematized or exaggerated".[19] However, it is also worth questioning whether this juxtaposition of "observation" versus "reasoning out", or "perceptual" versus "schematic",[20] can be applied to Leonardo's water studies in the first place. Leonardo's own example of falling snowflakes that are perceived as lines (*Libro di Pittura*, ch. 231a) is an excellent demonstration of how far "schematizations" can extend into the realm of the "sensory"[21] (see cat. X.15). Leonardo offers a psycho-physical explanation for the phenomenon: things leave behind their *impressioni* in the sensory organ, like tracks through which movement becomes perceptible.[22]

Yet, this phenomenon of impressing or imprinting on the observer's consciousness is not limited to the sensory organs. Rather, for Leonardo it is also essential to the appearance of water in motion, which manifests itself through the formation of interfaces, generating *impressioni*, or "projected" lines of motion.[23] Moreover, in practical terms flow structures can be visually clarified by "staining" water as it moves. In Codex Arundel folio 162 recto Leonardo stresses that the *scienza* of moving water can be made visible through experimentation ("E la vera scienzia di tal retrosi vederai nell'acqua caduta in iscalini interchiusa infra due piastre di vetro bianco e sottile"). On folio 25 recto in the early MS C he recommends visualizing turbulence in water by adding wine, for example. Eighteen years later, in MS F, Leonardo suggests revealing the "beautiful movements" of water using "grains of millet" (fol. 34v). In this, Leonardo anticipates methods that would be developed much later in the phenomenology of flow physics, for instance by Friedlieb Ferdinand Runge and Theodor Schwenk.[24]

Inertia, density, and the formation of interfaces are preconditions for visualizing the movements of fluid substances.[25] For Leonardo, water could thus function as a paradigm for the dynamic properties of air and fire as well. Yet, as Paul F. Neményi points out, Leonardo's hydrology never clearly differentiates between impulse and movement – a complex problem of which Leonardo was nonetheless aware.[26] The lines that appear especially in "stained" water are seams or boundaries which divide various quanta of moving water, but are themselves unmoved. This, however, brings up a problem of graphic representation: when observing the drawn representation of a vortex, the eye tends to inter-

pret the lines as dynamic traces of a mass in motion, and not as demarcations of what are relatively static contours occurring between distinct currents.

Leonardo seldom represents vortices in his earliest drawings of water; until the mid-1490s he draws them only hesitatingly, and with surprising awkwardness. A sketch from MS B (fol. 81r; fig. 3) is a good example of such early vortices, which without exception are pieced together from often angularly broken, repeatedly distributed lines, devoid of any dynamic quality. In MS C instead Leonardo separates the discrete motions of water into separate vectors, creating static waves that often resemble lattices – but which at this point he still understands to represent moving masses reflected at angles (see figs. 1, 2). Some of these early drawings are devoted to the problem of how the ideal, overlapping vectors of rivers become disturbed or disrupted, causing congestion and the destruction of shorelines. In this case, as seen in a sketch from MS C (fol. 26r), the trellised lines not only densify, but become contorted.

In MS A (*c.*1492), Leonardo studies the forms of motion that are caused by water falling into another body of water. These inquiries take the form of fairly unstructured representations of moving surfaces (see fig. 4), but also drawings that indicate movements taking place beneath the surface (fol. 58r).

Surface vortices already play an important role in MS H (*c.*1495),[27] even if their forms are often still imprecise.[28] However, Leonardo's interest the transformation of riverbeds soon leads him to begin representing vortices beneath the surface of currents as well.[29] Yet it is only in MS I (*c.*1497) that Leonardo begins to represent vortices in a systematic way. A ready graphic paradigm was offered by his earlier representations of Archimedean screws, connected in part with his speculations on perpetual motion machines.[30] In MS I (fol. 76r) Leonardo demonstrates that colliding currents do not simply bounce back like solid bodies but rather generate vortices (fig. 5). In this manuscript, the formation of vortices and the curved processes of water are depicted with increasingly long, continuous lines; the stroke of the pen adapts to its flowing object.[31] Spirals appear in streams like virtual bodies that have been modelled by water. Yet these spiralling bodies are not – as in the physics of solid bodies – surrounded by "empty" spaces, but by a *continuum* of water directly bordering them (fig. 6, see cat. IX.12).

Leonardo's studies of currents, the most quantitatively extensive of all his areas of research, might seem far removed from the problems and undertakings of an artist. Yet a closer look reveals strong resonances between art and science. Particularly, in his mature hydrodynamics the visualization of water gave Leonardo the opportunity to represent the paradoxical unity between seen forms, "stagnant" forms, and continuous flowing movement. Already in MS A, Leonardo notes emphatically that the eye, when it looks at moving water, is unable to remain still.[32] In the late MS E he emphasizes that vision is perpetually in motion and thereby inscribes "lines" into the perceptual field (fol. 80v, *c.*1514). Leonardo's theoretical writings on painting explore the paradoxical temporality of the image, which reveals itself both simultaneously ("in un medesimo tempo") and successively.[33] It is precisely this unity of simultaneity and succession that is also elucidated by the "ornamental" vortex forms that appear in his work after *c.*1495 (see figs. 7, 8).

