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From mythology to science: the development of scientific hydrological concepts in the Greek antiquity and its relevance to modern hydrology

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Abstract. Whilst hydrology is a Greek term, it has not been in use in the Classical literature but much later, during the Renaissance, in its Latin version, hydrologia. On the other hand, Greek natural philosophers created robust knowledge in related scientific areas, to which they gave names such as meteorology, climate and hydraulics. These terms are now in common use internationally. Within these areas, Greek natural philosophers laid the foundation of hydrological concepts and the hydrological cycle in its entirety. Knowledge development was brought about by search for technological solutions to practical problems, as well as by scientific curiosity to explain natural phenomena. While initial explanations belong to the sphere of mythology, the rise of philosophy was accompanied by attempts to provide scientific descriptions of the phenomena. It appears that the first geophysical problem formulated in scientific terms was the explanation of the flood regime of the Nile, then regarded as a paradox because of the spectacular difference from the river flow regime in Greece and other Mediterranean regions, i.e., the fact that the Nile flooding occurs in summer when in most of the Mediterranean the rainfall is very low. While some of the early attempts to explain it were influenced by Homer's mythical view (archaic period), eventually, Aristotle was able to formulate a correct hypothesis, which he tested through what it appears to be the first in history scientific expedition, in the turn from the Classical to Hellenistic period. This confirms the fact that the hydrological cycle was well understood during the Classical period yet it poses the question why Aristotle's correct explanation had not been accepted and, instead, ancient and modern mythical views had been preferred up to the 18th century.

ὁ βίος βραχὺς, ἡ δὲ τέχνη μακρὴ, ὁ δὲ καιρὸς ὀξὺς, ἡ δὲ πεῖρα σφαλερὴ, ἡ δὲ κρίσις χαλεπή
(*Life is short and Art long; the times sharp, experience perilous and judgment difficult.*)
Hippocrates, Aphorismi, 1.1.

歸根得旨　隨照失宗（*To return to the root is to find the meaning*)
Sengcan, Hsin Hsin Ming (Verses on the Faith Mind, translated by R.B. Clarke; original from https://www.sacred-texts.com/bud/zen/fm/fm.htm)

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1 Introduction – Ancient wisdom and its modern perception

In all ancient civilizations, the causes of natural processes, particularly the geophysical and hydrological, were attributed to supernatural powers, usually deities. Mythological explanations have been very influential in triggering social behaviours but also in developing human skills, such as imagination and symbolism. In this respect, the rich Ancient Greek mythology has been inspiring in the arts and continues to be even in modern times. This is illustrated in Figure 1, depicting the mythological battle of Hercules, the well-known hero, against Achelous, a deity personifying the most important river of Greece. The three panels in the figure represent different arts, different aesthetic styles and different periods: 6th century BC, 19th century and 20th century but with influences from the byzantine tradition.

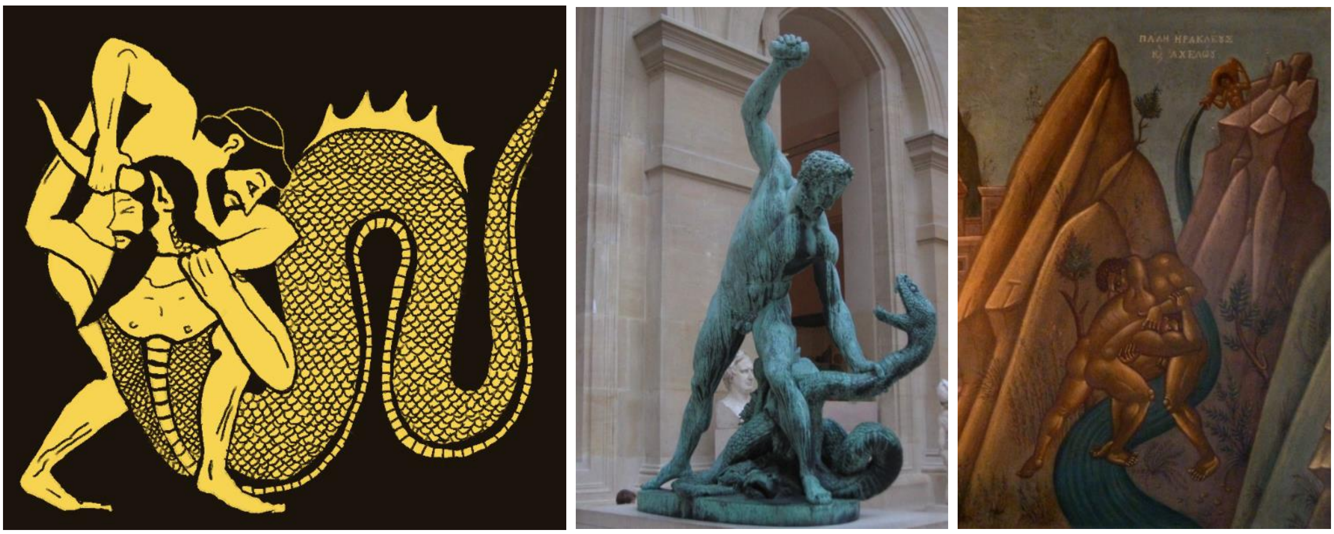

Figure 1: Different depictions of the mythological battle of Hercules against Achelous; (left) on an Attic red-figure vase, 6th century BC, kept in the British Museum (reproduced from Koutsoyiannis et al., 2007); (middle) in a modern sculpture, *Hercule combattant Achéloüs métamorphosé en serpent* by François Joseph Bosio in 1824 exhibited at the Louvre*; (right) on a wall painting in the Athens City Hall by Fotis Kontoglou in 1937-39 with byzantine aesthetics (reproduced from Koutsoyiannis et al., 2012).

The myth of the battle of Hercules against Achelous was later summarized by Strabo (Στράβων; 64 or 63 BC – c. 24 AD), the Greek geographer, as follows:

> *This gave occasion to a fable, how Hercules overcame the Achelous in fight, and received in marriage as the prize of his victory, Deianeira, daughter of Oeneus. Sophocles introduces her, saying, "My suitor was a river, I mean the Achelous, who demanded me of my father under three forms; one while coming as a bull of perfect form, another time as a spotted writhing serpent, at another with the body of a man and the forehead of a bull." Some writers add, that this was the horn of Amaltheia, which Hercules broke off from the Achelous, and presented to Oeneus as a bridal gift. Others, conjecturing the truth included in this story, say, that Achelous is reported to have resembled a bull, like other*

* https://commons.wikimedia.org/wiki/File:Hercule_Bosio_Louvre_LL325-1.jpg

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> *rivers, in the roar of their waters, and the bendings of their streams, which they term horns; and a serpent from its length and oblique course; and bull-fronted because it was compared to a bull's head; and that Hercules, who, on other occasions, was disposed to perform acts of kindness for the public benefit, so particularly, when he was desirous of contracting an alliance with Oeneus, performed for him these services; he prevented the river from overflowing its banks, by constructing mounds and by diverting its streams by canals, and by draining a large tract of the Paracheloitis, which had been injured by the river; and this is the horn of Amaltheia.** (Strabo, Geography, 10.2.19; English translation by H.C. Hamilton).

In addition to myth's summary, in this passage Strabo deciphers the symbolic meaning of the myth: the struggle of humans to control environmental threats and their victory, which is rewarded by the horn of Amaltheia, an eternal symbol of abundance. This deciphering has been possible after the revolution that occurred in Greece during the 6th century BC, the rise of φιλοσοφία (philosophy) and επιστήμη (science), and the mobilizing of λόγος (logos, reason) to explain not only the natural phenomena, such as rivers' overflowing, but also the human actions, such as the creation of myths.

Humans have never been reluctant in creating myths, even though their focus may change in different time periods. For example, in our era the dominant mythological element is that humans have replaced deities in ruling the universe and the natural processes (cf. anthropogenic climate change and Anthropocene—or, according to Sagoff, 2018, Narcisscene). Furthermore, in the current myth making, heroic feats are not the victories in the struggle with nature, but rather the protection of the nature from the destructive power of human sinners or demons.

Coming in hydrology, it is notable that Klemeš, (1986) used the myth of the Lernean Hydra to express the developing of misconceptions in modern hydrology: fighting them has been difficult because, as soon as one of its heads is struck off, two shoot up in its place. Therefore, there is abundance or such misconceptions, or modern hydrological myths, but here we will refer only to those about the origin and historical development of hydrology per se.

A first characteristic example is the following extract from Price (1989):

> *Today, our version of the hydrological cycle seems so logical and obvious that it is difficult to believe that it did not gain widespread acceptance until the 17th century. This was caused in large part by the tendency of the philosophers of Ancient Greece to distrust observations and by the tendency of later philosophers to accept the opinions of the Greeks almost without question. Plato advocated the search for truth by reasoning. He and his followers appear to have attached little importance to observations and measurements. Thus Aristotle, Plato's most famous pupil, was reportedly*

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* *ἀφ' ἧς αἰτίας καὶ μῦθος ἐπλάσθη τις: ὡς Ἡρακλέους καταπολεμήσαντος τὸν Ἀχελῶον καὶ ἐνεγκαμένου τῆς νίκης ἆθλον τὸν Δηιανείρας γάμον τῆς Οἰνέως θυγατρός, ἣν πεποίηκε Σοφοκλῆς τοιαῦτα λέγουσαν «μνηστὴρ γὰρ ἦν μοι ποταμός, Ἀχελῶον λέγω, ὅς μ' ἐν τρισὶν μορφαῖσιν ἐξῄτει πατρός, φοιτῶν ἐναργὴς ταῦρος, ἄλλοτ' αἰόλος δράκων ἑλικτός, ἄλλοτ' ἀνδρείῳ κύτει βούπρῳρος». προστιθέασι δ' ἔνιοι καὶ τὸ τῆς Ἀμαλθείας τοῦτ' εἶναι λέγοντες κέρας, ὃ ἀπέκλασεν ὁ Ἡρακλῆς τοῦ Ἀχελώου καὶ ἔδωκεν Οἰνεῖ τῶν γάμων ἕδνον· οἱ δ' εἰκάζοντες ἐξ αὐτῶν τἀληθὲς ταύρῳ μὲν ἐοικότα λέγεσθαι τὸν Ἀχελῶόν φασι, καθάπερ καὶ τοὺς ἄλλους ποταμούς, ἀπό τε τῶν ἤχων καὶ τῶν κατὰ τὰ ῥεῖθρα καμπῶν, ἃς καλοῦσι κέρατα, δράκοντι δὲ διὰ τὸ μῆκος καὶ τὴν σκολιότητα, βούπρῳρον δὲ διὰ τὴν αὐτὴν αἰτίαν δι' ἣν καὶ ταυρωπόν· τὸν Ἡρακλέα δὲ καὶ ἄλλως εὐεργετικὸν ὄντα καὶ τῷ Οἰνεῖ κηδεύσοντα παραχώμασί τε καὶ διοχετείαις βιάσασθαι τὸν ποταμὸν πλημμελῶς ῥέοντα καὶ πολλὴν τῆς Παραχελωίτιδος ἀναψύξαι χαριζόμενον τῷ Οἰνεῖ· καὶ τοῦτ' εἶναι τὸ τῆς Ἀμαλθείας κέρας.* (Στράβων, Γεωγραφικά, 10.2.19).

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able to teach that men have more teeth than women, when simple observation would have dispelled this idea. From a hydrological viewpoint, however, he had a more serious misconception – he believed that rainfall alone was inadequate to sustain the flow of rivers.

It is true that Plato (Figure 1) advocated the search for truth by reasoning as he regarded reasoning an important element distinguishing what is and what is not science (see below)—and we do not have any hesitation to support this view of Plato. However, all other information contained in this extract is mythology. In particular portraying Aristotle (Figure 3) as hating observation is absolutely absurd.

Figure 2: Πλάτων (Plato, 428/427 or 424/423 – 348/347 BC), Athenian philosopher of the Classical period, founder of the Platonic school and the Academy, the first higher education institution in the Western world. (Image source: Visconti, 1817; see section on Data availability for details.)

A careful search in the literature reveals that this absurd idea about Aristotle, including the joke about women's teeth is not Price's (1989) but Bertrand Russell's (1952):

Observation versus Authority: To modern educated people, it seems obvious that matters of fact are to be ascertained by observation, not by consulting ancient authorities. But this is an entirely modern conception, which hardly existed before the seventeenth century. Aristotle maintained that women have fewer teeth than men; although he was twice married, it never occurred to him to verify this statement by examining his wives' mouths.

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Figure 3: Ἀριστοτέλης (Aristotle; 384–322 BC), Greek philosopher of the Classical period, founder of the Lyceum and the Peripatetic school of philosophy. (Image source: Visconti, 1817.)

Now, what Aristotle has actually written is this:

Males have more teeth than females in the case of men, sheep, goats, and swine; in the case of other animals observations have not yet been made […] *The last teeth to come in man are molars called 'wisdom-teeth', which come at the age of about twenty years, in the case of both men and women. Cases have been known in women upwards of eighty years old where at the very close of life the wisdom-teeth have come up*.* (Aristotle, History of Animals, 2.3.2 – 2.4.1; English translation by D.W. Thompson).

Which Authority is right, Aristotle or Russell? Perhaps both—but they have different perceptions of nature. Russell seems to have a purely deterministic view, in which a rule, norm or formula (in this case the formula of 32 teeth per person) holds universally†. Aristotle, who is not a determinist (cf. his theory on *potentiality* and *actuality*; see section 3), as clearly seen in the above excerpt, trusts empirical Observation more—as evident in the extract. But what do we mean by *Observation*? Does information from school teachers, professors, books, TV, internet, model outputs, etc., classify as observation? In our view

* *Ἔχουσι δὲ πλείους οἱ ἄρρενες τῶν θηλειῶν ὀδόντας καὶ ἐν ἀνθρώποις καὶ ἐπὶ προβάτων καὶ αἰγῶν καὶ ὑῶν· ἐπὶ δὲ τῶν ἄλλων οὐ τεθεώρηταί πω.* […] *Φύονται δ' οἱ τελευταῖοι τοῖς ἀνθρώποις γόμφιοι, οὓς καλοῦσι κραντῆρας, περὶ τὰ εἴκοσιν ἔτη καὶ ἀνδράσι καὶ γυναιξίν. Ἤδη δέ τισι γυναιξὶ καὶ ὀγδοήκοντα ἐτῶν οὔσαις ἔφυσαν γόμφιοι ἐν τοῖς ἐσχάτοις*. (Ἀριστοτέλης, Τῶν περὶ τὰ ζῷα ἱστοριῶν, 2.3.2 – 2.4.1)

† Russell does not provide information on how he knew whether or not Aristotle examined his two wives' teeth, nor whether or not he himself examined his four wives' teeth. By the way, we did not find it polite to examine our own wives' teeth, but this would be irrelevant. We know, of course, that each of the two of us has fewer than 32 teeth, while in the past one of us had 33, but again this does not enable any type of induction—for the latter we would need a large sample of observations.

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not—and real observation can hardly confirm the universal validity of a formula referring to the real world. Some modern studies that could support the idea that, what Aristotle wrote in the above excerpt is a result of observation, is contained in Appendix A.

After this necessary parenthesis on odontology, which has some epistemological interest, we return to hydrology, presenting another useful extract from Price (1989):

> *The first person to make a forthright and unequivocal statement that rivers and springs originate entirely from rainfall appears to have been a Frenchman called Bernard Palissy, who put forward this proposition in 1580. Despite this, in the early 17th century many workers were still in essence following the Greeks in believing that sea water was drawn into vast caverns in the interior of the Earth, and raised up to the level of the mountains by fanciful processes usually involving evaporation and condensation. The water was then released through crevices in the rocks to flow into the rivers and so back to the sea.*

A similar extract from Todd and Mays (2005) is this:

> *As late as the seventeenth century it was generally assumed that water emerging from springs could not be derived from rainfall, for it was believed that the quantity was inadequate and the earth too impervious to permit penetration of rainwater far below the surface. Thus, early Greek philosophers such as Homer, Thales, and Plato hypothesized that springs were formed by seawater conducted through subterranean channels below the mountains, then purified and raised to the surface. Aristotle suggested that air enters cold dark caverns under the mountains where it condenses into water and contributes to springs.*

Finally, a recent text on the history of hydrology by Rosbjerg and Rodda (2019) contains the following:

> *It was, however, not before the beginning of the 1500s that a scientific approach to hydrology started to take off, albeit with a very slow starting speed. Leonardo da Vinci undertook physical experiments, e.g. measuring stream velocity, to support his advanced thoughts about hydrology* […]. *In 1575, Bernard Palissy, based on observations in nature, claimed that springs originated from rain, and 100 years later, in 1674, Pierre Perrault measured the rainfall, runoff and drainage area of the Seine River and concluded that rainfall was enough to support springs and rivers. The pathways, however, were not correctly described. In 1686, Edme Mariotte supported the findings of Perrault by contributing infiltration experiments, relating them to precipitation regimes and developing better streamflow measurements. Around 1700, Edmond Halley published the results of evaporation measurements, thereby contributing significantly to closing the hydrological cycle. Nevertheless, it was not before 1802 that John Dalton became the first to give a complete and correct description of the cycle based on reliable observations*. […]
>
> *At the general assembly of the IUGG in Rome in 1922, a delegate proposed a motion to form an additional section within the union to deal with the scientific problems in hydrology, such as "river-gauging, lake phenomena including seiches, run-off and evaporation, transport of material in suspension and in solution, glacier movement, etc." A*

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committee was set up to give its opinion on the desirability of such a new activity. The committee gave favourable advice and proposed that the new organism should be named Section of Scientific Hydrology. The adjective "scientific" was added to distinguish the section's participants from the 'charlatans and simpletons', who with the help of all sorts of rods tried to find water, calling themselves hydrologists, and also to make clear that the branch would not deal with the commercial exploitation of mineral waters.

In the following sections we will see that all above extracts contain useful information but also serious misinformation about the history of hydrology. Our method, already illustrated above, it to retrieve the ancient documents in their original version and quote relevant extracts, rather than resort to what modern scholars have said about them. We will see that not only was the notion of the hydrological cycle known to ancient Greek scholars, but hydrology appeared in the cradle of science. The first geophysical problem posed was hydrological: the explanation of the flooding of the Nile. The problem plagued scientists for almost three centuries before it was resolved by Aristotle. We will also trace the links of the developments in the early modern period (after the Renaissance) with the ancient thinkers, including Aristotle and Hippocrates; it is the strong link with the latter and the health aspects of water that dictated the adjective "scientific" in hydrology in the beginning of the 20th century. In other words, the need to distinguish it from the '*charlatans and simpletons*' (Rosbjerg and Rodda, 2019) does not correspond to reality—unless one characterizes medical doctors as such, which hopefully is not the case.

But before we proceed to the ancient and early modern developments in hydrology, is useful to find the origin for the misunderstanding of what ancient Greek science actually was. After some search in classical Greek texts, we suspect that the culprit is Plato and the misunderstanding stems from the following passage from his Dialogue Phaedo:

[Socrates:] *One of the chasms of the earth is greater than the rest, and is bored right through the whole earth; this is the one which Homer means when he says "Far off, the lowest abyss beneath the earth" and which elsewhere he and many other poets have called Tartarus. For all the rivers flow together into this chasm and flow out of it again, and they have each the nature of the earth through which they flow.* […] *And when the water retires to the region which we call the lower, it flows into the rivers there and fills them up, as if it were pumped into them; and when it leaves that region and comes back to this side, it fills the rivers here.*[*] (Plato, Phaedo, 14.112; English translation by H.N. Fowler).

While this story in Phaedo was adopted by many thinkers and scientists from Seneca (c. 4 BC–65 AD) to Descartes (1596-1650), it is a just a poetic metaphor, as indicated by the reference to Homer. It has a symbolic meaning as the philosophical subject of Phaedo is the immortality of the soul. It is not representative of Greek philosophers' views on nature, not even Plato's. In other Dialogues, Plato offers more consistent theories, e.g., in Critias:

[*] [Σωκράτης:] *τοῦτο* [το χάσμα] *ὅπερ Ὅμηρος εἶπε, λέγων αὐτό "τῆλε μάλ', ἧχι βάθιστον ὑπὸ χθονός ἐστι βέρεθρον" ὃ καὶ ἄλλοθι καὶ ἐκεῖνος καὶ ἄλλοι πολλοὶ τῶν ποιητῶν Τάρταρον κεκλήκασιν. εἰς γὰρ τοῦτο τὸ χάσμα συρρέουσί τε πάντες οἱ ποταμοὶ καὶ ἐκ τούτου πάλιν ἐκρέουσιν· γίγνονται δὲ ἕκαστοι τοιοῦτοι δι' οἵας ἂν καὶ τῆς γῆς ῥέωσιν.* […] *ὅταν τε οὖν ὑποχωρήσῃ τὸ ὕδωρ εἰς τὸν τόπον τὸν δὴ κάτω καλούμενον, τοῖς κατ' ἐκεῖνα τὰ ῥεύματα διὰ τῆς γῆς εἰσρεῖ τε καὶ πληροῖ αὐτὰ ὥσπερ οἱ ἐπαντλοῦντες· ὅταν τε αὖ ἐκεῖθεν μὲν ἀπολίπῃ, δεῦρο δὲ ὁρμήσῃ, τὰ ἐνθάδε πληροῖ αὖθις.* (Πλάτων, Φαίδων, 14.112α).

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> [Critias:] *Moreover, it was enriched by the yearly rains from Zeus, which were not lost to it, as now, by flowing from the bare land into the sea; but the soil it had was deep, and therein it received the water, storing it up in the retentive loamy soil and by drawing off into the hollows from the heights the water that was there absorbed, it provided all the various districts with abundant supplies of springwaters and rivers*.* (Plato, Critias, 111d; translation adapted from R.G. Bury).

Interestingly, in this excerpt Zeus is responsible for the rainfall process, the most complex and most difficult to understand. All other transformations of water throughout the hydrological cycle are natural. As we will see in next sections, others have completely expelled Zeus and other gods from the entire hydrological cycle.

The critics of Plato with respect to his scientific views should be aware that he was the author of the first work in history about epistemology, i.e., his Dialogue Theaetetus, and the first who tried to define *science* (*ἐπιστήμη*) per se therein:

> [Theaetetus:] *Science is true judgment, affirmed by reason, but that unreasoned is outside of the sphere of science*.† (Plato, Theaetetus, 201d; translation by authors).

Moreover, in his Dialogue Republic, Plato gives the following definition of philosophers, who in that period were not actually distinguished from scientists:

> [Glaucon:] *Who then are the true philosophers?* [Socrates:] *Those, I said, who are lovers of the vision of truth.*‡ (Plato, Republic, V, 475e; English translation by B. Jowett).

2 Hydrology at the birth of science

Natural philosophy and science start with Thales of Miletus (Figure 4), one of the Seven Sages of Greece and the father of the Ionian philosophical school. (Ionia was located at the western coast of Asia Minor by the Aegean Sea, which was inhabited by Greeks from ancient times till 1922 AD). As a philosopher is famous for the foremost importance he gave to water as a natural element, as well as for several apothegms.§ As a scientist he is known for his contribution in several areas, i.e.:

- *Mathematics*. He introduced deduction through theorems; he proved several theorems in geometry, including those bearing his name: the Thales' angle theorem and interception theorem.

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* *τὸ κατ' ἐνιαυτὸν ὕδωρ ἐκαρποῦτ' ἐκ Διός, οὐχ ὡς νῦν ἀπολλῦσα ῥέον ἀπὸ ψιλῆς τῆς γῆς εἰς θάλατταν, ἀλλὰ πολλὴν ἔχουσα καὶ εἰς αὐτὴν καταδεχομένη, τῇ κεραμίδι στεγούσῃ γῇ διαταμιευομένη, τὸ καταποθὲν ἐκ τῶν ὑψηλῶν ὕδωρ εἰς τὰ κοῖλα ἀφιεῖσα κατὰ πάντας τοὺς τόπους παρείχετο ἄφθονα κρηνῶν καὶ ποταμῶν νάματα*. (Πλάτων, Κριτίας, 111d).

† *τὴν μὲν μετὰ λόγου ἀληθῆ δόξαν ἐπιστήμην εἶναι, τὴν δὲ ἄλογον ἐκτὸς ἐπιστήμης*, (Πλάτων, Θεαίτητος, 201d).

‡ [Γλαύκων:] *τοὺς δὲ ἀληθινούς* [φιλοσόφους], *ἔφη, τίνας λέγεις;* [Σωκράτης:] *τοὺς τῆς ἀληθείας, ἦν δ' ἐγώ, φιλοθεάμονας*. (Πλάτων, Πολιτεία, Ε, 475e).

§ Different scholars may attribute each of them to more than one of Seven Sages. However, it would be relevant to mention two of them that could be useful to hydrologists. (a) «Ἐγγύα πάρα δ' ἄτα» (Surety brings ruin—one of the three maxims inscribed on the temple of Apollo in Delphi) (b) «Ἀσφαλές τὸ γενόμενον, ἀσαφές τὸ μέλλον» (Sure what happened, unclear the future).

