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From mythology to science: the development of scientific hydrological concepts in the Greek antiquity



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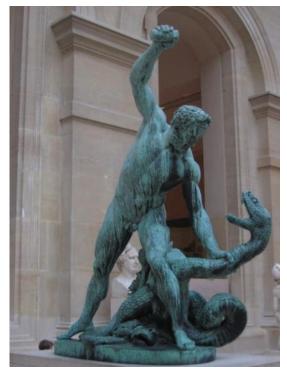
Presentation available online: http://itia.ntua.gr/1801/

Ancient Greek mythology has been inspiring — even in modern times



Athenian red-figure stamnos 6th BC, British Museum.

The myth of Hercules fighting Acheloos, a deity personifying the most important river of Greece, symbolizes the fight of men against the destructive power of rivers.



Hercules fighting Acheloos transformed into a snake in the Louvre; François Joseph Bosio, (1824) (wikipedia).

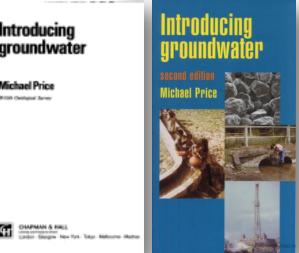


Hercules fighting Acheloos; wall painting in the Athens City Hall by Fotis Kontoglou, writer, painter and hagiographer of the 20th century.

Modern mythology about past knowledge can also be inspiring

An inspiring extract from Price (1989):

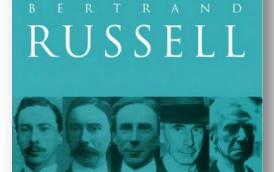
"Today, our version of the **hydrological cycle** seems so logical and obvious that **it is difficult to believe that it did not gain widespread acceptance until the 17**th **century**. This was caused in large part by the **tendency of the philosophers of Ancient**



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 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."

Tracing back the succession of inspirations regarding Aristotle and women's teeth

"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" (Russell, 1952).

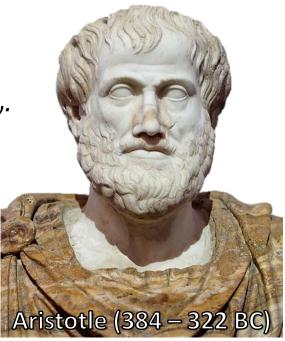


THE IMPACT OF Science on Society

The original text by Aristotle

« Έχουσι δὲ πλείους οἱ ἄρρενες τῶν θηλειῶν όδόντας καὶ ἐν ἀνθρώποις καὶ ἐπὶ προβάτων καὶ αίγῶν καὶ ὑῶν· ἐπὶ δὲ τῶν ἄλλων ού τεθεώρηταί πω. [...] Φύονται δ' οἱ τελευταῖοι τοῖς ἀνθρώποις γόμφιοι, οὓς καλοῦσι κραντῆρας, περὶ τὰ εἴκοσιν ἕτη καὶ ἀνδράσι καὶ γυναιξίν. Ἅδη δέ τισι γυναιξὶ καὶ ὀγδοήκοντα ἑτῶν οὕσαις ἕφυσαν γόμφιοι ἐν τοῖς ἑσχάτοις [...]» (Των περί τα ζώα ιστοριών, Β).

"Males have more teeth than females in the case of men, sheep, goats, and swine; in the case of other animals observations



Unless otherwise noted, images depicting persons are from wikipedia.

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 of eighty years old where at the very close of life the wisdom-teeth have come up [...]" (History of Animals/Book II).

Some epistemological questions

- What do we mean by *observation*? Does information from school teachers, professors, books, TV, internet, climate projections for the year 3000 AD, etc., classify as *observation*?
- Is the number of teeth:
 - □ A constant for all individuals? (and irrespective of sex?)
 - Varying among individuals
 - Varying among individuals and also varying in time for each individual? (like in a stochastic process?)
- How did Russell know whether or not Aristotle examined his two wives' teeth?
- And did Russell's himself examine his own four wives' teeth?

What do modern statistical data say?

Table 46. Mean number of permanent teeth among dentate adults 20–64 years of age, by selected characteristics: United States, National Health and Nutrition Examination Survey, 1988–1994 and 1999–2004

	1988–1994		1999–2004	
Characteristic	Mean	Standard error	Mean	Standard error
Age				
20–34 years	26.44	0.07	26.90	0.05
35–49 years	24.14	0.16	25.05	0.11
50–64 years	20.39	0.22	22.30	0.22
Sex				
Лаle	24.10	0.11	25.06	0.13
emale	23.86	0.14	24.90	0.08
Race and ethnicity				
White, non-Hispanic	24.28	0.14	25.23	0.13
Black, non-Hispanic	22.03	0.14	23.68	0.13
Mexican American	24.81	0.09	25.32	0.08

Official USA statistical data; Dye et al. (2007)

A first and second reason for the difference

(1) The number of teeth decreases with increasing age and women's life expectancy is longer by several years than men's.

(2) Women's teeth seem to be more fragile than men's.

		DMF teeth	
	Sex and age	1960-62	1971-74
	Both sexes, 35-74 years	19.1	20.2
	Men		
Official USA statistical data:	35-74 years	18.5	19.5
Harvey (1981). Average number of decayed (D), missing (M), and filled	35-44 years	17.2	18.4
	45-54 years	18.0 20.4 22.3	19.2 20.7 21.8
(F) permanent teeth per	Women		
person, among adults 35-74	35-74 years	19.7	20.8
years of age, by sex and age: United States, 1960-62 and 1971-74.	35-44 years	18.8 19.6 21.9 22.8	20.0 20.5 21.5 22.5

A third and fourth reason for the difference

(3) "Sex Disparities. Table 2 represents the distribution and prevalence of third molar **agenesis** [congenital lack of one or more teeth] according to sex. Frequency of third molar agenesis was higher in females than males" (Sujon et al., 2016).



Third Molar Agenesis and Dental Anomalies

Table 2. The frequency of agenesis according to sex.									
Sex	n	Agenesis	Prevalence	X ²	<i>p</i> value				
Male	2136	785	36.8%	5.02	.025*				
Female	2092	839	40.1%						

* p value < 0.05 is significant

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(4)"*Hyperdontia* [increase in number of teeth in relation to the normal dental formula] *is more common in males, and the degree* of sex difference is greater in blacks" and "The number of extra *teeth per person ranged from 1 to 8*" (Harris and Clark, 2008).

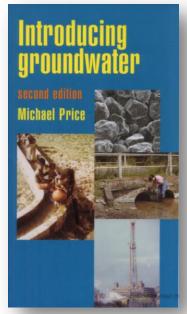
Modern mythology about past knowledge (contd.)

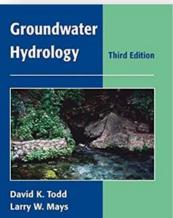
Another inspiring extract from Price (1989):

"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 & Mays (2005)

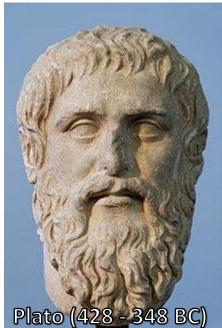
"As late as the seventeenth century it was generally assumed that water emerging from springs could not be derived from rainfall, for it was believed that the quantity was inadequate and the earth too impervious to permit penetration of rainwater far below the surface. Thus, early Greek philosophers 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."





Finding the culprit: Plato

[Σωκράτης:] «[...] τοῦτο [το χάσμα] ὅπερ Ὅμηρος εἶπε, λέγων αὐτό "τῆλε μάλ', ἦχι 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' οἴας 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» (Φαίδων, 14.112α).



[Socrates:] "[...] One of the chasms of the earth is greater than the rest, and is bored right through the whole earth; this [chasm] 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" (Phaedo, 14.112a).

Is this extract from Phaedo what the Greek philosophers said about the hydrological cycle?

While the view expressed in Phaedo was adopted by many thinkers and scientists from Seneca (*ca.* 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 the dialogue Phaedo is the **immortality of the soul.** It is not representative of Greek philosophers' views on Nature, not even Plato's. In other dialogs Plato offers more consistent theories:

«τὸ κατ' **ένιαυτὸν ὕδωρ** ἐκαρποῦτ' ἐκ Διός, ούχ ὡς νῦν ἀπολλῦσα ῥέον ἀπὸ ψιλῆς τῆς γῆς εἰς θάλατταν, ἀλλὰ πολλὴν ἕχουσα καὶ εἰς αὐτὴν καταδεχομένη, τῆ κεραμίδι στεγούσῃ γῆ διαταμιευομένη, τὸ καταποθὲν ἐκ τῶν ὑψηλῶν ὕδωρ εἰς τὰ κοῖλα ἀφιεῖσα κατὰ πάντας τοὺς τόπους παρείχετο ἄφθονα κρηνῶν καὶ ποταμῶν νάματα» (Πλάτων, Κριτίας, 111δ).

