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No. 301 | DECEMBER 3, 2024

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Demetris Koutsoyiannis, PhD, and Theano Iliopoulou, PhD

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CENTER FOR DATA ANALYSIS

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Understanding Climate: Gifts from the Nile

Demetris Koutsoyiannis, PhD, and Theano Iliopoulou, PhD

The Nile has given not only material gifts to Egypt and the world, but also intellectual gifts to science, especially to geoscience. The Nile still has much to teach science—especially about climatology, as it reflects climatic behaviors over vast areas in tropical and subtropical zones. These climatic behaviors have been documented across time with some of its extraordinarily long records surviving to present day. The records provide insights to the perpetual change of climate and support quantification of change in a stochastic framework.

Egypt to which the Greeks sail is land deposited for the Egyptians, the river's gift.[1]

—Herodotus

1. Introduction

With a length of about 6,700 kilometers (km), the Nile is the longest river on Earth. It discharges north into the Mediterranean Sea, and its western main branch, the White Nile, goes as far south as Lake Victoria in Uganda, the world's largest tropical lake and second-largest freshwater lake by surface area. Its eastern main branch, the Blue Nile, responsible for most of the Nile's discharge, has its source in the Ethiopian Highlands, beginning from Lake Tana, the largest lake in Ethiopia. The Nile's basin encompasses an enormous area, about 3.3 million km^2, more than 10 percent of the African continent, and is spread across 11 East African countries. (See Map 1, left.)

The Nile's water flows some 20 days to arrive in Egypt from Lake Tana along the Blue Nile, and 30 to 45 days or more from Lake Victoria along the White Nile. The economies of the Nile basin countries are heavily dependent on the use of water for agriculture, which accounts for more than half of the gross domestic product and employs more than 80 percent of the workforce.[2] The Nile supplies water for domestic, industrial, and agricultural use, hydropower generation, flood protection, and environmental and ecological management. Major existing water works include the Owen Falls Dam in Uganda, the Roseires, Sennar, and Merowe Dams in Sudan, the High Aswan Dam in Egypt, irrigation canals in Sudan and Egypt, and other smaller storage projects, barrages, and hydraulic works. As part of an ongoing basin-wide economic development initiative, numerous other projects are in planning or in construction. Among these, the Grand Ethiopian Renaissance Dam has been under construction since 2011 and is now near completion. When completed, it will be the largest hydroelectric power plant in Africa, with an installed power of 5.15 gigawatts (GW), part of which has already been installed and operated.

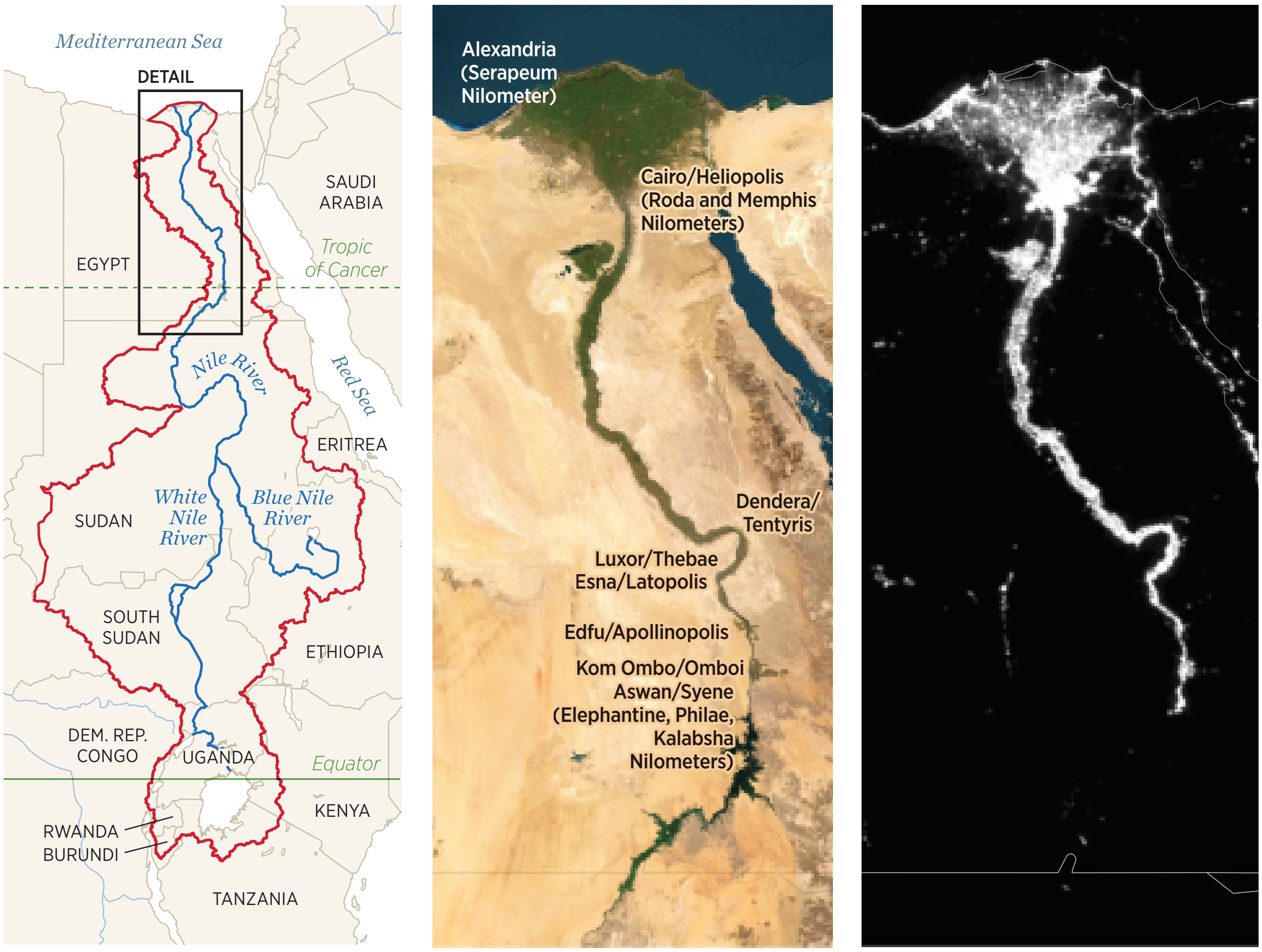
Almost all water flowing in the Nile is generated on 20 percent of the basin, while the remainder of the basin is in arid or semi-arid regions. Egypt and most of Sudan are completely dependent on the Nile for their water uses for they lie on the arid part of the basin. Map 1 (middle) shows the part of the basin belonging to Egypt. This image illustrates the importance of water (blue) to the landscape and the environment and ecology (green). As rainfall in Egypt is very low to non-existent (the mean annual precipitation at Cairo is 27 millimeters (mm), and 1 mm at Aswan),[3] the landscape's natural color is desert beige, except for a zone extending 5 km to 10 km to each bank of the Nile. This is green during the day and becomes bright white during the night (Map 1, right), thanks to the lights of human civilization, which it hosts.

The historian Herodotus (author of *The Histories*, considered the first to have treated historical subjects using a method of systematic historiographic investigation) called Egypt the Nile's gift[4] (see motto in the beginning of this *Special Report*), as the river brings not only the water that Egypt needs, but also the soil that made it fertile. Historically, that gift extended to much wider areas than Egypt. Since ancient times, Egypt has exported agricultural products, particularly grain, to many countries. In the Hellenistic period, under the rule of the Greeks (the Ptolemies), agriculture was organized and productivity increased significantly, tripling the amount of arable land[5] in Egypt and increasing trade. During the Roman period, Egypt became known as "Rome's breadbasket" as the Roman Empire largely depended on grain imports from the Nile valley.

Today, Egypt exports around 350 different agricultural products, such as potatoes, cotton, and fresh fruit, to countries in almost all continents. Egypt's agricultural exports amounted to more than 5 million tons per

MAP 1

Depictions of the Nile



(Left) The Nile basin divide (outlined in red), the countries shaping it, and its two main branches.
(Middle) Part of the basin and the contrast between water availability (blue-green) and shortage (desert beige). The locations of some of the ancient nilometers are marked, with the modern Arab and the old Greek names of the sites.
(Right) Same image as in the middle panel but taken at night, showing the nightlights and the contrast of the light by human civilization and natural darkness.

SOURCES: Authors' research. Nile basin is from World Bank, "Major River Basins of the World," last updated June 25, 2019, https://datacatalog.worldbank.org/search/dataset/0041426/Major-River-Basins-of-the-World (accessed August 23, 2024). Daytime satellite image is from Google Earth. Nighttime satellite image is from National Oceanic and Atmospheric Administration, National Centers for Environmental Information, "Version 4 DMSP-OLS Nighttime Lights Time Series," https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html (accessed August 23, 2024).

year in 2021,[6] with an increasing trend,[7] yet it is reliant on imports, particularly of wheat.[8]

But the subject of this *Special Report* is not the material gifts of the Nile to Egypt and the world at large. It is the gifts that the Nile has given to the development of science, especially to geoscience. The Nile has informed science from its cradle in roughly 600 BC to the modern day. Indeed, the Nile still has additional lessons to offer to science—especially to climatology, as the Nile reflects climatic behaviors over vast areas in tropical and subtropical zones. And these climatic behaviors have been documented across time with some of the records surviving to this day.

Mainstream science has invested in deterministic computer models of Earth's climate in attempts to unveil the unknown future with similarly unknown degrees of certainty. Past information, like that offered by the Nile, proposes an alternative path to contemplate the future and quantify its uncertainty. This path necessarily relies on stochastics and especially on Hurst-Kolmogorov (HK) dynamics (see "5. Reconciling with Uncertainty and Stochastics" below), named after the British hydrologist Harold Edwin Hurst, who devoted his lifetime to measuring and studying the Nile, and the Soviet mathematician Andrey Nikolayevich Kolmogorov, who invented the mathematics of this dynamics. However, only very few have understood the value of the alternative path and the usefulness of past information, especially that of the Nile.[9] This *Special Report* is intended to help to spread the word.