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- *Astronomy*. He predicted the solar eclipse in 28 May 585 BC.
- *Physics*. He studied static electricity by experimenting on amber (in Greek ήλεκτρον—electron) as well as magnetism.
- *Surveying engineering*. He measured the heights of pyramids and the distance of ships from the shore.
- *Hydraulic engineering*. He made a diversion of the river Halys for military purposes.

His contribution to hydrology is less known but it is important as he formulated for the first time in history a hydrological behaviour as a scientific problem, thus highlighting the importance of hydrology in the cradle of science. The problem is the so-called *paradox of the Nile* and, as we will see in section 4, the solution he gave is clearly wrong. Yet the important development is that he formulated the problem in scientific terms, expelling the divine element from natural processes.

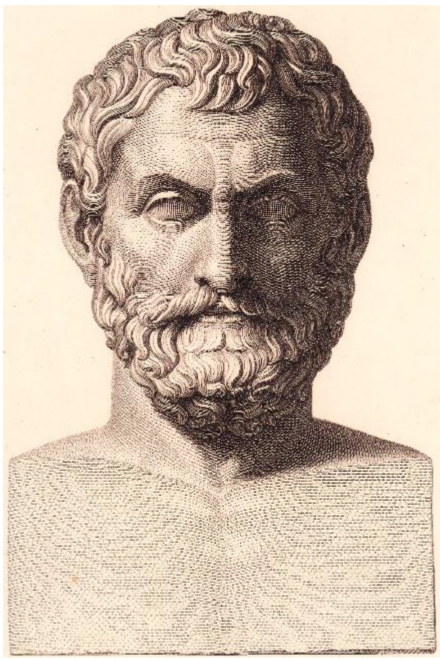

Figure 4: Θαλῆς ὁ Μιλήσιος (Thales of Miletus; c. 624/623 – c. 548/545 BC), one of the Seven Sages of Greece the first philosopher in the Greek tradition also recognized as the father of science (Image source: Visconti, 1817.)

Anaximander (c. 610 – c. 546 BC), who succeeded Thales in Miletus, is the first to dare write a book «Περί Φύσεως» ("On Nature"; lost), rejecting mythological and religious views. He understood the relationship of rainfall and evaporation:

> *Rain* [is created] *from the vapours which rise from earth by the sun*. (Hippolytus, Refutation of All Heresies, I, 5).*

Anaximenes (c. 586 – c. 526 BC), another philosopher from Miletus pupil of Anaximander, proclaimed Air as the *Arche* (origin) of the universe; naturally, thus, he devised logical explanations for the formation of wind, clouds, rain and hail:

* «*ὑετούς δὲ* [γίγνεσθαι] *ἐκ τῆς ἀτμίδος τῆς ἐκ γῆς ὑφ' ἥλιον ἀναδιδομένης*» (Ἱππόλυτος, Φιλοσοφούμενα ἢ Κατὰ Πασῶν Αἱρέσεων Ἔλεγχος, I, 5).

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the winds arise when the air becomes partially condensed and is lifted up; and when it comes together and more condensed, clouds are generated, and thus a change is made into water. And hail is produced when the water precipitating from the clouds freezes; and snow is generated when these clouds, being more moist, acquire congelation; and lightning is caused when the clouds are parted by force of the winds; […]. *And a rainbow is produced from solar rays falling on condensed air.*[*] (Hippolytus, Refutation of All Heresies, I, 6).

The entire hydrological cycle was described by Xenophanes (c. 570 – 478 BC), another Ionian philosopher, who supported his theory by the discovery of fossilized marine organisms at three island locations. Hippolitus (c. 170–235 AD; Christian theologian) attributes to him a theory of alternating periods of flood and drought. Xenophanes expressed his philosophy in poetic form (hexameters, elegies, iambics), as in the following fragment:

The sea is the source of water and the source of wind; for neither in the clouds <would there be nor any blasts of wind blowing forth> from within, without the mighty sea, nor river flows nor rain water from the sky. The mighty sea is father of clouds and of winds and of river.[†] (Fragment B 30, recovered from Geneva Scholia on Homer.)

Hydrology is the science of change and randomness; Heraclitus (Figure 5) described the nature of each in just a few words, using the metaphor of flow in the first case and of dice in the second case:

Πάντα ῥεῖ (*Everything flows*) (Heraclitus; quoted in Plato's Cratylus, 339-340)
Time is a child playing, throwing dice[‡] (Heraclitus; Fragment 52)

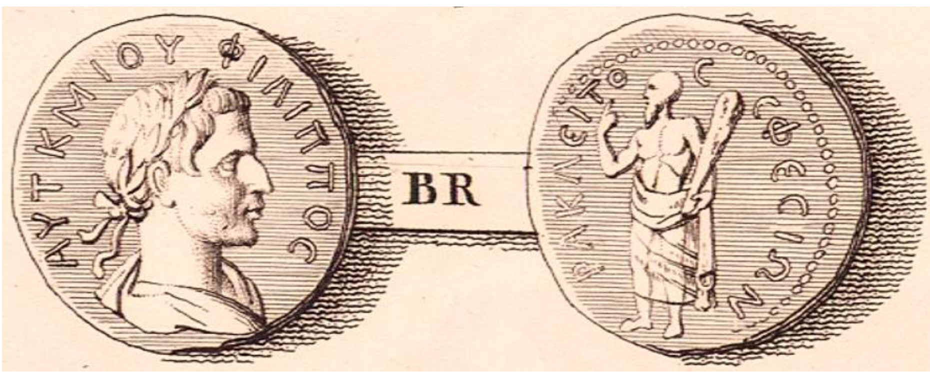

Figure 5: Ἡράκλειτος ὁ Ἐφέσιος (Heraclitus of Ephesus; c. 535 – c. 475 BC), Ionian philosopher, father of dialectics, depicted in the back facet of a coin whose front facet shows Philip. (Image source: Visconti, 1817.)

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[*] *ἀνέμους δὲ γεννᾶσθαι, ὅταν ἐκ <μέρους> πεπυκνωμένος ἀὴρ καὶ ἀρθεὶς φέρηται· συνελθόντα δὲ καὶ ἐπὶ πλεῖον παχυνθέντα νέφη γεννᾶσθαι καὶ οὕτως εἰς ὕδωρ μεταβάλλειν. χάλαζαν δὲ γίνεσθαι, ὅταν ἀπὸ τῶν νεφῶν τὸ ὕδωρ καταφερόμενον παγῇ· χιόνα δέ, ὅταν αὐτὰ ταῦτα ἐνυγρότερα ὄντα πῆξιν λάβῃ. ἀστραπὴν δ' ὅταν τὰ νέφη διιστῆται βίαι πνευμάτων·*[…] *ἶριν δὲ γεννᾶσθαι τῶν ἡλιακῶν αὐγῶν εἰς ἀέρα συνεστῶτα πιπτουσῶν*. (Ιππόλυτος, Φιλοσοφούμενα ἤ Κατὰ Πασῶν Αἱρέσεων Ἔλεγχος, I, 6.)

[†] *πηγὴ δ' ἐστὶ θάλασσ' ὕδατος, πηγὴ δ' ἀνέμοιο· οὔτε γὰρ ἐν νέφεσιν <γίνοιτό κε ἶς ἀνέμοιο ἐκπνείοντος> ἔσωθεν ἄνευ πόντου μεγάλοιο οὔτε ῥοαὶ ποταμῶν οὔτ' αἰ<θέρος> ὄμβριον ὕδωρ, ἀλλὰ μέγας πόντος γενέτωρ νεφέων ἀνέμων τε καὶ ποταμῶν*. (Ξενοφάνης ἐν τῷ Περὶ φύσεως· Απόσπασμα B 30.)

[‡] *«Αἰών παῖς ἐστι παίζων πεσσεύων.»*

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Interestingly, the former aphorism has become the emblem of the current hydrological decade (Montanari et al., 2013). The latter symbol, the dice, has been used by other famous aphorisms such as by Julius Cesar and by Einstein. Einstein expressed (in a less poetic manner) exactly the opposite view; however, the recent developments in physics seem to vindicate Heraclitus.

Anaxagoras of Clazomenae (Figure 6) was another Ionian philosopher who proved to be very influential in history. As he moved to Athens and taught there for about 30 years, he transplanted the ideas of Ionian philosophers to Athenians, having prominent students such as Pericles, Euripides, Sophocles, and Herodotus. He proposed a theory of "everything-in-everything," and was the first to give a correct explanation of eclipses. While his scientific theories were mostly related to astronomy, including the claims that the sun is a mass of red-hot metal and the moon is earthy, they also include hydrology:

> *The rivers receive their contents from the rains and from the waters in the earth; for the earth is hollow and has water in its hollow portions*.* (Hippolytus, Refutation of All Heresies, I, 7).

Figure 6: Ἀναξαγόρας ὁ Κλαζομένιος (Anaxagoras of Clazomenae; c. 500 – c. 428 BC), the philosopher who transplanted the Ionian philosophy to Athens, depicted in the back facet of a coin whose front facet shows a ribbed head of a woman representing the personified city of Clazomenae. (Image source: Visconti, 1817.)

Subsequently, Athens became the philosophical, scientific and political centre of the entire world for several centuries. This may seem as an historical paradox because it is a dry and infertile place. The paradox have been explained by the Athenian Thucydides (Figure 7), father of *scientific history*, who observed that infertility has also a good side and scarcity may be preferable to abundance:

> *The richest soils were always most subject to this change of masters; such as the district now called Thessaly, Boeotia, most of the Peloponnese, Arcadia excepted, and the most fertile parts of the rest of Hellas. The goodness of the land favoured the aggrandizement of particular individuals, and thus created faction which proved a fertile source of ruin. It also invited invasion. Accordingly Attica, from the poverty of its soil enjoying from a very remote period freedom from faction, never changed its inhabitants. And here is no inconsiderable exemplification of my assertion that the*

* *τοὺς δὲ ποταμοὺς καὶ ἀπὸ τῶν ὄμβρων λαμβάνειν τὴν ὑπόστασιν καὶ ἐξ ὑδάτων τῶν ἐν τῇ γῇ· εἶναι γὰρ αυτὴν κοίλην καὶ ἒχειν ὓδωρ ἐν τοῖς κοιλώμασιν.* (Ιππόλυτος, Φιλοσοφούμενα ἢ Κατὰ Πασῶν Αἱρέσεων Ἔλεγχος, I, 7.)

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*migrations were the cause of there being no correspondent growth in other parts. The most powerful victims of war or faction from the rest of Hellas took refuge with the Athenians as a safe retreat; and at an early period, becoming naturalized, swelled the already large population of the city to such a height that Attica became at last too small to hold them, and they had to send out colonies to Ionia.** (Thucydides, The Peloponnesian War, 1.2.3-6.)

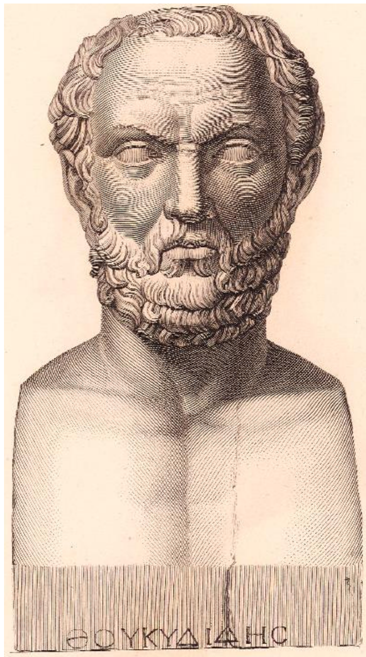

Figure 7: Θουκυδίδης (Thucydides; c. 460 – c. 400 BC) the Athenian historian dubbed the father of *scientific history*. (Image source: Visconti 1817.)

Among the philosophers who lived and taught in Athens, Aristotle has been the most influential in subsequent developments of philosophy and science, including hydrology; therefore, we devote to him the entire section 3. Among those who lived in other places of Greece we should mention Hippocrates (Figure 8) who lived in the island of Kos. He is often referred to as the father of medicine, but, as we will see, his contribution to the ancient and modern hydrology through his treatise *On Airs, Waters, Places* is not negligible. From this treatise we quote the following passage, in which he describes the hydrological cycle:

* *μάλιστα δὲ τῆς γῆς ἡ ἀρίστη αἰεὶ τὰς μεταβολὰς τῶν οἰκητόρων εἶχεν, ἥ τε νῦν Θεσσαλία καλουμένη καὶ Βοιωτία Πελοποννήσου τε τὰ πολλὰ πλὴν Ἀρκαδίας, τῆς τε ἄλλης ὅσα ἦν κράτιστα. διὰ γὰρ ἀρετὴν γῆς αἵ τε δυνάμεις τισὶ μείζους ἐγγιγνόμεναι στάσεις ἐνεποίουν ἐξ ὧν ἐφθείροντο, καὶ ἅμα ὑπὸ ἀλλοφύλων μᾶλλον ἐπεβουλεύοντο. τὴν γοῦν Ἀττικὴν ἐκ τοῦ ἐπὶ πλεῖστον διὰ τὸ λεπτόγεων ἀστασίαστον οὖσαν ἄνθρωποι ᾤκουν οἱ αὐτοὶ αἰεί. καὶ παράδειγμα τόδε τοῦ λόγου οὐκ ἐλάχιστόν ἐστι διὰ τὰς μετοικίας ἐς τὰ ἄλλα μὴ ὁμοίως αὐξηθῆναι· ἐκ γὰρ τῆς ἄλλης Ἑλλάδος οἱ πολέμῳ ἢ στάσει ἐκπίπτοντες παρ᾽ Ἀθηναίους οἱ δυνατώτατοι ὡς βέβαιον ὂν ἀνεχώρουν, καὶ πολῖται γιγνόμενοι εὐθὺς ἀπὸ παλαιοῦ μείζω ἔτι ἐποίησαν πλήθει ἀνθρώπων τὴν πόλιν, ὥστε καὶ ἐς Ἰωνίαν ὕστερον ὡς οὐχ ἱκανῆς οὔσης τῆς Ἀττικῆς ἀποικίας ἐξέπεμψαν.* (Θουκυδίδης, Ἱστορία τοῦ Πελοποννησιακοῦ Πολέμου, 1.2.3-6.)

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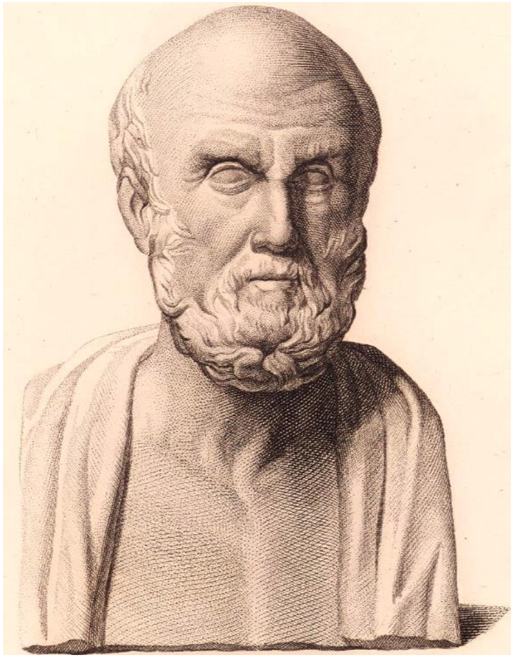

Figure 8: Ἱπποκράτης ὁ Κῷος (Hippocrates of Kos; c. 460 – c. 370 BC), the philosopher and physician of Classical Greece who is considered one of the most outstanding figures in the history of medicine. (Image source: Visconti, 1817.)

Rain waters, then, are the lightest, the sweetest, the thinnest, and the clearest; for originally the sun raises and attracts the thinnest and lightest part of the water, as is obvious from the nature of salts; for the saltish part is left behind owing to its thickness and weight, and forms salts; but the sun attracts the thinnest part, owing to its lightness, and he abstracts this not only from the lakes, but also from the sea, and from all things which contain humidity, and there is humidity in everything; and from man himself the sun draws off the thinnest and lightest part of the juices. […] *And in addition to this, when attracted and raised up, being carried about and mixed with the air, whatever part of it is turbid and darkish is separated and removed from the other, and becomes cloud and mist, but the most attenuated and lightest part is left, and becomes sweet* [i.e., not salty, freshwater], *being heated and concocted by the sun, for all other things when concocted become sweet. While dissipated then and not in a state of consistence it is carried aloft. But when collected and condensed by contrary winds, it falls down wherever it happens to be most condensed.*[*] (Hippocrates, De Aere Aquis et Locis, 8; English translation adapted from W.H.S. Jones).

[*] *περὶ δὲ τῶν ὀμβρίων καὶ ὁκόσα ἀπὸ χιόνος φράσω ὅκως ἔχει. τὰ μὲν οὖν ὄμβρια κουφότατα καὶ γλυκύτατά ἐστι καὶ λεπτότατα καὶ λαμπρότατα. τήν τε γὰρ ἀρχὴν ὁ ἥλιος ἀνάγει καὶ ἀναρπάζει τοῦ ὕδατος τό τε λεπτότατον καὶ κουφότατον. δῆλον δὲ οἱ ἅλες ποιέουσι. τὸ μὲν γὰρ ἁλμυρὸν λείπεται αὐτοῦ ὑπὸ πάχεος καὶ βάρεος καὶ γίνεται ἅλες, τὸ δὲ λεπτότατον ὁ ἥλιος ἀναρπάζει ὑπὸ κουφότητος· ἀνάγει δὲ τὸ τοιοῦτο οὐκ ἀπὸ τῶν ὑδάτων μοῦνον τῶν λιμναίων, ἀλλὰ καὶ ἀπὸ τῆς θαλάσσης καὶ ἐξ ἁπάντων ἐν ὁκόσοισι ὑγρόν τι ἔνεστιν. ἔνεστι δὲ ἐν παντὶ χρήματι. καὶ ἐξ αὐτῶν τῶν ἀνθρώπων ἄγει τὸ λεπτότατον τῆς ἰκμάδος καὶ κουφότατον.* […] *ἔτι δὲ πρὸς τούτοισιν ἐπειδὰν ἁρπασθῇ καὶ μετεωρισθῇ περιφερόμενον καὶ καταμεμιγμένον ἐς τὸν ἠέρα, τὸ μὲν θολερὸν αὐτοῦ καὶ νυκτοειδὲς ἐκκρίνεται καὶ ἐξίσταται καὶ γίνεται ἠὴρ καὶ ὀμίχλη, τὸ δὲ λαμπρότατον [p. 92] καὶ κουφότατον αὐτοῦ λείπεται καὶ γλυκαίνεται ὑπὸ τοῦ ἡλίου καιόμενόν τε καὶ ἑψόμενον. γίνεται δὲ καὶ τἄλλα πάντα τὰ ἑψόμενα αἰεὶ γλυκύτερα. ἕως μὲν οὖν διεσκεδασμένον ᾖ καὶ μήπω συνεστήκῃ, φέρεται μετέωρον. ὁκόταν δέ κου ἀθροισθῇ καὶ συστραφῇ ἐς τὸ αὐτὸ ὑπὸ ἀνέμων ἀλλήλοισιν ἐναντιωθέντων ἐξαίφνης, τότε καταρρήγνυται.* (Ιπποκράτης, Περὶ Ἀέρων, Ὑδάτων, Τόπων, 8.)

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In another passage, he expresses (in addition to the link of water and wine) the relationship of spring water temperature and depth of its origin:

> *The best* [waters] *are those that flow from high places and earthy hills. By themselves they are fresh and clear, and the wine they can stand is but little. In winter they are warm, in summer cold. They would naturally be so, coming from very deep springs.* (Hippocrates, De Aere Aquis et Locis, 7; English translation adapted from W.H.S. Jones).[*]

Apparently, the reference to "warm" and "cold" should be read relative to the environmental temperature as Hippocrates did not have an instrument to measure temperature in objective terms. Today we measure temperature to infer the depth.

Compared to modern knowledge, that contained in the above extracts of the ancient philosophers is incomplete and sometimes erroneous. This is normal as scientific knowledge is a result of endless and torturous process. It is not revelation knowledge like in religion.

3 Aristotle

Aristotle was student of Plato, but his theories were influenced by Ionian philosophers. Instead of continuing in Plato's Academy, he founded his own school, known as the Lycaeum or the Peripatetic school (Περιπατητική, meaning "by walking about"). His theories expand to all aspects of knowledge and are relevant not only in his period but throughout the entire history of science, including the recent period. Science and the Scientific Method owes him basic notions on research and laws on inference, sometimes referred to as Aristotelian Logic, exposed in his six books that are collectively known as the *Organon*, as well in his book *Metaphysics*. These includes the laws of *identity* (*Prior Analytics*[†]), *excluded middle* and *noncontradiction* (*Metaphysics*[‡]) and the distinction of *deduction* (*παραγωγὴ, ἀπόδειξις*) and *induction* (*ἐπαγωγὴ*). Furthermore, the *principle of parsimony* (also known as Ockham's razor) is expressed in at least three Aristotle's books (*Posterior Analytics*, *On the Heavens*, *Nicomachean Ethics*)[§].

Another concept introduced by Aristotle that has acquired great importance in modern science, particularly in physics and stochastics, is his dipole *potentiality* (*δύναμις*, Latin *potentia*) vs *actuality* (*ενέργεια*, Latin *actualitas*), formulated in his books *Physics*, *Metaphysics*, *Nicomachean Ethics* and *De Anima*. The first who utilized the dipole in modern science, namely in quantum physics, has been Heisenberg (1962):

---

[*] ἄριστα [ὕδατα] δὲ ὁκόσα ἐκ μετεώρων χωρίων ῥεῖ καὶ λόφων γεηρῶν. αὐτά τε γάρ ἐστι γλυκέα καὶ [60] λευκὰ καὶ τὸν οἶνον φέρειν ὀλίγον οἷά τέ ἐστιν. τοῦ δὲ χειμῶνος θερμὰ γίνεται, τοῦ δὲ θέρεος ψυχρά. οὕτω γὰρ ἂν εἴη ἐκ βαθυτάτων πηγέων (Ιπποκράτης, Περὶ ἀέρων, ὑδάτων, τόπων, 7).

[†] Ἀριστοτέλης, Αναλυτικὰ Πρότερα, 2.22.68a

[‡] Ἀριστοτέλης, Μετὰ τὰ φυσικά, 4.1011b, 4.1006b, 4.1008a

[§] Ἀριστοτέλης, Αναλυτικά Ύστερα, I.25, Περί Ουρανού, III.4; Ηθικά Νικομάχεια, 1094b.

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> *The most important of these* [features of the interpretation by Bohr, Kramers and Slater] *was the introduction of the probability as a new kind of "objective" physical reality, the "potentia" of the ancients such as Aristotle; it is, to a certain extent, a transformation of the old "potentia" concept from a qualitative to a quantitative idea.*

This Heisenberg's idea was quoted by Popper (1982), who fully incorporated it in his philosophical system, further extending it to claim, for example, that "Both classical physics and quantum physics are indeterministic". More recently this Aristotelian dipole has been proposed by several scientists and philosophers, independently of Popper, as a simpler, more comprehensible and more effective interpretation (Jaeger 2017, 2018; Kastner et al. 2018; Driessen 2019; Sanders 2018). In particular, Kastner et al. (2018), building on Heisenberg's (1962) idea, propose an ontological dualism of *actualities* (*res extensa*) and *potentia* (*res potentia*), with the latter not bounded by spacetime constraints and being transformed to the former by an acausal process.

Now coming to Aristotle's proposals that focus on hydrological processes, we should first mention his treatise *Meteorologica* which offers a great contribution to the explanation of hydrometeorological phenomena. As we know, the entire hydrological cycle is based on the phase change of water, which Aristotle understood in this way:

> *We maintain that fire, air, water and earth are transformable one into another, and that each one potentially exists in the others, as all have a single common underlying substratum, in which are ultimately resolved.*[*] (Meteorologica, I.1, 339a,b.)
>
> *The sun causes the moisture to rise; this is similar to what happens when water is heated by fire.*[†] (ibid., II.2, 355a 15.)
>
> *The vapour that is cooled, for lack of heat in the area where it lies, condenses and turns from air into water; and after the water has formed in this way it falls down again to the earth; the exhalation of water is vapour; air condensing into water is cloud*[‡] (ibid., I.9, 346b 30.)

In addition, he recognized the principle of mass conservation within the hydrological cycle:

> *Thus,* [the sea] *will never dry up; for* [the water] *that has gone up beforehand will return to it*[§] (ibid., II.3, 356b 26.)
>
> *Even if the same amount does not come back every year or in a given place, yet in a certain period all quantity that has been abstracted is returned*[**] (ibid., II.2, 355a 26.)