"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).

Hydrology at the birth of science

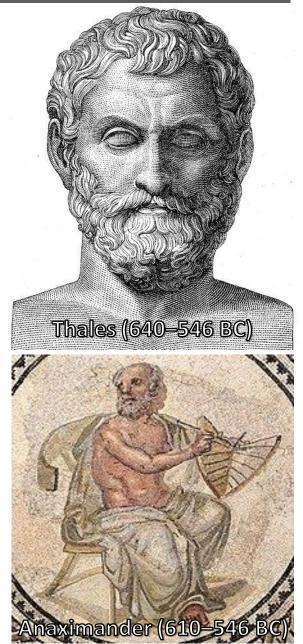
Thales of Miletus, one of the Seven Sages of Greece, is regarded as the **father of natural philosophy and science**. In addition to his scientific achievements on geometry and astronomy, he dealt with the *paradox of the Nile* (see below) thus highlighting the **importance of hydrology in the birth of science**.

His successor Anaximander is the first to dear write a book « $\Pi \epsilon \rho i \Phi i \sigma \epsilon \omega \varsigma$ » ("On Nature"; lost), rejecting mythological and religious views. He understood the relationship or rainfall and evaporation:

«ὑετούς δὲ [γίγνεσθαι] έκ τῆς άτμίδος τῆς ἐκ γῆς ὑφ' ἥλιον άναδιδομένης» (Ιππόλυτος, Φιλοσοφούμενα ἤ Κατὰ Πασῶν Αὶρέσεων Ἔλεγχος, Ι, 5).

"Rain is created from the vapours which rise from earth by the sun" (Hippolytus of Rome, Refutation of All Heresies, I, 5;

https://books.google.gr/books?id=9HCOCwAAQBAJ).



Atmospheric phenomena and Anaximenes

Anaximenes was another philosopher from Miletus, who proclaimed Air as the "Arche" (origin) of the universe; naturally, thus, he devised logical explanations for the formation of wind, clouds, rain and hail:

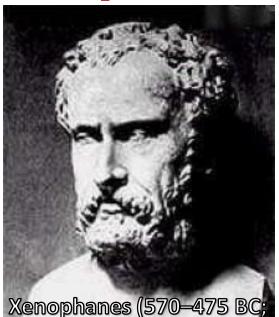
«[...] άνέμους δὲ γεννᾶσθαι, ὅταν ἐκ <μέρους> πεπυκνωμένος ὁ ἀὴρ καὶ ἀρθεὶς φέρηται συνελθόντα δὲ καὶ ἐπὶ πλεῖον παχυνθέντα νέφη γεννᾶσθαι καὶ οὕτως είς ὕδωρ μεταβάλλειν. χάλαζαν δὲ γίνεσθαι, ὅταν ἀπὸ τῶν νεφῶν τὸ ὕδωρ καταφερόμενον παγῇ χιόνα δέ, ὅταν αὐτὰ ταῦτα ἐνυγρότερα ὄντα πῆξιν λάβῃ. ἀστραπὴν δ΄ ὅταν τὰ νέφη διιστῆται βίαι πνευμάτων [...]. ἶριν δὲ γεννᾶσθαι τῶν ἡλιακῶν αὐγῶν είς ἀέρα συνεστῶτα πιπτουσῶν»

"[...] 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 and Xenophanes

Xenophanes, another Ionian philosopher, supported his theory by the discovery of fossilized marine organisms at three island locations. Hippolitus 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:

«πηγὴ δ' ἐστὶ θάλασσ' ὕδατος, πηγὴ δ' ἀνέμοιο[·] οὕτε γὰρ ἐν νέφεσιν <γίνοιτό κε ῖς ἀνέμοιο ἐκπνείοντος> ἕσωθεν ἄνευ πόντου μεγάλοιο οὕτε ῥοαὶ ποταμῶν οὕτ' αί<θέρος> ὄμβριον ὕδωρ, άλλὰ μέγας πόντος γενέτωρ νεφέων ἀνέμων τε καὶ ποταμῶν» (Ξενοφάνης ἐν τῷ Περὶ φύσεως[·] Απόσπασμα Β 30[·] http://www.poesialatina.it/_ns/Greek/testi/Xenophanes/Fragmenta.html)



Xenophanes (570–475 BC; Internet Encyclopedia of Philosophy)

"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 rivers" (Fragment B 30, recovered from Geneva Scholia on Homer; https://en.wikisource.org/wiki/Fragments_of_Xenophanes)

Anaxagoras bringing science to Athens

Anaxagoras of Clazomenae lived and taught in Athens for ~30 years and transplanted the ideas of Ionic 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

Anaxagoras (510 – c. 428 BC) – from a coin of Klazomenae (~ 190-30 BC) seated on globe, (http://www.ancientcoinage.org/poets-philosophersastronomers-etc.html)

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:

«**τοὺς δὲ ποταμοὺς καὶ ἀπὸ τῶν ὅμβρων λαμβάνειν τὴν ὑπόστασιν** καὶ ἐξ ὑδάτων τῶν ἐν τῆ γῆ[·] εἶναι γὰρ αυτὴν κοίλην καὶ ἒχειν ὓδωρ ἐν τοῖς κοιλώμασιν» (Ιππόλυτος, Φιλοσοφούμενα ή Κατὰ Πασῶν Αὶρέσεων Ἔλεγχος, Ι, 7).

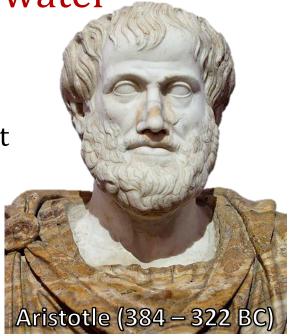
"*The rivers receive their contents from the rains* and from the waters in the earth; for the earth is hollow and has water in its hollow portions" (Hippolytus, Refutation of All Heresies, I, 7).

Aristotle and the phase change of water

Aristotle was student of Plato, but his theories were influenced by Ionic philosophers. His theories expand to all aspects of knowledge; in particular his treatise *Meteorologica* offers a great contribution to the explanation of hydrometeorogical phenomena:

«ἕτι δ' ἡ ὑπὸ τοῦ ἡλίου ἀναγωγὴ τοῦ ὑγροῦ ὁμοία τοῖς θερμαινομένοις ἐστὶν ὕδασιν ὑπὸ πυρός» (Μετεωρολογικά, Β2)

"the sun causes the moisture to rise; this is similar to what happens when water is heated by fire" (Meteorologica, II.2, 355a 15)



«συνίσταται πάλιν ἡ άτμὶς ψυχομένη διά τε τὴν ἀπόλειψιν τοῦ θερμοῦ καὶ τὸν τόπον, καὶ γίγνεται ὕδωρ έξ ἀέρος[.] γενόμενον δὲ πάλιν φέρεται πρὸς τὴν γῆν. ἕστι δ' ἡ μὲν έξ ὕδατος ἀναθυμίασις ἀτμίς, ἡ δ' έξ ἀέρος είς ὕδωρ νέφος»

"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).

Aristotle and mass conservation

Aristotle recognized the principle of mass conservation within the hydrological cycle:

«ὥστε [τὴν θάλατταν] ούδέποτε ξηρανεῖται[.] πάλιν γὰρ έκεῖνο φθήσεται καταβὰν είς τὴν αύτὴν τὸ προανελθόν».

"Thus, [the sea] will never dry up; for [the water] that has gone up beforehand will return to it" (ibid., II.3, 356b 26).

«κἂν μὴ κατ' ένιαυτὸν άποδιδῷ καὶ καθ' ἑκάστην ὁμοίως χώραν, ἀλλ' ἕν γέ τισιν τεταγμένοις χρόνοις ἀποδίδωσι πᾶν τὸ ληφθέν».

"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).

Aristotle and Change

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

«άλλὰ μὴν εἴπερ καὶ οἱ ποταμοὶ γίγνονται καὶ φθείρονται καὶ μὴ άεὶ οἱ αὐτοὶ τόποι τῆς γῆς ἕνυδροι, καὶ τὴν θάλατταν ἀνάγκη μεταβάλλειν ὁμοίως. τῆς δὲ θαλάττης τὰ μὲν ἀπολειπούσης τὰ δ' ἐπιούσης ἀεὶ φανερὸν ὅτι τῆς πάσης γῆς ούκ ἀεὶ τὰ αὐτὰ τὰ μέν ἐστιν θάλαττα τὰ δ' ἤπειρος, ἀλλὰ μεταβάλλει τῷ χρόνῳ πάντα».