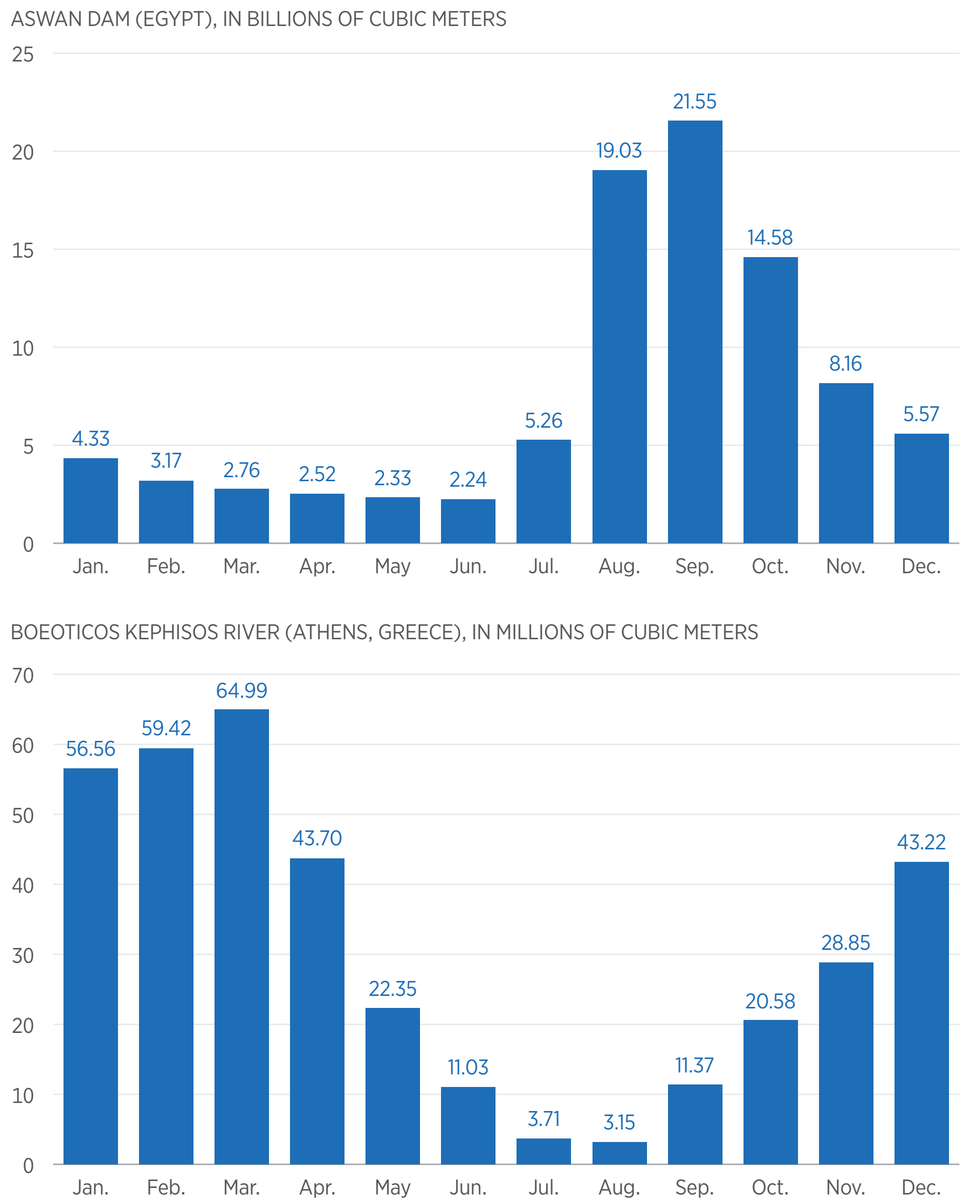
2. The Nile as a Trigger of Science

The hydroclimatic behavior of the Nile represents the first geophysical problem in history, posed and studied in the framework of science at its birth. Humanity owes the first scientific perspective of the Nile's behavior to Thales of Miletus (c. 624/623 BC–c. 548/545 BC), one of the Seven Sages of Greece. He is regarded as the father of Greek philosophy and of science, and his contributions include discoveries in mathematics, astronomy, physics, geophysics, geodesy, and hydraulic technology.

Thales tried to explain the hydrological "paradox" or "puzzle" of the Nile's floods, that is the fact that flooding occurs in summer when in all other rivers outflowing to the Mediterranean it occurs in winter. (See Chart 1.) Thales's explanation is incorrect, as he hypothesized that the winds in Egypt are responsible for this unique behavior of the Nile. However, more important than a correct explanation is the fact that the problem was studied, for the first time in history, as a scientific problem. Thales tried to explain a

CHART 1

Contrast in Seasonality Between the Nile and Other Mediterranean Rivers



Mean monthly flows at Aswan Dam in Egypt, after naturalization of the observational data (estimation of the natural flows based on data of regulated flows) (upper), compared with mean monthly flows of a typical Mediterranean river, the Boeoticos Kephisos River, located north of Athens, Greece (lower).

SOURCE: Authors' research.

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natural behavior on physical, rather than hyperphysical, grounds, which was the standard before him.

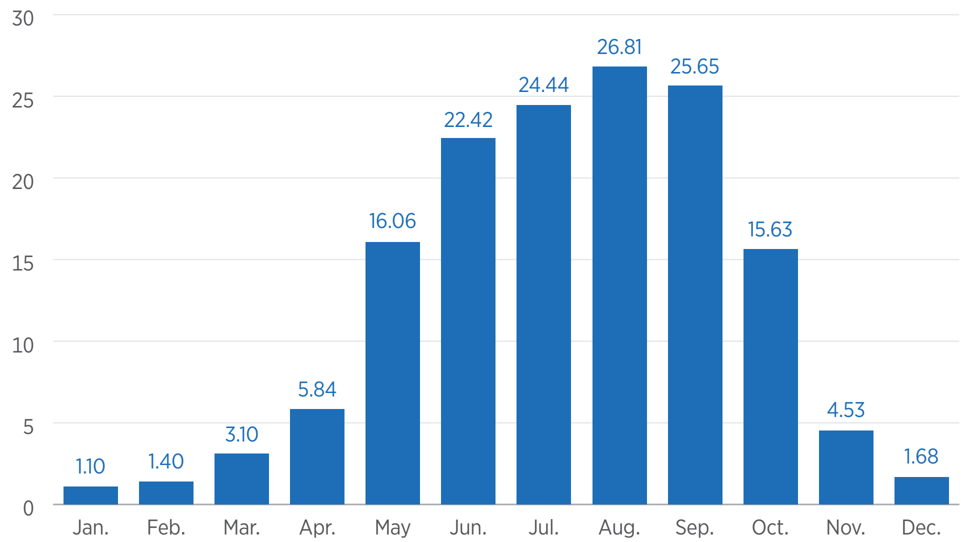
Herodotus conveys two other theories additional to Thales's and also proposes his own. All of them are erroneous and some are not free of mythical elements. The correct theory was proposed some three centuries after Thales by Aristotle (384–322 BC, founder of the Lyceum and the Peripatetic school of philosophy and author of about 400 books, many of which are lost). He wrote a book on the "puzzle," titled Περὶ τῆς τοῦ Νείλου ἀναβάσεως (On the Inundation of the Nile), which has not survived. However, there is a treatise in Latin titled *Liber Aristotelis de Inundacione Nili* (Aristotle's Book on the Inundation of the Nile), in short De Nilo, which is presumably a Latin translation of Aristotle's lost text. The treatise was left out of Corpus Aristotelicum (Works of Aristotle), but recent developments support the case that it is the translation of Aristotle's genuine text.[10] De Nilo starts with the question to be answered, continues with what today would be called a 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 there remains one explanation—Aristotle's own theory. In brief, the theory is that monsoons bring heavy rainfall to Ethiopia during the summer months, and this causes the Nile flooding. The theory is indeed correct, as seen in Chart 2, which shows the rainfall volume in part of the Blue Nile basin in Ethiopia.

The most amazing detail about Aristotle's tackling of the Nile puzzle is that he verified his theory by observation. He persuaded Alexander the Great, who was his student, to organize an expedition, in the frame of his military campaign in Egypt. This was the first scientific expedition in history. The information about it reached the modern world in an indirect way, as the original texts have been lost. The famous Library of Alexandria was burned several times, while the Imperial Library in Constantinople was destroyed in 1204 by the Crusaders, and the remaining libraries in the city were destroyed by the Ottomans in 1453. Few books were saved, one of which is Patriarch Photius's (c. 810/820–893) *Myriobiblon or Biblioteheca* (where *Myriobiblon* means "Ten Thousand Books"), composed of 279 reviews of books that he had read. This book, perhaps the first collection of book reviews in history, written in Greek, was printed in 1611 with a Latin translation. One of the books reviewed is a lost one titled *Life of Pythagoras* by an anonymous author. The book contained the information about Aristotle's decisive contribution in solving the Nile paradox and the expedition in Ethiopia for the theory's verification. (See excerpt in Appendix A8. "Photius, *Myriobiblon or Biblioteheca*, Life of Pythagoras.")

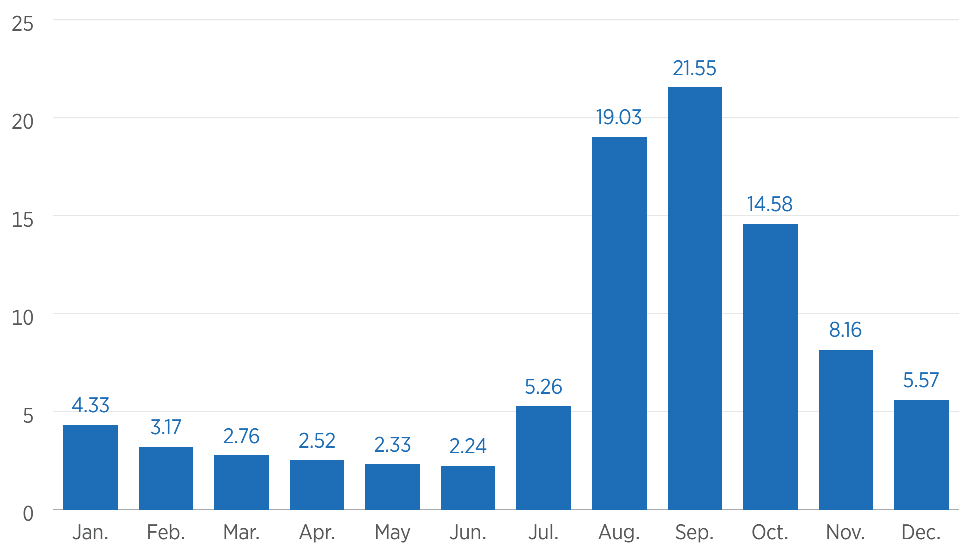
CHART 2

Explanation of the Peculiar Seasonality of the Nile

AVERAGE DAILY RAINFALL FOR PART OF THE BLUE NILE CATCHMENT IN ETHIOPIA, IN BILLIONS OF CUBIC METERS PER MONTH



ASWAN DAM, IN BILLIONS OF CUBIC METERS



Average daily rainfall volume over an area of about 74,000 square kilometers within the Blue Nile catchment at Ethiopia (a rectangle with diagonal at points 9°N, 35°E and 12°N, 37°E) (upper), and mean monthly flows at Aswan Dam reproduced from Chart 1 (upper), for visual comparison (lower) .

SOURCE: Authors' research. For more information, see Appendix B.

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The above story is hardly known to modern scientists, yet several of its aspects could be highly relevant to modern scientific developments. These aspects are discussed by trying to answer the following questions.

- *Was Aristotle's theory on the Nile flooding accepted in his time or later in Roman times?* The reply is clearly no. Mythological views were more charming than scientific views, and hence, they continued to be popular during Roman times.

- *When was the correct theory accepted?* This question is studied in detail by Demetris Koutsoyiannis (one of the authors of this *Special Report*) and Nikos Mamassis.[11] The surprising answer is that it took 21 centuries for the theory to be accepted—or better, reinvented, as Aristotle's text was lost. One would expect that, after the first quantification of the hydrological cycle in the 17th century, the correct explanation for the cause of the Nile's flooding would be accepted. However, the truth is that a new mythology was developed around a theory of the "niter," which was an imaginative element, abundant in the soil of Egypt that, presumably, when activated by some strange conditions, caused the flooding of the Nile, while rainfall in Ethiopia had a minor role, if any. This mythical theory was popular among the most respected learned societies in Europe (including the British Royal Society and France's and Germany's scientific societies). It took the visit to the origins of the Blue Nile of the Scottish traveler James Bruce and the publication of his book[12] for the modern mythical theory to cease.

- *Why was Aristotle's incorrect geocentric system so popular while his correct explanation of the Nile was unpopular?* This question is difficult to answer, but it is important to bear in mind that (a) the authority of the proposer, which indeed Aristotle was, is not a sufficient condition for a theory to be accepted, and (b) scientific truth, even if confirmed by observation, does not necessarily lead to acceptance by the public or even scientists.

These observations are of both diachronic and very modern interest. The case of Aristotle's correct theory on the Nile flooding is not the only one of this type. Another similar case is Aristarchus's heliocentric model, which remained unpopular despite the fact that it was embraced by Archimedes.[13] Both scientific theories were kept hidden or rejected for centuries.