The development of Leonardo's hydrological studies was consequential for his practice as a draughtsman and painter in two respects, one thematic and the other formal. Thematically: even in his earliest drawings Leonardo represents *landscape* as a realm perpetually modified by water (see cat. nos. II.3 and II.8). As an actor that ceaselessly both models and dissolves forms, water is central to Leonardo's late landscape drawings (see the series of the "Adda Landscapes", Windsor, RL 12398–400; mountain landscapes in black chalk, RL 12389, 12390, 12396, 12397). This culminates in the late "deluge" drawings (RL 12376–86; see cat. nos. X.16 and X.17), which depict water levelling entire cities, valleys, and mountains.

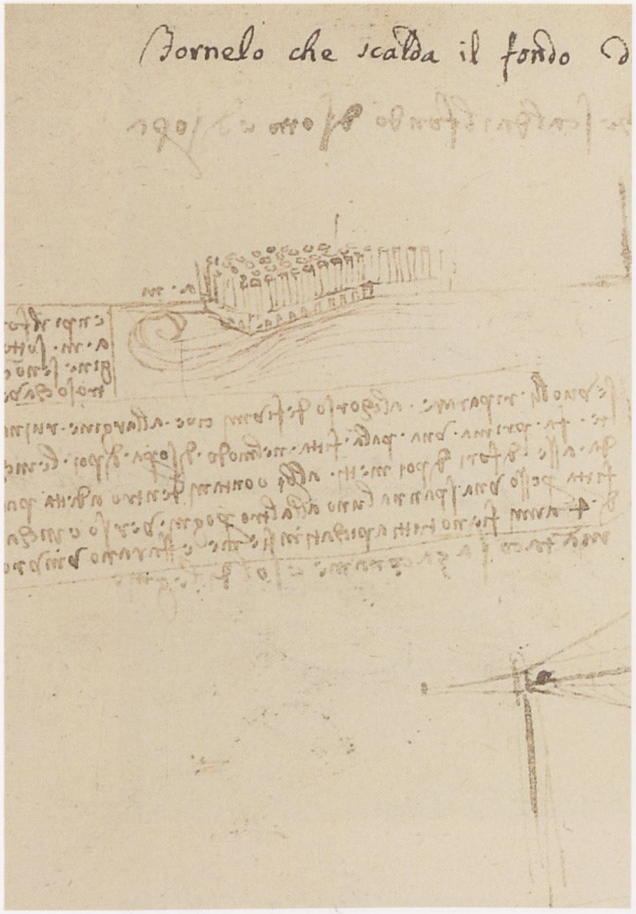
Formally: along with his work on mechanical friction (see Madrid Codex 8937),[34] Leonardo's hydrological studies of the 1490s were the catalyst for his modification of the straight hatchings that dominated his drawings until 1500, the most significant turning point in his graphic style. The new, curved hatchings impart a sense both of volume and of mo-

3. Leonardo da Vinci, *Movement of Water,* Parigi, Bibliothèque de l'Institut de France, MS B, fol. 81r, detail

4. Leonardo da Vinci, *Studies of Flowing Water,* Paris, Bibliothèque de l'Institut de France, MS A, fol. 24v

5. Leonardo da Vinci, *Studies of Mechanics and Flowing Water,* Paris, Bibliothèque de l'Institut de France, MS I, fol. 76r, detail