"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).

Aristotle and experimentation

Aristotle also understood by experiment that salt contained in water is not evaporated:

«ὅτι δὲ γίγνεται ἀτμίζουσα πότιμος καὶ ούκ είς θάλατταν συγκρίνεται τὸ ἀτμίζον, ὅταν συνιστῆται πάλιν, πεπειραμένοι λέγωμεν»

"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 philosopher, 495 – 570 AD), that:

"Sailors, when they labour under a scarcity of fresh water at sea, boil the seawater, 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" (Morewood 1838; see also quotation by Alexander of Aphrodisias, peripatetic philosopher, fl. 200 AD, in Forbes, 1970).

Aristotle and the solution of the Nile paradox

Aristotle's treatise «Περὶ τῆς τοῦ Νείλου ἀναβάσεως» [De inundacione Nili] is lost. However, a work by an anonymous author contained in Patriarch Photios' (~810/820 –893) Bibliotheca, which was published in 1653, gives important information about Aristotle's decisive contribution in solving the Nile paradox.

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ΙΒΛΙΟΘΗΚΗ B PHOTI BIBLIOTHECA

ΦΩΤΙΟΥ

LIBRORV M QVOS LEGIT ET CENSVIT THOTIVS PATRIARCHA CONSTANTINOPOLITANYS.

Grace edidit DAVID HOESCHELIVS Augustanus, & notis illustrauit.

Latine veroreddidit & Scholin anxit ANDREAS SCHOTTVS ANTVERPIANVS.

Opus infigne, è quo Theologi, Medici, Philofophi, Hiflorici, Oratores, & Philologi vberrimum fructum & iucandifimum capere pollunt.

Hacoltima ed tione recognitum , lecifque aliquit fun integritati reflitutum;



PHOTII BIBLIOTHECA.

מאת אין דעי לייצמי דא מיש שישידעיד. סטע בעייני ש דטי אולטי מי שי ל עלע לי אייף אל אולווי, דבי ל עוצמי איסר WOEREIT.

On oi imina Trioun x + א אמוכיי דע מצומוס-Are vi sibrh יווייי לאאו דעדם שופוני לו מוזות דרומודעי לאאו ש- עודוע-פידופיניגי לאס ד או האעלפוימי דטאנטי איג דעידו-פין שויטולט ליאלינו דע טיצפא , דע כי " לעוב מאולטוב" * al. vois. אעטעלעם ין למעדה וכוצמוףש)י כוצמוףאעלעם איזיא-A linent Marts) או כא דשידמי זייסי) oi "פיוחחמן מיבוטו, כמ ד in what. and uginar, T and & Auoras T apannar uper 10 delata in altiffimos Athiopia montes deci-ווסגעשינים לופיד) איז דטעב בדמודואב דס אונים Tis uronuberris. inti In Tau Ta incregulua, שבאנה אדו שוק ט אחצרים לוב טףבה ז מושוחהומהי אי morra & a gega ziron Buan amoral () virtus nai בא ד ניודף דאדשי ל אוֹגאט אאוועעטפו דע שיפע, אדי ד אוא שאעלכוים ל בחפיי דידשי גישיי אין דאיד Aesorians imes (marsion to. autic 20 אחל דוב CUOROC IPTO VETTVOHOEV, a Erworas The fay & A-Nigar Spor & Maxedora eig cheirug Tug Tortug , Ri Ster & ainar of F Neins authorac a bana Ger, 20 thiopix maxime ficcis, vbi nunquam hiems eft D's phone, a's To to courn arege Anua Est. a't 3n כל קמוופים, לח כל ניודע מוצנו. איז דם של של לביי,

להו כא דווג באפטדמידטוב דט אווה ל מושרוחהומה כא כוב שדו אוועשי שדו שלשף לבוי צעעלמויל ד שובשה דאבי. Sous vieres give St.

AFAGAPXIAOT AOTOI.

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geniis vetò prodelle. Eteliz venti ardentifimo zftatistempore flant, hac de caufa : Sol jam fublimis, & à locis meridionalibus ad septentrionem conuerfus; foluit liumida ad Borcani, que foluta acremi deinde ventos gignunt : è quorum numeto & Etefiz funt, & spiritu scilicet, qui ex humidis folutis ad septentrionem oritur. Ad oppositas verò plagas metidionales feruntur, coque dunt. Cum autem condensari, & frequentes fuerint, pluuias creant, è quibus aftiuo tempore Nilus auctus exundar, ex auftralibus lo- Nilw. Yille cis, & aridis profluens, idemque Ariftoteles Theophilation inucltigando comperit. Ipfe enim ingenij with Mawilij præftantia hoc deprehendit, cum æquum pu- Imp Uo. 7. extallet Alexadrum Macedonem ad en loco mit- trime, Herade rete, vt oculis causam incrementi Nili flu- inivur. minis cognosceret. Propierea afferit hoc non amplius dubium elle. Clarè enim patet è pluuiis augeri. Er land mirum, quod in locis Æneque pluuia, tempore cltatis dentifimi oriantur imbres.

> EX AGATHARCHIDE excetptz historiz,

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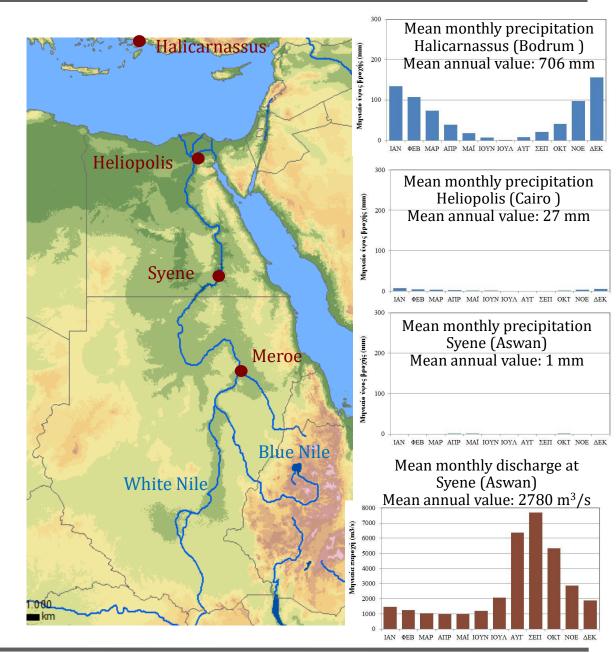
Elafa vade.

[INTERPRETE LAVRENTIO

What was the Nile paradox?

The first great problem related to a natural behaviour and put in scientific terms was the cause of the Nile floods. It was debated for almost three centuries (Burstein, 1976).

What puzzled Greek thinkers was the different hydrological regime compared to other Mediterranean rivers: the Nile floods occur in summer rather than during winter.



Problem statement by Herodotus

«τοῦ ποταμοῦ δὲ φύσιος πέρι οὔτε τι τῶν ἱρέων οὔτε ἄλλου οὐδενὸς παραλαβεῖν έδυνάσθην. πρόθυμος δὲ ἕα 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 ὁπίσω ἀπέρχεται ἀπολείπων τὸ ῥέεθρον, ὥστε βραχὺς τὸν χειμῶνα ằπαντα διατελέει ἐὼν μέχρι οῦ αὖτις τροπέων τῶν θερινέων. τούτων ὦν πέρι οὐδενὸς οὐδὲν οἶός τε ἐγενόμην παραλαβεῖν παρὰ τῶν Αἰγυπτίων, ἱστορέων αὐτοὺς **ἤντινα δύναμιν ἕχει ὁ Νεῖλος τὰ ἕμπαλιν πεφυκέναι τῶν ἄλλων ποταμῶν**: ταῦτά τε δὴ τὰ λελεγμένα βουλόμενος είδέναι ἱστόρεον καὶ ὅ τι αὔρας ἀποπνεούσας μοῦνος ποταμῶν πάντων οὐ παρέχεται» (Ηροδότου Ιστορίαι, 2, 19).

"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 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).

First explanation described by Herodotus

«άλλὰ **Ἑλλήνων μὲν τινὲς ἐπίσημοι βουλόμενοι γενέσθαι σοφίην** ἕλεξαν περὶ τοῦ ὕδατος τούτου τριφασίας ὁδούς: τῶν τὰς μὲν δύο τῶν ὁδῶν οὐδ΄ ἀξιῶ μνησθῆναι εί μὴ ὄσον σημῆναι βουλόμενος μοῦνον».

"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).