3. The Nile as a Trigger of Metrology

It is a common conviction that measurement—and thus quantification of the Earth processes—is a modern development. Some intellectuals, such as Bertrand Russell,[14] went even further to support the idea that observation was not practiced by ancient scientists. However, the study of the history of Nile management reveals that measurement of its level goes back to the depth of millennia. Some of the ancient instrumental records have survived and constitute priceless information to understand the Earth processes and, in particular, climate.

The Nile valley is one of the places where the earliest civilizations in human history developed. The era of ancient Egypt follows the unification of Upper and Lower Egypt in c. 3150 BC and starts with the Egyptian Archaic Period also known as the Early Dynastic Period. It includes Dynasties I and II, lasting until c. 2686 BC, at the beginning of the Old Kingdom (c. 2686 BC–c. 2181 BC). With Dynasty I, the Egyptian capital moved from Thinis to Memphis. During the Old Kingdom, also known as the Age of the Pyramids, Egypt attained its first sustained peak of civilization. This was the first of the three so-called Kingdom periods, followed by the Middle Kingdom (c. 2055 BC–1650 BC) and New Kingdom (c. 1550 BC–c. 1069 BC), which mark the high points of its civilization. The periods between and after these Kingdom periods, known as First, Second, and Third Intermediate periods, are characterized by decline and are sometimes called the Dark Ages.[15] After the Third Intermediate period, the Late Period (672 BC–332 BC) is followed by the Hellenistic period (332 BC–30 AD, ruled by Greeks), the Roman period (30 AD–313 AD), the Byzantine period (313 AD–641 AD), and the Islamic period (641 AD–present).

The measurement of Earth was essential for agricultural management in the Nile Valley, as well as the administration of the country, including taxation; certainly, this triggered developments in metrology. Herodotus and Aristotle agree that this happened for the first time in Egypt, but they disagree on the real cause. Herodotus calls the measurement of Earth *geometry* (γεωμετρίη < γῆ = earth, land, and μέτρον, measure; see excerpt in Appendix A2) while Aristotle calls it *mathematical arts* (μαθηματικαὶ τέχναι; see Appendix A3). Today, it is rather called *geodesy* (γεωδαισία < γῆ = earth, land, and δαίω, divide, that is, "division of Earth"), a term also introduced by Aristotle (Metaphysics, 997b26). Herodotus attributes the origin of Earth's measurement to the practical needs, but Aristotle emphasizes the intellectual conditions in society: "mathematical sciences originated in the neighborhood of Egypt, because there the priestly class was allowed leisure."

One may speculate that both are right and that both practical needs as well as intellectual developments are triggers of new knowledge.

However, this *Special Report* focuses on another type of measurement: *hydrometry*, the measurement of water. From the very beginning of the Old Kingdom, Egyptians practiced measurement of the Nile level, particularly during the annual flood. They often kept records of the measurements, some of which have survived. The oldest records of the Nile floods were carved on a large stone stele during Dynasty V and include 63 levels of flood water, which go back to the reign of King Djer early in Dynasty I (c. 3050 BC). The most valuable surviving fragment of this monument is the Palermo Stone.[16] Other fragments, either belonging to the same monument or to one exactly resembling it in scale and arrangement, were later recovered from the Memphis area and are kept for the most part in the Cairo Museum.[17]

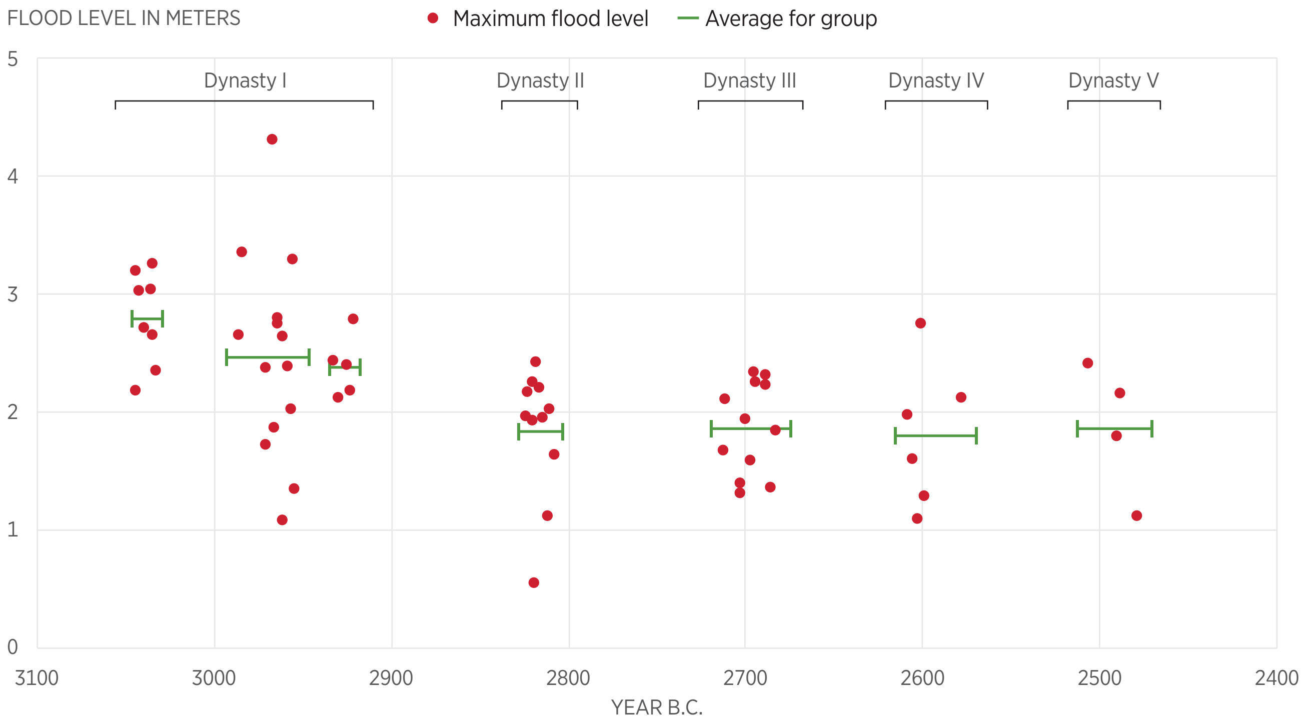
The information inscribed contains (a) the names of the pharaohs of Dynasties I to V, as well as those of their mothers; (b) their doings during each year of their reign; and (c) indications of the height reached by the Nile inundation in that particular year. The height is indicated in the measurement units of Ancient Egypt: cubits, spans, palms, and fingers. The cubit corresponds to 0.524 meters and is divided into seven hands/palms or 28 fingers or two spans. This, known as royal Egyptian cubit, signifies the first standard in the history of metrology. The first record of a permanent standard is dated 2900 BC, when it was carved from black granite. The cubit was decreed to be the length of the pharaoh's forearm plus the width of his hand, and replica standards were given to builders. However, in this early metrology, which was generally kept for millennia,[18] up to the 20th century AD, neither the length of the cubit nor the number of subdivisions were constant; for example, in some cases the fingers of a cubit are 24 rather than 28 and there are cases where the cubit size, as re-measured today in nilometers, is a low as 0.5 meters and as high as 0.55 meters.[19]

The astronomer Barbara Bell,[20] who also contributed to the field of climate history with her studies of ancient Egypt, has provided a graph of the measurements during Dynasty I and the Old Kingdom (Dynasties II–V), which is reconstructed here after digitization. (See Chart 3.) The measurements form seven distinct groups, separated by periods without measurements. The average flood level for each group of measurements is also shown in Chart 3.

The most important observation in Chart 3 is the much higher flood levels during Dynasty I than in those of subsequent periods. Even though the zero point of flood level is arbitrary and there is uncertainty about the location where the measurements were taken, Rushdi Said[21] tried to

CHART 3

The Oldest Surviving Observations of Flood Levels on Earth



Maximum annual flood levels during the Dynasty I and the Old Kingdom of Egypt (Dynasties II-V; c. 2686—c. 2181 BC) from the Palermo Stone and other related fragments, believed to have been measured at Memphis. The zero point of flood level is arbitrary.

SOURCE: Authors' research. For more information, see Appendix B.

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calculate the flood discharges represented by the measurements and to compare them to modern day floods. Assuming that the measurements represent the height of the flood in the Memphis basin, he asserts that the floods during Dynasties III–V were of the magnitude of 130 km^3 per year, comparable to the highest discharge on the modern Nile flow record (141 km^3 in 1878 AD). In contrast, the floods of Dynasty I must have been some 50 percent higher and in the range of 200 km^3 per year. The direct conclusion is that climate used to change substantially during the era of the earliest pharaohs.

No records have been found from the First Intermediate period (First Dark Age). However, during the Middle Kingdom and specifically during the reign of Pharaoh Amenemhat III, the maximum annual flood levels were inscribed on the bordering cliffs of a constricted part of the Nile at

Semna—Kumma in Nubia (modern Sudan, about 350 km south of Aswan). A different method of inscription was used in this case: The highest rise of the Nile in each year was registered by a mark, indicating the year of the pharaoh's reign, cut in the granite, and written in a horizontal row of hieroglyphics, either on one of the blocks forming the foundation of the fortress, or on the cliff, and, particularly, on the east bank.[22]

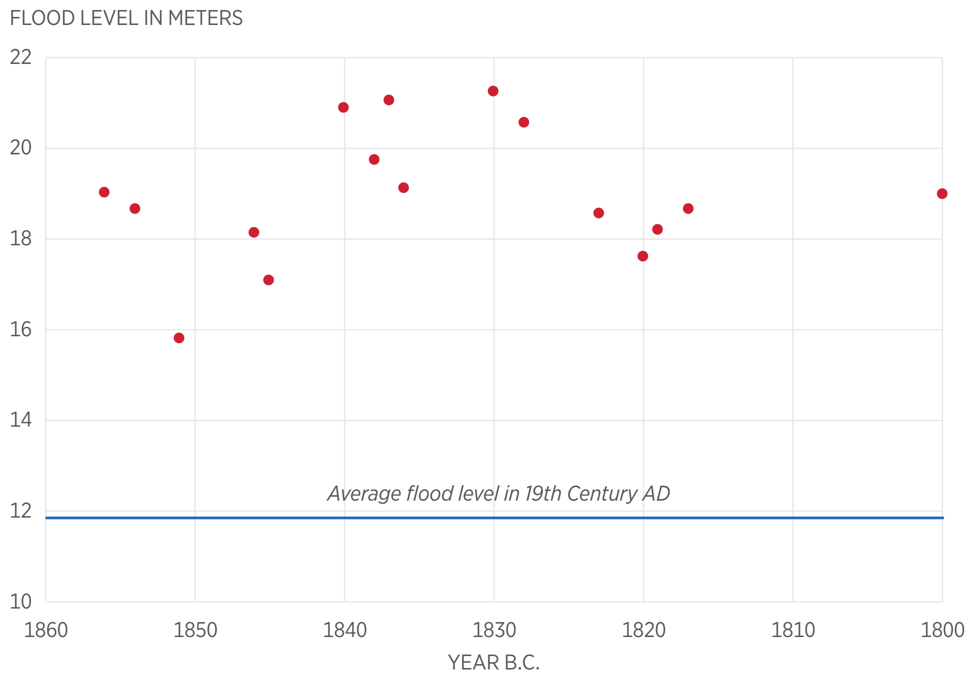
Lepsius[23] investigated these inscriptions and Said[24] has analyzed them. According to Lepsius, 18 of these markings still remain. Thirteen of them were made during the reign of Amenemhat III, and five were made in the time of his two successors. One single mark only, that of the ninth year of Amenemhat III, has been preserved in its original place on one of the building stones. Said[25] provides the measurements for 16 distinct years, which are reproduced in Chart 4.