Furthermore, Aristotle penetrated into the concept of *change*. He was fully aware that the Earth changes through the ages and that rivers are formed and disappear in the course of time:

---

[*] *φαμὲν δὴ πῦρ καὶ ἀέρα καὶ ὕδωρ καὶ γῆν γίγνεσθαι ἐξ ἀλλήλων, καὶ ἕκαστον ἐν ἑκάστῳ ὑπάρχειν τούτων δυνάμει, ὥσπερ καὶ τῶν ἄλλων οἷς ἕν τι καὶ ταὐτὸν ὑπόκειται, εἰς ὃ δὴ ἀναλύονται ἔσχατον.* (Μετεωρολογικά, A1, 339a,b.)

[†] *ἔτι δ' ἡ ὑπὸ τοῦ ἡλίου ἀναγωγὴ τοῦ ὑγροῦ ὁμοία τοῖς θερμαινομένοις ἐστὶν ὕδασιν ὑπὸ πυρός*. (αὐτόθι, B2, 355a 15.)

[‡] *συνίσταται πάλιν ἡ ἀτμὶς ψυχομένη διά τε τὴν ἀπόλειψιν τοῦ θερμοῦ καὶ τὸν τόπον, καὶ γίγνεται ὕδωρ ἐξ ἀέρος· γενόμενον δὲ πάλιν φέρεται πρὸς τὴν γῆν. ἔστι δ' ἡ μὲν ἐξ ὕδατος ἀναθυμίασις ἀτμίς, ἡ δ' ἐξ ἀέρος εἰς ὕδωρ νέφος.* (αὐτόθι, A9, 346b 30.)

[§] *ὥστε* [τὴν θάλατταν] *οὐδέποτε ξηρανεῖται· πάλιν γὰρ ἐκεῖνο φθήσεται καταβὰν εἰς τὴν αὐτὴν τὸ προανελθόν.* (αὐτόθι, B3, 356b 26.)

[**] *κἂν μὴ κατ' ἐνιαυτὸν ἀποδιδῷ καὶ καθ' ἑκάστην ὁμοίως χώραν, ἀλλ' ἔν γέ τισιν τεταγμένοις χρόνοις ἀποδίδωσι πᾶν τὸ ληφθέν.* (αὐτόθι, B2, 355a 26.)

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But if rivers are formed and disappear and the same places were not always covered by water, the sea must change correspondingly. And if the sea is receding in one place and advancing in another it is clear that the same parts of the whole earth are not always either sea or land, but that all changes in course of time.* (ibid., I.14, 353a 16.)

In the Introduction we stressed the importance given by Aristotle on observation. He also conducted experimentation. In the following passage he explains that he found by experiment that the salt contained in water is not evaporated:

Salt water when it turns into vapour becomes drinkable [freshwater] *and the vapour does not form salt water when it condenses again; this I know by experiment*.† (ibid., II.3, 358b.)

This has certainly found technological application in desalination (removal of salt from sea water), useful in a country with scarcity of fresh water and many shores and islands. Thus, we learn from a commentary on Aristotle's Meteorologica II, written by Olympiodorus the Peripatetic (a 5th-century philosopher), that:

Sailors, when they labour under a scarcity of fresh water at sea, boil the sea-water, and suspend large sponges from the mouth of a brazen vessel, to imbibe what is evaporated, and in drawing this off from the sponges, they find it to be sweet [fresh] *water.*‡

4 The Nile paradox and its solution by Aristotle

As already mentioned in the Introduction, the flooding of the Nile has been the first geophysical problem posed in scientific terms. The problem plagued scientists for almost three centuries before it was resolved by Aristotle but it took much more before this correct explanation was generally accepted by the scientific community. What was regarded as a paradox was the different hydrological regime compared to other Mediterranean rivers: Nile floods occur in summer. Figure 9 illustrates the reasons why it was regarded a paradox using modern data of the Nile flows on monthly scale, along with monthly precipitation data at stations in the wider area.

The problem is originally stated by the historian Herodotus (Figure 10) in the following manner:

Concerning the nature of the river, I was not able to gain any information either from the priests or from others. I was particularly anxious to learn from them why the Nile, at the commencement of the summer solstice, begins to rise, and continues to increase for a hundred days—and why, as soon as that number is past, it forthwith retires and contracts its stream, continuing low during the whole of the winter until the summer solstice comes round again. On none of these

---

* *ἀλλὰ μὴν εἴπερ καὶ οἱ ποταμοὶ γίγνονται καὶ φθείρονται καὶ μὴ ἀεὶ οἱ αὐτοὶ τόποι τῆς γῆς ἔνυδροι, καὶ τὴν θάλατταν ἀνάγκη μεταβάλλειν ὁμοίως. τῆς δὲ θαλάττης τὰ μὲν ἀπολειπούσης τὰ δ᾽ ἐπιούσης ἀεὶ φανερὸν ὅτι τῆς πάσης γῆς οὐκ ἀεὶ τὰ αὐτὰ τὰ μέν ἐστιν θάλαττα τὰ δ᾽ ἤπειρος, ἀλλὰ μεταβάλλει τῷ χρόνῳ πάντα.* (αὐτόθι, A.14, 353a 16.)

† *ὅτι δὲ γίγνεται ἀτμίζουσα πότιμος καὶ οὐκ εἰς θάλατταν συγκρίνεται τὸ ἀτμίζον, ὅταν συνιστῆται πάλιν, πεπειραμένοι λέγωμεν.* (αὐτόθι, B3, 358b.)

‡ Quoted from Morewood (1838); see also quotation by Alexander of Aphrodisias, peripatetic philosopher (fl. 200 AD), in Forbes (1970).

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points could I obtain any explanation from the inhabitants, though I made every inquiry, wishing to know what was commonly reported— they could neither tell me what special virtue the Nile has which makes it so opposite in its nature to all other streams, nor why, unlike every other river, it gives forth no breezes from its surface.[*] (Herodotus, The Histories, 2, 19, English translation by G. Rawlinson.)

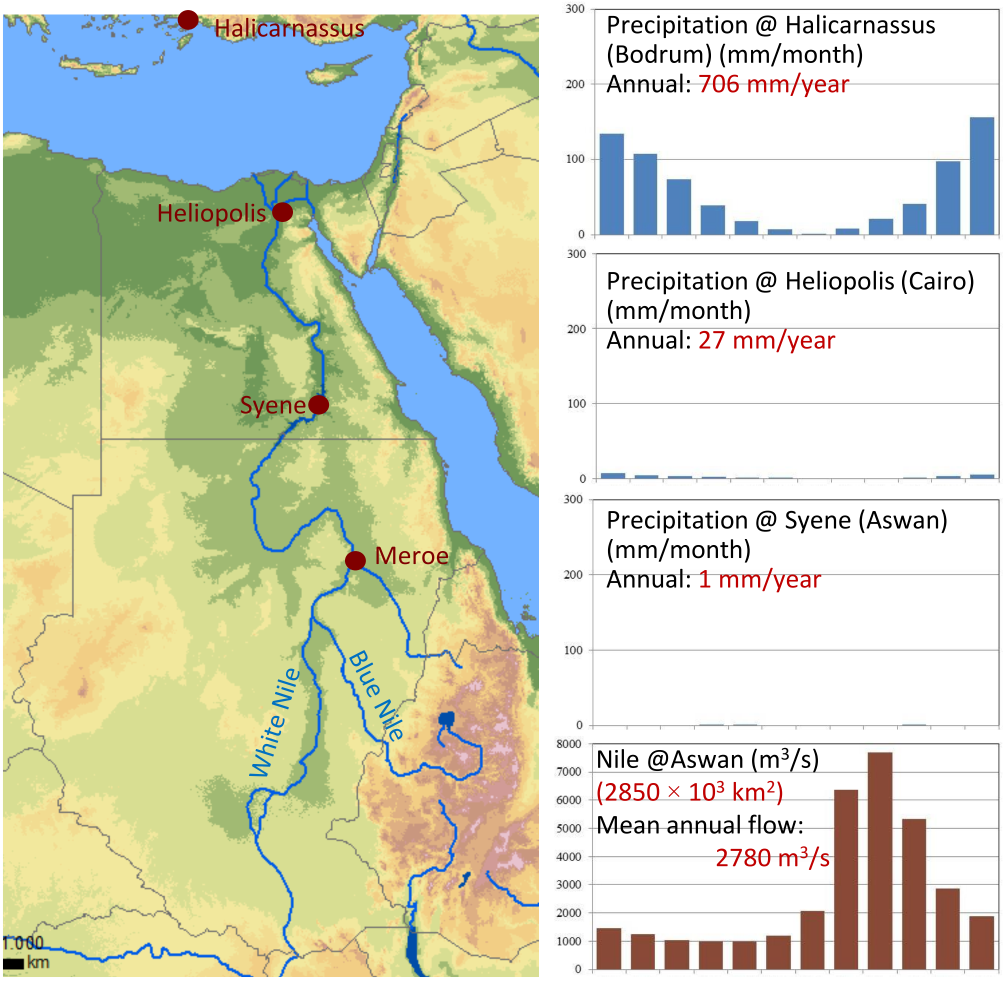

Figure 9: Map of the Nile area along with graphs of mean monthly precipitation (from modern measurements; months Jan. to Dec.) at characteristic ancient sites and mean monthly flow at Aswan (Syene).

[*] *τοῦ ποταμοῦ δὲ φύσιος πέρι οὔτε τι τῶν ἱρέων οὔτε ἄλλου οὐδενὸς παραλαβεῖν ἐδυνάσθην. πρόθυμος δὲ ἔα τάδε παρ᾽ αὐτῶν πυθέσθαι, ὅ τι κατέρχεται μὲν ὁ Νεῖλος πληθύων ἀπὸ τροπέων τῶν θερινέων ἀρξάμενος ἐπὶ ἑκατὸν ἡμέρας, πελάσας δὲ ἐς τὸν ἀριθμὸν τουτέων τῶν ἡμερέων ὀπίσω ἀπέρχεται ἀπολείπων τὸ ῥέεθρον, ὥστε βραχὺς τὸν χειμῶνα ἅπαντα διατελέει ἐὼν μέχρι οὗ αὖτις τροπέων τῶν θερινέων. τούτων ὦν πέρι οὐδενὸς οὐδὲν οἷός τε ἐγενόμην παραλαβεῖν παρὰ τῶν Αἰγυπτίων, ἱστορέων αὐτοὺς ἥντινα δύναμιν ἔχει ὁ Νεῖλος τὰ ἔμπαλιν πεφυκέναι τῶν ἄλλων ποταμῶν· ταῦτά τε δὴ τὰ λελεγμένα βουλόμενος εἰδέναι ἱστόρεον καὶ ὅ τι αὔρας ἀποπνεούσας μοῦνος ποταμῶν πάντων οὐ παρέχεται.* (Ἡρόδοτος, Ἱστορίαι, 2, 19.)

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Figure 10: Ἡρόδοτος (Herodotus; c. 484 – c. 425 BC), ancient Greek historian, author of *Ἱστορίαι* (*The Histories*), considered the first to have treated historical subjects using a method of systematic investigation (by collecting materials and then critically arranging them into an historiographic narrative). (Image source: Visconti, 1817.)

Herodotus's spirit to seek physical explanations for natural phenomena, which reflects the more general trend developed in Greece after Thales, is contrasted here with the Egyptian people's attitude (including their priests) who seem to have been uninterested for physics. Subsequently, Herodotus describes three explanations given by Greeks, without mentioning their names, but only their ambition to achieve reputation for wisdom:

> *Some of the prominent Greeks, however, wishing to get a reputation for wisdom, have offered explanations of the phenomena of the river, for which they have accounted in three different ways. Two of these I do not think it worth while to speak of, further than simply to mention what they are.*[*] (ibid. 2, 20.)

The first explanation is this:

> *One says that the Etesian* [i.e. monsoon] *winds cause the rise of the river by preventing the Nile-water from running off into the sea. But in the first place it has often happened, when the Etesian winds did not blow, that the Nile has risen according to its usual wont; and further, if the Etesian winds produced the effect, the other rivers which flow in a direction opposite to those winds ought to present the same phenomena as the Nile, and the more so as they are all*

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[*] *ἀλλὰ Ἑλλήνων μὲν τινὲς ἐπίσημοι βουλόμενοι γενέσθαι σοφίην ἔλεξαν περὶ τοῦ ὕδατος τούτου τριφασίας ὁδούς· τῶν τὰς μὲν δύο τῶν ὁδῶν οὐδ' ἀξιῶ* μνησθῆναι *εἰ μὴ ὅσον σημῆναι βουλόμενος μοῦνον*. (αὐτόθι, 2, 20.)

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*smaller streams, and have a weaker current. But these rivers, of which there are many both in Syria and Libya, are entirely unlike the Nile in this respect.** (ibid. 2, 20.)

He continues:

The second opinion is even more unscientific than the one just mentioned, and also, if I may so say, more marvellous. It is that the Nile acts so strangely, because it flows from the ocean, and that the ocean flows all round the earth. […] *As for the writer who attributes the phenomenon to the ocean, his account is involved in such obscurity that it is impossible to disprove it by argument. For my part I know of no river called Ocean, and I think that Homer, or one of the earlier poets, invented the name, and introduced it into his poetry*.† (ibid. 2, 21&23.)

Finally:

The third explanation, which is very much more plausible than either of the others, is positively the furthest from the truth; for there is really nothing in what it says, any more than in the other theories. It is, that the inundation of the Nile is caused by the melting of snows. Now, as the Nile flows out of Libya, through Ethiopia, into Egypt, how is it possible that it can be formed of melted snow, running, as it does, from the hottest regions of the world into cooler countries? Many are the proofs whereby any one capable of reasoning on the subject may be convinced that it is most unlikely this should be the case. The first and strongest argument is furnished by the winds, which always blow hot from these regions. The second is that rain and frost are unknown there. Now whenever snow falls, it must of necessity rain within five days, so that, if there were snow, there must be rain also in those parts. Thirdly, it is certain that the natives of the country are black with the heat, that the kites and the swallows remain there the whole year, and that the cranes, when they fly from the rigors of a Scythian winter, flock thither to pass the cold season. If then, in the country whence the Nile has its source, or in that through which it flows, there fell ever so little snow, it is absolutely impossible that any of these circumstances could take place.‡ (ibid. 2, 22.)

* *τῶν ἡ ἑτέρη μὲν λέγει τοὺς ἐτησίας ἀνέμους εἶναι αἰτίους πληθύειν τὸν ποταμόν, κωλύοντας ἐς θάλασσαν ἐκρέειν τὸν Νεῖλον. πολλάκις δὲ ἐτησίαι μὲν* οὔκων *ἔπνευσαν, ὁ δὲ Νεῖλος τὠυτὸ ἐργάζεται. πρὸς δέ, εἰ ἐτησίαι αἴτιοι ἦσαν, χρῆν καὶ τοὺς ἄλλους ποταμούς, ὅσοι τοῖσι ἐτησίῃσι ἀντίοι ῥέουσι, ὁμοίως πάσχειν καὶ κατὰ τὰ αὐτὰ τῷ Νείλῳ, καὶ μᾶλλον ἔτι τοσούτῳ ὅσῳ ἐλάσσονες ἐόντες ἀσθενέστερα τὰ ῥεύματα παρέχονται. εἰσὶ δὲ πολλοὶ μὲν ἐν τῇ Συρίῃ ποταμοὶ πολλοὶ δὲ ἐν τῇ Λιβύῃ, οἳ οὐδὲν τοιοῦτο πάσχουσι οἷόν τι καὶ ὁ Νεῖλος.* (αὐτόθι, 2, 20.)

† *ἡ δ᾽ ἑτέρη ἀνεπιστημονεστέρη μὲν ἐστὶ τῆς λελεγμένης, λόγῳ δὲ εἰπεῖν θωμασιωτέρη· ἣ λέγει ἀπὸ τοῦ Ὠκεανοῦ ῥέοντα αὐτὸν ταῦτα μηχανᾶσθαι, τὸν δὲ Ὠκεανὸν γῆν περὶ πᾶσαν ῥέειν.* […] *ὁ δὲ περὶ τοῦ Ὠκεανοῦ λέξας ἐς ἀφανὲς τὸν μῦθον ἀνενείκας οὐκ ἔχει ἔλεγχον· οὐ γὰρ τινὰ ἔγωγε οἶδα ποταμὸν Ὠκεανὸν ἐόντα, Ὅμηρον δὲ ἤ τινὰ τῶν πρότερον γενομένων ποιητέων δοκέω τὸ οὔνομα εὑρόντα ἐς ποίησιν ἐσενείκασθαι.* (αὐτόθι, 2, 21&23.)

‡ *ἡ δὲ τρίτη τῶν ὁδῶν πολλὸν ἐπιεικεστάτη ἐοῦσα μάλιστα ἔψευσται· λέγει γὰρ δὴ οὐδ᾽ αὕτη οὐδέν, φαμένη τὸν Νεῖλον ῥέειν ἀπὸ τηκομένης χιόνος· ὃς ῥέει μὲν ἐκ Λιβύης διὰ μέσων Αἰθιόπων, ἐκδιδοῖ δὲ ἐς Αἴγυπτον. κῶς ὦν δῆτα ῥέοι ἂν ἀπὸ χιόνος, ἀπὸ τῶν θερμοτάτων ῥέων ἐς τὰ ψυχρότερα τὰ πολλά ἐστι· ἀνδρί γε λογίζεσθαι τοιούτων πέρι οἵῳ τε ἐόντι, ὡς οὐδὲ οἰκὸς ἀπὸ χιόνος μιν ῥέειν, πρῶτον μὲν καὶ μέγιστον μαρτύριον οἱ ἄνεμοι παρέχονται πνέοντες ἀπὸ τῶν χωρέων τουτέων θερμοί· δεύτερον δὲ ὅτι ἄνομβρος ἡ χώρη καὶ* ἀκρύσταλλος *διατελέει ἐοῦσα, ἐπὶ δὲ χιόνι πεσούσῃ πᾶσα ἀνάγκη ἐστὶ ὗσαι ἐν πέντε ἡμέρῃσι, ὥστε, εἰ ἐχιόνιζε, ὕετο ἂν ταῦτα τὰ χωρία· τρίτα δὲ οἱ ἄνθρωποι ὑπὸ τοῦ καύματος μέλανες ἐόντες. ἰκτῖνοι δὲ καὶ χελιδόνες δι᾽ ἔτεος ἐόντες οὐκ ἀπολείπουσι, γέρανοι δὲ φεύγουσαι τὸν χειμῶνα τὸν ἐν τῇ Σκυθικῇ χώρῃ γινόμενον φοιτῶσι ἐς χειμασίην ἐς τοὺς τόπους τούτους. εἰ τοίνυν ἐχιόνιζε καὶ ὅσον ὦν ταύτην τὴν χώρην δι᾽ ἧς τε ῥέει καὶ ἐκ τῆς ἄρχεται ῥέων ὁ Νεῖλος, ἦν ἂν τούτων οὐδέν, ὡς ἡ ἀνάγκη ἐλέγχει.* (αὐτόθι, 2, 22.)

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Information about who supported each of the three explanations has later been given by later authors, e.g., Aetius, the 1st- or 2nd-century AD doxographer and Eclectic philosopher. Interestingly, the first explanation is attributed to Thales, which verifies our claim about the strong link of hydrology with science (or natural philosophy), at the dawn of the latter:

> *Thales thinks that the Etesian winds* [monsoons], *blowing straight on to Egypt, raise up the mass of the Nile's water through cutting off the outflow by the swelling of the sea coming against it*.* (Aetius IV, 1, 1).

The second view was supported by Euthymenes of Massalia (Εὐθυμένης ὁ Μασσαλιώτης; fl. early 6th century BC), a Greek explorer from Massilia (Marseille), who explored the coast of West Africa. The third seems to have been supported by Anaxagoras and in another version by Democritus (460–370 BC).

Herodotus does not accept any of the three explanations and proceeds to give his own:

> *Perhaps, after censuring all the opinions that have been put forward on this obscure subject, one ought to propose some theory of one's own. I will therefore proceed to explain what I think to be the reason of the Nile's swelling in the summer time. During the winter, the sun is driven out of his usual course by the storms, and removes to the upper parts of Libya. This is the whole secret in the fewest possible words; for it stands to reason that the country to which the Sun-god approaches the nearest, and which he passes most directly over, will be scantest of water, and that there the streams which feed the rivers will shrink the most*.† (Herodotus, The Histories, 2, 24).

Apparently, all explanations are wrong. Yet two of them, the first and the third, are scientific, while the second is mythical and Herodotus's one contains mythical elements and a belief of a flat Earth.

Modern knowledge of the hydrological regime of Nile's basin, illustrated in Figure 11 by means of graphs of monthly flow and precipitation at several sites, clearly shows that the origin of floods are the high precipitation rates in the Blue Nile in Ethiopea, driven by monsoons and peaking in July and August.

Was any ancient philosopher able to find a correct explanation? In particular, what was the opinion of Aristotle, who lived a century after Herodotus? Here comes another puzzle, which seems to have been resolved very recently. The reason for such delay is the fact that most of the Greek texts, which certainly contained relevant information, have been lost. Alexandria's library was accidentally burned by Romans at least twice (by Julius Cesar and Aurelian) and perhaps redestroyed by Arabs (Caliph Omar). The Imperial Library of Constantinople was destroyed in 1204 by the knights of the Fourth Crusade and again in 1453 the Fall of Constantinople, invaded by Ottoman Turks, was accompanied by destruction of the city's libraries.

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* *Θαλῆς τοὺς ἐτησίας ἀνέμους οἲεται πνέοντας τῇ Αἰγύπτῳ ἀντιπροσώπους ἐπαἱρειν τοῦ Νείλου τόν ὄγκον διά τό τάς ἐκροάς αὐτοῦ τῇ παροιδήσει τοῦ ἀντιπαρήκοντος πελάγους ἀνακόπτεσθαι*. (Αέτιος IV, 1, 1).

† *εἰ δὲ δεῖ μεμψάμενον γνώμας τὰς προκειμένας αὐτὸν περὶ τῶν ἀφανέων γνώμην ἀποδέξασθαι, φράσω δι᾽ ὅ τι μοι δοκέει πληθύνεσθαι ὁ Νεῖλος τοῦ θέρεος· τὴν χειμερινὴν ὥρην ἀπελαυνόμενος ὁ ἥλιος ἐκ τῆς ἀρχαίης διεξόδου ὑπὸ τῶν χειμώνων ἔρχεται τῆς Λιβύης τὰ ἄνω. ὡς μέν νυν ἐν ἐλαχίστῳ δηλῶσαι, πᾶν εἴρηται· τῆς γὰρ ἂν ἀγχοτάτω τε ᾖ χώρης οὗτος ὁ θεὸς καὶ κατὰ ἥντινα, ταύτην οἰκὸς διψῆν τε ὑδάτων μάλιστα καὶ τὰ ἐγχώρια ῥεύματα μαραίνεσθαι τῶν ποταμῶν*. (Ἡρόδοτος, Ἱστορίαι, 2, 24.)