«τῶν ἡ ἑτέρη μὲν λέγει τοὺς ἐτησίας ἀνέμους εἶναι αίτίους πληθύειν τὸν ποταμόν, κωλύοντας ἐς θάλασσαν ἐκρέειν τὸν Νεῖλον. πολλάκις δὲ ἐτησίαι μὲν οὕκων ἕπνευσαν, ὁ δὲ Νεῖλος τώυτὸ ἐργάζεται. πρὸς δέ, εί ἐτησίαι αἴτιοι ἦσαν, χρῆν καὶ τοὺς ἄλλους ποταμούς, ὅσοι τοῖσι ἐτησίῃσι ἀντίοι ῥέουσι, ὁμοίως πάσχειν καὶ κατὰ τὰ αύτὰ τῷ Νείλῳ, καὶ μᾶλλον ἕτι τοσούτῳ ὅσῳ ἐλάσσονες ἐόντες ἀσθενέστερα τὰ ῥεύματα παρέχονται. είσὶ δὲ πολλοὶ μὲν ἐν τῇ Συρίῃ ποταμοὶ πολλοὶ δὲ ἐν τῇ Λιβύῃ, οἳ οὐδὲν τοιοῦτο πάσχουσι οἶόν τι καὶ ὁ Νεῖλος.»

"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 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).

Second explanation described by Herodotus

«ἡ δ' ἑτέρη ἀνεπιστημονεστέρη μὲν ἐστὶ τῆς λελεγμένης, λόγω δὲ είπεῖν θωμασιωτέρη: ἡ λέγει ἀπὸ τοῦ Ώκεανοῦ ῥέοντα αὐτὸν ταῦτα μηχανᾶσθαι, τὸν δὲ Ώκεανὸν γῆν περὶ πᾶσαν ῥέειν. [...] ὁ δὲ περὶ τοῦ Ώκεανοῦ λέξας ἐς ἀφανὲς τὸν μῦθον ἀνενείκας οὐκ ἔχει ἕλεγχον: οὐ γὰρ τινὰ ἕγωγε οἶδα ποταμὸν Ώκεανὸν ἐόντα, Ὅμηρον δὲ ἡ τινὰ τῶν πρότερον γενομένων ποιητέων δοκέω τὸ οὕνομα εὑρόντα ἐς ποίησιν ἐσενείκασθαι.»

"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).

Third explanation described by Herodotus

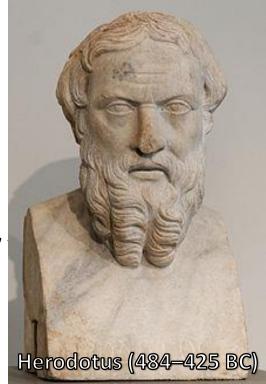
«ἡ δὲ τρίτη τῶν ὁδῶν πολλὸν ἐπιεικεστάτη ἑοῦσα μάλιστα ἔψευσται: λέγει γὰρ δὴ οὐδ' αὕτη οὐδέν, φαμένη τὸν Νεῖλον ῥέειν ἀπὸ τηκομένης χιόνος: ಏς ῥέει μὲν ἐκ Λιβύης διὰ μέσων Αίθιόπων, ἐκδιδοῖ δὲ ἐς Αἴγυπτον. κῶς ὧν δῆτα ῥέοι ἂν ἀπὸ χιόνος, ἀπὸ τῶν θερμοτάτων ῥέων ἐς τὰ ψυχρότερα τὰ πολλά ἐστι; ἀνδρί γε λογίζεσθαι τοιούτων πέρι οἴω τε ἑόντι, ὡς οὐδὲ οίκὸς 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 ἀνάγκῃ ἐστὶ ὗσαι ἐν πέντε ἡμέρῃσι, ὥστε, εἰ ἑχιόνιζε, ὕετο ἀν ταῦτα τὰ χωρία: τρίτα δὲ οἱ ἄνθρωποι ὑπὸ τοῦ καύματος μέλανες ἑόντες. ἰκτῖνοι δὲ καὶ χελιδόνες δι' ἕτεος ἑόντες οὐκ ἀπολείπουσι, γέρανοι δὲ φεύγουσαι τὸν χειμῶνα τὸν ἐν τῇ Σκυθικῇ χώρῃ γινόμενον φοιτῶσι ἐς χειμασίην ἐς τοὺς τόπους ἡ ἀνάγκῃ ἐλέγχει.»

"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).

Herodotus' own explanation

«εί δὲ δεĩ 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 ἕρχεται τῆς Λιβύης τὰ ἄνω. ὡς μέν νυν ἐν ἐλαχίστῷ δηλῶσαι, πᾶν εἴρηται: τῆς γὰρ ἂν ἀγχοτάτω τε ἦ χώρης ο**ὗτος ὁ θεὸς καὶ κατὰ ἤντινα, ταύτην οίκὸς διψῆν** ὑδάτων μάλιστα καὶ τὰ ἐγχώρια ῥεύματα μαραίνεσθαι τῶν ποταμῶν.»

"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" (ibid. 2, 24).

Who supported the three explanations discussed by Herodotus?

Aetius, the 1st- or 2nd-century AD doxographer and Eclectic philosopher, reveals the supporters of the three explanations.

Interestingly, **the first explanation is attributed to Thales**, which highlights the strong link of hydrology with science (or natural philosophy), at the dawn of the latter:

«Θαλῆς τοὺς ἐτησίας ἀνέμους οϊεται πνέοντας τῷ Αίγύπτῷ ἀντιπροσώπους ἐπαίρειν τοῦ Νείλου τὸν ὄγκον διὰ τὸ τάς ἐκροὰς αὐτοῦ τῷ παροιδήσει τοῦ ἀντιπαρήκοντος πελάγους ἀνακόπτεσθαι» (Αέτιος IV, 1, 1).

"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 was supported by Euthymenes of Massalia (Εύθυμένης ὸ Μασσαλιώτης; fl. early 6thcentury 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).

The solution of the paradox by Aristotle

«Ότι οἱ ἐτήσιαι πνέουσι κατὰ τὸν καιρὸν τοῦ ἀκμαιοτάτου θέρους δι΄ αίτίαν 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 Αίθιοπίας, καὶ πολλὰ καὶ ἀθρόα γινόμενα ἀπεργάζεται ὑετούς' καὶ ἐκ τῶν ὑετῶν τούτων ὁ Νεῖλος πλημμυρεῖ τοῦ θέρους, ἀπὸ τῶν μεσημβρινῶν καὶ ξηρῶν τόπων ἀρκτικώτερος γινόμενος λύει τὰ ὑγρὰ τὰ ἐν ταῖς ἄρκτοις' λυόμενα δὲ ταῦτα ἐκφερόμενα προσπίπτει τοῖς ὑψηλοτάτοις ὅρεσι τῆς Αίθιοπίας, 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' **αύτὸς γὰρ ἀπὸ τῆς φύσεως ἔργῷ κατενόησεν, ἀξιώσας πέμψαι Ἀλέξανδρον τὸν Μακεδόνα είς ἐκείνους τοὺς τόπους καὶ ὄψει τὴν αἰτίαν τῆς τοῦ Νείλου αύξήσεως παραλαβεῖν. Διό φησιν ὡς τοῦτο οὐκέτι πρόβλημά ἑστιν' ὥφθη γὰρ φανερῶς ὅτι ἐξ ὑετῶν αὕξει. Καὶ <λύεται> τὸ παράδοξον, <ὅτι> ἐν τοῖς ξηροτάτοις τόποις τῆς Αίθιοπίας, έν οἶς οὕτε χειμὼν οὕτε ὕδωρ ἐστί, ξυμβαίνει τοῦ θέρους πλείστους ὑετοὺς γίνεσθαι» (Ανώνυμος, Βίος Πυθαγόρου, στο Φωτίου, Μυριόβιβλον, Anon, https://el.wikisource.org/wiki/Μαρτυρίαι_(Αριστοτέλης).**

"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's 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" (Anonymus, Life of *Pythagoras*, in Photios, Bibliotheca, http://remacle.org/bloodwolf/erudits/photius/pythagore.htm)

Verification of the story by other philosophers

«Έρατοσθένης δὲ οὐκέτι φησὶν <πρόβλημα εἶναι> οὐδὲ ζητεῖν χρῆναι περὶ τῆς αὐξήσεως τοῦ Νείλου, σαφῶς καὶ ἀφικομένων τινῶν είς τὰς τοῦ Νείλου πηγὰς καὶ τοὺς ὅμβρους τοὺς γιγνομένους ἑωρακότων, ὥστε κρατύνεσθαι τὴν Ἀριστοτέλους ἀπόδοσιν» (Πρόκλος ο Λύκιος, Σχόλια, Πλάτωνος Τίμαιος, 22 E—I 121, 8 Diehl).