What is most interesting in this graph is the comparison of the measurements with the flood level in modern times. According to Lepsius,[26] the latter is 11.84 meters and "according to the statements of the most experienced boatmen, does not change from year to year." This value is agreed with by Said who marks it as the average flood level of the 19th century. On the other hand, the average of the measurements in Chart 4 is 18.96 meters (or 19.14 meters according to Lepsius), more than seven meters higher. This fact was not warmly accepted by some scholars, who attributed the difference to factors like sedimentation or construction of ancient dams. These explanations are not plausible, as discussed by Said. Change in the climatic conditions is a simple and plausible explanation. According to Said's[27] calculations, the typical Middle Kingdom floods were of the magnitude of 180 km^3 per year, 30 percent higher than the highest discharge on the modern Nile flow record (141 km^3 in 1878 AD). At the same time, they are lower than the floods in the period of Dynasty I (about 200 km^3 per year, as mentioned). The direct conclusion is that climate continued to change substantially in subsequent pharaohs' eras (and still does so today).

Later in the Middle Kingdom period, there were two important events, for which written information is available. The first is the famine corresponding to the biblical story of Joseph and the pharaoh's dream of the seven fat cows and the seven skinny cows (see full text in Appendix A1), which both Barbara Bell[28] and Rushdi Said[29] date to an uncertain number of years preceding 1740 BC. Specifically, Bell links this story with an inscription in the tomb of Sobek-nakht, which was decorated in the three-year reign of Sobekhotep III, just prior to c. 1740 BC, and reads: "I was a man who protected the afflicted against the powerful...who supplied the granaries of the god...who summoned his entire energy every time he saw an insufficient

CHART 4

Flood Levels During the Middle Kingdom of Egypt



Maximum annual flood levels as inscribed on the bordering cliffs of a constricted part of the Nile at Semna–Kumma in Nubia (about 350 km south of Aswan) during the Middle Kingdom of Egypt (c. 2055 BC—c. 1650 BC) and specifically during the reign of pharaoh Amenemhat III (or Amenemhet III; regnal c. 1860—c. 1814 BC; Dynasty XII). The last point at 1800 BC is from the period of the reign of pharaoh Sobekhotep (c. 1803—c. 1800 BC; Dynasty XIII). The absolute dating is uncertain, as is the relative dating of the last point.

SOURCE: Authors' research. For more information, see Appendix B.

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flood." She also refers to another, undated tomb inscription that reads, "I gave grain to the entire country, I saved my town from famine.... [N]o one has done what I did." This biblical story is of great climatic importance as it is perhaps the oldest text referring to a long-lasting drought, as well as to the natural behavior of clustering in time of similar events (such as dry or wet years), as first quantified by Harold Hurst.[30]

Benoit Mandelbrot and James Wallis[31] used the term *Joseph effect* for this behavior, which today is more often called Hurst-Kolmogorov behavior. The importance of the story extends to good management practices, in which the storage of goods (in this case in granaries) during periods of abundance can mitigate the adverse consequences in periods of shortage. Storage is also a practice used for water per se, traditionally with the use of cisterns, which store water during the wet period of the year to be consumed in the dry period, and today with the construction of large-scale reservoirs that perform over-year regulation (that is, storing water during years of water surplus to be consumed in years of deficit).

The second extraordinary event is a great flood inferred from two fragments of a stele of the 13th Dynasty, found in Karnak, referring to regnal year four of a Pharaoh Sobekhotep. The relevant portion reads:

> Year 4, IV Shomu, the five epagomenal days under the majesty of this god [Sobekhotep]… His majesty proceeded to the hall of this temple, Hapi [the Nile god], the Great, has been seen coming towards his majesty and *the hall of this temple full of water. His majesty was wading in it together with the workmen*. (Emphasis added.)

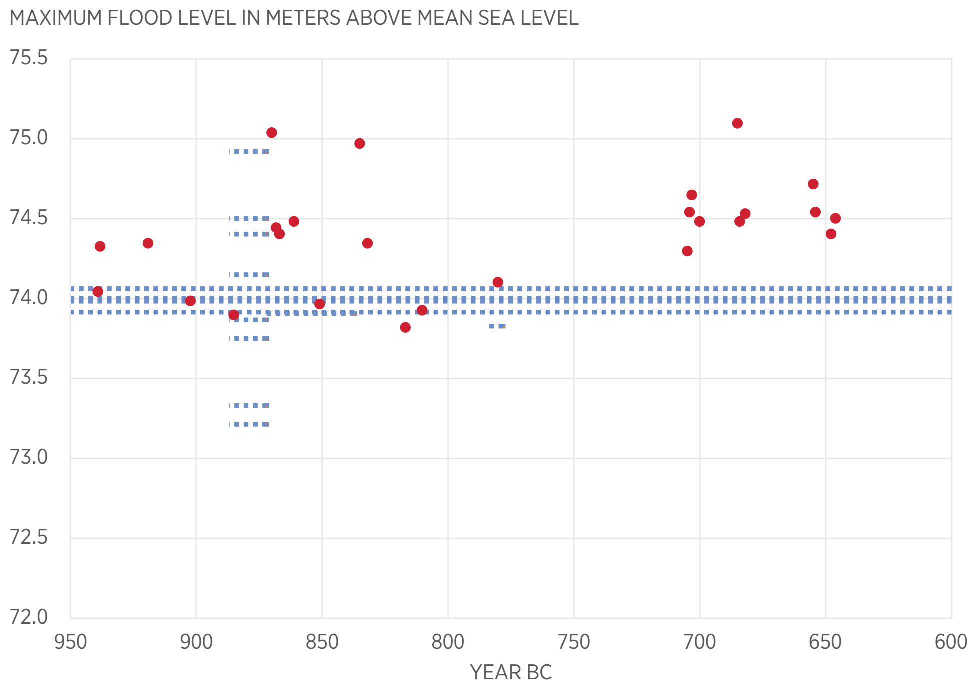
This is quoted in Bell,[32] who following earlier researchers, identified the pharaoh with Sobekhotep VIII and dated it to the 1600s BC. Such extraordinary flood events happen often, reflecting probability distributions of natural events which generally have heavy tails (opposite to the normal distribution, which has light tails). This behavior has been named *Noah effect* by Mandelbrot and Wallis[33] and a *black swan* event by Nassim Taleb.[34]

The next records of Nile floods that have survived are of the Third Intermediate period. The maximum annual levels were inscribed on the quay of Karnak temple in Luxor. Forty-five records were identified by Legrain[35] and studied by later researchers.[36] The characteristics of the inscriptions are similar to those in Semna—Kumma, as described above, mentioning the name of the pharaoh and regnal year.

Ventre Pacha[37] listed all the flood level marks. Based on his and additional information on pharaohs' chronologies, as well as remarks by Gerard Broekman,[38] a graph is compiled in the form of a time series. (See Chart 5.) The highest record on the quay is at 75.09 meters above sea level (c. 685 BC during pharaoh Taharqo's reign), which means that the Karnak temple was flooded at a depth of 84 centimeters above the floor of the hall. Assuming an elevation of the Nile bed at 64 meters above sea level, building on Pacha's data, and making some calculations, Said[39] found that the largest flood is 2 meters higher than the largest modern flood of 1878. The minimum flood recorded in this period is at 73.22 meters above sea level (c. 870s BC–880s BC), or 9.22 meters above the assumed elevation of the Nile bed of 64 meters above sea level. According to Said, this means that the lowest flood level of the entire record exceeds the highest one in the modern period

CHART 5

Flood Levels During the Third Intermediate Period of Egypt



Maximum annual flood levels as inscribed on the quay of Karnak during the Third Intermediate Period of Egypt (c. 1069 BC—c. 672 BC). The measurements with uncertain dating are shown as dotted lines, extending over the likely period. The datum of the graph of 72 m above sea level is the ground level of the temple at about 700 BC.

SOURCE: Authors' research. For more information, see Appendix B.

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of measurements. This again testifies to the change of climate through the centuries.

Measuring of the Nile levels continued in the subsequent periods, even though records before the seventh century AD have not survived. For the Late Period of ancient Egypt, Herodotus, who refers to the adequate level of inundation for the flooding of the area of 15 cubits or 16 cubits, testifies: "now, if the river rise not at the least to sixteen or fifteen, the land is not flooded,"[40] while he says that this was smaller in earlier centuries.

In the Hellenistic period, under the reign of Ptolemies, measurement of Nile levels became more systematic, and measuring devices were installed in several locations along the Nile. These devices were given a name for first time, which were the Greek words *niloscopeion*, according to the historian

Diodorus Siculus (first century BC), and *nilometrion*, according to the Greek geographer Strabo (c. 64 BC–c. 24 AD). The modern term "nilometer" comes from the latter name. Archeologists have identified several nilometers of that era, whose locations are shown in Map 1 (middle). Remnants of most of the devices exist today at archaeological sites.[41] A famous one, the Elephantine nilometer, was mentioned by Strabo in the first century BC (see Appendix A5) and was depicted in a drawing of 1821 by Charles-Louis-Fleury Panckoucke.[42]

The usefulness of the nilometer is described by both Diodorus Siculus (see Appendix A4) and Strabo (see Appendix A5). This usefulness is related to administrative and managerial issues, rather than scientific tasks. Administrators, by letting the people know the flood level and its evolution, in particular, and the cease of the rise of flood level, helped them to better schedule their agricultural activities, as well as to manage the operation of canals, which were abundant in Egypt. Knowing the flood level was also important for regulating the taxation per year, as people's income depended on the flood level.

Hence, the flood level was important for Egyptians' life and happiness. According to Pliny the Elder (*The Natural History*; see Appendix A7), the most desirable water depth was 16 cubits, and it brought joy to people; 15 cubits or 14 cubits removed anxiety; 13 cubits brought hunger; and 12 cubits brought the horror of famine. Levels a bit above 16 cubits were not a problem, but beyond 18 cubits brought disaster. Accordingly, the nilometers were marked in cubits using the Greek numbering system: ΙΒ = 12, ΙΓ = 13, ΙΔ = 14, ΙΕ = 15, Ιϛ = 16 (the optimum), ΙΖ = 17, ΙΗ = 18, ΙΘ = 19, Κ =20, ΚΑ = 21, and so on. These marks became popular across Egypt.

Public feasts were celebrated in honor of the Nile and according to the nilometer indications. Naturally, then, nilometers became sacred objects with religious dimensions. As such, they were transplanted in other places of the Greco–Roman world, irrelevant to the Nile, in the frame of what has been called Egyptomania.[43] For example, archaeologists have identified structures resembling nilometers in Delos, Rhodes, Gortyn, and other sites in Greece in sanctuaries devoted to the Egyptian goddess Isis.[44] Nilometers also acquired an artistic value and were depicted in artwork and even coins. A nice example of the Byzantine period is kept at the Louvre,[45] and additional examples can be found in the *Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures*[46] and *The Nile: Natural and Cultural Landscape in Egypt*.[47]

In the Byzantine period, nilometers were also in use and perhaps advanced through additional inventions (possibly by Egypt's governor Nicetas) in the period of the emperor Heraclius.[48] At the same time, the

Christians, in their attempt to dismantle paganism, removed sacred nilometers from sanctuaries and placed them to Christian churches and monasteries[49] and even used them for decoration of churches.[50] For example, in the Holy Patriarchal Monastery of Saint George in Cairo, a byzantine nilometer was incorporated[51] (perhaps that of the fortress of Babylon) and traces of it have survived to date.[52]

The most famous nilometer data are from the Islamic period. When Arabs conquered Egypt in 641 AD, they found there several nilometers in use, and they built more. The first known Arab nilometer is that in Helwan, near Memphis, around 700 AD.[53] It was destroyed shortly after and was replaced by a new nilometer on the southern tip of the island of Roda in Cairo.[54] This nilometer was built in 715 AD, rebuilt in 861 AD after it had been swept away by water, and maintained several times since. Water entered through three tunnels and filled the nilometer chamber up to river level. The measurements were taken at a marble octagonal column (with a Corinthian crown) standing in the center of the chamber, graded and divided into 19 cubits.[55] It is still in place as a museum and tourist attraction. It is no longer in operation, as the completion of the Aswan dam regulated the Nile's level downstream.