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420 Among the manuscripts that were saved, one Patriarch Photius's (c. 810/820 – 893) *Myriobiblon* or *Biblioteheca*, composed of 279 reviews of books which he had read. This book, perhaps the first in history collection of book-reviews, written in Greek, was printed in 1611with Latin translation (Figure 12). One of the books reviewed is a lost one entitled *Life of Pythagoras* by an anonymous author. The book contained important information about Aristotle's decisive contribution in solving the Nile paradox, which Photius summarizes as follows:

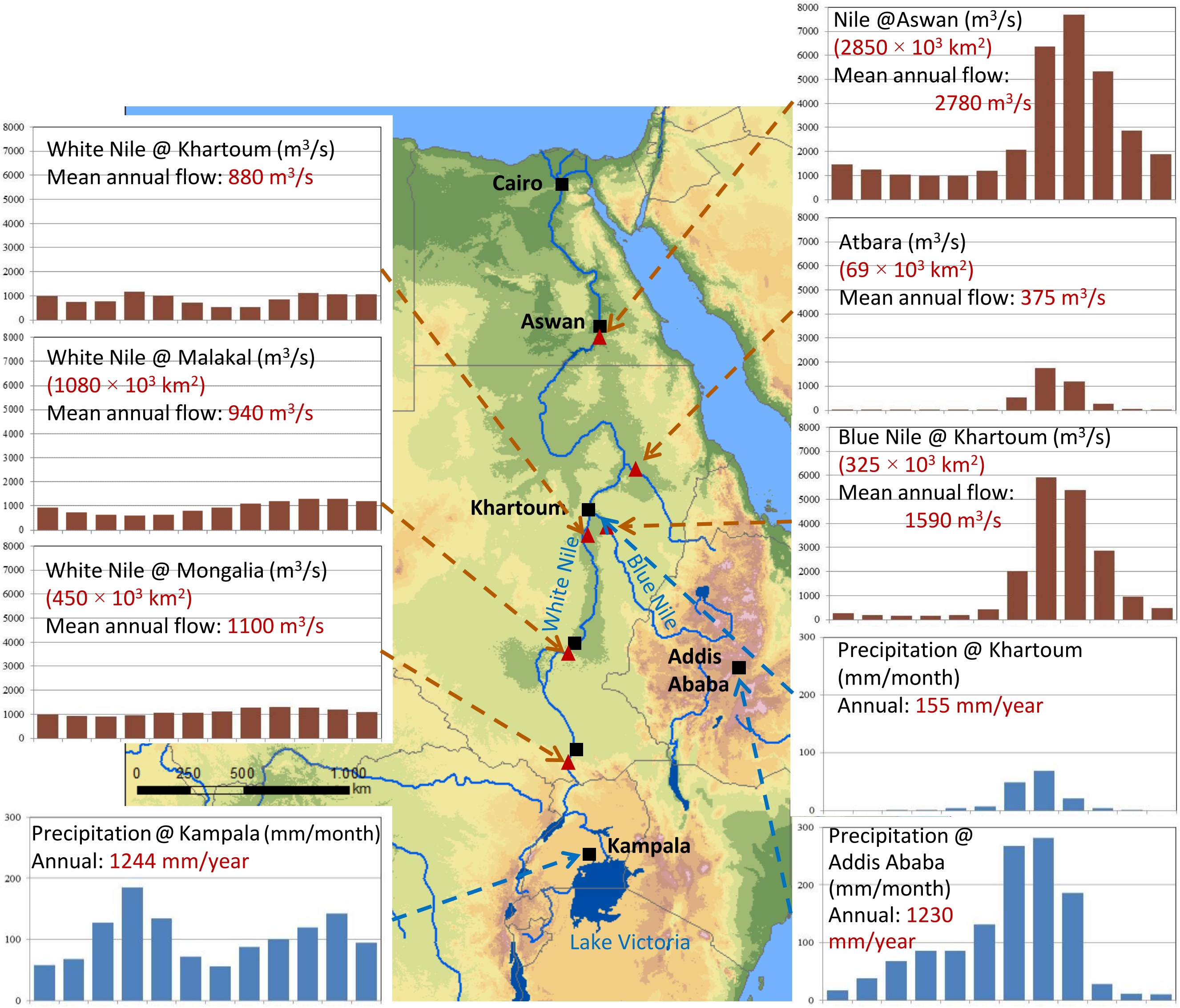

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Figure 11: As in Figure 9 but with additional modern information of precipitation and Nile flow (mean monthly values, Jan. to Dec.) at locations south of Aswan (Syene).

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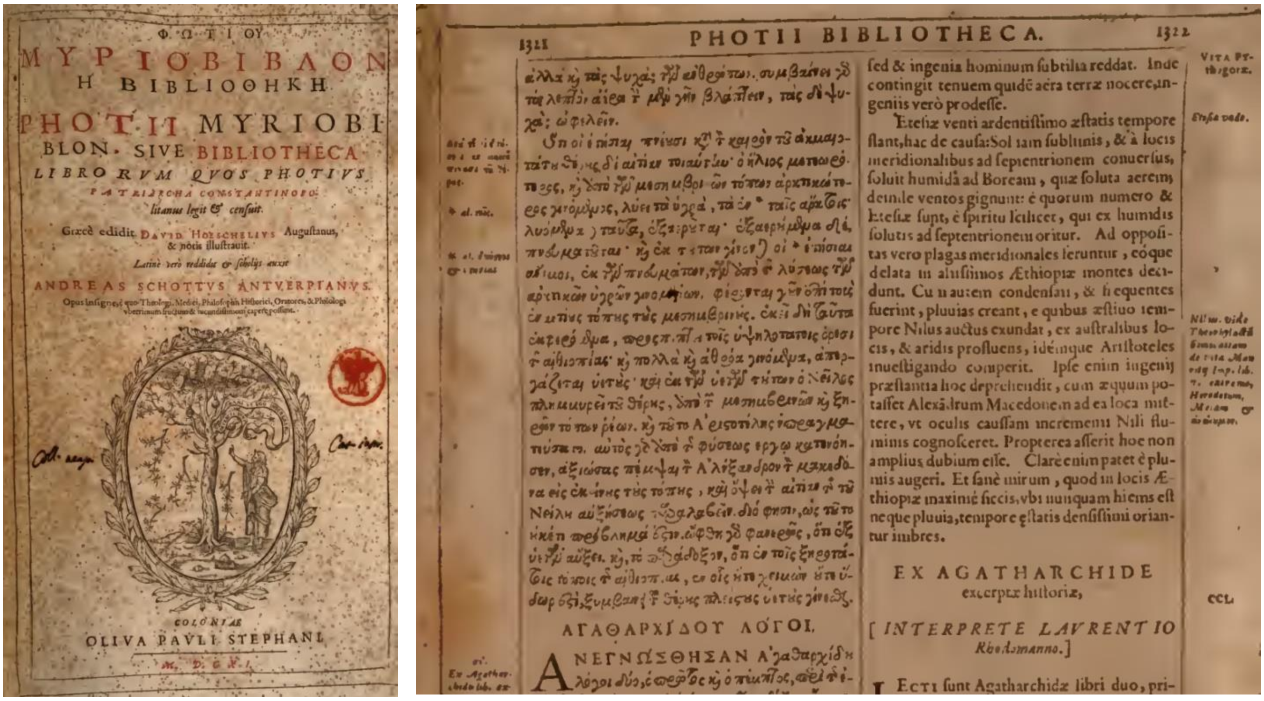

Figure 12: Title page and part of another page from Patriarch Photius's Μυριόβιβλον ἢ Βιβλιοθήκη (Myriobiblon sive Biblioteheca), printed in 1611. The page depicted is that referring to the first scientific expedition in history, ordered by Aristotle and executed by his pupil Alexander the Great.

The Etesian winds [i.e., monsoons] *blow during the peak of the summer for this reason: The sun, at the zenith passing from south to north, disintegrates the moisture from the arctics and once this moisture is disintegrated, it evaporates and gives rise to monsoons* […] *When they reach the high mountains of Ethiopia and concentrate there, they produce rains. These rains in full summer cause the flood of the Nile and make it overflow, while it flows at the northern arid regions. This was analysed by Aristotle, who, by the superiority of his mind, understood it. He demanded to send Alexander of Macedonia to these regions, and to find, by sight, the cause of the flooding of the Nile. That is why they say there is not a problem anymore. It became apparent by sight that the flow is increased by these rains. And this solved the paradox that in the driest Ethiopian* [i.e. African] *places where there is no winter nor rain, it happens that in the summer strong rainfalls occur*" *(Photius, 1611, On Life of Pythagoras by Anonymous, translation by authors).

* *Ὅτι οἱ ἐτήσιαι πνέουσι κατὰ τὸν καιρὸν τοῦ ἀκμαιοτάτου θέρους δι᾽ αἰτίαν τοιαύτην. Ὁ ἥλιος μετεωρότερος καὶ ἀπὸ τῶν μεσημβρινῶν τόπων ἀρκτικώτερος γινόμενος λύει τὰ ὑγρὰ τὰ ἐν ταῖς ἄρκτοις· λυόμενα δὲ ταῦτα ἐξαεροῦται, ἐξαερούμενα δὲ πνευματοῦται, καὶ ἐκ τούτων γίνονται οἱ ἐτήσιαι ἄνεμοι* […]. *Ἐκεῖ δὴ ταῦτα ἐκφερόμενα προσπίπτει τοῖς ὑψηλοτάτοις ὄρεσι τῆς Αἰθιοπίας, καὶ πολλὰ καὶ ἀθρόα γινόμενα ἀπεργάζεται ὑετούς· καὶ ἐκ τῶν ὑετῶν τούτων ὁ Νεῖλος πλημμυρεῖ τοῦ θέρους, ἀπὸ τῶν μεσημβρινῶν καὶ ξηρῶν τόπων ῥέων. Καὶ τοῦτο Ἀριστοτέλης ἐπραγματεύσατο· αὐτὸς γὰρ ἀπὸ τῆς φύσεως ἔργῳ κατενόησεν, ἀξιώσας πέμψαι Ἀλέξανδρον τὸν Μακεδόνα εἰς ἐκείνους τοὺς τόπους καὶ ὄψει τὴν αἰτίαν τῆς τοῦ Νείλου αὐξήσεως παραλαβεῖν. Διό φησιν ὡς τοῦτο οὐκέτι πρόβλημά ἐστιν· ὤφθη γὰρ φανερῶς ὅτι ἐξ ὑετῶν αὔξει. Καὶ <λύεται> τὸ παράδοξον, <ὅτι> ἐν τοῖς ξηροτάτοις τόποις τῆς Αἰθιοπίας, ἐν οἷς οὔτε χειμὼν οὔτε ὕδωρ ἐστί, ξυμβαίνει τοῦ θέρους πλείστους ὑετοὺς γίνεσθαι* (Φωτίου *Μυριόβιβλον*, Βίος Πυθαγόρου Ανωνύμου).

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It is reminded that Alexander (Figure 13) was student of Aristotle and was exchanging letters with him (and his mother Olympias), addressing his as *professor* (*καθηγητὴν*) during his campaign to Asia and Africa. Therefore, the information contained in the latter extract is not implausible. In our view this is very important information as it describes the first scientific expedition in history in order to confirm a scientific hypothesis.

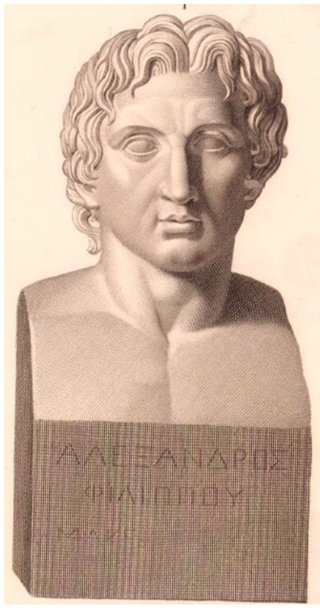

Figure 13: Αλέξανδρος ὁ Μακεδών / ὁ Μέγας (Alexander of Macedon / the Great; 356 BC –323 BC). (Image source: Visconti, 1817).

Confirmation of the truth of the story is provided by other ancient authors, such as Proclus (Πρόκλος, 412 – 485 AD; Neoplatonist philosopher), John the Lydian (Ἰωάννης Λαυρέντιος ὁ Λυδός; a 6th-century Byzantine administrator) and Cleomedes (Κλεομήδης, astronomer who lived sometime between the mid-1st century BC and 400 AD):

> *Eratosthenes, however, says, it is no longer requisite to investigate the cause of the increase of the Nile, once some have reached at the springs of the Nile and saw the rains that occur there, so as to corroborate what is said by Aristotle*.[*] (Proclus, Commentary on Plato's Timaeus, 22 E—I 121, English translation by T. Taylor.)

> *For since Ethiopia is girdled by mountains higher than ours, as it receives the clouds that are driven by the Etesian* [winds], *the Nile swells. As Callisthenes the Peripatetic also says in the fourth book of his Hellenica that he campaigned with Alexander the Macedonian, and when he was in Ethiopia he found that the Nile is driven down by the endless rain-storms that take place in that* [area].[†] (John the Lydian, On the Months, 4, 107, English translation by M.Hooker.)

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[*] *Ἐρατοσθένης δὲ οὐκέτι φησὶν <πρόβλημα εἶναι> οὐδὲ ζητεῖν χρῆναι περὶ τῆς αὐξήσεως τοῦ Νείλου, σαφῶς καὶ ἀφικομένων τινῶν εἰς τὰς τοῦ Νείλου πηγὰς* καὶ *τοὺς ὄμβρους τοὺς γιγνομένους ἑωρακότων, ὥστε κρατύνεσθαι τὴν Ἀριστοτέλους ἀπόδοσιν*. (Πρόκλος ο Λύκιος, Σχόλια, Πλάτωνος Τίμαιος, 22 E—I 121)

[†] *τῆς γὰρ Αἰθιοπίας ὑψηλοῖς παρὰ τὰ καθ' ἡμᾶς ὄρεσι διεζωσμένης ὑποδεχομένης τε τὰς νεφέλας πρὸς τῶν ἐτησίων ὠθουμένας, ἐκδιδόναι τὸν Νεῖλον. ὡς καὶ* <Καλλισθένης> *ὁ Περιπατητικὸς ἐν τῶι τετάρτωι βιβλίωι τῶν Ἑλληνικῶν <φησιν ἑαυτὸν συστρατεύσασθαι Ἀλεξάνδρωι τῶι*

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It is said that when continuous rains precipitate around Ethiopia during the summer and especially in its height; it is thus implied that it is because of them that the Nile increases. Indeed, this is how Poseidonius refers. (Cleomedes, De motu circulari corporum caelestium, 59, translation by the authors.)*

A doxographer, so-called Anonymus Florentinus, has also written a short treatise in Greek (published with two alternative titles†) about the Nile's flow, which includes the following:

Callisthenes the historiographer objects those said a little while ago, supported by Anaxagoras and Euripides. They say, presenting his own considered opinion, that from the rise of the Dog Star [beginning of July] *up to the rise of Arcturus* [mid-September]*, in which time the monsoons winds blow, many showers occur in Ethiopia. These winds, they say, bring the clouds to Ethiopia. When the clouds strike against the mountains, huge quantities of water precipitate through which the Nile overflows.* (Anonymus Florentinus on the Nile, translation by the authors.)‡

Furthermore, it appears that, during the Byzantine period, Aristotle's theory was confirmed by additional visits in the area. The Byzantine emperor Justinian sent an ambassador called Nonnosus (Νόννοσος) to the king of the Axumites (in Ethiopia and parts of the Arabian Peninsula) around 530 AD. He wrote an account of that visit, now lost, that was read and summarized by Photius in his *Bibliotheca*. Here is the relevant extract, in which it should be noted that the term "winter" is meant to denote the rainfall season:

When the sun enters Cancer, Leo, and Virgo, it is summer as far as Ave, as with us, and the atmosphere is extremely dry; but from Ave to Axumis and the rest of Aethiopia, it is severe winter, not throughout the day, but beginning from midday, the sky being covered with clouds and the country flooded with violent rains. At that time also the Nile, spreading over Egypt, overflows and irrigates the land. But when the sun enters Capricornus, Aquarius, and Pisces, the atmosphere, conversely, floods the country of the Adulites as far as Ave, while it is summer from Ave to Axumis and the rest of Aethiopia, and the fruits of the earth are ripe.§ (Photius, 1611, on Nonnosus History, translated by J.H. Freese).

Μακεδόνι, καὶ γενόμενον ἐπὶ τῆς Αἰθιοπίας εὑρεῖν τὸν Νεῖλον ἐξ ἀπείρων ὄμβρων κατ' ἐκείνην γενομένων> καταφερόμενον. (Ἰωάννης Λαυρέντιος ὁ Λυδός, De mensibus, 4, 107.)

* *ἐπεὶ καὶ περὶ τὴν Αἰθιοπίαν ὄμβροι συνεχεῖς καταφέρεσθαι ἱστοροῦνται περὶ τὸ θέρος καὶ μάλιστα τὴν ἀκμὴν αὐτοῦ· ἀφ΄ ὧν καὶ ὁ Νεῖλος πληθύειν τοῦ θέρους ὑπονοεῖται. Ὁ μὲν οὖν Ποσειδώνιος οὕτω φέρεται.* (Κλεομήδους, Κυκλική Θεωρία Μετεώρων, 59)

† (a) «Περί τῆς τοῦ Νείλου ἀναπληρώσεως διάφοραι δόξαι», https://books.google.gr/books?id=zMc7AAAAcAA; (b) «Περί τῆς τοῦ Νείλου αναβάσεως», https://books.google.gr/books?id=i1IZAAAAYAAJ.

‡ *Καλλισθένης δ' ὁ ἱστοριογράφος πρὸς τὰ μικρῷ πρότερον εἰρημένα ὑπ' Ἀναξαγόρου τε καὶ Εὐριπίδου ἀντεῖπεν. αὐτὸς δὲ τὴν αὐτοῦ γνώμην φησίν, ὑδάτων πολλῶν καὶ λαμπρῶν γινομένων κατὰ τὴν Αἰθιοπίαν κατὰ τὰς τοῦ κυνὸς ἀνατολὰς ἕως τῆς ἐπιτολῆς ἀρκτούρου, καθ' οὓς χρόνους καὶ οἱ ἐτησίαι πνέουσιν ἄνεμοι· τούτους γάρ φησι τοὺς ἀνέμους μάλιστα τὰ νέφη φέρειν πρὸς τὴν Αἰθιοπίαν· ᾧν καὶ προσπιπτόντων πρὸς τα ὄρη καταρρήγνυσθαι πολὺ πλῆθος ὕδατος, ἀφ' οὗ τον Νείλον ἀναβαίνειν.* (Ανώνυμος Φλωρεντίνος, «Περί τῆς τοῦ Νείλου ἀναπληρώσεως διάφοραι δόξαι» ή «Περί τῆς τοῦ Νείλου αναβάσεως»).

§ *Τοῦ γὰρ ἡλίου τὸν καρκίνον τε καὶ λέοντα καὶ παρθένον διερχομένου, μέχρι μὲν τῆς Αὔης ὥσπερ καὶ παρ΄ ἡμῖν θέρος τε καὶ ξηρότης διακρατεῖ τὸν ἀέρα, ἀπὸ δὲ τῆς Αὔης ἐπὶ τὴν Αὔξουμιν καὶ τὴν ἄλλην Αἰθιοπίαν χειμὼν ἐπίκειται σφοδρός, οὐ δι΄ ὅλης ἡμέρας, ἀλλὰ γὰρ ἀπὸ μεσημβρίας ἀρχόμενος ἑκάστοτε, συννεφῆ τε τὸν ἀέρα ποιῶν καὶ ὄμβροις ῥαγδαίοις τὴν χώραν ἐπικλύζων. Τηνικαῦτα δὲ ἄρα καὶ ὁ Νεῖλος πολὺς ἐπὶ τὴν*

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Additional evidence is provided by Cosmas Indicopleustes (Κοσμᾶς Ἰνδικοπλεύστης, a 6th-century AD Greek merchant and traveller), who made several voyages to India during the reign of emperor Justinian about which he wrote in his book Christian Topography.

In addition to these references in Greek, there has been a treatise in Latin entitled *Liber Aristotelis de Inundacione Nili*, (in short De Nilo) which is presumably a Latin translation of a lost text in Greek by Aristotle, whose Greek tile should be *Περὶ τῆς τοῦ Νείλου ἀναβάσεως*:* The treatise was left out of Corpus Aristotelicum and received little scholarly attention. However, Rose (1886) published the full Latin script of De Nilo, while an improved transcription thereof has been recently published by Beullens (2014). There have been also translations of the work in two modern languages, French (Bonneau, 1971) and Dutch (Beullens, 2011). Some recent developments support the case that it is a translation of a genuine text by Aristotle or at least contains some portions of an original work by the philosopher (Beullens, 2014). The new evidence is: (a) the publication of a papyrus (P. Oxy. 4458), which was shown to contain a short quotation from the original Greek text of De Nilo (Jakobi and Luppe, 2000) and (b) the observation that the quotation by Anonymus Florentinus almost literally follows the wording of De Nilo, if it be back translated to Greek (Beullens, 2014).

De Nilo has the form of an Aristotelian problem, starting with the question to be solved:

> *How can it be explained that while other rivers swell in winter and become much smaller in summer, the Nile as the only river that flows into the sea, in the summer expands over a vast area and become so wide that only the villages stand out as islands?*† (Liber Aristotelis de Inundacione Nili, 1, translation by authors based on Google translation of the Dutch text by Beullens, 2011.)

The text continues with what we would call today literature review, enumerating the explanations already given by other authors about the phenomenon (including those referred to by Herodotus) and then rejecting them one by one with logical arguments, until it remains one, Aristotle's own theory, as precisely quoted by Anonymus Florentinus.

Overall, there is overwhelming evidence that Aristotle had resolved the paradox in scientific terms. However, it is relevant to ask the question: How long did it take for the scientific (and wider) community to assimilate and completely accept this scientific truth? The surprising answer to this question is: 21 centuries.

Already from the 1st century BC, the following passage by Stabo indicates the reluctance to accept the explanation:

> *but the fact that the rising of the river results from rains should not have been investigated, nor yet should this matter have needed such witnesses as Poseidonius mentions; for instance, he says that it was Callisthenes who states that the summer rains are the cause of the risings, though Callisthenes took the assertion from Aristotle, and Aristotle from*

Αἴγυπτον ἐρχόμενος πελαγίζει τε καὶ κατάρδει τὴν γῆν. Ὅτε δὲ ὁ ἥλιος τὸν αἰγόκερών τε καὶ ὑδρηχόον καὶ ἰχθύας ἐπιπορεύεται, ἀνάπαλιν ὁ ἀὴρ τοῖς μὲν Ἀδουλίταις μέχρι τῆς Αὔης ὄμβροις ἐπικλύζει τὴν χώραν, τοῖς δὲ ἀπὸ τῆς Αὔης μέχρι Αὐξούμεως καὶ τῆς ἄλλης Αἰθιοπίας θέρος τέ ἐστι καὶ τὰ ὡραῖα τηνικαῦτα τούτοις ἡ γῆ παραδίδωσιν. (Φωτίου Μυριόβιβλον, Νοννόσου Ιστορία)

* It is referred to with this title in a comment to Aristotle's Meteorologica by pseudo-Alexander, contained in Rose (1886, p. 191).

† *Propter quid aliis fluminibus in hyeme quidem augmentatis, in estate autem multo factis minoribus, solus eorum qui in mare fluunt, multum estate excedit fitque tantus ut civitates sole supersint velut insule?* (Liber Aristotelis de Inundacione Nili, 1, script from Beullens, 2014)

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Thrasyalces the Thasian (one of the early physicists), and Thrasyalces from someone else, and he from Homer, who calls the Nile "heaven-fed": "And back again to the land of Aegyptus, heaven-fed river." (Strabo, Geography, 17.1.5, translated by H.L. Jones). *

Here we may remark that by attributing the explanation to Thrasyalces (an old natural philosopher, probably of the 5th century BC, from the island of Thasos), Srtabo devalues Aristotle's contribution, hiding the fact that, even if Thrasyalces had indeed made the same conjecture, there is a big difference as Aristotle verified the hypothesis by observation (*ὄψει—by sight*) through Alexander's expedition. Furthermore, Strabo seems to equate all explanations, eventually matching the Aristotle's scientific one with Homer's mythological.

And indeed, the mythological views are more charming and, hence, they continued to be popular during the Roman times. The Roman epicurean philosopher Lucretius (c. 99 – c. 55 BC) and the stoic philosopher Seneca (4 BC –65 AD), both of whom wrote about Nile, did not rely on Aristotle's scientific explanation. Rather, they were fascinated by the Nile for its mystery, not its demystification. An excellent summary of the reasons is contained in the following quotation by Merrills (2017):

The metaphysical qualities of the Nile—a river that replicated each year the origins of the world, and which overspilled its banks even into the bathhouses and taverns of Pompeii—were essential to its resonance in the Roman world.

The reference to Pompei encapsulates the archaeological evidence of sacred objects and iconographies for Nile and its waters.

And what about modern times? Were the mythical views abandoned after the first quantification of the hydrological cycle in the 17th century (section 6)? This question is studied in detail in Appendix 5. In brief, the surprising answer is that a new mythology was developed around a "theory" of the "nitre" which was a mythical element that presumably caused the flooding of the Nile, while rainfall in Ethiopia had a minor role, if any. It took the visit to the origins of the Blue Nile of the Scottish traveller James Bruce and the publication of his book (Bruce, 1813) for the modern mythical theory to cease.

5 Prominent scientists of the Hellenistic period with relevance to geosciences and hydrology

The Hellenistic period, which starts with the death of Alexander in 323 BC and ends with the emergence of the Roman Empire in 31 BC, is marked by the wide dissemination of the Greek civilization and the flourishing of science. During this period several important scientific developments and breakthroughs had occurred, some of which were not accepted as consensus theories for centuries. The reluctance to Aristotle's theory on Nile is repeated in several other cases.

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* *τὸ δ' ὅτι ἐξ ὄμβρων αἱ ἀναβάσεις μὴ ζητεῖν, μηδὲ τοιούτων δεῖσθαι μαρτύρων οἵους Ποσειδώνιος εἴρηκε. φησὶ γὰρ Καλλισθένη λέγειν τὴν ἐκ τῶν ὄμβρων αἰτίαν τῶν θερινῶν παρὰ Ἀριστοτέλους λαβόντα, ἐκεῖνον δὲ παρὰ Θρασυάλκου τοῦ Θασίου (τῶν ἀρχαίων δὲ φυσικῶν εἷς οὗτος) ἐκεῖνον δὲ παρ' ἄλλου, τὸν δὲ παρ' Ὁμήρου διιπετέα φάσκοντος τὸν Νεῖλον «ἂψ δ' εἰς Αἰγύπτοιο διιπετέος ποταμοῖο».* (Στράβων, Γεωγραφικά, 17.1.5).