"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, 8 Diehl)

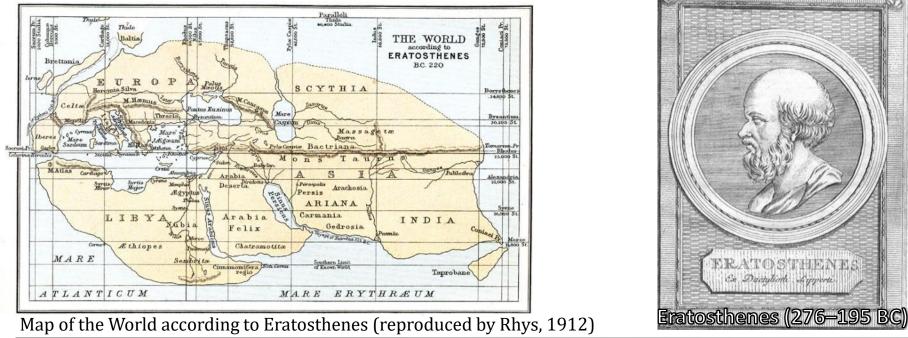
«τῆς γὰρ Αίθιοπίας ὑψηλοῖς παρὰ τὰ καθ' ἡμᾶς ὄρεσι διεζωσμένης ὑποδεχομένης τε τὰς νεφέλας πρὸς τῶν ἐτησίων ώθουμένας, ἐκδιδόναι τὸν Νεῖλον. ὡς καὶ <Καλλισθένης> ὁ Περιπατητικὸς ἐν τῶι τετάρτωι βιβλίωι τῶν Ἑλληνικῶν (124 F 12) <φησιν ἑαυτὸν συστρατεύσασθαι Ἀλεξάνδρωι τῶι Μακεδόνι, καὶ γενόμενον ἐπὶ τῆς Αίθιοπίας εὑρεῖν τὸν Νεῖλον ἐξ ἀπείρων ὄμβρων κατ' ἐκείνην γενομένων> καταφερόμενον» (Ἰωάννης Λαυρέντιος ὁ Λυδός, De mensibus, 4, 107).

"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).

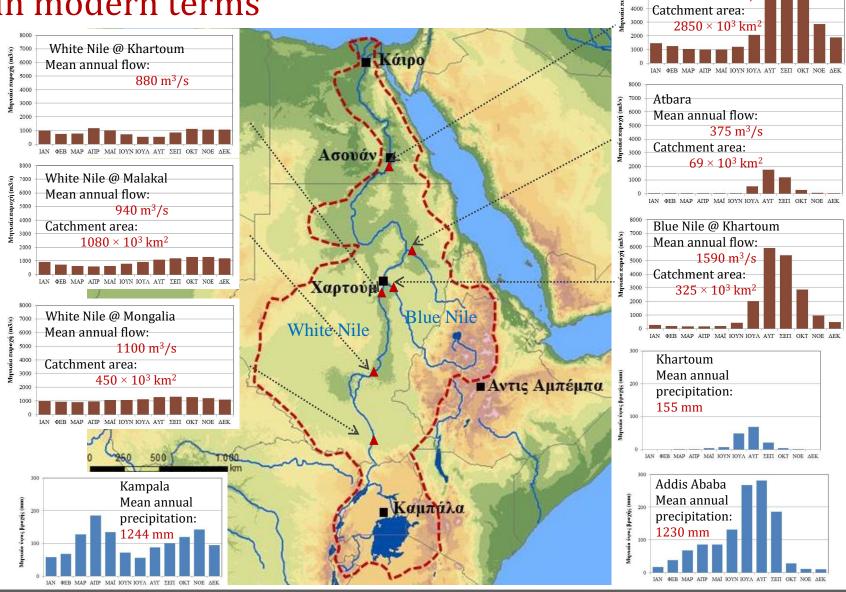
What about Eratosthenes?

Eratosthenes, head of the Library at Alexandria, among other achievements, calculated 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 exactly under 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 is often credited by several authors (regrettably including Koutsoyiannis, 2014) for solving the paradox of the Nile. However, in view of the information provided here (Proclus, see previous slide), 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).



The Nile (non)paradox in modern terms



Nile @Aswan

Mean annual flow:

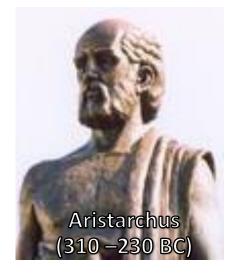
2780 m³/s

7000

6000

5000

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





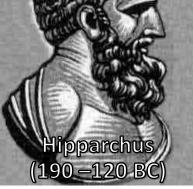
Archimedes (287 - 212 BC)

Heliocentric model for the solar system 1800 years before Copernicus

Calculations on the relative sizes of the Sun, Earth and Moon Archimedes' principle and hydrostatics

Archimedes' screw (still in use for pumping)

Infinitesimals and a first version of integral calculus



Introduction of the term $K\lambda(\mu\alpha)$ (pl. $K\lambda(\mu\alpha\tau\alpha)$ = Climate(s), meaning the inclination angle of the incoming sunbeams

Classification of Earth's climates

Hero of Alexandria (fl. ~150 BC* or ~50 AD) *see Woodcroft (1851)

Use of the term *Υδραυλικόν (hydraulic*) όργανον (for a musical instrument)

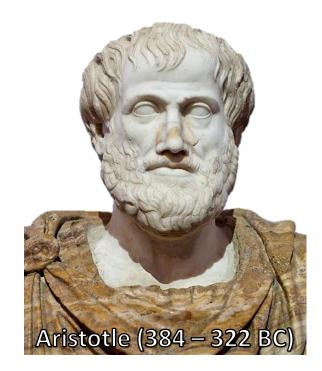
Notion of *discharge* and its measurement

Study of pressure; Steam machines; Pneumatics

Back to Aristotle: importance of seeking the truth

«φίλος μέν Σωκράτης, άλλά φιλτάτη ή άλήθεια» (Latin version: "Amicus Socrates, sed magis amica veritas") "Socrates is dear (friend), but truth is

dearest" (Ammonius, Life of Aristotle)



«δόξειε δ' ἂν ἴσως βέλτιον εἶναι καὶ δεῖν ἐπὶ σωτηρία γε τῆς ἀληθείας καὶ τὰ οίκεῖα ἀναιρεῖν, ἄλλως τε καὶ φιλοσόφους ὄντας: ἀμφοῖν γὰρ ὄντοιν φίλοιν ὄσιον προτιμᾶν τὴν ἀλήθειαν»

"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).

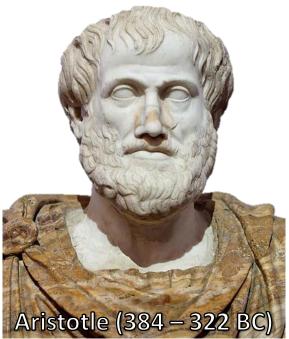
Other contributions by Aristotle: logic, precision, change

Λογική, συλλογισμός, επαγωγή Logic, deduction, induction (Aristotle, Organon)

«...τοσοῦτον τάκριβὲς ἐπιζητεῖν καθ' ἕκαστον γένος, έφ' ὄσον ἡ τοῦ πράγματος φύσις ἐπιδέχεται»

"... look for precision in each class of things just so far as the nature of the subject admits"

(Aristotle, Nicomachean Ethics, 1094b)

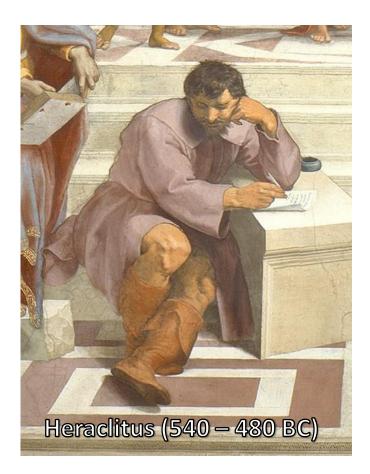


«Μεταβάλλει τῷ χρόνῳ πάντα» "All is changing in the course of time" (Aristotle; Meteorologica, I.14, 353a 16)

Hydrology is the science of change and randomness; Heraclitus described the nature of each in a few words

«Πάντα ῥεῖ» "Everything flows" (Heraclitus; quoted in Plato's Cratylus, 339-340)

«Αίών παῖς ἐστι παίζων πεσσεύων» "*Time is a child playing, throwing dice*" (Heraclitus; Fragment 52)



It takes courage to formulate scientific theories —now as well as then

«ὁ γὰρ πρῶτος σαφέστατόν τε πάντων καὶ θαρραλεώτατον περὶ σελήνης καταυγασμῶν καὶ σκιᾶς λόγον εἰς γραφὴν καταθέμενος Άναξαγόρας οὕτ' αὐτὸς ἦν παλαιὸς οὕτε ὁ λόγος ἕνδοξος, ἀλλ' ἀπόρρητος ἕτι καὶ δι' ὀλίγων καὶ μετ' εὐλαβείας τινὸς ἢ πίστεως βαδίζων. οὐ γὰρ ήνείχοντο τοὺς φυσικοὺς καὶ μετεωρολέσχας τότε καλουμένους, ὡς εἰς αἰτίας ἀλόγους καὶ δυνάμεις ἀπρονοήτους καὶ κατηναγκασμένα πάθη διατρίβοντας τὸ θεῖον, ἀλλὰ καὶ **Πρωταγόρας ἕφυγε, καὶ Ἀναξαγόραν** εἰρχθέντα μόλις περιεποιήσατο Περικλῆς, καὶ Σωκράτης, οὐδὲν αὐτῷ τῶν γε τοιούτων προσῆκον, ὅμως ἀπώλετο διὰ φιλοσοφίαν» (Πλουτάρχου Βίοι Παράλληλοι, Νικίας, 23).