Every year, the maximum flood level was recorded and communicated to the population. In addition, the minimum water level that occurred before the start of the flood was registered, marked as *former* (or *ancient*) water. (See Appendix A10.)

Omar Toussoun[56] compiled a table of the annual minimum and maximum water levels from 622 to 1921 (see also Said[57] about the original sources of this information). From 622 to 1470 (849 years), the record is almost uninterrupted, but there are large gaps later. This instrumental record of measurements surviving to date is the longest in world history. Interestingly, the surviving record starts at 622, which is Year 1 of the Islamic calendar, known as Hegira. Most probably, the measurements after 715 are from the Roda nilometer; the measurements between 700 and 715, from the Helwan nilometer; and the measurements between 622 and 700, from the older Memphis nilometer (elsewhere referred to as the *house of inundation*), which had been standing in that place since antiquity, or the newer Byzantine nilometer in the fortress of Babylon in Cairo. One may speculate that there existed records at Memphis before 622, too, but they were not preserved, perhaps because this period would be judged less important by the Arabs.

In his book, which is now in open access, Toussoun provided the values of minimum water level both in cubits and in the metric system, in meters above sea level. Koutsoyiannis[58] converted them into water depths assuming a datum for the river bottom of 8.80 meters. Here, a zero point linearly varying in time is used to take account of the rise of the riverbed through the centuries, due to accumulation of sediments. According to Said,[59] the floor of the Roda nilometer is at 8.15 meters above sea level and this level is regarded as a representative zero point for the year 641. In a reconstruction of the nilometer scale in 1861, the zero point was put at 8.81 meters above sea level. Hence, to convert the level to water depth, an estimated riverbed level is subtracted, which is found by linear interpolation with time using these two values (8.15 meters above sea level and 8.81 meters above sea level) and their corresponding chronologies. This results in a rate of riverbed change due to sediment accumulation of 53 millimeters per century. The resulting time series of annual minimum and maximum water depths for 622 to 1470 is shown in Chart 6.

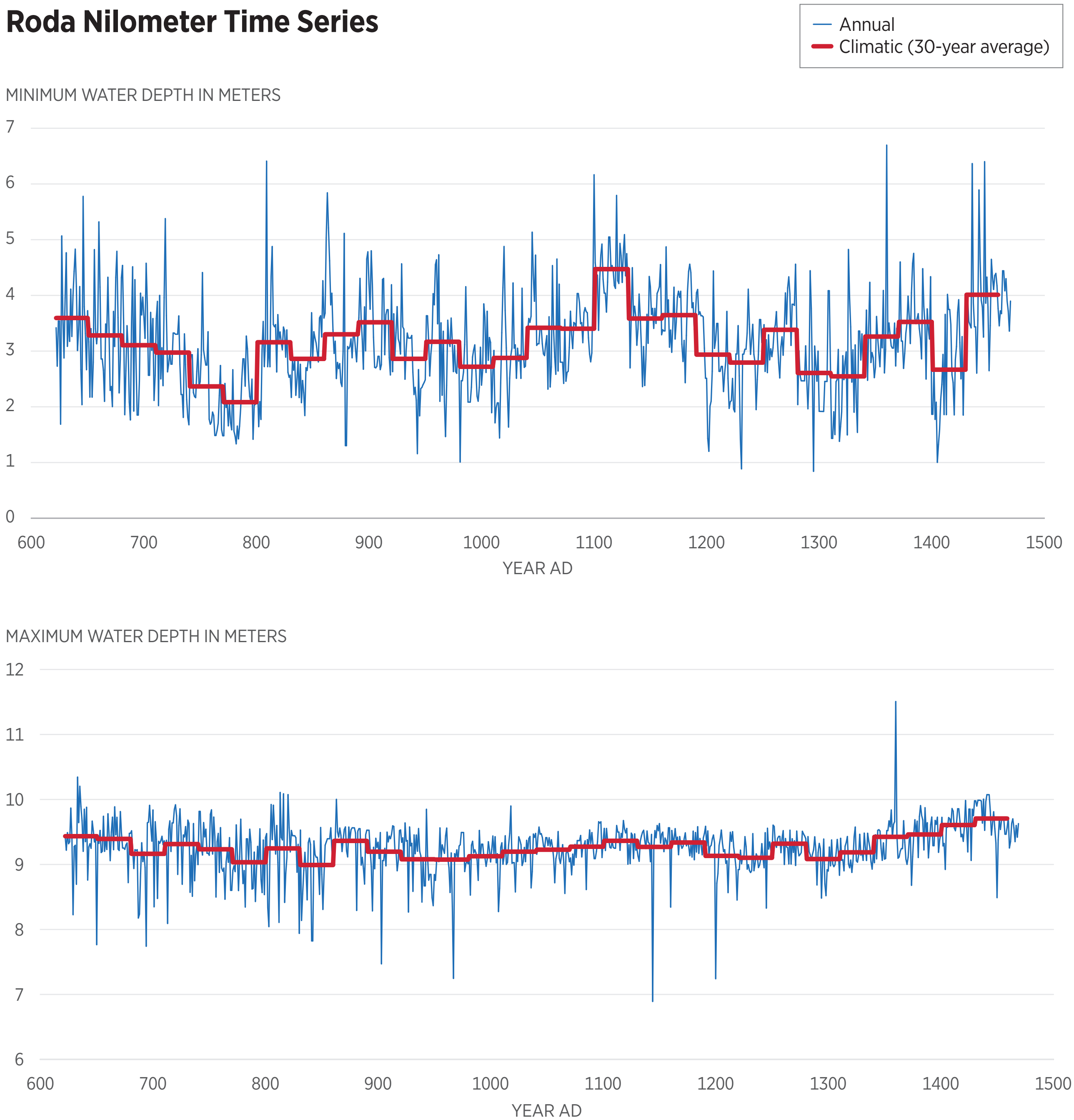
The quantified aspects of these time series are discussed in the subsequent sections. Undoubtedly, the information they contain is not complete, as they do not provide any indication about the duration of flood or drought. Also, their reliability is not as high as in modern measurements, because the conditions under which they were taken and reported may have changed through the centuries. Yet, the quality of the construction of the nilometer is impressive, much higher than in modern water-level measuring devices. In addition, there is some background information, in terms of old reporting of some of the conditions or their consequences, which in some cases confirm the data. Toussoun also reproduced these reported notes.

The highest maximum water level occurred in 1360 (elevation 20.05 meters, depth 11.5 meters) and indeed this is confirmed by reports. (See Appendix A10.) One of the lowest minimum water levels on record, that of the 1405 (elevation 9.57 meters, depth 1.0 meter), is also confirmed by a reported note that "the Nile was dry, so that one crossed it with ford" (Appendix A10). In other cases, the Nile is reported as even drier, that is, "hidden in the earth, to the point that nothing remained of it" or with no water at all (Appendix A10).[60] However, the chronologies of these latter notes do not correspond to the nilometer record.

The maximum water depth has the greatest socioeconomic importance as it determines the annual agricultural production. Yet it does not suffice to assess whether the production was high or low. For example, in 1295, the year in which the lowest minimum level occurred, there is no note for that minimum. Interestingly, the maximum is noted as 16 cubits and 17 fingers, which could be interpreted as satisfactory for agricultural production. However, the note continues: "[T]hen it [the maximum level] decreased,

CHART 6

Roda Nilometer Time Series



Annual minimum (upper) and maximum (lower) water depths of the Nile at Cairo based on the Roda nilometer and earlier ones after and before 715 AD, respectively.

SOURCE: Authors' research. For more information, see Appendix B.

and there was a famine." This shows the importance of flood duration, for which no systematic information is available.

For the year 1144, in which the lowest maximum level was registered (elevation 15.32 meters, depth 6.89 meters), there is no note. However, there exists documentary evidence for the year 1200, in which the second-lowest maximum water depth was registered (elevation 15.70 meters, depth 7.24 meters), by the Arab physician, philosopher, historian, grammarian, and traveler ʿAbd al-Laṭīf al-Baghdādī,[61] who stayed in Egypt in that period. His text goes far beyond confirming that there was a drought. It describes extreme social behaviors triggered by the drought and the resulting famine. An excerpt of the latter (Appendix A9) describes one of the most horrific reactions in human history (cannibalism, including parents eating their children).

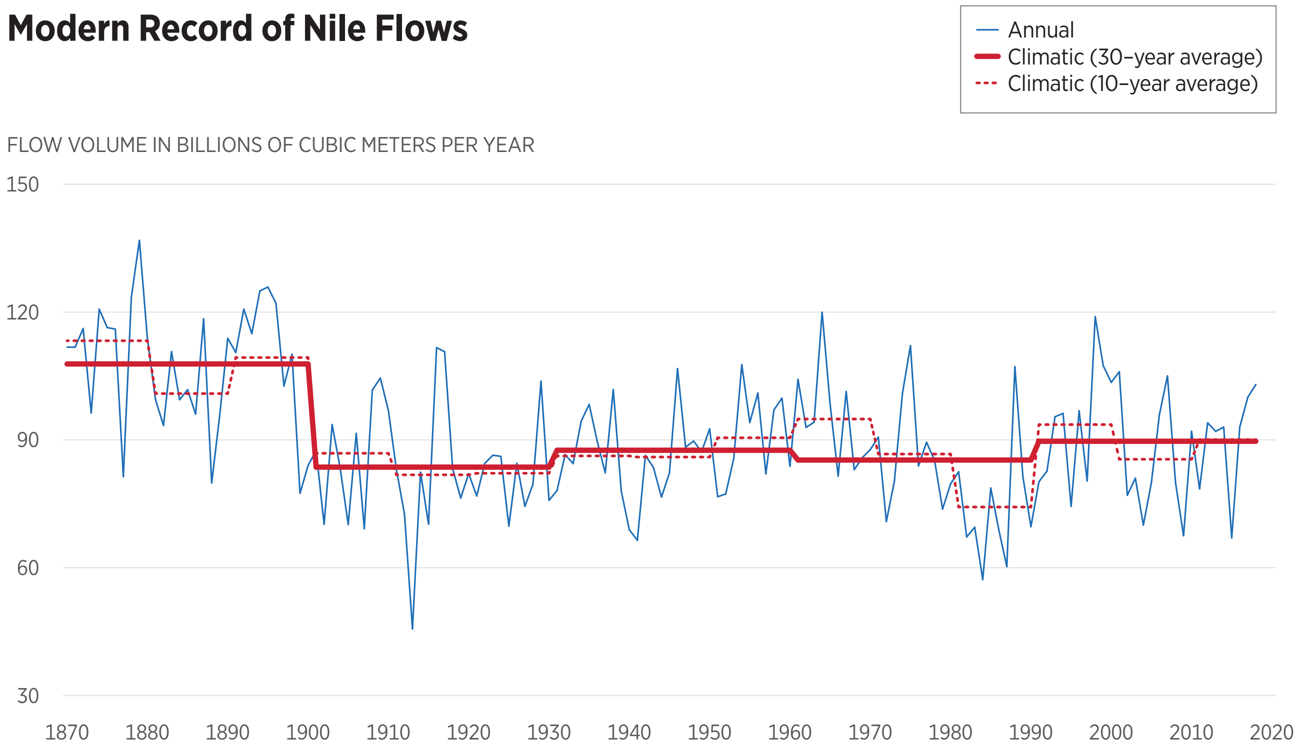
A similar drought (elevation 15.58 meters, depth 7.25 meters) occurred in 967, and it appears that the social reactions were similar (see Hassan,[62] quoting the Egyptian historian Taqi el-Dine Al-Maqrizi, 1365–1441), while it was estimated that 600,000 people died of starvation and famine-related diseases—a quarter of Egypt's population.[63] Atrocities were reported in much older periods, too. A text attributed to Ankhtifi, an officer during Dynasty IX (2160 BC–2025 BC), inscribed in the walls of his tomb (approximately 35 km from Luxor) in Nile's bank, contains the phrase: "All of Upper Egypt was dying of hunger and people were eating their children."[64]