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Aristarchus of Samos (Ἀρίσταρχος ὁ Σάμιος; c. 310 – c. 230 BC; mathematician and astronomer), introduced the heliocentric model for the solar system 1800 years before Copernicus. He also said that the stars were distant suns and made calculations on the relative sizes of the Sun, Earth and Moon. Notably, before him also the Pythagorean philosopher Philolaus (c. 470 – c. 385 BC) had moved the Earth from the center of the cosmos and made it a planet, but in Philolaus's system Earth does not orbit the Sun but rather a central fire. Interestingly, Copernicus in the manuscript of his book *De revolutionibus* included a citation to Philolaus and Aristarchus but he crossed it out before publication (Figure 14). The point that was crossed out, translated in English (Gingerich, 1973, 1985), reads:

> *And if we should admit that the motion of the Sun and Moon could be demonstrated even if the Earth is fixed, then with respect to the other wandering bodies there is less agreement. It is credible that for these and similar causes (and not because of the reasons that Aristotle mentions and rejects), Philolaus believed in the mobility of the Earth and some even say that Aristarchus of Samos was of that opinion. But since such things could not be comprehended except by a keen intellect and continuing diligence, Plato does not conceal the fact that there were very few philosophers in that time who mastered the study of celestial motions.*

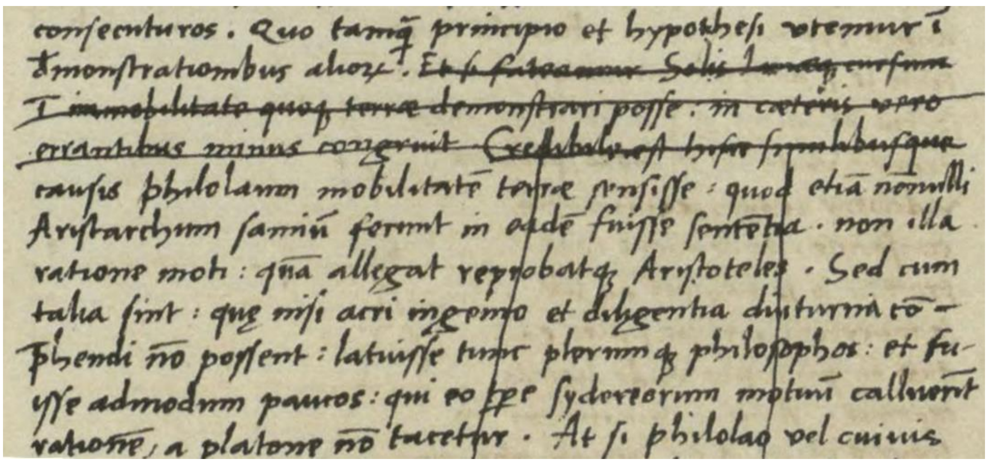

Figure 14: Part of page 22 of Book 1 of Copernicus's manuscript showing the references to Philolaus, Aristarchus and the Greek cosmology, which he crossed out before publication of his book *De revolutionibus* (source: http://copernicus.torun.pl/en/archives/De_revolutionibus/1/?view=gallery&file=1&page=22).

While Aristarchus's ideas were contrary to "consensus theory" for 1800 years, it is important to notice that they were adopted by Archimedes (c. 287 – c. 212 BC), the leading scientist (mathematician, physicist, engineer, inventor and astronomer) of the Hellenistic world, who is regarded to be perhaps the greatest mathematician of all time[*]. In fact, as his treatise *The Sand Reckoner* provides the most precious information about Aristarchus's ideas. Specifically, Archimedes writes:

[*] This is illustrated by the fact that the Fields Medal (regarded as the highest honour for mathematicians) depicts Archimedes. The reader may be find as food for thought about the history of civilization the fact that the head of Archimedes in the medal is synthesized by the imagination of the artist (Tropp, 1976), as there is original sign about it, neither in sculpture nor in coins (that is the reason we do not included any illustration about him in this paper).

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> *It is hypothesized* [by Aristarchus of Samos] *that the fixed stars and the Sun remain unmoved and the Earth revolves about the Sun in the circumference of a circle, with the Sun lying in the middle of the orbit and the sphere of the fixed stars, situated about the same centre as the Sun, is so great that the circle in which the Earth is hypothesized to revolve, bears such a proportion to the distance of the fixed stars as the centre of the sphere bears to its surface.*[*] (Archimedes, The Sand Reckoner, I, translation by the authors based on I. Vardi).

It has been speculated (Vardi, 1997) that Archimedes chose, among different cosmological theories, Aristarchus's for the single reason that it was the one yielding largest size of the universe—as he wanted that size as large as possible for his calculations of big numbers. However, we believe that a mind of the calibre of Archimedes would not choose a theory on this basis and certainly would not consider it if he thought it was erroneous.

It is well known that Archimedes offered several important contributions in mathematics, including the concept of infinitesimals and a first version of integral calculus. From the hydrological perspective, important is the principle named after him and the foundation of hydrostatics. From his inventions most relevant to hydrology is Archimedes' screw, which is still in wide use for pumping.

While some early Greek philosophers believed that the Earth is flat, Pythagoras and later Aristotle provided arguments that it is round. Now, Eratosthenes (Ἐρατοσθένης, c. 276 – c. 195/194 BC; a mathematician, geographer, poet, astronomer, and music theorist; head of the Library at Alexandria), among other achievements, calculated with remarkable accuracy (<2.5%) the Earth's circumference by measuring, at the noon of the day of summer solstice, the shadow cast by a gnomon at Alexandria and the distance between and Alexandria and Syene, where the latter is situated close to the Tropic of Cancer. Eratosthenes also calculated, in following the windings of the Nile, the distances between several points on the Nile up to Meroe (Strabo, Geography, 17.1.2; Rawlins, 1982). Perhaps because of this, he has often been credited by several authors (including Koutsoyiannis, 2014) for solving the paradox of the Nile. However, in view of the information provided here (section 4), his achievement seems to be no more than a further verification of Aristotle's theory. He also seems to have been aware of the earlier expedition to the Nile sources for the purpose of proving Aristotle's theory (Burstein, 1976). Despite the advancements in geography during the Hellenistic period, the achieved geographical representation of the Earth was rather poor (Figure 15).

Geography is also related to climatology and through climate to hydrology. The notion of climate has been studied by Aristotle, who used another term, crasis (κρᾶσις = mixture, blend). The term climate (κλίμα, pl. κλίματα) was introduced by Hipparchus (Figure 16). Its etymology from the verb κλίνειν (= to incline) expresses the dependence of climate on the seasonal pattern of inclination angles of the incoming sunbeams. Perhaps his most remarkable achievement is the discovery of the

[*] *Ὑποτίθεται γὰρ* [υπό Ἀριστάρχου τοῦ Σαμίου] *τὰ μὲν ἀπλανέα τῶν ἄστρων καὶ τὸν ἅλιον μένειν ἀκίνητον, τὰν δὲ γᾶν περιφέρεσθαι περὶ τὸν ἅλιον κατὰ κύκλου περιφέρειαν, ὅς ἐστιν ἐν μέσῳ τῷ δρόμῳ κείμενος, τὰν δὲ τῶν ἀπλανέων ἄστρων σφαῖραν, περί τὸ αὐτὸ κέντρον τῷ ἁλίῳ κειμέναν τῷ μεγέθει τηλικαύταν εἶμεν, ὥστε τὸν κύκλον, καθ' ὅν τὰν γᾶν ὑποτίθεται περιφέρεσθαι, τοιαύταν ἔχειν ἀναλογίαν ποτὶ τὰν τῶν ἀπλανῶν ἀποστασίαν, οἷαν ἓχει τὸ κέντρον τᾶς σφαίρας ποτὶ τὰν ἐπιφάνειαν.* (Ἀρχιμήδης, Ψαμμίτης, Ι).

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precession of the equinoxes, one of the cycles in Earth's motion, with period of about 21 000 years, that determine the long-term changes of the climate. This constitutes one of the several now called Milankovitch cycles.

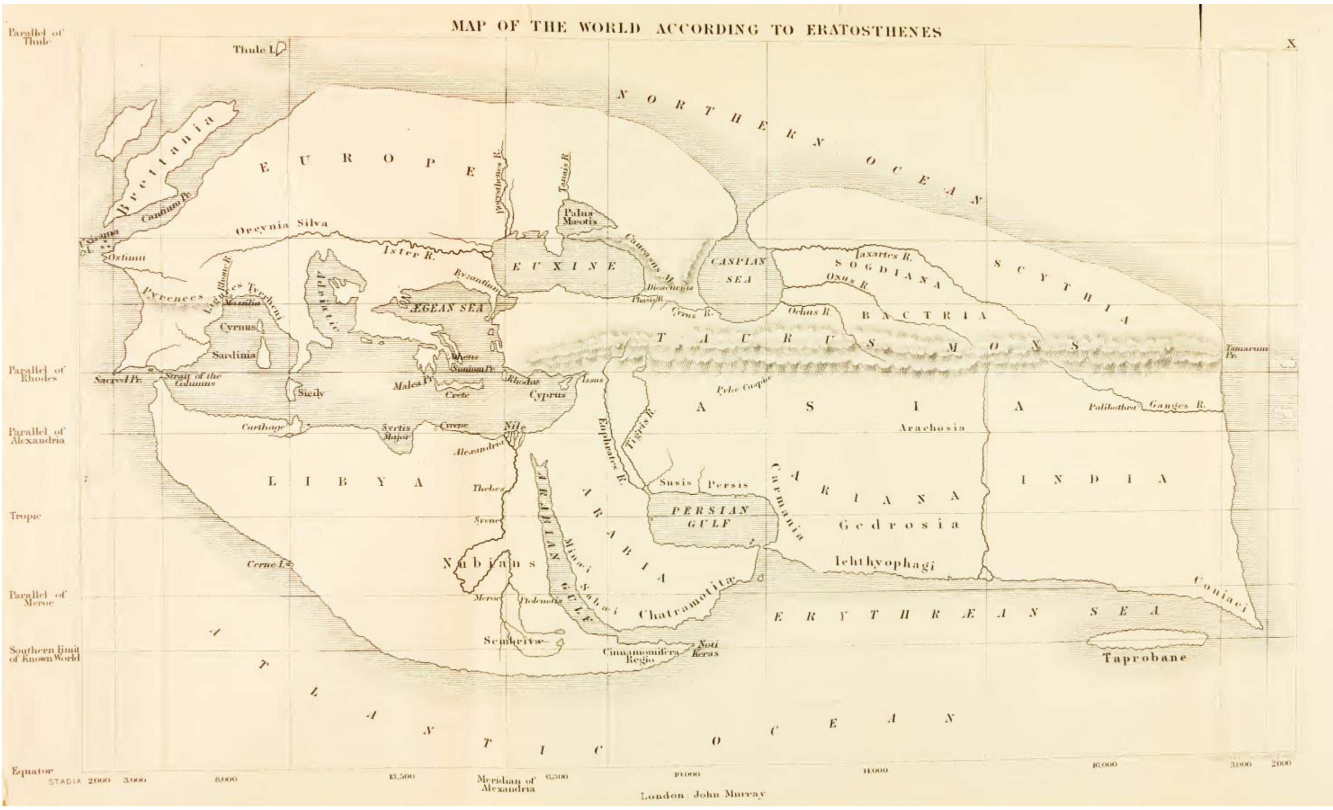

Figure 15: Map of the World according to Eratosthenes (reproduced from Bunbury, 1883).

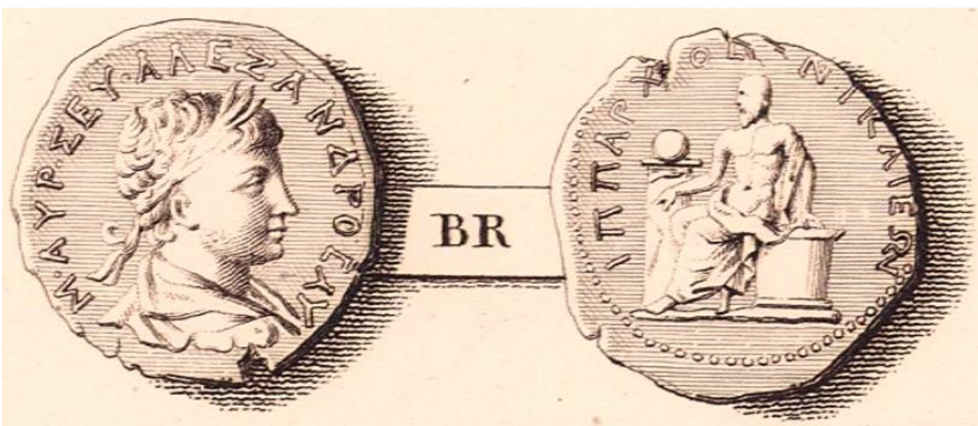

Figure 16: Ἵππαρχος ὁ Νικαεύς (Hipparchus of Nicaea; c. 190 – c. 120 BC), Greek astronomer, geographer and mathematician founder of trigonometry and discoverer of the precession of the equinoxes. Hipparchus is depicted in the back facet of a coin whose front facet shows the Roman emperor Severus Alexander (M. ΑΥΡ. ΣΕΥ. ΑΛΕΞΑΝΡΟΣ ΑΥ = Marcus Aurelius Alexandros Augustus) (Image source: Visconti, 1817.)

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The scientist of the Hellenistic period with the greatest contribution to hydrology is Heron (Hero) of Alexandria (Ἥρων ὁ Ἀλεξανδρεύς; mathematician and engineer who most likely lived in the 1st century BC or the 1st AD; see Woodcroft, 1851). He studied the notion of pressure and pneumatics and invented a steam machine. He introduced the term hydraulic (organ) for a musical instrument operated by hydraulics (*ὑδραυλικὸν ὄργανον*), which he describes in his book *Pneumatica* (*Πνευματικὰ*; Schmidt, 1899, p. 192, "*Ὑδραυλικοῦ ὀργάνου κατασκευὴ*"; Woodcroft, 1851, p. 105). His contribution to hydrology is that he introduced the concept of discharge and its measurement. Here is the relevant passage from his book *Dioptra* (*Διόπτρα*):

> Given a spring, to determine its flow, that is, the quantity of water which it delivers. *One must, however, note that the flow does not always remain the same. Thus, when there are rains the flow is increased, for the water on the hills being in excess is more violently squeezed out. But in times of dryness the flow subsides because no additional supply of water comes to the spring. In the case of the best springs, however, the amount of flow does not contract very much. Now it is necessary to block in all the water of the spring so that none of it runs of at any point, and to construct a lead pipe of rectangular cross section. Care should be taken to make the dimensions of the pipe considerably greater than those of the stream of water. The pipe should then be inserted at a place such that the water in the spring will flow out through it. That is, the pipe should be placed at a point below the spring so that it will receive the entire low of water. Such a place below the spring will be determined by means of the dioptra. Now the water that flows through the pipe will cover a portion of the cross-section of the pipe at its mouth. Let this portion be, for example, 2 digits* [in height]. *Now suppose that the width of the opening of the pipe is 6 digits. 6 × 2=12. Thus, the flow of the spring is 12* [square] *digits. It is to be noted that in order to know how much water the spring supplies it does not suffice to find the arca of the cross section of the flow which in this case we say is 12 square digits. It is necessary also to find the speed of flow, for the swifter is the flow, the more water the spring supplies, and the slower it is, the less. One should therefore dig a reservoir under the stream and note with the help of a sundial how much water flows into the reservoir in a given time, and thus calculate how much will flow in a day. It is therefore unnecessary to measure the arca of the cross section of the stream. For the amount of water delivered will be clear from the measure of the time.*[*] (Hero, Dioptra, 31, English translation by Cohen, 1958.)

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[*] Πηγῆς ὑπαρχούσης ἐπισκέψασθαι τὴν ἀπόρρυσιν αὐτῆς, τουτέστι τὴν ἀνάβλυσιν, ὅση ἐστίν. *εἰδέναι μέντοι χρὴ ὅτι οὐκ ἀεὶ ἡ ἀνάβλυσις ἡ αὐτὴ διαμένει. ὄμβρων μὲν γὰρ ὄντων ἐπιτείνεται διὰ τὸ ἐπὶ τῶν ὀρῶν τὸ ὕδωρ πλεονάζον βιαιότερον ἐκθλίβεσθαι, αὐχμῶν δὲ ὄντων ἀπολήγει ἡ ῥύσις διὰ τὸ μὴ ἐπιφέρεσθαι πλέον ὕδωρ. αἱ μέντοι γενναῖαι πηγαὶ οὐ παρὰ πολὺ τὴν ἀνάβλυσιν ἴσχουσιν. δεῖ οὖν περιλαβόντα τὸ πᾶν τῆς πηγῆς ὕδωρ, ὥστε μηδαμόθεν ἀπορρεῖν, σωλῆνα τετράγωνον μολιβοῦν ποιῆσαι, στοχασάμενον μᾶλλον μείζονα πολλῷ τῆς ἀποθύσεως· εἶτα δι' ἑνὸς τόπου ἐναρμόσαι αὐτὸν ὥστε δι' αὐτοῦ τὸ ἐν τῇ πηγῇ ὕδωρ ἀπορρεῖν. δεῖ δὲ αὐτὸν κεῖσθαι εἰς τὸν ταπεινότερον τῆς πηγῆς τόπον, ὥστε ἔχειν αὐτὴν ἀπόρρυσιν. τὸν δὲ ταπεινότερον ἐπιγνωσόμεθα τῆς πηγῆς τόπον διὰ τῆς διόπτρας. ἀπολήψεται οὖν τὸ ἀπορρέον διὰ τοῦ σωλῆνος ὕδωρ ἐν τῷ περιστομίῳ τοῦ σωλῆνος· οἷον ἀπολαμβάνει[ν] δακτύλους β· ἐχέτω δὲ καὶ τὸ πλάτος τοῦ περιστομίου τοῦ σωλῆνος δακτύλους ς· ἑξάκις δύο γίνονται ιβ· <ἀποφανούμεθα δὴ τὴν ἀνάβλυσιν τῆς πηγῆς δακτύλων ιβ>. εἰδέναι δὲ χρὴ ὅτι οὐκ ἔστιν αὔταρκες πρὸς τὸ ἐπιγνῶναι, πόσον χορηγεῖ ὕδωρ ἡ πηγή, [ἢ] τὸ εὑρεῖν τὸν ὄγκον τοῦ ῥεύματος, ὃν λέγομεν εἶναι δακτύλων ιβ, ἀλλὰ καὶ τὸ τάχος αὐτοῦ· ταχυτέρας μὲν γὰρ οὔσης τῆς ῥύσεως πλέον ἐπιχορηγεῖ τὸ ὕδωρ, βραδυτέρας δὲ μεῖον. διὸ δεῖ ὑπὸ τὴν τῆς πηγῆς ῥύσιν ὀρύξαντα τάφρον τηρῆσαι ἐξ ἡλιακοῦ ὡροσκοπίου, ἐν τινὶ ὥρᾳ πόσον ἀπορρεῖ ὕδωρ ἐν τῇ τάφρῳ, καὶ οὕτως στοχάσασθαι τὸ ἐπιχορηγούμενον ὕδωρ ἐν τῇ ἡμέρᾳ πόσον ἐστὶν, ὥστ' οὐδὲ ἀναγκαῖόν ἐστι τὸν ὄγκον τῆς ῥύσεως τηρεῖν· διὰ γὰρ τοῦ χρόνου δήλη ἐστὶν ἡ χορηγία.* (Ἡρων ο Αλεξανδρεύς, Διόπτρα, Schoenne, 1976.)

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6 From antiquity to modern science

Modern hydrology owes a lot to several philosophers and scientists of the Renaissance, starting from the 15th century. Excellent account about this period can be found in several books and papers on the history of hydrology: Biswas (1970), Dooge (1959, 1974, 2003) and Wendland et al. (1998). A major breakthrough during the Renaissance was the recognition of the importance of the empirical basis in hydrological phenomena, acquired by observation, measurement and experiment. Leonardo da Vinci (1452–1519) the great artist, scientist and engineer, was also a great experimentalist and gave particular focus to water flow. This is testified by his book Del Moto e Misura dell' Acqua, written around 1500 (but published much later; da Vinci, 1828) and many of his manuscripts (see also Pfister et al., 2009). Benedetto Castelli (1578–1643), a student of Galileo and professor of mathematics at the universities of Rome and Pisa, also made measurements as seen from his book Della Misura dell' Acque Correnti (Castelli, 1628). There he explains how he installed a rain gauge in Perugia in order to provide a basis for estimating the variations in level of the Trasimeno Lake (Dooge, 2003) and controlling the discharge of its outlet. He also used floats to measure the stream velocity (Wendland et al., 1998).

As already mentioned in the Introduction and articulated in the above references, Pierre Perrault (1611-1680; Receiver General of Finances for Paris), Edme Mariotte (c. 1620 –1684; French physicist and priest), Edmond Halley (1656 – 1742; English physicist, mathematician, astronomer, geophysicist and meteorologist) and John Dalton (1766 –1844; English chemist, physicist, and meteorologist) have been the pioneers of the quantification of the hydrological cycle through measurement, but not of the concept of hydrological cycle per se, which is earlier. Indeed, Bernard Palissy (c. 1510 – c. 1589; French Huguenot potter, hydraulics engineer and craftsman) and several other scientists of the 16th century, whose lives and works are extensively reviewed by Biswas (1970), had contributed in shedding light on the hydrological cycle. However, the concept is in fact by centuries older as documented in the previous sections.

Perrault's book is instructive in this respect, as the author puts his own work in the perspective of the old literature. Interestingly, he published his book anonymously in 1674 in French, as well as an extended abstract in English (Anonymous, 1675), but a few years later the book was republished with his name (Perrault, 1678), while more recently a full translation in English appeared (Perrault, 1967). In its first part, constituting about half of the book, he critically reviews other philosophers, ancient Greek (Plato, Aristotle, Epicurus), Roman (Vitruvius, Seneca, Pliny), medieval (Thomas Aquinas) and early modern (Scaliger, Cardano, Agricola, Dobrzenski, van Helmont, Lydiat, Davity, Descartes, Gassendi, François the Jesuit, Palissy and others). In particular he appears to disagree with Vitruvius, Gassendi, François and Palissy, whose ideas he refers to as the Common Opinion (l'Opinion Commune). In the second part he presents his measurements, calculations and theories. Referring to the River of Seine, his final result is this:

> *So that there needs but the sixth part of the Rain and Snow-water that falls in a year, to run continually through the whole year*. (Anonymous, 1675).

Interestingly, Perrault also refers to the Nile as follows:

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But when there would be countries where it never rains, that would not prevent rivers from flowing which would have their sources in other countries where it rains, as does the Nile which flows in Egypt where it does not rain. […]

Continuation of the Author's opinion.

After having rejected the Common Opinion, after having shown that the water which flows in the Rivers for a year is not so considerable as Aristotle and those who followed him imagined, and that the rains can provide sufficient water to maintain their course for a year, it only remains for me to show how the waters of the rain and the snow that have fallen in the Rivers, can come out through the top of the mountains to make springs.[*] (Perrault, 1678, p. 207, translation by authors based on Google Translate.)

This is puzzling as in fact Aristotle's theory on the Nile was exactly this, i.e., that rainfall in another area (Ethiopia) was provided the water to sustain the flow (actually flood) of the Nile.

One interesting observation is that none of the celebrated publications of all these pioneers, namely da Vinci (1828), Palissy (1844), Castelli (1628), Perrault (1678), Mariotte (1700), Halley (1687) and Dalton (1802), contains the term *hydrology*. This raises the question, how and when did this term appear? The question is studied in full detail in Appendix C and the findings can be summarized in the following points:

- The term *hydrology* is Greek (*ὑδρολογία* from *ὕδωρ* = water and *λόγος* = reason) but not ancient Greek.
- Most probably it appeared for first time in its French variant, *hydrologie*, in 1614 in a book of medical and philosophical orientation (Landrey, 1614), following the Hippocratic approach on the relationship of water and health.
- It further appeared in other books of the 17th and 18th centuries mostly in Latin but also in modern languages and mostly with medical and philosophical orientation, but also chemical, mineralogical and physical.
- In the end of the 18th century and during the 19th century, the domain covered by the term hydrology is expanded to include natural sciences (physics, meteorology, climatology), geography and hydraulics.
- In the end of the 19th century, an international congress of hydrology and climatology was held in Biarritz, France, in which hydrology was divided in two branches, medical hydrology and scientific hydrology; key persons of that congress were medical doctors but there was also one explorer and geographer, and one meteorologist.