"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 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; cf. I. Velikovsky, Anaxagoras, http://www.varchive.org/ce/orbit/anax.htm; note, 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).

Concluding remarks

- Scientific theories are mostly wrong. It is a matter of time for any theory to be replaced by a better one.
- Naturally, all theories developed in the dawn of science (2600 years ago) have been replaced. This does not make them non-scientific.
- It is a good practice to study the history of science, recognize the past contributions and give credit to those who made them. (Notifications: (a) consulting original texts is useful; (b) humour is different from arrogance).
- This study –of the history of hydrology in particular– 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, experimentation, measurement, and observation were all used by ancient philosophers, particularly by Aristotle.
- As evident from our 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.

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Appendix: The appearance of the term hydrology

- Several terms related to hydrology appear in ancient Greek literature. Specifically:
 - The conveyance of water or liquids is termed ὑδραγωγία (ἡ), and a person (or device) related to it ὑδραγωγός.
 - The modern term ὑδραυλικἡ (hydraulics) stems from ὑδραυλικὸν (hydraulic) ὄργανον, a musical instrument operated by hydraulics and invented by Ctesibius; it is also known as ὕδραυλις (ἡ), which is played by a musician called ὑδραύλης.
 - 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.
 - 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 or μετεωρολογικός (cf. Plato's Phaedro 270a and Aristotle's Meteorologica).
 - Determ *climate* stems from $\kappa\lambda i\mu\alpha$ (meaning the inclination angle of the incoming sunbeams; pl. $\kappa\lambda i\mu\alpha\tau\alpha$); a property pertaining to $\kappa\lambda i\mu\alpha$ is $\kappa\lambda i\mu\alpha\tau\kappa\delta\varsigma$.
- Hydrology is also a Greek word, i.e. ὑδρολογία, but it does not appear in the ancient Greek literature; a close match is ὑδρολόγιον (pl. ὑδρολόγια), which however is a water-clock; as a scientific term with the modern meaning, hydrologia appeared after the Renaissance in Latin, Italian and Spanish (hydrologie in French and German and hydrology in English).

First appearance of "hydrologia" in a book in print

Wenechai hegory Hanne My lyc infitte lorfe Commentarij ad Tit.Digest. DE ERBORVM SIGNIFICATIONE. Trum illustrium Iuris interpretum, LCIATI, BRECHÆI, FORNERIL Quibus ea qua ad hanc materiam spectant, accuratifime tractantur, atque explicantur. Acceffit Index rerum ac verborum locupletifimus. LVGDVNI Apud Franciscum Fabrum. 1589

BRECHÆVS.

VIVSQVE DIEI. (Diem D. Basilius Magnus in bexæmere, dixit illum elle actem quem Sol illuminet, cum eft in eo dimidio globo, qui fuper terram eft collocatus. Aristoteles autem scripfit elle Solis excurfum ab Oriente in Occafum. Varie autem diei etymon autores claffici difcutiunt. JQuidam enim dixerunt an re Ais diem dictum , quod Iupiter diei fit Dominus & rector. Alij verò quòd Dei opus fit,dici exiftimant. Nonnulli à dio tractum volunt, quod lumen fub calo effe dicimus. Vt fub dio elle, id eft fub tegmine cœli. Sed M. Varro diem ex Deo dictum allerit. Graci suipar appellant, quam nos, diem propterea quod (vt autor eft Plato) iueipoven, id eft, lumen è tenebris emicuit hominibus fummopere defiderantibus ac congratulantibus. ¶Qua de caufa prius veteres (ait ipfe Plato) inipar feripferunt. Pofteritas autem inipar ac tadem inipar, nonnulli verò quali muspar, id eft . manfuetam dici crediderunt. ¶ Dierum fanè rationem atque ordinem à feptem vagis errantibuíque stellis, quos Planetas appellamus, Gentes dixerunt : quod etiam ab Indis observatum Philoftra. in vitam Apollonij Tyanzi tradit, Iarcham feilicet feptem annulos Apollonio dediffe ftellarum feptem nominibus cognominatos : quorum fingulos diebus fingulis geftabat Apollonius.Quod & recitat & rider Eufebrus Pamphil.in libris magaration ivas fitudic. Hos iptum etiam Dion hilto.lib.7. & 30.& ex ipfo Dione Io. Xiphilinus in vitam Pompey tradit & profequitur, referens eam, que à Grecis dia rearapar appellatur, harmoniam, qua Mufices totius rationem ac firmamentum contineri antiqui crediderunt, ad eas stellas, quibus vniuersus cœli ornatus & compositio distinguitur, & ad eum ordinem quo earum fingulæ feruntur, fumpto deinde principio ab extremo orbe Saturni, proximis duobus relicitis quarti orbis principem enumerans, post duobus aliis prætermislis, ad septimum perveniendo, ficque has ipfas stellas earúmque principes deos in orbem recensendo, ad dies adaptat adzquarque : vnde cos dies cum mulica ratione quodammodo conuenire allerit. Hoc autem inuentum Egyptiorum effe creditur. J Dies fiquidem diuerfis appellationibus, à rerum effectis cognominarunt veteres. Nam quoldam nominabant intercilos, alios, flatos, profettos, feitos, quos Plutarchus impelles dicit : quemadmodum à Suida al apis mazers availes an ad actiones minime idonei & consenientes, Præliares, Communicarios, pandiculares, nundinarum, intercalares, luftricos, & quos Medici sessiuse à seslusie appellant, id eft, decretorios & indicatorios: & inftos à decemuiris, qui numero triginta dabantur iudicatis confessi ac debiti conquirenda pecunia caula, quam disfoluerent:eratque veluti quoddam iuftitium, id eft iuris inter eos cellatio quædam: quibus diebus nihil cum his iure agi pollet, vt teftatur Gellius lib.20. magnum quoque diem appellamus qui finem longis laboribus imponit. Quod Alc.latius dixit lib.8. Parerg.c.8. & lib.4. c.11. coldem etiam in naturales & artificiales diuidebant: de quo paulo post dicemus.

M AXIMA PARS HORARVM. Scribit Plinius, & poft illum Cenfotinus, horarum víum noménque diuturnis temporibus latuiffe apud Romanos: & id quidem ccc. & eo amplius annis:nec víquam xij. Tab.leges, de horis feciffe mentionem. At primim quidem Ægyptios. pôft deinde Gręcos horologia compoluifle tradunt: quz etiam ab antiquis Solaria dieta funt v rushesia & horaria atque horographia. Vocauerunt etiam hydrologia, & Clepfydras, ob id quòd ex aquz commenfutatione aliquando componerentur. Plinius quoque horofcopa vafa appellauit. Fabulantur poëte horas fummi louis. & Themidis effe filias. Quod Orpheus in hymno docet his verbis, si par 307 alisse Siud se rad lluxis marfes evocuin 71. dies 71. geiper media de commence. See Homerus foripfit horas cœli foribus prefidere, quem imitatus Ouid. lib. Faitornm, cum ipfis horis dixit Ianum cœleftibus Ianuis preeffe. Prefidee, inquit, Foribus cœli enn michus beris.

Here hydrologia seems to be plural of hydrologion, i.e. Clepsydra – hourglass)

Hydrologie ou Discours de l'Eaue

HYDROLOGIE OV B-6/5. DISCOVRS DE. L'EAV.E.

Auquel est amplemét declarée la vertu & puissance des eaues Medicinales, principalement de celles de Villeconte prés Billon, & de Sainct Meaulps prés Rion en Auuergne.