The Roda nilometer continued its operation during the Ottoman occupation of Egypt (1517 to the end of the 19th century) and after that, but later data became sparse. However, since 1870, a continuous record of monthly discharges was kept as modern measurements of the Nile flows have been taken at Aswan dam. Starting in 1915, the Physical Department of Egypt (then a British protectorate) with Harold Hurst as its head, was responsible for collecting hydrological data from the whole Nile basin in Egypt, Sudan, and East Africa and for performing a large amount of related research. River and lake levels were measured at more than a hundred sites while discharge measurements were taken. Rating curves were derived to calculate river flows, while rainfall records were collected throughout the basin. The results of this work were published in a series of many volumes titled *The Nile Basin*.[65]

The modern record of Nile discharge at Aswan is somewhat tricky to compile. Up to 1965, the data are publicly available from the Global Runoff Data Centre (GRDC).[66] Beyond 1965, data need to be naturalized (that is, natural flows need to be estimated from water balance, based on observed data of regulated flows), and are not publicly available in that form. In this

CHART 7

Modern Record of Nile Flows



Modern record of annual flows of the Nile at Aswan, after naturalization.

SOURCE: Authors' research. For more information, see Appendix B.

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Special Report, digitized published graphs are used to continue the formation of the records. For the mean annual discharge up to 2018, a graph by Kevin Wheeler and his co-authors[67] is digitized. For the monthly scale up to 2001, graphs from Demetris Koutsoyiannis, Huaming Yao, and Aris Georgakakos[68] and Hayana Dullah and co-authors[69] are also digitized. Chart 7 depicts the thus formed time series of annual flows at Aswan.

4. Lessons Still Unlearned: The Nile and Climatology

Climatology is tightly connected to analysis of data on the climatic system (atmosphere, hydrosphere, lithosphere, and biosphere) and the characterization of the related processes on a range of time scales, particularly large ones. (See a collection of definitions in Koutsoyiannis.[70]) This characterization is based on statistics, or better on stochastics, which is a field wider than statistics; in stochastics, time has a hypostasis, which is typically absent in statistics, while time dependence of the climatic processes is of prominent importance. In turn, climatology, the scientific field of studying climate, is tightly connected to data, that is, observation of the climatic processes, and their statistical and stochastic analysis.

The case of the Nile, for which instrumental data have existed for many centuries, offers a unique opportunity to understand climate and, more specifically, its perpetual change. And indeed, the Nile records described above, spanning a period from the 32nd century BC to the 21st century AD, attest to the case that climate always changed.

The three latest records (the nilometer record of annual minimum water depth, the nilometer record of annual maximum water depth, and the Aswan annual flow volume) allow quantification of climatic values and their change. The most common convention for a climatic value is the time average of a 30-year period. Therefore, in Chart 6 (nilometer) the averages of consecutive 30-year periods are plotted, in addition to the annual values. Observing the 30-year period from 771 to 800 (upper panel of Chart 6), the climatic minimum depth was 2.08 meters, while from 1101 to 1130, it was 4.47 meters, more than twice as high. The variability of the maximum water level is smaller—another unique characteristic of the Nile. Yet, climatic variability is evident in Chart 6, as shown by the downward and upward shifts and trends. As discussed in "3. The Nile as a Trigger of Metrology" above, there were periods in the past with average flood levels that were likely 50 percent higher than the highest in the modern period.

The flow volumes of the modern period, shown in Chart 7, also show climatic variability. Here, the span of measurements is 148 years—quite large compared with other modern records, but much shorter compared to the 849 years of Chart 6. Thus, for more insightful depictions of climatic changes, the 10-year climatic values are also plotted, in addition to the 30-year ones. The most characteristic change is the downward shift of the flow volume from 107.8 km^3 per year between 1871 and 1900 to 83.6 km^3 per year during the next 30-year period, from 1901 to 1930, a decline of 22.5 percent.

As simple as it may be that climate is naturally changing, the scientific community is reluctant to accept it as a fact. It usually seeks an external agent that causes the change, so as to blame change on that agent. The current agent—the universal scapegoat—is human carbon dioxide (CO_2) emissions. Apparently, CO_2 emissions did not have an effect more than a hundred years ago, but scientists' imagination never fails to find external, mostly anthropic, agents to blame.

In the case of the downward shift of the Nile flow around 1900, that agent was the old Aswan Dam, also known as Aswan low dam, which was constructed between 1899 and 1902 with a reservoir size of 5.3 km^3, against 132 km^3 of the newer Aswan high dam, which was constructed between 1960 and 1970, 7 km upstream of the old dam.

The great hydrologist Vit Klemeš[71] debunked the incorrect theory that a dam with reservoir storage about 5 percent of the mean annual inflow volume before its construction could cause a 22 percent reduction in the inflow volume. Klemeš criticized the original paper that had proposed this explanation:

> [T]he authors considered only one possibility: the first filling of the old Aswan dam which occurred in the season 1902–1903. And they did not take it as a hypothesis to be verified but as an established fact—the one fact on which the entire structure of their model rests.... [T]he discrete event of the Aswan dam's filling seemed like a self-evident cause, especially to engineers which is what most of the authors of that paper were—an example of jumping to conclusions about the "underlying physics," based on personal biases rather than objective analysis. The essence of the result of what the authors claimed to be a "rigorous analysis" is the representation of the historic flow record as a time series fluctuating about a mean which undergoes a downward jump of 22% exactly at the time when the Aswan dam was filled.... The lack of realism of the authors' postulated causal model (the filling of Aswan dam) for the sudden drop in the mean flow of the Nile is exposed by the fact that, around the turn of the century, a similar drop in the mean also occurred in precipitation over a vast region including much of the tropical Africa and the West Indies...—a drop that can hardly be attributed to the Aswan dam! Indeed, [the observed time series] indicates that the drop in the Nile flows commenced already before 1900 as did that in the tropical precipitation... but [this] was ignored because it did not fit into the preconceived aim of fitting an "intervention" model to the data.

This is not meant to maintain that human influences on the Nile flows remained negligible. On the contrary, after the construction of the Aswan high dam these are very significant, and this is the reason why naturalizing the flows for the period later than 1965 is required before utilizing them. As the Nile approaches its outlet on the Mediterranean, human influences become dramatic. Varis[72] stated that the exploitation of the Nile water has become so intense that little flows into the Mediterranean; only 0.4 km^3 from the more than 90 km^3 of water entering the Aswan high dam are released annually to the sea. The rest either evaporates from Lake Aswan, irrigation systems, or arable land or is lost from the surface water pool by way of other processes, such as infiltration. Evidently, this has substantial environmental impacts.

Another usual agent to blame, when the data do not agree with expectations, is to denounce them (more specifically, the part of them that disagrees with "theory") as inaccurate or unreliable. This also happened with the Nile flows before 1900. It was Hurst himself who defended their reliability, maintaining that, though they were of lower accuracy, being based on measured levels and a later rating curve, they were supported by the records from the Halfa gauge (300 km upstream of Aswan) and by more recent flood levels.[73]

The nilometer time series were also criticized even from the very publication of Hurst's paper,[74] which is accompanied by relevant discussion. Again, Hurst defended their reliability arguing that the behavior reflected in them also appears in other records he examined.

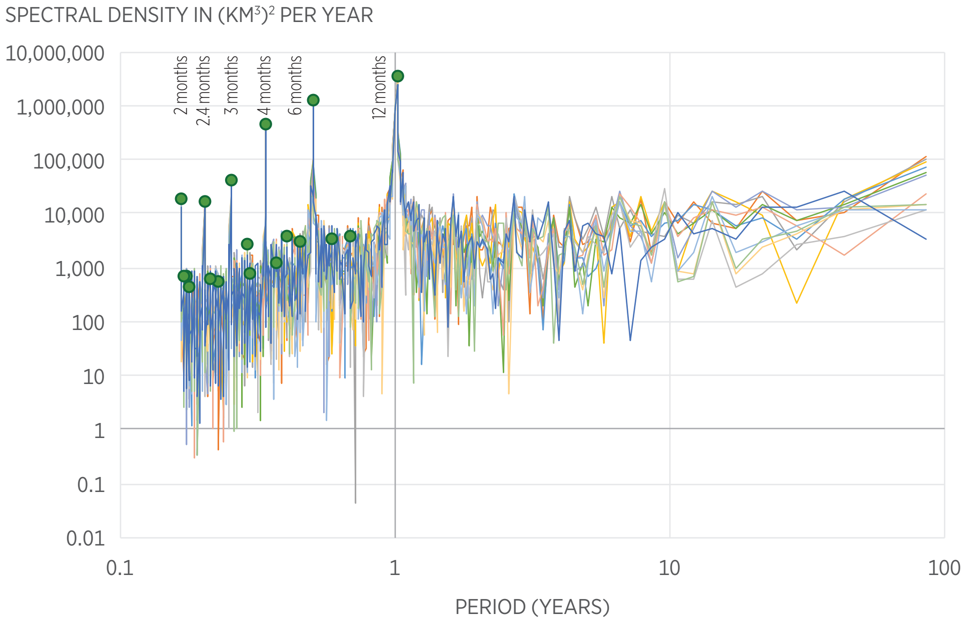
Once blaming the data for an undesirable behavior fails, a next usual step is to search for deterministic controls in them, which would allow even long-range predictions. The well-known stochastic tool of power spectrum (or another integral transform of the data) is typically employed to identify over-annual periodicities in the time series. For example, Koutsoyiannis and Georgakakos,[75] reviewing other studies, list many alleged periodic oscillations, for example of 2.2, 4.2, 5, 7, 19, 21, 64, 76, and 256 years. (See also Said.[76]) However, the claimed periodicities are suspicious.

Indeed, the plethora of periods detected for the same time series, which are numbers asymmetric to each other, may rather indicate a stochastic (erratic) behavior, in which every frequency could appear with certain weight. Most of the studies suffer from one or more of the following caveats: (a) They miss the fact that the empirical power spectrum (periodogram) is a realization of a highly varying stochastic process, displaying many "false" peaks and thus being far different from the (usually smooth) theoretical power spectrum; (b) they test the significance of detected periods against white noise, while, apparently, a white noise hypothesis is totally inconsistent with the Nile's behavior; (c) they undervalue the estimation uncertainty in stochastic processes with high autocorrelation.