This explains that the *International Association of Scientific Hydrology* (IASH), which was established in 1922, adopted the term *scientific hydrology*, rather than simply *hydrology*, to distinguish itself from medical associations. The foundation of

[*] *Mais quand il y auroit de ces pays-là où il ne pleut jamais, cela n'empescheroit pas qu'il n'y coulast des Rivieres qui auroient leurs sources en d'autres pays où il pleut, comme fait le Nil qui coule en Egypte où il ne pleut point.* […]
Suite de l'opinion de l'Auteur
Apres avoir rejette l'Opinion Commune, après avoir fait voir que l'eau qui coule dans les Rivières pendant une année n'est pas si considérable que se l'est figuré Aristote & ceux qui l'ont suivy, & que les pluyes peuvent fournir des eaux suffisamment pour entretenir leur cours durant une année; il ne me reste plus qu'à faire voir comment les eaux de la pluye & de la neige tombées dans les Rivières, peuvent sortir par le haut des montagnes pour faire des sources. (Perrault, 1678, p. 207)

IASH and its domain are described in the following extract from Lyons (1922), who writes about the first meeting of the International Union of Geodesy and Geophysics (IUGG) held at Rome in 1922:

> *the proposal had been made that an additional section should be formed to deal with the scientific problems which arise in various hydrological investigations, such as rivergauging, lake phenomena including seiches, run-off and evaporation, transport of material in suspension and in solution, glacier movement, etc. A committee examined the matter carefully and reported in favour of forming a Section of Scientific Hydrology. The recommendation was adopted by the General Assembly, which nominated Mr. B. H. Wade of the Physical Department, Cairo, as president, and Prof. G. Magrini as secretary.*

Later, at the XV IUGG General Assembly in Moscow in 1971, the Association replaced the term *scientific hydrology* in its name with the unfortunate term *hydrological sciences* (in plural).

On the other hand, the branch of medical hydrology continued to exist but with a declining activity. Today there still exist university departments (e.g. the Department of Medical Hydrology of the Complutense University of Madrid, 1912 – today)[*], as well as national and international organizations (e.g. the International Society of Medical Hydrology and Climatology[†] each year convening in World Congresses[‡], yet no so populated and rich in activity as their "scientific" hydrological counterparts).

In the meantime, specifically in the 1960s, hydrology (without an adjective) acquired a clear definition as a science (UNESCO, 1963, 1964):

> *Hydrology is the science which deals with the waters of the earth, their occurrence, circulation and distribution on the planet, their physical and chemical properties and their interactions with the physical and biological environment, including their responses to human activity*.

This definition complemented an earlier one by the US Ad Hoc Panel on Hydrology (1962), adding an essential element, the interaction of water with human activity. This definition, however, does not explicitly recognize the link of hydrology with hydraulic engineering (despite the fact that it was this very link that advanced it as a modern quantitative scientific discipline; Koutsoyiannis, 2014) nor with health issues (despite the facts exhibited above). It is probable that in the future such links would be reinstated, particularly after the importance given recently on health issues. However, those colleagues who may propose new sciences linking water with engineering or with health, should be aware that such links are as old as Thales and Hippocrates.

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[*] In the University of Athens there existed a Chair of Clinical Hydrology and Climatotherapy (1938-1953), while the Greek Rheumatology Society had been earlier named Greek Society of Rheumatology and Hydrology (Ελληνική Εταιρεία Ρευματολογίας και Υδρολογίας)

[†] http://www.ismh-direct.net/info.aspx?sp=1

[‡] http://www.ismh-direct.net/hirek.aspx?s=0&archiv=1

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7 Epilogue

Scientific theories are mostly wrong. It is a matter of time for any theory to be replaced by a better one. Naturally, most of the theories developed in the dawn of science (2600 years ago) have been replaced. This does not make them unscientific.

It is a good practice to study the history of science, recognize the past contributions and give credit to those who made them. This necessitates consulting original texts as citations by later authors, particularly to the works of the greatest minds, may distort the original meaning. And there is a lot of distortion, accompanied with remarkable arrogance, about the contribution of ancient scientists in geophysics—and hydrology in particular. Certainly, the ancient theories contain elements that are blatantly incorrect, according to modern knowledge, but these do not justify treating them with arrogance. Here we preferred to highlight the more correct elements, which justify our respect and admiration.

The study of the history of the development of scientific ideas is useful as it reveals the effectiveness of thought and logic, which were the basic tools of ancient philosophers, in compiling a sensible world vision with some admirable elements, even though other elements are inconsistent according to modern knowledge. As the information provided here shows, in addition to thought and logic, observation, experimentation and measurement were all used by ancient philosophers, particularly by Aristotle.

As evident from present day terminology (meteorology, climate, hydraulics), modern science is not independent from the ancient one. Advances of the Greek antiquity have been particularly seminal for the modern science after the Renaissance.

The above discourse may be useful to learn several lessons that are pretty relevant in our times. First, it is useful to have in mind that, in accordance to Plato's definition quoted in the Introduction, scientists are "lovers of the vision of truth". The importance of seeking the truth is also highlighted by Aristotle in the following quotations:

> *Socrates is dear* [friend], *but truth is dearest.*[*] (Ammonius, Life of Aristotle.)

> *Still perhaps it would appear desirable, and indeed it would seem to be obligatory, especially for a philosopher, to sacrifice even one's closest personal ties in defense of the truth. Both are dear to us, yet it is our duty to prefer the truth*[†] (Aristotle, Nicomachean Ethics 1096a11).

A second lesson, perhaps not obvious from our discourse, is that it takes courage to formulate scientific theories —now as well as then. A relevant extract is the following, by Plutarch:

> *The first man to put in writing, most clearly and most courageously of all, the explanation of the moon's illumination and darkness, was Anaxagoras. But he was no ancient authority, nor was his account in high repute. It was still under seal of secrecy, and made its way slowly among a few only, who received it with a certain caution rather than with confidence. For people did not tolerate the natural philosophers and stargazers, as they were then called, because they*

[*] *φίλος μέν Σωκράτης, ἀλλά φιλτάτη ἡ ἀλήθεια*. (Latin version: *Amicus Socrates, sed magis amica veritas*.)

[†] *δόξειε δ' ἂν ἴσως βέλτιον εἶναι καὶ δεῖν ἐπὶ σωτηρίᾳ γε τῆς ἀληθείας καὶ τὰ οἰκεῖα ἀναιρεῖν, ἄλλως τε καὶ φιλοσόφους ὄντας: ἀμφοῖν γὰρ ὄντοιν φίλοιν ὅσιον προτιμᾶν τὴν ἀλήθειαν*.

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reduced the divine agency down to unreasoning causes, blind forces, and necessary incidents. Even Protagoras was exiled, Anaxagoras was imprisoned and with difficulty rescued by Pericles, and Socrates, though he had nothing whatever to do with such matters, nevertheless lost his life because of philosophy.[*] (Plutarch, Nicias, 23; translation by I. Velikovsky in Anaxagoras.[†])

Note that Anaxagoras was charged of impiety and he was sentenced to death by the Athenian court. He avoided this penalty by leaving Athens, and he spent his remaining years in exile. From Plutarch's information we may infer that Anaxagoras enjoyed the gratitude of his student Pericles. Similar is the relationship of Aristotle and his student Alexander the Great. This, however, does not happen all the time in history. (A remarkable counterexample is the contribution of Kolmogorov, Alexandrov and other students of Egorov, to convict their mentor likely to death—an attempt which was prevented by intervention of Kapitsa and ultimately by a decision of Stalin; Graham and Kantor, 2009).

Courage is a necessary condition for formulating scientific theories but it does not suffice for the acceptance of the theories, even if they are correct. This is a third lesson, which also suggests that the dilemma posed by Russel, Observation vs Authority (see Introduction), is not principal—not even the more relevant dilemma Scientific Truth vs. Authority. Rather, the above discourse points to a more characteristic dilemma, Scientific Truth vs. Public Acceptance. This is both diachronic and also very modern. The case of Aristotle's correct theory on the Nile flooding, which was also confirmed by observation through the first scientific expedition in history, is the most characteristic. Neither the fact that Aristotle was an Authority, nor the backing of the theory by Observation helped acceptance of the theory. Aristarchus's heliocentric model is another similar case. Both scientific theories were kept hidden or rejected for centuries. Mythology has been more popular than science not only in ancient times but also in modern ones (cf. the "nitre theory" on the Nile flooding).

[*] *ὁ γὰρ πρῶτος σαφέστατόν τε πάντων καὶ θαρραλεώτατον περὶ σελήνης καταυγασμῶν καὶ σκιᾶς λόγον εἰς γραφὴν καταθέμενος Ἀναξαγόρας οὔτ᾽ αὐτὸς ἦν παλαιὸς οὔτε ὁ λόγος ἔνδοξος, ἀλλ᾽ ἀπόρρητος ἔτι καὶ δι᾽ ὀλίγων καὶ μετ᾽ εὐλαβείας τινὸς ἢ πίστεως βαδίζων. οὐ γὰρ ἠνείχοντο τοὺς φυσικοὺς καὶ μετεωρολέσχας τότε καλουμένους, ὡς εἰς αἰτίας ἀλόγους καὶ δυνάμεις ἀπρονοήτους καὶ κατηναγκασμένα πάθη διατρίβοντας τὸ θεῖον, ἀλλὰ καὶ Πρωταγόρας ἔφυγε, καὶ Ἀναξαγόραν εἱρχθέντα μόλις περιεποιήσατο Περικλῆς, καὶ Σωκράτης, οὐδὲν αὐτῷ τῶν γε τοιούτων προσῆκον, ὅμως ἀπώλετο διὰ φιλοσοφίαν.* (Πλουτάρχου Βίοι Παράλληλοι, Νικίας, 23.)

[†] http://www.varchive.org/ce/orbit/anax.htm.

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Appendix A On the human teeth problem and the debate of Russell and Aristotle

The problem of the number of humans' teeth and the "debate" of Russell and Aristotle has some merit to examine from an epistemological viewpoint. A relevant question is this. What is actually the number of humans' teeth:

- a constant for all individuals (irrespective of sex)?
- varying among individuals?
- varying among individuals and also varying in time for each individual (like in a stochastic process)?

Modern official statistical data of the USA (Dye et al., 2007) confirm that male humans have a slightly higher number of teeth than females (25.1±0.11 and 23.86±0.14 respectively in the period 1988-1994, while both numbers increased by about 1 in 1999-2004; notice in both sexes the number is considerably smaller than 32). A first reason for the difference is that the number of teeth decreases with increasing age and women's life expectancy is longer by several years than men's. A second reason is that women's teeth seem to be more fragile than men's; specifically, official USA statistical data (Harvey, 1981) suggest that the average number of decayed, missing, and filled permanent teeth per person, among adults of 35-74 years of age, was 18.5 and 19.7 for male and female, respectively, in 1960-62 and increased by about one in both sexes in 1971-74. A third reason of sex disparities is the fact that molar agenesis (congenital lack of one or more teeth; Sujon et al., 2016) is lower in males (38.6%) than in females (40.1%). A fourth reason is that hyperdontia (additional teeth in relation to the normal dental formula, which according to observations ranged from 1 to 8) is more common in males (Harris and Clark, 2008).

The gap between the life duration of women and men is currently about 5 years (75.20 for women, 70.41 on a global basis[*]). While life expectancy varies across countries within the range 51 to 88 years, the gap between the two sexes is almost constant, at about 5 years. We can speculate that, because of the more frequent wars in the times of Aristotle, this gap would be greater and, given that the number of teeth is an decreasing function of age, the difference would be greater and Aristotle's observation would be correct. Fragility might also have played a bigger role in ancient times as the dentistry was not as developed as today.

Appendix B: Modern imaginative explanations of the Nile floods[†]

Johann Michael Vansleb (or Vanslebius or F. Vansleb—F. for Father; 1635 – 1679; a German theologian and linguist) who travelled in Egypt in 1672-73 published a book about Egypt in 1677 in French and a year later in English (Vansleb, 1678). Among other things, he provides an imaginative explanation for the Nile floods. He contends that yearly the Nile's level "begins to increase and decrease on a certain day precisely", namely on 17 June and on 24 September, respectively. He reports

[*] https://ourworldindata.org/grapher/life-expectancy-of-women-vs-life-expectancy-of-women.

[†] In all quotations in this Appendix we have kept the spelling of the original, which may differ from the common current one,

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some mysterious "drops" that synchronise with the beginning of the inundation, that is "a kind of a Dew which falls towards the last quarter of the night, near the morning", while the rainfall in Ethiopia starts later, in July. Therefore, he asserts that:

> *The increase of the River proceeds from several causes; the first and the chief is, the fermentation caused in it by this Dew*

while he includes in the causes, with secondary role, the rainfall in Ethiopia and the westerly winds, which

> *blow strait into the River Nilus and hinder the fresh water from coming out, so that it returns back, and causeth the River to swell.*

Interestingly, even before Vansleb's trip and book, the French physician and philosopher Marin Cureau de la Chambre (1594 – 1669) published a book citing other travellers to Egypt (e.g., the Venetian physician and botanist Prospero Alpini or Prosper Alpinus; 1553 –1617), in which he adopts the cause of floods by this mysterious dew, but also introduces the *nitre* (also referred to as *niter* in some English books) "theory" (de la Chambre, 1665). His book was also presented in Britain with a summary published in the Philosophical Transactions (Oxford), from which we quote the following (Anonymous, 1665–1666b):

> A DISCOURSE ABOUT THE CAUSES OF THE INUNDATION OF THE NILE, in French. *The Author of this Book is Monsieur dela Chambre, who being perswaded from several Circumstances, that accompany the Overflowing of this River, that it cannot proceed from Rain, ventures to assign for a Cause of it, and of all the other effects that happen at the time of its swelling, the Niter, wherewith that water abounds.*
> […] *'Tis affirm'd, that 3 or 4 days before that River begins to overflow, all its water is troubled: that then there falls a certain Dew, which hath a fermenting vertue, and leavens a Paste exposed to the Air. […] the Niter, which the Nile is stored with, is the cause of all these strange effects* [inundation], *and of many others, by him alledged. For, saith he, when the Nitre is heated by the heat of the Sun, it ferments, and mingling with the water, troubles it, and swells it, and makes it pass beyond its banks; after the same manner, as the Spirits in new Wine render it troubled, and make it boyle in the vessel.*
> […] *the Author undertakes to prove, that all those strange effects cannot be attributed to Rain or Snow, and that the overflowing of the Nile always happens at certain day.*

It appears that the dew and nitre theories had subsequently become popular in Oxford. Thus, Charles Leigh (English physician and naturalist 1662–1701?) in a letter to Robert Plot ("Professor of Chymistry in the University of Oxford" and "Director of Experiments to the Philosophical Society of Oxford, and one of the Secretaries of the Royal Society"; 1640 – 1696), published in Philosophical Transactions (Leigh, 1684), writes:

> *By Monsieur de la Chambre, it is affirmed that three or four days before the Nile begins to overflow, there falls a certain dew which hath a fermenting vertue, and leavens a past expos'd to the air, and at that time saith Pliny, and Monsieur*

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> *de la Chambre the Nitre Pits grow full of Nitre. And Sands, Vanslebius and several say, that tho 500 in a day die in Grand Cairo of the Plague before the beginning of the inundation of Nile, yet the very day after there does not one die, which doubtless could not proceed from any other reason, then because at that time, the air was impregnated with this Volatile Alkaly, for at that time the Nitre Pits grow full and this dew falls; (this I think) may sufficiently hint to us the great use of its volatile spirit especially in pestilential distempers.*

Subsequently this view was adopted by Plot himself, who wrote (Plot, 1686):

> *The Origine of* [the] *increase* [of Nile's level] *the learned Vanslebius (who lived there some years and carefully observed it) thinks chiefly to proceed from the fall of certain drops, somewhat like dew, that mixing with the waters cause such a fermentation and corruption in them that they expand themselves and swell to a great height, long before it can any way be possibly effected by the great rains in Habessia* [= Abyssinia, Ethiopia].

He further proceeded to contend:

> *The learned Cambraeus as cited by Gassendus* [Petrus Gassendi; 1592 –1655] *thinks this fermentation to be caused by Niter, wherewith the Country and especially the Channel of the River is acknowledged to abound, which being heated by the Sun, thus dilates it self and makes the River to swell.*

From a systematic search in Philosophical Transactions, it turns out that there was at least one scholar who opposed those theories: the Dutch manuscript collector Isaacus Vossius (Isaac Voss; 1618 –1689). His book written in Latin (Vossius, 1666) was also presented in the Transactions (Anonymous, 1665–1666a,c), where from the latter we quote this:

> [Vossius] *easily gives an account, why the Nile yearly overflows about the end of June: For, as at that time there falls much rain in Æthiopia, it must needs be, that the Nile, whose source is in that Country, should then overflow, when those rains begin, and subside, when they cease.*

Interestingly, Vossius's (1666) view is not far from Aristotle's and he quotes Greek authors to support it, namely, Cleomedes, Nonnosus and Cosmas Indicopleustes (see section 4).

However, Vossius's view remained unpopular. According to Garnier (1892), during the 18th century:

> *The learned societies of France, England, and Germany recognised the nitrous salt in the fertilising essence of Nile water, dung, snow, rain water, and other real or imaginary manures; and the whole scientific world extolled in extravagant terms the virtues of a compound the true nature of which it had as yet failed to grasp.*

This is reflected in the popularity of the use of the word *nitre* in books written in the languages of these three countries. As shown in Figure B1 this name is not in use any more, but in the 18th century its use had peaked, exceeding those of the word *Nile*.

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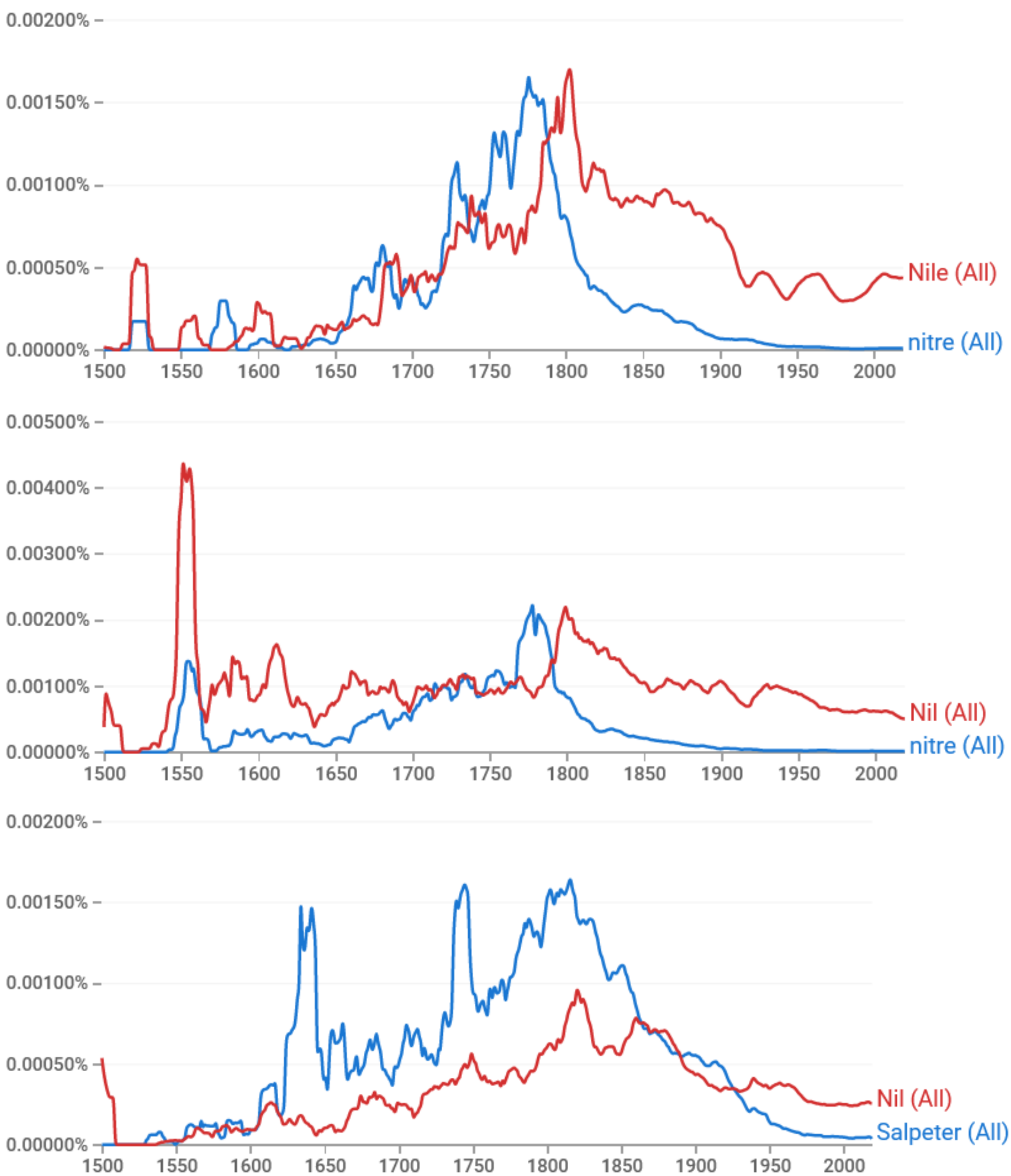

Figure B1: Frequency of appearance of the indicated words in books hosted in the Google books platform (https://books.google.com/ngrams/) in three languages: (upper) English; (middle) French; (lower) German.

840 Complete dismissal of these imaginative theories would require additional modern evidence and thus it had to wait a century, up to the end of the 18th century. Then, James Bruce (1730 –1794), a Scottish traveller and travel writer who visited North Africa and Ethiopia, including the origins of the Blue Nile, wrote with a modest tone of irony (Bruce, 1813):

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I shall now mention a treatise of a modern philosopher, wrote expressly upon this subject; I mean a discourse on the causes of the inundation of the Nile, by M. de la Chambre, printed at Paris in quarto, 1665, where, in a long dedication, he modestly assures the king, he is persuaded that his majesty will consider, as one of the glories of his reign, the discovery of the true cause of the Nile's inundation, which he had then made, after it had baffled the inquiry of all philosophers for the space of 2000 years; and, indeed, the cause and the discovery would have been both very remarkable, had they been attended with the least degree of possibility. […] *M. de la Chambre says, that the nitre, with which the ground in Egypt is impregnated, ferments like a kind of paste, occasioning the Nile to ferment likewise, and thus increases the mass of water so much, that it spreads over the whole land of Egypt.*

Far be it from me to bear hard upon those attempts with which the ancients endeavoured to solve those phaenomena, when, for want of a sufficient progress in experimental philosophy and observation, they were generally destitute of the proper means; but there is no excuse for a man's either believing or writing, that earth, impregnated with so small a quantity of any mixture as not to be discernible to the eye, smell, or taste, could periodically swell the waters of a river, then almost dry, to such an immensity, as to cover the whole plains of Egypt, and discharge millions of tons every day into the sea.

Appendix C: The appearance of the term *hydrology*

Several terms related to hydrology appear in ancient Greek literature, which are etymologized from the noun *ὕδωρ* (hydor, water). Specifically:

- The conveyance of water or liquids is termed *ὑδραγωγία* (ἡ) and a person (or device) related to it *ὑδραγωγός*.
- The actions of drawing, fetching or distributing water are termed *ὑδρεία*, *ὕδρευσις* and *ὑδροπαροχία*; a person related to them is termed *ὑδροπάροχος* and a guard or inspector of aqueducts or irrigation works *ὑδροφύλαξ*.
- The action or art of seeking or discovering water is termed *ὑδροσκοπία*, *ὑδροσκοπική* or *ὑδροφαντική* (verb: *ὑδροσκοπέω*); a person related to it is *ὑδρόσκοπος*, *ὑδρογνώμων* or *ὑδροφάντης* and a related instrument is *ὑδροσκόπιον*.

These, however, have not been transplanted to the international scientific or technological vocabulary, where words of Latin origin (e.g. aqueduct) dominated. On the other hand, the following Greek terms have become global:

- The modern term *ὑδραυλική* (*hydraulics*) stems from *ὑδραυλικὸν ὄργανον* (*hydraulic organon*), first used by Hero for a musical instrument operated by hydraulics. Earlier, Ctesibius (Κτησίβιος; fl. 285–222 BC) invented the instrument called *ὕδραυλις* (ἡ) (*hydraulis*), which is played by a musician called *ὑδραύλης* (*hydraules*). Its etymology stems from *ὕδωρ* (water) and *αὐλός* (*aulos*; pipe, flute, clarinet). Thus, the term *hydraulics* was not introduced by Robert Boyle (1627-1691), as commonly written (Biswas, 1970, p. 225), but almost two millennia earlier.

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- The term *meteorology* stems from *μετεωρολογία*, which in turn stems from *μετέωρα* (*meteors*; note, in the ancient literature, in addition to hydrometeors, meteors include the heavenly bodies); a person who studies *μετεωρολογία* is *μετεωρολόγος* (*meteorologos*, meteorologist) or *μετεωρολογικός* (*meteorologicos*, meteorologic) (cf. Plato's *Phaedro* 270a and Aristotle's *Meteorologica*).
- The term *climate* stems from *κλίμα* (meaning the inclination angle of the incoming sunbeams; pl. *κλίματα*); a property pertaining to *κλίμα* is *κλιματικός*.