> Par Iehan Landrey Par Medecin du ROT

Monfieur de Heere Doyen 2005 S. Aignan d'Orleans.

A ORLEANS. ParFabian Hotot Imprimeur ordinaire du Roy.

163 63 63 Kg HYDROLOGIE ou discours de l'eaue. Ce que les anciens ont dit de l'eaue. CHAPITRE I. Ovs 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

Hydrologie chofe, Crambe recocta mors eft. C'est pourquoy nous parlons en general de l'eau, produisas le tesmoignage de Pindare is up destor l'eau trefbone, c'eft à cause des proprietez & vertus qui en sortet. Cecy à possble incité les Sages de la Grece de nommer la matiere de toutes choses, fange. C'est la do-Arine d'Eugubinus, l. Cofmop. carla terre mellee auec l'eau, felon Moyfe produit prefque toutes choses. Ie ne veux entrer au tres-haut mystere caché sous le messange qu'a fait le Sauueur du monde, de la terre auec fa faliue, lors qu'il a voulu guarir l'aueugle né, ce

https://archive.org/details/BIUSante_30326

In most of the early uses of *hydrology*, its content is related to medicine and physiology.

Appearance in Apiaria Universae Philosophiae Mathematicae (an encyclopedic collection of mathematical curiosities)

APIARIA VNIVERSÆ PHILOSOPHIÆ MATHEMATICÆ, IN QVIBVS PARADOXA. Et noua pleraque Machinamenta ad vsus eximios traducta. & facillimis demonstrationibus confirmata. ILLVSTRISS. ET EXCELLENTISS. D. MATTHIAE GALASSO SAC. ROM. IMPERII COMITI, &c. A Coll, Tridentino Soc. Jefu dicata. OPVS Non modo Philosophis Mathematicis, fed & Physicis, Anatomicis, Militaribus viris, Machinaria, Mufica, Poefica, Agraria, Architectura, Mercatura profefforibus, &c. vulifsimum; Curiosissimis inuentis refertum, sigur arum areis formis cusarum numerosá, Speciosa varietate ornatum, S in duos Tomos distributum; Vna cum gemino copiosissimo Indice altero propositionum, altero rerum. TOMVS SECVNDVS. ACCESSIT AD FINEM HVIVS SECUNDI TOMI EVCLIDES APPLICATVS, Et conditus ex Apiarijs, indicatis vfibus eximijs præcipuarum propofitionum in prioribus fex libris Euclideorum Elementorum. MARIO BETTINO BONONIENSI E SOC. IESV, olim in publico Parmensi Gymnasio Philosophia Mathematica, & Philosophia Moralis Lectore.

https://books.google.com/books?id=Z_VIAAAAcAAJ

BONONIÆ

Typis Io. Baptifiz Ferronij com facolrate Superiorum. Anno falutis M.DC. XXXXII.

T. II.

1642

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A book about Hydrologia Peripatetica

I V.

FORTVNII LICETI,

GENVENSIS,

In almo Palladio Patauino quondam Medici Theorici fupremae fedis ex L. Com.,

DISPVTATIO

DE

MARIS TRANQVILLITATE;

Arte per oleum, & anchoram comparanda,

EX EIVS

HYDROLOGIA PERIPATETICA

desumta.

ΨΤΙΝΙ,

Fortunius LICETUS (or Fortunio Liceti, 1577–1657, an Italian physician and philosopher).

FORTVNII LICETI

quoque refutet : nam licet amici fint ambo, fanctum tamen est veritatem ipsis in honore anteponere. Tot itaque rationibus ego Philosophus incitatus, tantorumque virorum, quales fuerunt Xenophon & Plato permotus exemplis, idem ego discipulus admirandi Præceptoris Aristotelis famam, & veram doctrinam a Plutarcho & Vicomercato potissimum scriptis acrioribus accusatam, defendere nunc aggredior; Vtinam felici successi arduam enim mihi quæstionem hanc suturam esse perspicio, quia Classici funt, virique doctissimi quibuscum nunc disputandum est: Sed quia circa res arduas versari, virtutis ess, laudisque plenum; nobilem hanc prouinciam capeffere libuit, oblatam nobis vitro Spartam exornare tentantes. Rem igitur aggrediamur diuinis auspiciis. Spiritus Sancti gratia illuminet fensus & corda nostra.

De oleo & Anchora proiectis, fluctus maris tumentes tranquillantibus. Disputatio Prima.

[4] opufc.

P Lutarchus ille, Philosophorum eruditissimus, agens de [4] primo frigido, condemnare videtur Aristotelem, quasi male philosophatum de olei operatione in promouenda maris tranquillitate; scribit enim sua lingua PLVTARCHVS. Των δι άλλων ύχρων διαφανές, μάλισα το έλαιοι ές ιπλείσω χρώμθυον αίερι. τωτα δίττεμείερον ή καφότης,

37 δι ην επιπολαζει πάση, υ ανό τθ άερος άναγερόμδμον. ποιεί δε 38 δι ην επιπολαζει πάση, υ ανό τθ άερος άναγερόμδμον. ποιεί δε 39 είω γαλήρην έν τη Θαλαττη, τοῖς χυ μασην επιρ ρ΄αινομενον 38 30 δια την λειότητα τθ άνεμων άπολισθαινόνταν, ώς Αρισστέλης 30 έλεγεν. άλλα παντί μεν υ γρω το χύμα διαχείται πληττόμενον. 30 ideft : Ad hæc de reliquis humoribus maxime pellucidum 30 eft oleum, quia plurimum in fe habet aeris; cui rei certo id 61

Hydrologia in tres partes

HYDROLOGIA Breyis quidem, attamen fundamentalis. in tres partes divisa: Das ift: Ein furtes doch grundliches Belches NEPTUNUS mit leiner betrühten Schwallb. 2Baffer. Bottin der HydorRille. in benfenn eines Medici und Philofophi, gehalten. In dem erften Theil wird geredet / Erftlich pon Dem 2Baffer felbften/ und wie es Das erfte 2Befen aller Dinge ; Bweptens / Dag auf bem Deer alle Brunnen unb Sluffe ibren Urfprung nehmen; Drittens/ wodurch bas Deere Daffer fich verfuffe; Biertens/ wovon der Gauer.Brunnen Urfprung/ und in fpecie, mas bes Schwallbacher Sauer. Brunnens Balt fepe. Sin dem andern Theil aber wird gehandelt von aller Bader Urfprung; Zwentens von ihren Kräfften; Und brittens/ marum einige beiß/ andere marm/ andere Lau/ andere aber gang falt entipringen. In dem dritten Theil aber wird in fpecie von Dem Schlangen-Bad und deffen Rrafften gehandelt/ und zwar fo / daß dermaffen verboffentlich Darburch niemand mird touffiret merben ; Auffgeset von EBERHARDO MELCHIORE, Phil. & Med. Arch. olim Haffiaco, poft Naffovico, Confilii Vangionum Secretioris. In Verlegung des AUTORIS. franchfurt am Mayn/ Ben Johann David Junnern zu finden. 1694 MDC XCIV. -

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Address auf dem Borlirtheil/ fo ietziger Zeit Beit- Klüglinge/ über viefe meine Hydrologiam gefprochen / nemlich/daß beffer thun würde/wan folche umreiffe Beburt/dem Staub der Bergeffenheit zu verzehren überließ/ als contra torrentem, fo vieler fürtrefflicher Medicorum, gantz neue Opiniones an des Tages Liecht zu bringen/ fo habe leicht ex ungue leonem chlieffen tömen/nehmlich/daß diefes Berecklein/auffer allen Zweiffel einige

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British Hydrology in Latin

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CHAP. II.

Hydrology.

I. Quandoquidem admiranda nonnulla & infolita de Lacu Vettero O- An Account of laus Magnus, aliiq; referant Scriptores; operæ pretium duxi in the Lake Vetdicti Lacus indolem, & Scriptorum Fidem penitius inquirere : Inque iis ter, in Swequæ propriis Obfervationibus experiri non liceret, eorum indagare Te- den; by Dr. ftimonia, qui in Vicinia habitantes, & antiqua commendati fide, veris n. 298. p. Narrationibus meis fatisfacere possent Quæftionibus. 1938.