It is not too difficult to assess whether a peak appearing in the periodogram is "real," manifesting a deterministic oscillation, or "false," a reflection of a random effect. If it is "real," it will appear at the same frequency if a part of the time series is used, for example, splitting the sample in two halves (or in three tertiaries) or sliding the starting point by a certain number of time steps forming different sequences with same length. Such an exercise is shown in Chart 8, which depicts a "spaghetti graph" of 12 periodograms,

CHART 8

Spectral Analysis of the Modern Nile Flows



Spaghetti graph of 12 periodograms, each produced from a sequence of 1,024 terms of the monthly times series of Aswan flows. The first item of each of the different sequences lags that of the previous sequencies by 48 months (four years). The dots denote the average peaks in the cases that have synchrony for all 12 components.

SOURCE: Authors' research.

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each produced from a sequence of 1024 terms of the monthly times series of Aswan flows with different starting points. The period is plotted on the horizontal axis, instead of the frequency which is more commonly used in such graphs.

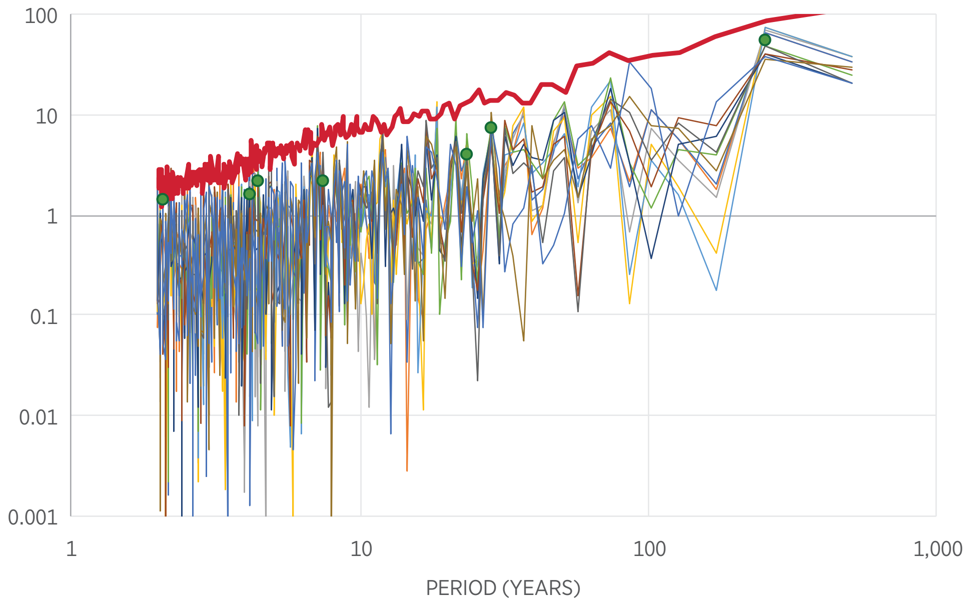
Evidently, the peak that appears at the period of $a = 1$ year is "real" and corresponds to Earth's annual orbit around the sun. All 12 components of the spaghetti graph peak at one year. Also real are the harmonics at smaller periods, that is, at $a_i = a/i$, $i = 1,2,3,4,5,6$. There also appears some synchronization of peaks for other periods smaller than annual, but these peaks are small. For periods longer than one year, synchronization of peaks of all 12 components never appears at any period, which indicates that no real peak appears.

Chart 9 provides similar information, but for the nilometer time series. There appears some synchronization of peaks for some periods, denoted

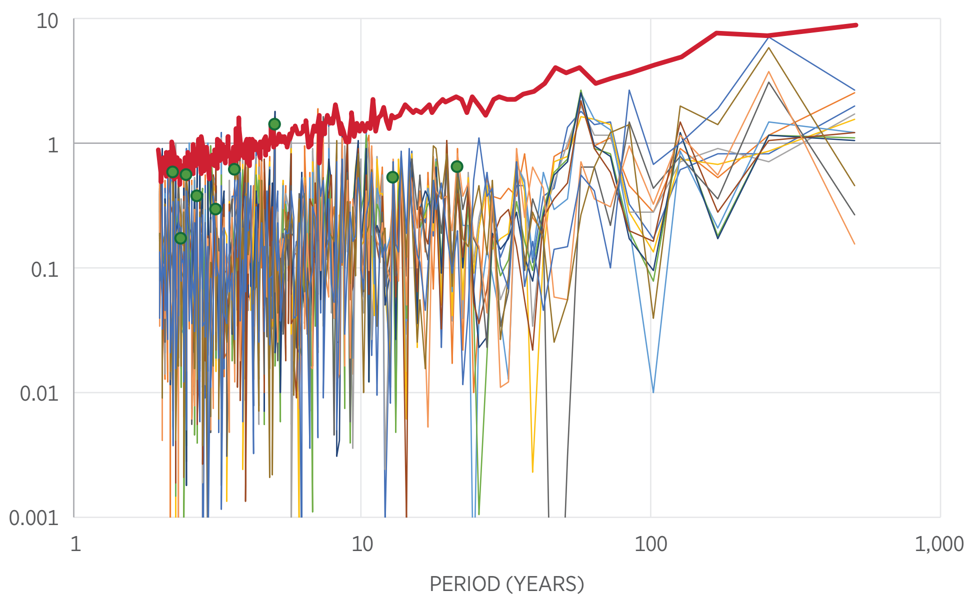
CHART 9

Spectral Analysis of the Nilometer Data

NILOMETER MINIMUM WATER DEPTHS, SPECTRAL DENSITY (M^2 YEAR)



NILOMETER MAXIMUM WATER DEPTHS, SPECTRAL DENSITY (M^2 YEAR)



Spaghetti graphs of 12 periodograms, each produced from a sequence of 512 terms of the annual times series of nilometer minimum (upper) and maximum (lower) water depths. The first item of each of the different sequences lags that of the previous sequence by 30 years. The dots denote the average peaks in the cases that have synchrony for all 12 components. The thick line is the 99 percent upper prediction limit derived by Monte Carlo simulation from an HK model fitted to the nilometer minimum and maximum water depths.

SOURCE: Authors' research.

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by dots in the graph, whose magnitude is small. To quantify the statistical significance of these peaks, a Monte Carlo simulation is used based on HK models fitted separately to the nilometer minimum and maximum water depths (see "5. Reconciling with Uncertainty and Stochastics" below). For the case of minimum water depth, all peaks are below the 99 percent prediction limit, indicating that the peaks are not statistically significant at the 1 percent level. For the case of maximum water depth, there is one peak at the period of five years that slightly exceeds the 99 percent prediction limit. However, at that period, no peak appears at the periodogram of the minimum water level nor at that of the modern record of flow volumes.

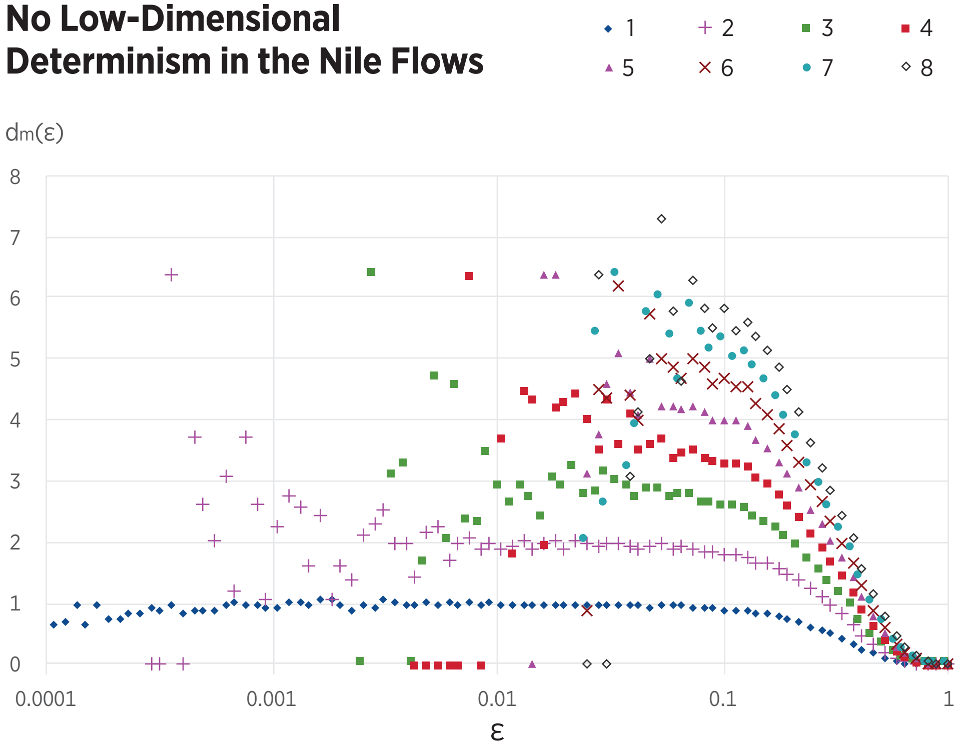
All in all, the quest for periodic oscillations in the Nile is not fruitful at all. Another possible quest for deterministic controls would be to seek low-dimensional determinism. Possible non-periodic deterministic controls, or deterministic attractors, could be detected by using the entropy notion. More specifically this is done by inspecting the information content, expressed as an entropic dimension, of an array of m variables (where m is called the embedding dimension) associated with the time series. From a time series of observations x_i and for increasing trial values of m, sequences of vectors of x_i of size m, dimensions d_m are estimated and tested whether $d_m = m$ or $d_m < m$. In the latter case (meaning that the space where the system dynamics lies does not cover the entire embedding space), there is evidence for deterministic dependence of some of the variables that are coordinates of the embedding space. The algorithmic details of the procedure, among which is the use of a Rényi generalized entropy, a radius ε and the so-called correlation sums, regarded to provide more accurate estimates of d_m can be found in Koutsoyiannis.[77] As shown in Chart 10 (reproduced from Koutsoyiannis and Georgakakos[78]), application of the standard algorithm on the Nile monthly flow series does not reveal any low-dimensional deterministic controls. For small m, the figure clearly shows that $d_m(\varepsilon)$ tends to m as ε tends to 0. For higher embedding dimensions, the algorithm requires enormously many points to provide reliable estimates;[79] but, obtaining reliable estimates with a sample size of 131 × 12 = 1,572 cannot be hoped for. Nonetheless, the figure again shows a tendency for entropic dimensions to equal embedding dimensions.

Some researchers have ascribed deterministic effects, which they characterize as "nonstationarities," to the rising or falling large-scale "trends" identified by statistical time series analysis methods. This, however, is an inconsistent view of natural variability.[80]

A final issue to examine in the framework of seeking deterministic relationships is to identify causal relationships between the Nile flows and other

CHART 10

No Low-Dimensional Determinism in the Nile Flows



Estimated entropic dimensions dm(ε) versus length scale ε for embedding dimensions m = 1 to 8 calculated from the series of standardized monthly flows of Nile assuming time lag 6.

SOURCE: Authors' research. For more information, see Appendix B.