Hydrology is also a Greek word, i.e., *ὑδρολογία* (feminine noun transliterated in Latin as *hydrologia*), but it does not appear in the ancient Greek literature.[*] The closest match it contains is *ὑδρολόγιον* (*hydrologion*, a noun in neuter gender), which however is a water-clock. Its plural, *ὑδρολόγια*, is transliterated in Latin as hydrologia, precisely the same as the transliteration of *ὑδρολογία* (notice that in Greek there is a difference in the location of the accent). Among the first books published after the invention by Gutenberg of mechanical printing press, was the Lexicon of Festus (in Latin), typically dated to the 2nd century, with original title *De Verborum Significatione* (On the Meaning of Words). This does not contain the term *hydrologia*, but commentaries on it published several years after do. Thus, this term appears in the book of Commentaries on *de Verborum Significatione* by three famous interpreters (Alciatus, Brechaeus, Fornerius, 1589, p. 10) but from the context it becomes clear that it is plural of *hydrologion* (or *hydrologium* in Latin). It also appears with the same meaning in an encyclopaedic collection of mathematical curiosities by Bettinus (1642).

According to our own search in digital archives of old books, the first containing the term *hydrology* in its French version, *hydrologie*, is the book by Landrey (1614). Other books whose title (or subtitle) contains the term hydrology, published in the 17th through 19th century, are listed in Table C1 and illustrated in Figure C1 to Figure C12. It appears that the main orientation of those books was medical. At the end of the 19th century an international congress of hydrology and climatology was held at Biarritz, France (in Bay of Biscay close to the Spanish borders) as reported by Symons (1887), in which a distinction was made between *medical hydrology* and *scientific hydrology*. The key persons of that congress, shown in Figure C13, appear to be mostly medical doctors. For most of them we found their details which are as follows:

- Maxime Durand-Fardel (1815-1899), French medical doctor and explorer; coauthor (with Eugène Le Bret and Jules Lefort) of *Dictionnaire Général des Eaux Minérales et d'Hydrologie Médicale*, 4 vol., 1860.[†]
- Joseph Louis Félix Garrigou (1835-1920), French medical doctor and prehistorian; chair of medical hydrology at Toulouse (1891).[‡]
- Antoine Thomson d'Abbadie d'Arrast (1810-1897), Irish-born French explorer, geographer, ethnologist, linguist and astronomer.[§]

[*] Indeed, *The Liddell, Scott, Jones Ancient Greek Lexicon* (LSJ; the best-known Ancient Greek dictionary) does not contain the entry *ὑδρολογία*.

[†] https://fr.wikipedia.org/wiki/Maxime_Durand-Fardel.

[‡] https://en.wikipedia.org/wiki/F%C3%A9lix_Garrigou.

[§] https://en.wikipedia.org/wiki/Antoine_Thomson_d%27Abbadie.

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- Luigi Chiminelli (1816-1901), Italian medical doctor, specialized in medical hydrology; founder of the periodical *L'Idrologia Medica* (1879), later renamed *L'Idrologia e la Climatologia Medica* (1881).*
- Enoch Heinrich Kisch (1841-1918) Austrian medical doctor, balneologist and gynecologist born in Prague; author of *Allgemeine Balneologische Zeitung V1, Book 2: Monatsschrift Für Balneologie, Hydrologie Und Klimatologie* (1867).†
- George James Symons (1838-1900), British meteorologist; founder and manager of the British Rainfall Organisation, and a dense and widely distributed network of raingauges throughout the British Isles.‡

Table C1. Books published in the 17th through 19th century whose title (or subtitle) contains the term hydrology (or the equivalent term in another language).

No.	Author (year)	Title	Language	Scope*	Illustration
1	Landrey (1614)	Hydrologie ou Discours de l'Eaue	French	M,P	Figure C1
2	Licetus (1655)	Hydrologiae Peripateticae Disputationes de Maris Tranquillitate	Latin	P	Figure C2
3	Derham (1685)	Hydrologia Philosophica	English	M,P	Figure C3
4	Melchiore (1694)	Hydrologia Brevis Quidem	German	M	Figure C4
5	Vinayma (1738)	Hydrologia, o Tratado de las Aguas Ferrugíneas …	Spanish	M	Figure C5
6	Wallerius (1751)	Hydrologie	German†	C	Figure C6
7	Cartheseur (1758)	Rudimenta hydrologiae systematicae	Latin	M	Figure C7
8	Hanovius (1765)	Philosophiae Naturalis sive Physicae Dogmatica … Continens Aërologiam et Hydrologiam	Latin	P	Figure C8
9	Monnet (1772)	Nouvelle Hydrologie	French	C	Figure C9
10	Eliseo (1790)	Physicae Experimentalis Elementa … Hydrostatica, Hydrodinamica, Hydraulica, Hydrologia	Latin	H,N	Figure C10
11	Barrington (1850)	A Treatise on Physical Geography Comprising Hydrology, Geognosy, Geology, Meteorology…	English	G	Figure C11
12	Beardmore (1862)	Manual of Hydrology	English	H	Figure C12

* Main scope classified as follows: C- Chemistry, mineralogy, G: Geography; H: Hydraulics; M; Medicine; N: Natural sciences (physics, meteorology, climatology); P: Philosophy.

† Translation from the original edition in Swedish (1748)

* https://www.treccani.it/enciclopedia/luigi-chiminelli_(Dizionario-Biografico)/.

† https://en.wikipedia.org/wiki/Enoch_Heinrich_Kisch, http://jewishencyclopedia.com/articles/9348-kisch.

‡ https://en.wikipedia.org/wiki/George_James_Symons.

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HYDROLOGIE OV DISCOVRS DE L'EAVE.

Auquel eſt amplemẽt declarée la vertu & puiſſance des eaues Medicinales, principalement de celles de Ville-conte prés Billon, & de Sainct Meaulps prés Rion en Auuergne.

Par Iehan Landrey Pariſien, Medecin du ROY.

A Monſieur de Heere Doyen de S. Aignan d'Orleans.

A ORLEANS. Par Fabian Hotot Imprimeur ordinaire du Roy. 1614.

HYDROLOGIE ou diſcours de l'eaue.

Ce que les anciens ont dit de l'eaue.

CHAPITRE I.

NOvs ne pouuons methodiquement diſcourir des eaues medicinales ou minerales, qu'en commençant par le genre, proceder à l'eſpece ſuiuant la doctrine du Philoſophe, autrement il faudroit vſer d'vne tautologie ou ennuyeuſe redicte d'vne meſme

2 *Hydrologie*

choſe, *Crambe recocta mors eſt.* C'eſt pourquoy nous parlons en general de l'eau, produiſãs le teſmoignage de Pindare ὕδωρ ἄριστον l'eau treſbõne, c'eſt à cauſe des proprietez & vertus qui en ſortẽt. Cecy à poſſible incité les Sages de la Grece de nommer la matiere de toutes choſes, fange. C'eſt la doctrine d'Eugubinus, *l. Coſmop.* car la terre meſlee auec l'eau, ſelon Moyſe produit preſque toutes choſes. Ie ne veux entrer au tres-haut myſtere caché ſous le meſlange qu'a fait le Sauueur du monde, de la terre auec ſa ſaliue, lors qu'il a voulu guarir l'aueugle né, ce

Figure C1: Title page and first two pages of the book *Hydrologie ou Discours de l'Eaue* by Jehan (Jean) Landrey (a French King's doctor) (Landrey, 1614). From the title page it becomes clear that the book is about the virtue and power of medicinal waters (la vertu & puissance des eaues médicinales). In the first pages the author declares that he follows the doctrine of the philosopher to begin with the genus and proceed to the species, while he quotes Pindar's verse *ὕδωρ ἄριστον* (*l'eau tres bone*; *water is best*; the exact quotation is *ἄριστον μὲν ὕδωρ*, Pindar, Olympian Odes, 1).

FORTVNII LICETI GENVENSIS IN ALMO PALLADIO PATAVINO Medici Theorici Supremæ Sedis ex L.Com. HYDROLOGIÆ PERIPATETICÆ Diſputationes

De Maris tranquillitate, arte per oleum, & anchoram comparanda: Deque fluminum ortu e montibus, in Meteorologia propoſito: Nec non de Lacus Aſphaltitis in Syria ſtupendis proprietatibus vtcunque ad fabulas relatis.

S. D. N. ALEXANDRO VII. PONTIFICI MAXIMO DD.

FORTASSE LICEBIT

VTINI, Ex Typographia Nicolai Schiratti. MDCLV. ANNVENTIBVS SVPERIORIBVS.

FORTVNII LICETI 1

Ad ſuam HYDROLOGIAM Peripateticam

PRÆFATIO

Tractationis argumentum & ſcopum Autoris aperiens.

PArentibus honorem [a] ſummum exhibendum, opemque ſemper eſſe ferendam, præſertim vita iam [b] functis; Præceptoresque genitoribus comparari, ac tantum non [c] anteponi, præclara ſunt Ariſtotelis apophthegmata, ea ratione vallata, quod ſi ab illis vitam, ab his adipiſcimur vt bene viuamus; ſique filiorum illi corpora curant, & enutriunt, hi diſcipulorum animos probis moribus communiunt, & alunt doctrinæ pabulis. Quæ quidem omnia vt pridem excitare valuerunt ſapientiſſimos viros, [d] Platonem & eius æmulumne an condiſcipulum dicam [e] Xenophontem ad Apologiam conſcribendam pro Socrate, communi Magiſtro, ab Anito & Melito inique accuſato laſciuiæ ac impietatis; & ab Athenienſibus propterea iniquiſſime potione cicutæ in cuſtodia e viuis ſublato: ita dubio procul diſcipulus vnuſquiſque, videns exiſtimationem & monumenta ſui Præceptoris vita iam functi a quopiam iniuſte labefactari, pietate ac ſumma veluti religione tenetur honori mortui Magiſtri conſulere, opemque ferre; ac eo magis, ſi doctrinæ veritas fallarum argumentationum tenebris ac telis obrui circumfodique videatur; etenim [f] rectius eſt, ac neceſſarium, vt pro veritatis incolumitate quilibet, ſpeciatimque Philoſophus propria

A quo-

[a] 9 Eth. cap.2.
[b] 19 ſect. probl.9.
[c] Laert. in vit. Ariſ. Patri.to.1. lib.1.
[d] i Apol. Socr.
[e] i Apol. pro Socr.
[f] 1.Eth. cap.6.

Figure C2: Title page and first page of the book *Hydrologiae Peripateticae Disputationes de Maris Tranquillitate* by Fortunio Liceti (1577–1657, an Italian physician and philosopher) (Licetus, 1655). The adjective *Peripatetica* in the book title shows the influence of Aristotle (whose School was named Περιπατητική Σχολή) on Liceti. The title page summarizes the content of the book (origin of the rivers from the mountains, meteorology, Dead Sea/Lacus Asphaltitis etc.). The names of Aristotle, Plato, Xenophon and Socrates appear already in the first page. The content of the book includes descriptions of various rivers in Asia, Africa (including the Nile) and Europe (mostly Greece).

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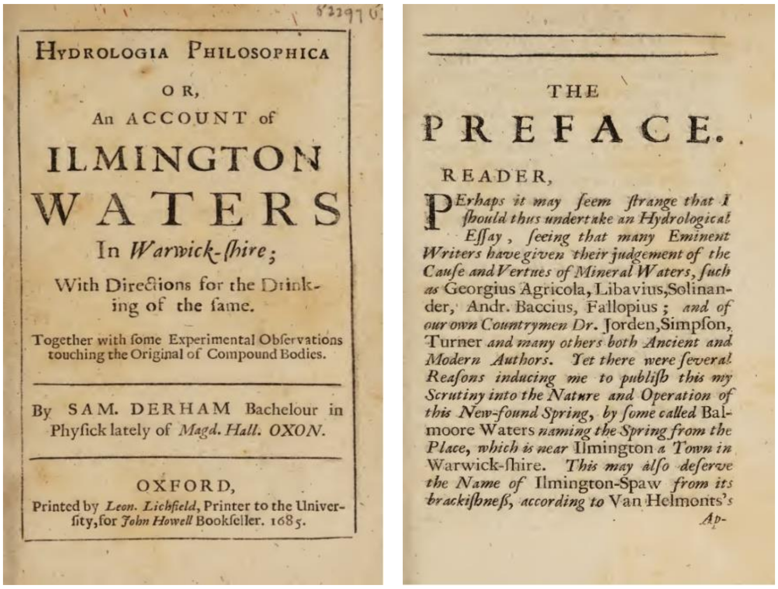
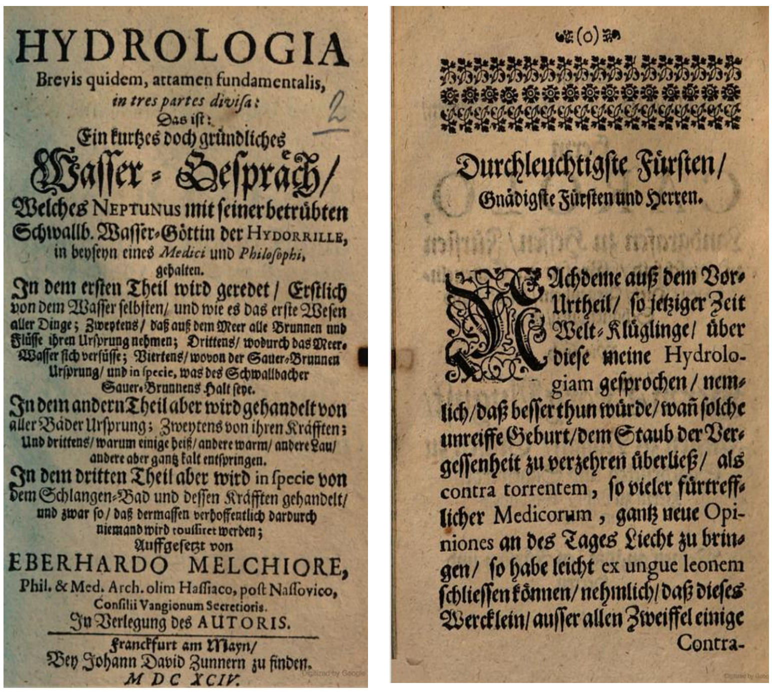

HYDROLOGIA PHILOSOPHICA
OR,
An ACCOUNT of
ILMINGTON
WATERS
In Warwick-ſhire;
With Directions for the Drink-ing of the ſame.
Together with ſome Experimental Obſervations touching the Original of Compound Bodies.
By SAM. DERHAM Bachelour in Phyſick lately of Magd. Hall. OXON.
OXFORD,
Printed by Leon. Lichfield, Printer to the Univer-ſity, for John Howell Bookſeller. 1685.

THE
PREFACE.
READER,
PErhaps it may ſeem ſtrange that I ſhould thus undertake an Hydrological Eſſay, ſeeing that many Eminent Writers have given their judgement of the Cauſe and Vertues of Mineral Waters, ſuch as Georgius Agricola, Libavius, Solinander, Andr. Baccius, Fallopius; and of our own Countrymen Dr. Jorden, Simpſon, Turner and many others both Ancient and Modern Authors. Yet there were ſeveral Reaſons inducing me to publiſh this my Scrutiny into the Nature and Operation of this New-found Spring, by ſome called Balmoore Waters naming the Spring from the Place, which is near Ilmington a Town in Warwick-ſhire. This may alſo deſerve the Name of Ilmington-Spaw from its brackiſhneſs, according to Van Helmont's Ap-

Figure C3: Title page and first page of the book *Hydrologia Philosophica* by Samuel Derham (1577–1657, a British physician*) (Derham, 1685). As clarified in its subtitle, the book is not quite philosophical but refers to properties of the water of a particular spring.


HYDROLOGIA
Brevis quidem, attamen fundamentalis, in tres partes diviſa:
Das iſt:
Ein kurtzes doch gründliches
Waſſer-Geſpräch/
Welches NEPTUNUS mit ſeiner betrübten Schwallb. Waſſer-Göttin der HYDORRILLE, in beyſeyn eines Medici und Philoſophi, gehalten.
In dem erſten Theil wird geredet/ Erſtlich von dem Waſſer ſelbſten/ und wie es das erſte Weſen aller Dinge; Zweytens/ daß auß dem Meer alle Brunnen und Flüſſe ihren Urſprung nehmen; Drittens/ wodurch das Meer-Waſſer ſich verſüſſe; Viertens/ wovon der Sauer-Brunnen Urſprung/ und in ſpecie, was des Schwallbacher Sauer-Brunnens Halt ſeye.
In dem andern Theil aber wird gehandelt von aller Bäder Urſprung; Zweytens von ihren Kräfften; Und drittens/ warum einige heiß/ andere warm/ andere Lau/ andere aber gantz kalt entſpringen.
In dem dritten Theil aber wird in ſpecie von dem Schlangen-Bad und deſſen Kräfften gehandelt/ und zwar ſo/ daß dermaſſen verhoffentlich dardurch niemand wird rouſſiret werden;
Auffgeſetzt von
EBERHARDO MELCHIORE,
Phil. & Med. Arch. olim Haſſiaco, poſt Naſſovico, Conſilii Vangionum Secretioris.
In Verlegung des AUTORIS.
Franckfurt am Mayn/
Bey Johann David Zunnern zu finden.
M DC XCIV.

Durchleuchtigſte Fürſten/
Gnädigſte Fürſten und Herren.
NAchdeme auß dem Vor-Urtheil/ ſo jetziger Zeit Welt-Klüglinge/ über dieſe meine Hydrologiam geſprochen/ nemlich/ daß beſſer thun würde/ wañ ſolche unreiffe Geburt/ dem Staub der Vergeſſenheit zu verzehren überließ/ als contra torrentem, ſo vieler fürtreff-licher Medicorum, gantz neue Opi-niones an des Tages Liecht zu brin-gen/ ſo habe leicht ex ungue leonem ſchlieſſen können/ nehmlich/ daß dieſes Wercklein/ auſſer allen Zweiffel einige Contra-

Figure C4: Title page and first page of the book *Hydrologia Brevis Quidem* by Eberhard Melchior (unknown details) (Melchiore, 1694).

* https://www.oxforddnb.com/view/10.1093/ref:odnb/9780198614128.001.0001/odnb-9780198614128-e-7527.

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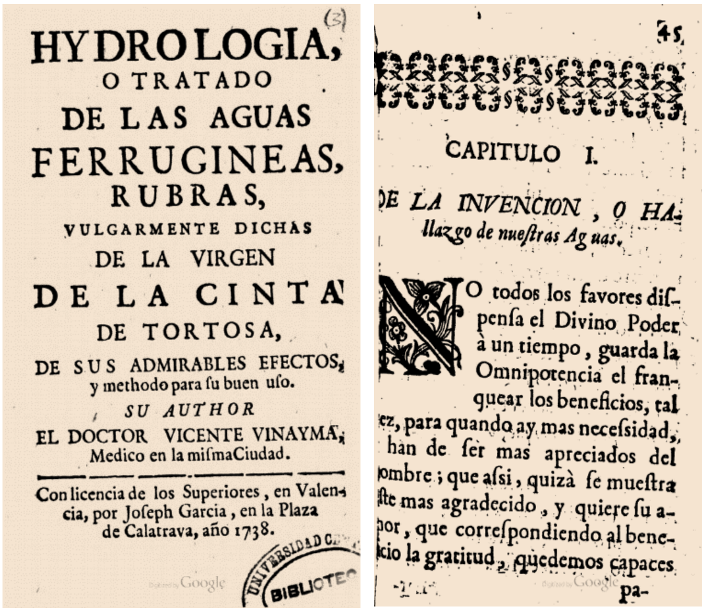


HYDROLOGIA,
O TRATADO
DE LAS AGUAS
FERRUGINEAS,
RUBRAS,
VULGARMENTE DICHAS
DE LA VIRGEN
DE LA CINTA
DE TORTOSA,
DE SUS ADMIRABLES EFECTOS,
y methodo para su buen uso.
SU AUTHOR
EL DOCTOR VICENTE VINAYMA,
Medico en la mismaCiudad.

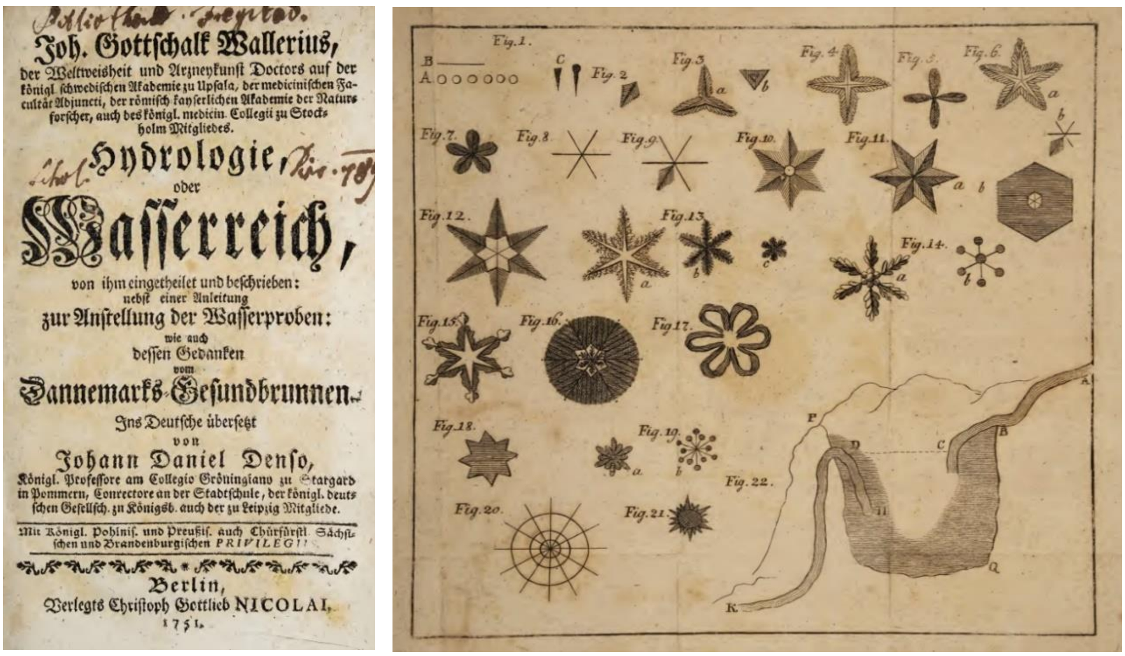
Con licencia de los Superiores, en Valencia, por Joseph Garcia, en la Plaza de Calatrava, año 1738.

CAPITULO I.

DE LA INVENCION, O HAllazgo de nuestras Aguas.

NO todos los favores dispensa el Divino Poder à un tiempo, guarda la Omnipotencia el franquear los beneficios, tal vez, para quando ay mas necessidad, han de ser mas apreciados del hombre; que assi, quizà se muestra mas agradecido, y quiere su amor, que correspondiendo al beneficio la gratitud, quedemos capaces pa-

Figure C5: Title page and first page of chapter 1 of the book *Hydrologia, o Tratado de las Aguas Ferrugíneas* … by Vicente Vinayma (a Spanish medical doctor; unknown details) (Vinayma, 1738). The book underlines a divine link of water.



Joh. Gottschalk Wallerius,
der Weltweisheit und Arzneykunst Doctors auf der königl. schwedischen Akademie zu Upsala, der medicinischen Facultät Adjuncti, der römisch kayserlichen Akademie der Naturforscher, auch des königl. medicin. Collegii zu Stockholm Mitgliedes.
Hydrologie,
oder
Wasserreich,
von ihm eingetheilet und beschrieben:
nebst einer Anleitung
zur Anstellung der Wasserproben:
wie auch
dessen Gedanken
vom
Dannemarks Gesundbrunnen.
Ins Deutsche übersetzt
von
Johann Daniel Denso,
Königl. Professore am Collegio Gröningiano zu Stargard in Pommern, Conrectore an der Stadtschule, der königl. deutschen Gesellsch. zu Königsb. auch der zu Leipzig Mitgliede.
Mit Königl. Pohlnis. und Preußis. auch Chürfürstl. Sächsischen und Brandenburgischen PRIVILEGII
Berlin,
Verlegts Christoph Gottlieb NICOLAI,
1751.

Figure C6: Title page and last page with figures of the book *Hydrologie* by Johan Gottschalk Wallerius (1709-1785; a Swedish chemist and mineralogist*), translated to German by Johann Daniel Denso[†] (Wallerius, 1751) from the original edition in Swedish (*Hydrologia*; Wallerius, 1748).

* https://en.wikipedia.org/wiki/Johan_Gottschalk_Wallerius.

[†] https://de.wikipedia.org/wiki/Johann_Daniel_Denso.