Lacus Vetteri a Septentrione Meridiem usque vergens de Alkersundio Nericiæ ad Jonekopiam Smolandiæ 14 Suecica metitur Milliaria, quorum quodlibet 5 vel 6 Milliaria Anglica, & decem unum fere conficiunt Gradum : Latitudine vero 3, nonnunquam vix 2 superat Milliaria. Lacus ob elevatiores Montium colles, qui hunc in ipfo littore fæpius ambiunt, nonnunquam paulo remotiores prominent, adstantibus femper apparet ad latera depressus. Profunditate gaudet infigni, adeo vero inæquali, ut aliquibus in locis ad 80, in confiniis vero Oftrogothiæ diverfis, paucifq; Westrogothiæ ad trecentas ufq; orgyas nullum reperias fundum. Civis quidam Vadstenensis Benedictus Amberni, qui ut ad littora Civitatis Grennensis Vetteri exploraret profunditatem, aliquot Orgyarum funes, fecuri loco ponderis appenfa, demiferat, fundo autem nuíquam reperto, cum funes iterum collegerat, fecuri deperdita, cranium equi chordæ exacté alligatum obtinuit. Similis item abyfus ad præcipitia montis Ohmensis, quæ parietis Occidentalis nomine infig-.niuntur,

Spanish Hydrologia & German Hydrologie

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 fu buen ufo. SU AUTHOR EL DOCTOR VICENTE VINAYMA, Medico en la mismaCiudad. Conlicencia de los Superiores, en Valena cia, por Joseph Garcia, en la Plaza de Calatrava, año 1738. NADCE



Hydrology in Geography

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> > 1762

INTRODUCTION to GEOGRAPHY.

civilized. It may be observed in general, that among all people and nations of the Earth, there are some men of a reasonable, and others of an unreasonable disposition or turn of mind; as there are also in every country graceful and aukward, candid and disingenuous, virtuous and vitious, mild and austrere, polite and ill-bred, noble and ignoble persons.

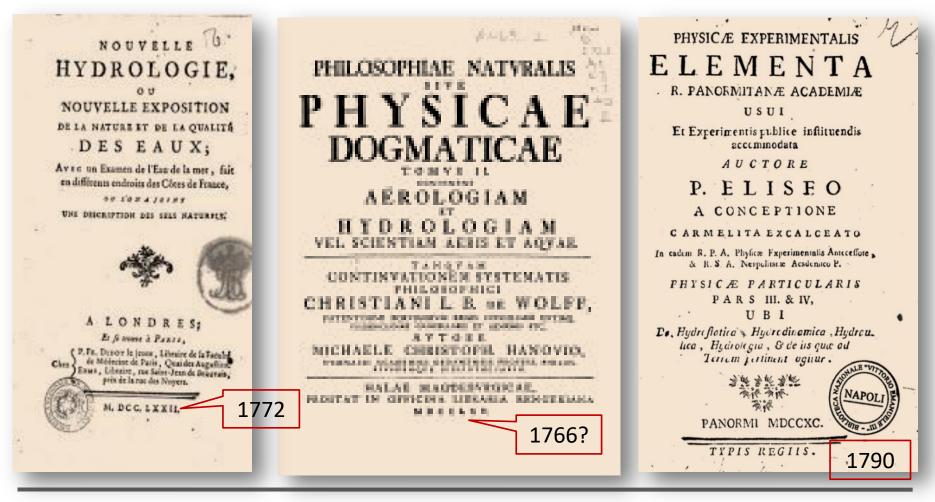
Of the WATER.

§. 71. It remains, laftly, that we treat of the Water on the furface of the Earth ; and this branch of Geography is by fome termed Hydrography. Dr. Wallerius was the first who made accurate enquiries into the AQUEOUS KINGDOM, or Hydrology, and claffed it among the other Kingdoms of Nature. We may divide the Water into two principal Genera, namely, into COMMON and MINERAL Water. COMMON Water, or that which is called fweet or fresh Water, has no particular tafte, fmell, or colour, and falls either in dew, rain, or fnow from the air, whither it was conveyed from the Earth in vapours and exhalations; or elfe it is found on the Earth in its proper channels and cavities. Running Water is the lighteft among the latter fort, and is also called living Water; of which, Spring-Water, which fprings naturally out of the Earth, and continually keeps running, is a species. Springs, in all appearance, owe their origin to mountains, on which the vapours exhaled from the Earth fall in dew, rain, and fnow; which, penetrating into the mountains, are collected together, and break out in fprings below. Those springs which arise in fandy eminences produce the pureft Water. Most fprings are perennial, or flow constantly ; others begin to run in fpring, on the melting of the fnow or ice, and ceafe again towards autumn, and are called temporal Springs. Others again flow only for certain hours of the day, and fome of these only in fummer, which must be owing to certain fubterraneous cavities in the mountains from which they are fupplied. Many fprings emit Water as cold as ice, and yet bubble up and make a noife, like a pot boiling over the fire; which feems to be owing to the rarefied fubterraneous air. Some fprings rife and fall as if they were regulated by the ebbing and flowing of the fea. In many places Wells are also dug in which water is collected for use.

§. 72. Running Springs produce Brooks; and a conflux of feveral Brooks form a Rivulet, or Stream; and many Streams or Rivulets uniting together make one great current, called a River. Rivers have a fleep or fhelving bottom; and the greater the flope or declivity, the more rapid and ftronger is their current. If the bed or channel of a River be very wide, its rapidity is not fo great as when it is narrow. The water of Streams and Rivers often falls down from a precipice; and as the Rivers which form them happen to be fmaller or greater, fo are the cafcades fmaller or greater in proportion. Several Rivers alfo, at certain feafons of the year, being increafed Vol. I.

49

Nouvelle Hydrologie – Physicae Dogmaticae – Physicae Experimentalis Elementa (cum hydrostatica, hydrodinamica, hydraulica, hydrologia)



D. Koutsoyiannis & N. Mamassis, From mythology to science 49

Hydrology within Physical Geography Scientific Hydrology vs. Medical Hydrology

A TREATISE

PHYSICAL GEOGRAPHY,

COMPRESS

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

BY A. BARRINGTON.

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By G. J. SYMONS, F.R.S., F.R.MET.Soc., SECRETARY.

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

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WATER PIPES UNDER PRESSURE.-Tables 8a and 8b.

This will be seen upon reference to Mr. Leslie's paper "On the flow of water through pipes," &c, before referred to, and the discussion which ensued thereupon. For very small pipes or flat rates of inclination, or waere a closer approximation to accuracy may be desired, somewhat better results may be obtained by using Du Buât's formula, viz. :---

 $\frac{307 (\sqrt{r}-0.1)}{\sqrt{\frac{l}{h}-L} (\sqrt{\frac{l}{h}+1.6})} = 0.3 (\sqrt{r}-0.1) = \text{Velocity in inches per second.}$

r = dia ="Mean radius" or Hydraulic mean depth in inches.

L = Hyperbolic Log. of the term to which it is prefixed. Hyperbolic Log. = Common Log. \times 2.30258. When reduced

TABLE OF HEIGHTS OF MAXIMUM FLOODS OF THE PO DURING THE NINETEENTH CENTURY,

As registered at various points on the river above summer low water, which at Piacenza is 132.3 feet above the sea level; at Cremona, 104.2 feet; at Isola Pescaroli, 89.2 feet; at Casalmaggiore, 74.8 feet.

Name of Station.	Dist, from the Sea,	13th	12th	15th	16th	13th	20th	8th	6th	1841 31st Oct.	20th	20th	1st	1000
Piacenza Cremona Isola Pescaroli	76.9 66.5 53.9	13.0 19.6 19.6 19.6 10.6 10.7 15.9 15.9 15.4 15.4 15.4 15.4 15.4 15.4 15.4 15.4	···· 25.7 27.0 20.1 29.1 27.0 27.4 10.0 ····	19.8 19.1 27.0 27.9 30.1 28.6 26.8 25.8 24.2	16.1 17.7 18.6 25.8 27.8 28.4 26.6 25.8 25.8 24.2	17.1 178.6 20.9 18.1 19.7 18.1 26.9 17.7 18.1 26.0 24.6	10.470 18.70 19.1 25.5 27.0 27.0 27.0 27.0 20.3 0 24.0	17.8 19.1 1 20.8 19.1 1 20.8 29.1 2 29.1 29.1 2 29.1 2 29.	23.0 24.4 18.7 18.5 25.5 26.9 28.4 27.1 26.3 25.0 28.4 27.1 26.3 25.0	18.4 18.9 21.2 26.1 25.8 27.5 29.7 27.6	25.6 26.2 18.3 20.0 21.2 25.6 20.7 27.5 29.9 28.1 26.6 	26.9 27.3 18.8 19.4 21.8 26.1 27.1 28.1 28.1 28.1 28.5 26.8 	10, 2 19, 2 21, 1 10, 2 21, 1 16, 8 28, 6 30, 7 28, 2 28, 2 29, 2 29, 2 20, 20, 20, 20, 20, 20, 20, 20, 20, 20,	18.7 28.0 10.8 21.6 21.5 19.3 31.7 29.7