6. Leonardo da Vinci, *Studies of Flowing Water,* Paris, Bibliothèque de l'Institut de France, MS I, fol. 81r, detail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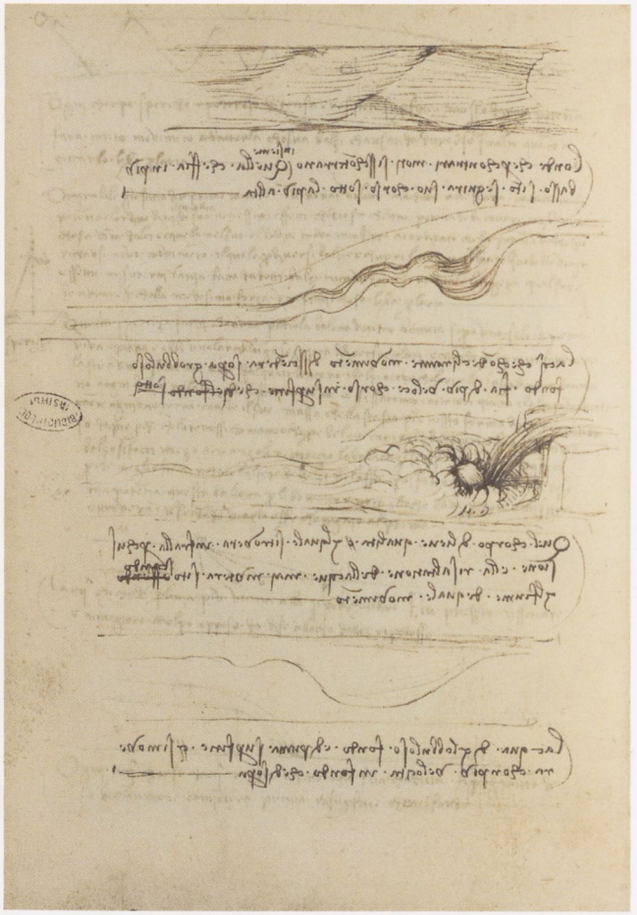

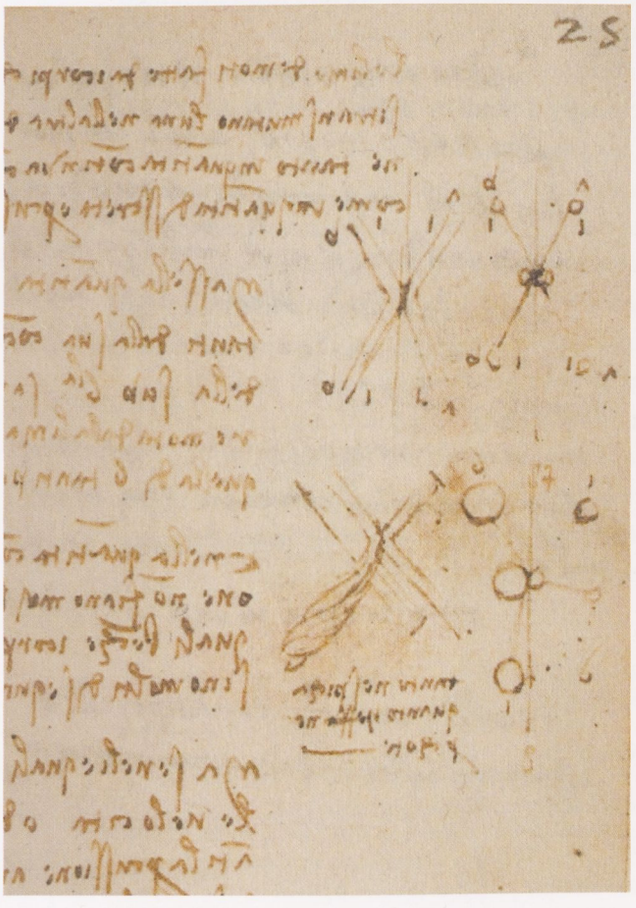
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7. Leonardo da Vinci, *Studies of Flowing Water*, Paris, Bibliothèque de l'Institut de France, MS F, fol. 8r, detail

8. Leonardo da Vinci, *Studies of Flowing Water*, The Royal Collection / HM Queen Elizabeth II, no. 12660v

tion, modelling objects and bodies much as water does the forms of currents[35] (see cat. IV.6.3).

Alongside this more dynamic graphic rendering in his studies of currents around 1500, Leonardo also developed a new figural ideal and new methods of composition. His studies for *Leda with the Swan* anticipate the *Figura Serpentinata* for which Giovan Paolo Lomazzo would later use the metaphor of flames[36] (see cat. IV.6.4). An oppositional screw connecting around a central axis, the motif is difficult to imagine in Leonardo's work without simultaneous developments in his hydrodynamics.[37]

Moreover, Leonardo's study of currents also had a significant impact on his compositional methods. The tight clustering of bodies seen in his works after 1495, in which empty spaces are avoided (*Last Supper*, Milan; cartoon of *Madonna and Child with St Anne*, London), can on the one hand be linked to formal ideas derived from sculpture.[38] On the other hand, as a hydrologist Leonardo was already increasingly finding occasion to represent a compact *continuum* of individual currents within a single body of water. The writhing equestrian skirmish of the *Battle of Anghiari* can be seen as exemplifying Leonardo's conception of flowing water as the antagonism of different forces in the continuum of a single mass. Finally, there are clear parallels between Leonardo's development of labile or transient compositions (*Madonna and Child with St Anne*, Paris, Louvre) and his late hydrology, in which both the forms of individual rivers and the relationship between land and water likewise appear as unstable, temporary constellations.