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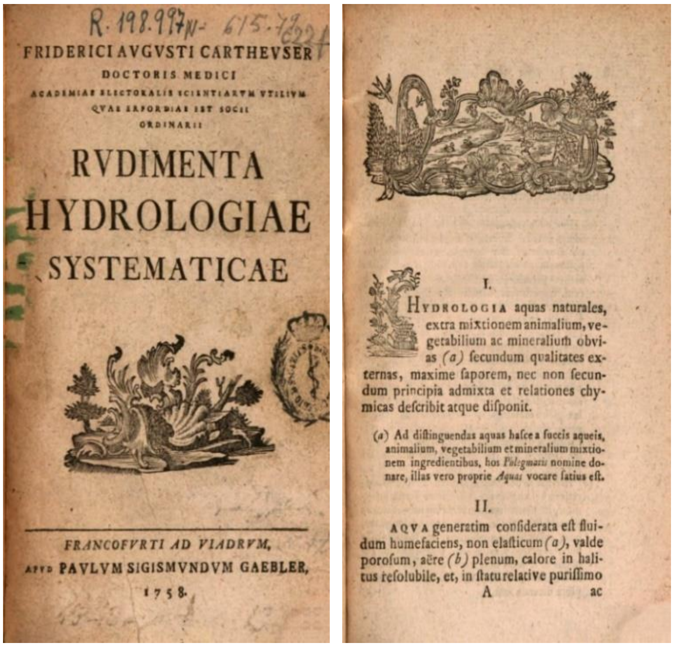

FRIDERICI AVGVSTI CARTHEVSER
DOCTORIS MEDICI
ACADEMIAE ELECTORALIS SCIENTIARVM VTILIVM QVAE ERFORDIAE EST SOCII ORDINARII
RVDIMENTA
HYDROLOGIAE
SYSTEMATICAE

FRANCOFVRTI AD VIADRVM,
APVD PAVLVM SIGISMVNDVM GAEBLER,
1758.

I.

Hydrologia aquas naturales, extra mixtionem animalium, vegetabilium ac mineralium obvias (a) ſecundum qualitates externas, maxime ſaporem, nec non ſecundum principia admixta et relationes chymicas deſcribit atque diſponit.

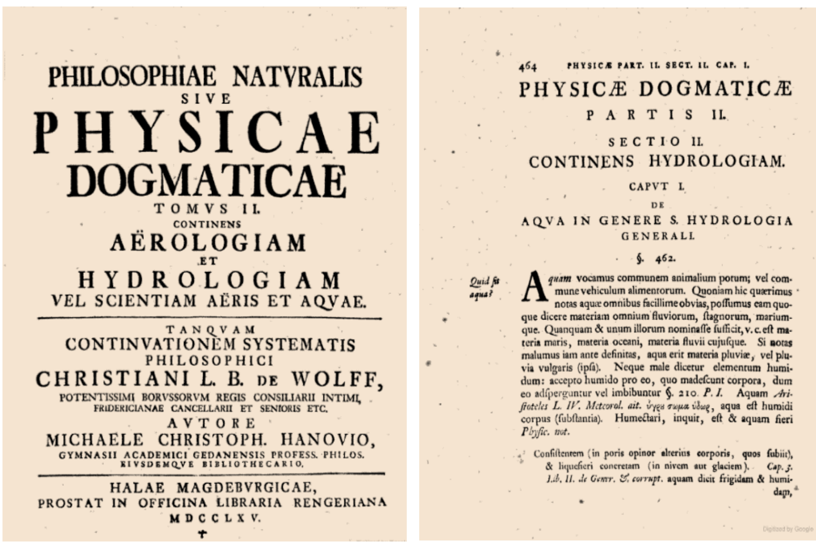
(a) Ad diſtinguendas aquas haſce a ſuccis aqueis, animalium, vegetabilium et mineralium mixtionem ingredientibus, hos *Phlegmatis* nomine donare, illas vero proprie *Aquas* vocare ſatius eſt.

II.

Aqva generatim conſiderata eſt fluidum humefaciens, non elaſticum (a), valde poroſum, aëre (b) plenum, calore in halitus reſolubile, et, in ſtatu relative puriſſimo

A ac

Figure C7: Title page and first page of the book *Rudimenta hydrologiae systematicae* by Friedrich August Charteuser (medical doctor; unknown further details) (Cartheseur, 1758).


PHILOSOPHIAE NATVRALIS
SIVE
PHYSICAE
DOGMATICAE
TOMVS II.
CONTINENS
AËROLOGIAM
ET
HYDROLOGIAM
VEL SCIENTIAM AËRIS ET AQVAE.
TANQVAM
CONTINVATIONEM SYSTEMATIS
PHILOSOPHICI
CHRISTIANI L. B. DE WOLFF,
POTENTISSIMI BORVSSORVM REGIS CONSILIARII INTIMI, FRIDERICIANAE CANCELLARII ET SENIORIS ETC.
AVTORE
MICHAELE CHRISTOPH. HANOVIO,
GYMNASII ACADEMICI GEDANENSIS PROFESS. PHILOS. EIVSDEMQVE BIBLIOTHECARIO.
HALAE MAGDEBVRGICAE,
PROSTAT IN OFFICINA LIBRARIA RENGERIANA
MDCCLXV.

464 PHYSICAE PART. II. SECT. II. CAP. I.

PHYSICÆ DOGMATICÆ
PARTIS II.
SECTIO II.
CONTINENS HYDROLOGIAM.
CAPVT I.
DE
AQVA IN GENERE S. HYDROLOGIA GENERALI.
§. 462.

Quid ſit aqua?

A*quam* vocamus communem animalium potum; vel commune vehiculum alimentorum. Quoniam hic quærimus notas aquæ omnibus facillime obvias, poſſumus eam quoque dicere materiam omnium fluviorum, ſtagnorum, mariumque. Quanquam & unum illorum nominaſſe ſufficit, v. c. eſt materia maris, materia oceani, materia fluvii cujuſque. Si notas malumus iam ante definitas, aqua erit materia pluviæ, vel pluvia vulgaris (ipſa). Neque male dicetur elementum humidum: accepto humido pro eo, quo madeſcunt corpora, dum eo adſperguntur vel imbibuntur §. 210. *P. I.* Aquam *Ariſtoteles L. IV. Meteorol. ait.* ὑγρα σωμα ὑδωρ, aqua eſt humidi corpus (ſubſtantia). Humectari, inquit, eſt & aquam fieri *Phyſic. not.*

Conſiſtentem (in poris opinor alterius corporis, quos ſubiit), & liquefieri concretam (in nivem aut glaciem). *Cap. 3. Lib. II. de Gener. & corrupt.* aquam dicit frigidam & humidam,

Figure C8: Title page and first page of the book *Philosophiae Naturalis sive Physicae Dogmaticae* (vol. 2 of 4) by Michaele Christoph Hanovius (Michael Christoph Hanov, 1695-1773; a German meteorologist, historian and mathematician[*]) (Hanovius, 1765). The book cover states that it is a continuation of the philosophical system of the German philosopher Christianus de Wolff[†]. An impressive element in the title is the "dogmatic" character, which today would be regarded inconsistent with physics. In addition to hydrologia, the book contains aerologia, perhaps influenced by the Hippocratic discourse "Περί αέρων, υδάτων, τόπων".

[*] https://en.wikipedia.org/wiki/Michael_Christoph_Hanow.

[†] https://en.wikipedia.org/wiki/Christian_Wolff_(philosopher).

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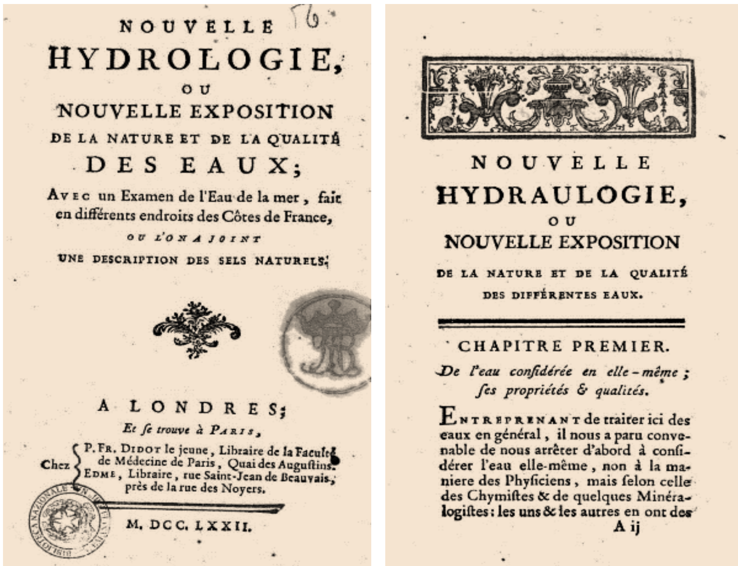


NOUVELLE
HYDROLOGIE,
OU
NOUVELLE EXPOSITION
DE LA NATURE ET DE LA QUALITÉ
DES EAUX;
Avec un Examen de l'Eau de la mer, fait en différents endroits des Côtes de France,
OU L'ON A JOINT
UNE DESCRIPTION DES SELS NATURELS;

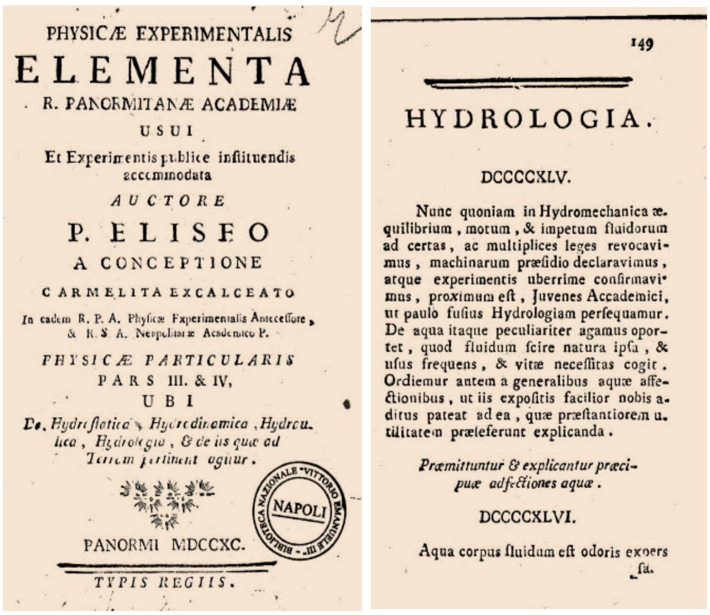
A LONDRES;
Et se trouve à PARIS,
Chez P. FR. DIDOT le jeune, Libraire de la Faculté de Médecine de Paris, Quai des Augustins.
EDME, Libraire, rue Saint-Jean de Beauvais, près de la rue des Noyers.
M. DCC. LXXII.

NOUVELLE
HYDRAULOGIE,
OU
NOUVELLE EXPOSITION
DE LA NATURE ET DE LA QUALITÉ
DES DIFFÉRENTES EAUX.

CHAPITRE PREMIER.
De l'eau considérée en elle-même; ses propriétés & qualités.

ENTREPRENANT de traiter ici des eaux en général, il nous a paru convenable de nous arrêter d'abord à considérer l'eau elle-même, non à la maniere des Physiciens, mais selon celle des Chymistes & de quelques Minéralogistes: les uns & les autres en ont des
A ij

Figure C9: Title page and first page of the book *Nouvelle Hydrologie* by Antoine Grimoald Monnet (1734-1817; a French mineralogist*) (Monnet, 1772). In addition to the quality of potable water, it examines the sea water and the natural salts (sels naturels). Notable is the spelling "hydraulogie" (likely influenced by *hydraulics*) in the first page, also used throughout the entire book, which is different from that in the book cover, "hydrologie".



PHYSICÆ EXPERIMENTALIS
ELEMENTA
R. PANORMITANÆ ACADEMIÆ
USUI
Et Experimentis publice instituendis accommodata
AUCTORE
P. ELISEO
A CONCEPTIONE
CARMELITA EXCALCEATO
In eadem R. P. A. Physicæ Experimentalis Antecessore, & R. S. A. Neapolitanæ Academico P.
PHYSICÆ PARTICULARIS
PARS III. & IV.
UBI
De Hydrostatica, Hydrodinamica, Hydraulica, Hydrologia, & de iis quæ ad Terram pertinent agitur.
PANORMI MDCCXC.
TYPIS REGIIS.

149
HYDROLOGIA.
DCCCCXLV.

Nunc quoniam in Hydromechanica æquilibrium, motum, & impetum fluidorum ad certas, ac multiplices leges revocavimus, machinarum præsidio declaravimus, atque experimentis uberrime confirmavimus, proximum est, Juvenes Accademici, ut paulo fusius Hydrologiam persequamur. De aqua itaque peculiariter agamus oportet, quod fluidum scire natura ipsa, & usus frequens, & vitæ necessitas cogit. Ordiemur autem a generalibus aquæ affectionibus, ut iis expositis facilior nobis aditus pateat ad ea, quæ præstantiorem utilitatem præseferunt explicanda.

Præmittuntur & explicantur præcipuæ adfectiones aquæ.

DCCCCXLVI.

Aqua corpus fluidum est odoris expers

Figure C10: Title page and first page of the book *Physicae Experimentalis Elementa* by p. Eliseo a Conceptione (Eliseo della Concezione, 1725-1809, an Italian scholar†) (Eliseo a Conceptione, 1790). The book contains hydrostatics, hydrodynamics, hydraulics and hydrology.

* https://fr.wikipedia.org/wiki/Antoine_Grimoald_Monnet.

† https://www.treccani.it/enciclopedia/eliseo-della-concezione_(Dizionario-Biografico)/.

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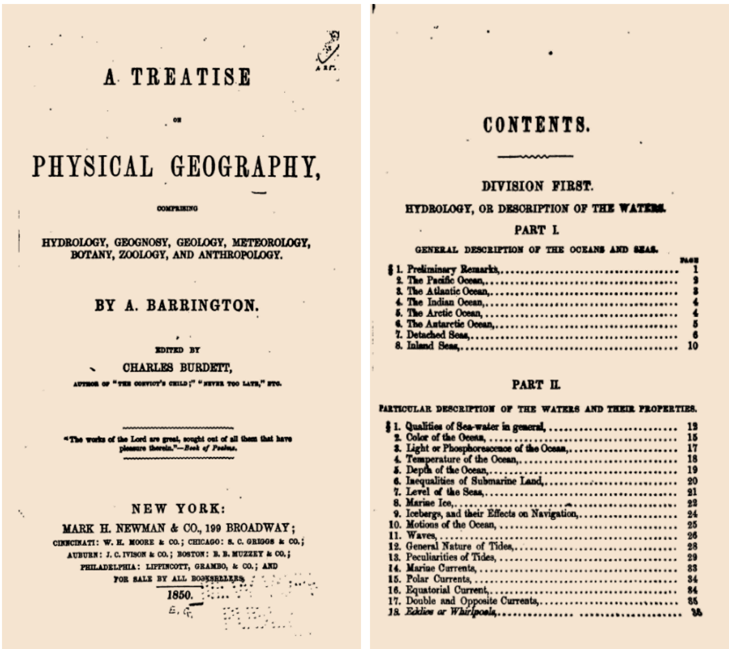


A TREATISE

ON

PHYSICAL GEOGRAPHY,

COMPRISING

HYDROLOGY, GEOGNOSY, GEOLOGY, METEOROLOGY, BOTANY, ZOOLOGY, AND ANTHROPOLOGY.

BY A. BARRINGTON.

EDITED BY

CHARLES BURDETT,

AUTHOR OF "THE CONVICT'S CHILD;" "NEVER TOO LATE," ETC.

"The works of the Lord are great, sought out of all them that have pleasure therein."—Book of Psalms.

NEW YORK:

MARK H. NEWMAN & CO., 199 BROADWAY;

CINCINNATI: W. H. MOORE & CO.; CHICAGO: S. C. GRIGGS & CO.;

AUBURN: J. C. IVISON & CO.; BOSTON: B. B. MUZZEY & CO.;

PHILADELPHIA: LIPPINCOTT, GRAMBO, & CO.; AND

FOR SALE BY ALL BOOKSELLERS.

1850.

CONTENTS.

DIVISION FIRST.

HYDROLOGY, OR DESCRIPTION OF THE WATERS.

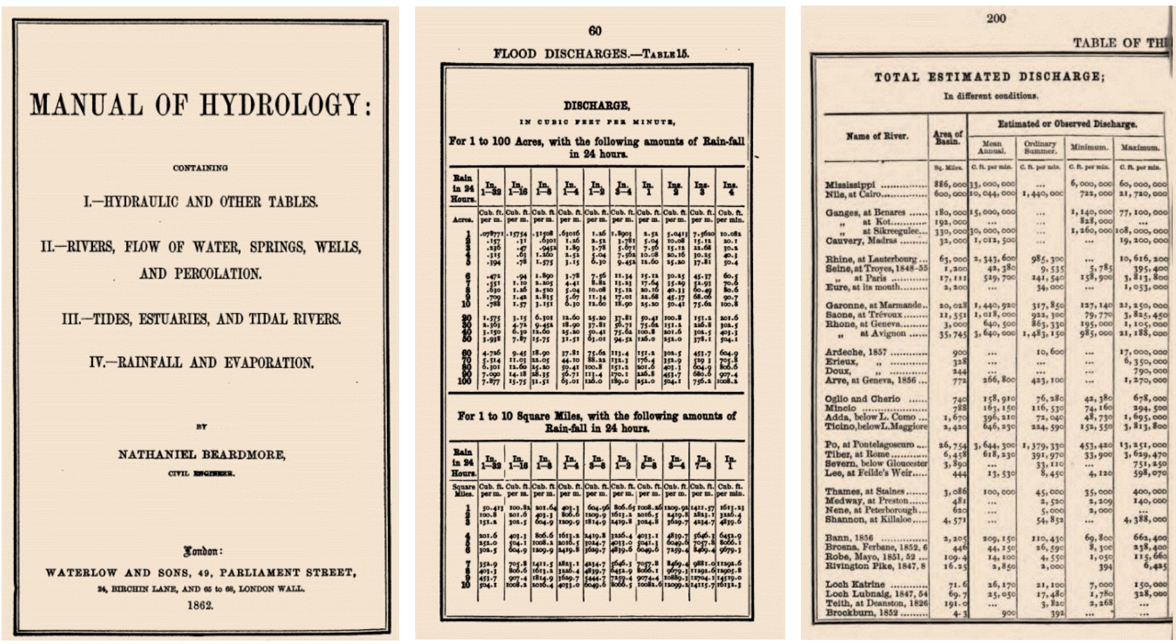
PART I.

GENERAL DESCRIPTION OF THE OCEANS AND SEAS.

PART II.

PARTICULAR DESCRIPTION OF THE WATERS AND THEIR PROPERTIES.

960 **Figure C11: Title page and first page of the Contents of the book *A Treatise on Physical Geography* by A. Barrington (1850), whose first chapter is devoted to hydrology, beginning with a geographic description of the oceans.**



MANUAL OF HYDROLOGY:

CONTAINING

I.—HYDRAULIC AND OTHER TABLES.

II.—RIVERS, FLOW OF WATER, SPRINGS, WELLS, AND PERCOLATION.

III.—TIDES, ESTUARIES, AND TIDAL RIVERS.

IV.—RAINFALL AND EVAPORATION.

BY

NATHANIEL BEARDMORE,

CIVIL ENGINEER.

London:

WATERLOW AND SONS, 49, PARLIAMENT STREET,

24, BIRCHIN LANE, AND 65 TO 66, LONDON WALL.

1862.

60

FLOOD DISCHARGES.—TABLE 15.

DISCHARGE,

IN CUBIC FEET PER MINUTE,

For 1 to 100 Acres, with the following amounts of Rain-fall in 24 hours.

For 1 to 10 Square Miles, with the following amounts of Rain-fall in 24 hours.

200

TABLE OF THE

TOTAL ESTIMATED DISCHARGE;

In different conditions.

Name of River. | Area of Basin. | Estimated or Observed Discharge: Mean Annual. | Ordinary Summer. | Minimum. | Maximum.

Mississippi; Nile, at Cairo; Ganges, at Benares; Cauvery, Madras; Rhine, at Lauterbourg; Seine, at Troyes; Eure, at its mouth; Garonne, at Marmande; Saone, at Trévoux; Rhone, at Geneva; Ardeche, 1857; Erieux; Doux; Arve, at Geneva, 1856; Oglio and Cherio; Mincio; Adda, below L. Como; Ticino, below L. Maggiore; Po, at Pontelagoscuro; Tiber, at Rome; Severn, below Gloucester; Lee, at Feilde's Weir; Thames, at Staines; Medway, at Preston; Nene, at Peterborough; Shannon, at Killaloe; Bann, 1856; Brosna, Ferbane, 1852; Robe, Mayo, 1851; Rivington Pike, 1847; Loch Katrine; Loch Lubnaig, 1847; Teith, at Deanston, 1826; Brockburn, 1852

Figure C12: Title page and two pages from the book *Manual of Hydrology* by Nathaniel Beardmore, (1816-1872, a British civil engineer[*]) (Beardmore, 1862). Page 60 provides a generic transformation of rainfall to river discharge and p. 200 gives discharge
965 **observations or estimates of big rivers.**

[*] https://en.wikipedia.org/wiki/Nathaniel_Beardmore.

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ON THE PROCEEDINGS OF THE

INTERNATIONAL CONGRESS OF HYDROLOGY AND CLIMATOLOGY AT BIARRITZ,

OCTOBER 1886.

BY G. J. SYMONS, F.R.S., F.R.MET.SOC., SECRETARY.

[Read December 15th, 1886.]

After several addresses had been delivered the Bureau was constituted as follows, and the meeting closed :—

President.	Dr. Durand-Fardel.
Secretary.	Dr. Garrigou.
Vice-Presidents.	M. Antoine d'Abbadie. Dr. Martineau. M. O'Shea.
Vice-Presidents (Foreign).	M. Chiminelli, of Florence. M. Kisch, of Prague. M. Soutschinsky, of St. Petersburg. M. Symons, of London. M. Taboada, of Madrid.

At 8 p.m. there was a reception at the Palais-Biarritz (formerly the Villa Eugénie), in order to facilitate personal intercourse between the members.

On October 2nd the sectional work began, three sections sitting at once. The sittings began at 8.30 a.m. and lasted till about noon; resuming at 2 p.m. and closing about 4 p.m. The list of papers as printed did not by any means include all that were read; but even as it stood the programme was sufficiently formidable, the number of memoirs for each section being respectively—

I. *Scientific Hydrology.*—Water analysis, micro-organisms, collection of mineral waters, geological influences, bathing apparatus, 34.

II. *Medical Hydrology.*—Physiological and medical questions, 40.

III. *Climatology, scientific and medical*, 35.

Figure C13: Part of the paper *On the proceedings of the international congress of hydrology and climatology at Biarritz* (Symons, 1887).

Acknowledgments. We thank the organizers of the EGU 2018 session HS1.8, History of Hydrology (and Editors of the special issue) Okke Batelaan, Keith Beven, Laurent Pfister and Roberto Ranzi for their invitation which motivated this research.

Funding. We received no funding for this research but conducted it for scientific curiosity.

Conflicts of Interest: We declare no conflict of interest

Data availability. The classical texts of the Greek antiquity are contained in several archives, among which we highlight: (a) original ancient Greek texts with translations in modern Greek in http://www.greek-language.gr/digitalResources/ancient_greek/library/index.html; (b) original ancient Greek texts without translation in https://el.wikisource.org/wiki/; (c) ancient Greek and Latin texts with translations in English in http://www.perseus.tufts.edu/hopper/collection?collection=Perseus:collection:Greco-Roman (also linked in https://topostext.org/all-texts.php). Here, unless otherwise specified the source (c) has been used. The most comprehensive Ancient Greek Lexicon, known as Liddell – Scott – Jones (LSJ) is in the public domain in https://lsj.gr/. Old books are made available in the public domain by the Internet Archive, https://archive.org/details/texts, which contains 28 million books with entries going back to beginning of typography. Unless otherwise specified in the list of References, this was the source of the old books perused here. The iconographies used in the paper have been taken from engravings by Visconti (1817), which are available on public domain at https://archive.org/details/gri_33125010850713/ and https://arachne.dainst.org/entity/1884649. The accompanying three-volume publication Visconti (1824-1826) provides information on the origin of the depiction and explanations why these are likely original, taken from sculptures and coins. An older publication with some depictions is the book by Thevet (1584), but these depictions are not necessary original. In a later publication by Wallis (1894) most depictions seem to be redrawings of those in Visconti (1817). All these are in public domain and are currently reproduced in common platforms such as Wikipedia. The depictions in Raphael's School of Athens (https://en.wikipedia.org/wiki/The_School_of_Athens) are also commonly used but they not necessarily correspond to the original faces as Raphael used several models, including himself

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