[1] See the monumental compilation of Leonardo's hydrological texts by Macagno, 1988–89. See also the overview by Pfister, 2009. In its main points, my contribution follows the detailed arguments made in Fehrenbach 1997, pp. 193–256. I would like to extend my sincere gratitude to Marisa Mandabach (Harvard/Hamburg) for her translation of my text and her precious suggestions.

[2] See *Leonardo e le vie d'acqua* 1983; Beltrame 1987; *Leonardo, l'acqua e il Rinascimento* 2004; Marani 2010[d].

[3] See for example Codex Arundel, fol. 57v.

[4] See Fehrenbach 1996.

[5] *Gli ingegneri del Rinascimento* 1996. See also the contributions in *Arte e scienza delle acque* 2003.

[6] See Biswas 1970, 124. See also Hellmann 1904 (with index of sources); Hofmann 1909.

[7] See also Macagno 1989 and *Leonardo da Vinci. Experience* 2006.

[8] *De re aedificatoria* X, 10–12 (see *Leon Battista Alberti* 1988).

[9] Martini ed. 1967, vol. I, pp. 28, 178–97. On quattrocento hydrology see *Prima di Leonardo* 1991, pp. 272ff.

[10] The continuity of the current is considered a fundamental discovery of Leonardo by most scholars. See Favaro 1919, p. 276; Marcolongo 1937; Neményi 1962, p. 58; Biswas 1970, p. 143; Cavalconte 1971, p. 152f.; Levi 1982, p. 411f.; Truesdell 1982, p. 317; Macagno 1989, pp. 226ff.

[11] See for example MS M, fol. 65r; this manuscript also shows a project to examine all conceivable material combinations of riverbeds (fol. 64v). Musings on the connection between the form of a current, its speed, and the movement of solid particles are found especially in MS H (see fols. 2r, 30r, 46r, 47v, 53r, 128r).

[12] See for example Codex Leicester, fols. 15A:15r (26–27); 17A:20 verso (7–12).

[13] See also the superb essay by Nanni 2010.

[14] A few observations on this (with a focus on the "Cantico delle acque") in Codex Arundel, fol. 57v in Vecce 1997. (I thank Carlo Vecce for indicating his essay.)

[15] Cf. "[...] risaltamento somergimento surgimento declinatione elevatione cavamento consummamento [...]" (MS I, fol. 72r)

[16] Gombrich 1969, p. 180.

[17] Ibid., p. 176.

[18] Kemp 1990, p. 18.

[19] Neményi 1962, p. 59.

[20] See Strong 1979, p. 392.

[21] "Parfois, les trances de ce qu'il a imaginé se laissent voir sur les sables, sur les eaux; parfois sa rétine elle-même peut comparer, dans le temps, à quelque objet la forme de son déplacement." Valéry 1919, p. 64.

[22] See for example Codex Atlanticus, fol. 1002r.

[23] See MS F, fol. 9r: "Perché le impressioni generate nella superfizie dell'acqua si mantengano alquanto tempo nell'essere portate dal corso delle acque?"

[24] See Schwenk 1996; Runge 2014.

[25] See Neményi 1962, pp. 61–84.

[26] See for instance Codex Leicester, fol. 18B:18v (13), where Leonardo restricts the "intersegation" of currents to the relative *impeti* or impulses. Already in MS A, fol. 61r, Leonardo posits that in the circular spreading of waves, no matter actually moves; rather there is simply a transmission of impulses (*tremore*). In MS F, Leonardo identifies this linear impulse as an *impressione*, thus once again connecting hydrology with psychology and specifically with optics ("Perché il moto delle impressioni dell'acque penetran l'una nell'altra sanza mutazion della lor prima figura?" fol. 9r). See Windsor RL 12661r, and Codex Atlanticus, fol. 180r (both *c.*1510).

[27] See MS H, fol. 64r.

[28] See ibid., fols. 53v, 70r.

[29] Ibid., fol. 68v.

[30] See MS Forster I[2], fols. 41r–v, 42v, 43v, 52v, 53r, 54v.

[31] See MS I, fols. 79r, 115v, 108v, 115r.

[32] "Se tu riguardi il movimento dell'acqua, l'occhio tuo non si può fermare ma fa a similitudine delle cose vedute" (MS A, fol. 58v).

[33] On this, see Fehrenbach 2002.

[34] See Marani 1984[b].

[35] See Fehrenbach 2006.

[36] See Davis 2009.

[37] See MS F, fol. 14v: "Quali retrosi naturali [...] nel lor processo si voltano in contrari moti, [...] quali di contrari moti si congiungano." Naturally, there are, in addition, rudiments in Leonardo's earlier drawings and paintings: cf. *St Sebastian*, Hamburg, Kunsthalle; cat. V.1).

[38] Marani 1999[b], ed. 2000, pp. 259–61.