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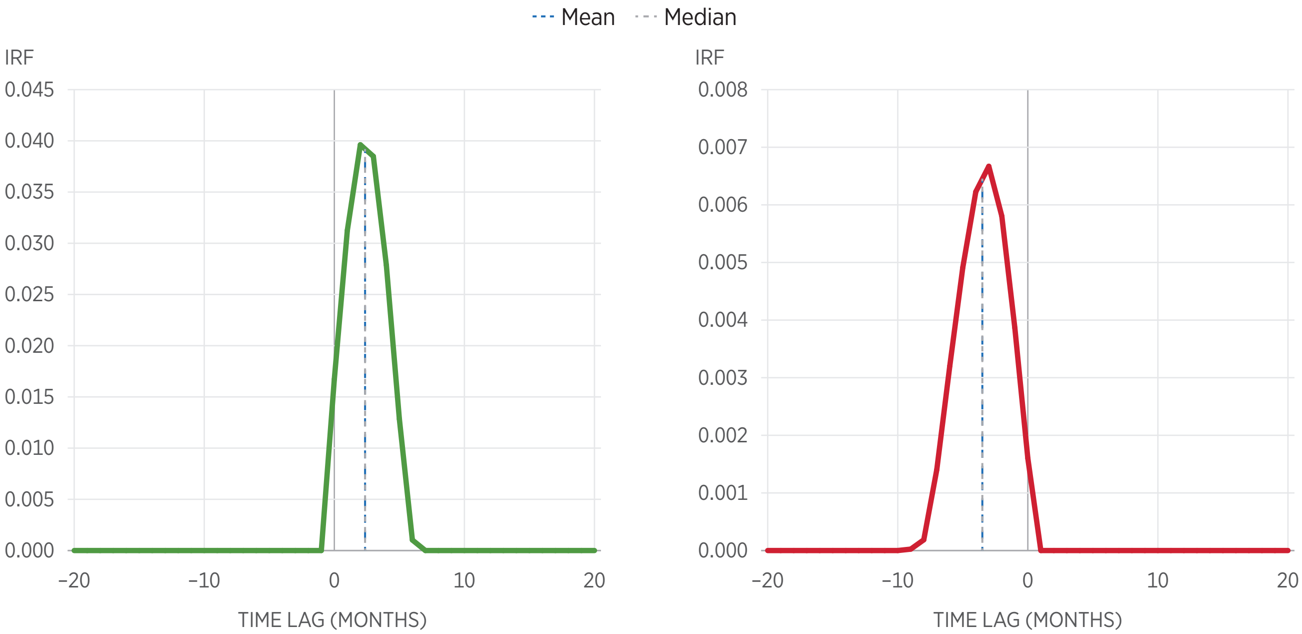
Earth processes. The causal relationship of rainfall over the Nile catchment to the river's flow has been obvious since at least Aristotle's time. On the other hand, several researchers have identified influences of large-scale atmospheric-oceanic processes, such as the El Niño–Southern Oscillation (ENSO). Here, examining the latter relationship requires correlating the standardized monthly flows of the Nile with the U.S. National Oceanic and Atmosphere Administration's Southern Oscillation Index (SOI). The maximum correlation coefficient appears at lag 4 (that is, four months) and is rather low, at only 0.09.

However, if the entire range of meaningful time lags is taken into account using the impulse response function (IRF), and a method newly proposed by Koutsoyiannis and co-authors,[81] then the explained variance by the relationship reaches 26 percent. This explained variance is equivalent to a correlation coefficient between the Nile flows and a linear expression of lagged SOI values greater than 0.5. The IRF is shown in Chart 11 (left),

CHART 11

Potentially Causal Connection Between ENSO and Nile Flows



Intermediate regional floods (IRFs) for Southern Oscillation Index (SOI)–Nile flow based on monthly time series of the two quantities (left); SOI → Nile flow (potentially causal system) and (right); Nile flow → SOI (potentially anticausal system).

SOURCE: Authors' research.

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where the relevant lags range from 0 months to 6 months, signifying a potential causal relationship, with the ENSO as the cause and the Nile's flow as the effect. By reversing the causality direction, an anticausal system, as shown in Chart 11 (right), is identified which, again, suggests the ENSO as the potential cause and the Nile's flow as the effect.

Notably, the explained variance of 0.26 is low, if the next month's flow prediction is sought. For comparison, by using solely past flow values in a stochastic model for medium-range prediction, Koutsoyiannis and co-authors[82] were able to achieve an explained variance of 0.67. It is possible that by also incorporating the potentially causal relationship with the ENSO, the explained variance would further increase and the medium-range prediction improve.

However, such predictions are meaningful only for short to medium range. For long-term predictions, the models cannot help. Even if a process is identified that could be regarded as a potential cause, such as the ENSO, the future of that cause is also unpredictable. *A fortiori*, when investigating the climate, such analyses are not relevant at all. Rather, the lessons learned from the Nile records suggest that:

- Climate change is perpetual,
- Long-term deterministic controls that could enable predictability can hardly be identified, and, thus,
- Future climate is uncertain.

5. Reconciling with Uncertainty and Stochastics

The common perception is that what is not characterized as deterministic is thought to be random, that is, uncertain. However, in a purely random process, large time scales tend to stabilize the average. As this average represents a climatic value, the analogue of a random process is equivalent to a stable climate. And when there is no change, the uncertainty vanishes over long time periods. This is illustrated in Chart 12, where the upper panel is identical to the upper panel of Chart 6, showing the minimum water depths of the nilometer. In the lower panel, the time order of the actual time series is disturbed by resampling from the same time series at random. Now, taking the 30-year time averages, also plotted in both graphs, there are major differences. In the actual case, the climatic values change, while in purely random case, there is almost climate stability. Thus, an actual climatic process is more unpredictable than a purely random process.

It is not too difficult to quantify the change within stochastics and devise a stochastic model for climate. The concept of variance suffices to this aim. Let us take as an example the time series of the nilometer minimum water depths $x_1, x_2, \ldots, x_{849}$ and calculate the sample estimate of the variance $\gamma(1)$, where the argument (1) indicates time scale of one year. The time series of the averages at time scale of two years is formed as:

$$x_1^{(2)} := \frac{x_1 + x_2}{2}, \quad x_2^{(2)} := \frac{x_3 + x_4}{2}, \quad \ldots, \quad x_{424}^{(2)} := \frac{x_{847} + x_{848}}{2} \tag{1}$$

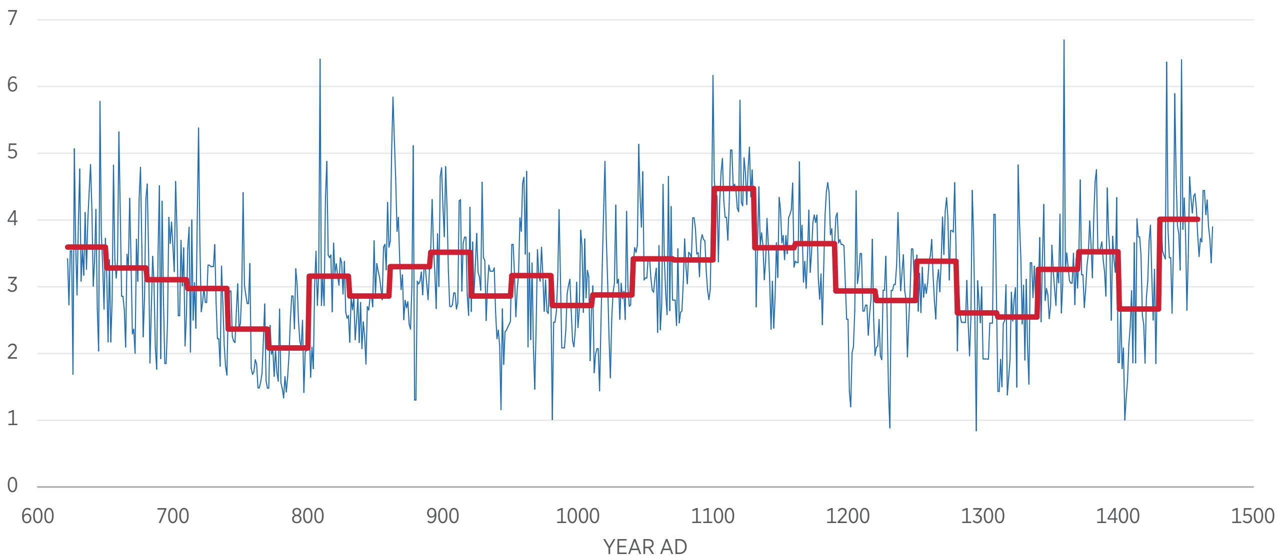
and the sample estimate of variance $\gamma(2)$ is calculated. Forming a time series at time scale 3, 4, ... (years), the same procedure is repeated up to scale 84 (years):

CHART 12

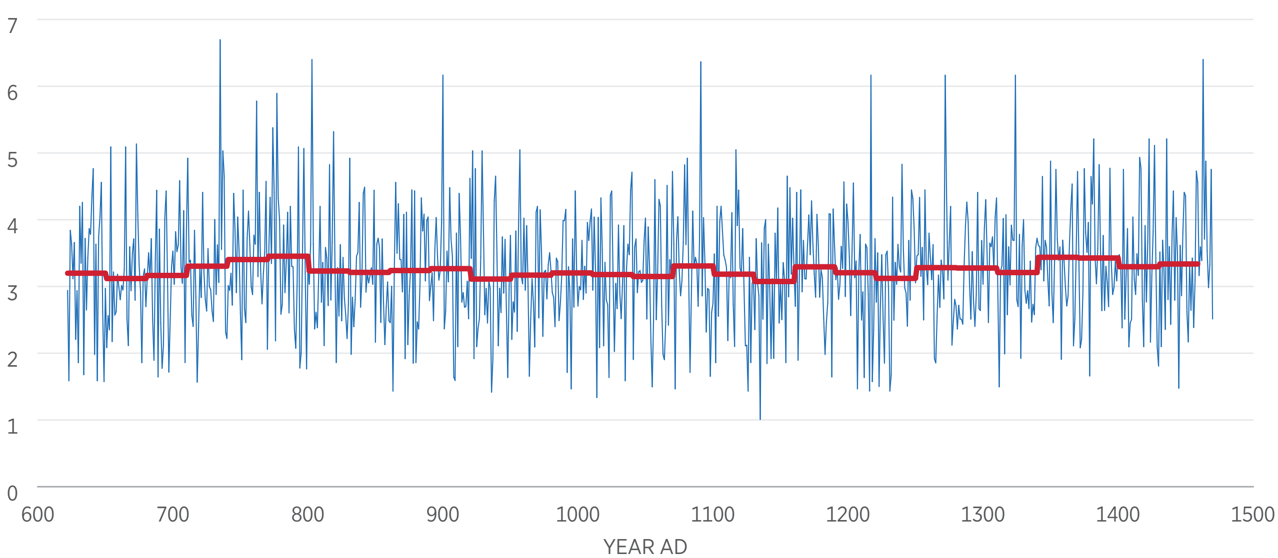
Enhanced Uncertainty in Natural Processes Compared to Random Processes

Annual
Climatic (30-year average)

ACTUAL MINIMUM WATER DEPTHS IN METERS



RANDOM MINIMUM WATER DEPTHS IN METERS



Annual minimum water depths of the Nile at Cairo (upper) at their actual times that they occurred (this is a copy of Chart 6, upper), and (lower) at arbitrary times, redistributed at random.

SOURCE: Authors' research.

$$x_1^{(84)} := \frac{x_1 + \cdots + x_{84}}{84}, \quad \ldots, \quad x_{10}^{(84)} := \frac{x_{757} + \cdots + x_{840}}{84} \tag{2}$$

From this, the variance $\gamma(84)$ is estimated. Here, the maximum scale 84 is the 1/10 of the record length so that there are 10 data points, $x_1^{(84)}, \ldots, x_{10}^{(84)}$, as a minimum to provide a reliable estimate of the variance. Next, plotting the sequence of variance $\gamma(k)$ *vs*. scale k using logarithmic axes, as estimated from the time series $x_i^{(1)} \equiv x_i, x_i^{(2)}, \ldots, x_i^{(84)}$ yields Chart 13.

The logarithmic plot of the variance $\gamma(k)$ *vs*. scale k, which has been termed the *climacogram,* is a useful tool to characterize both change and uncertainty. If the time series x_i represented a purely random process, the climacogram would be a straight line with slope = –1, as implied by the classical statistical law:

$$\gamma(k) = \frac{\gamma(1)}{k} \tag{3}$$

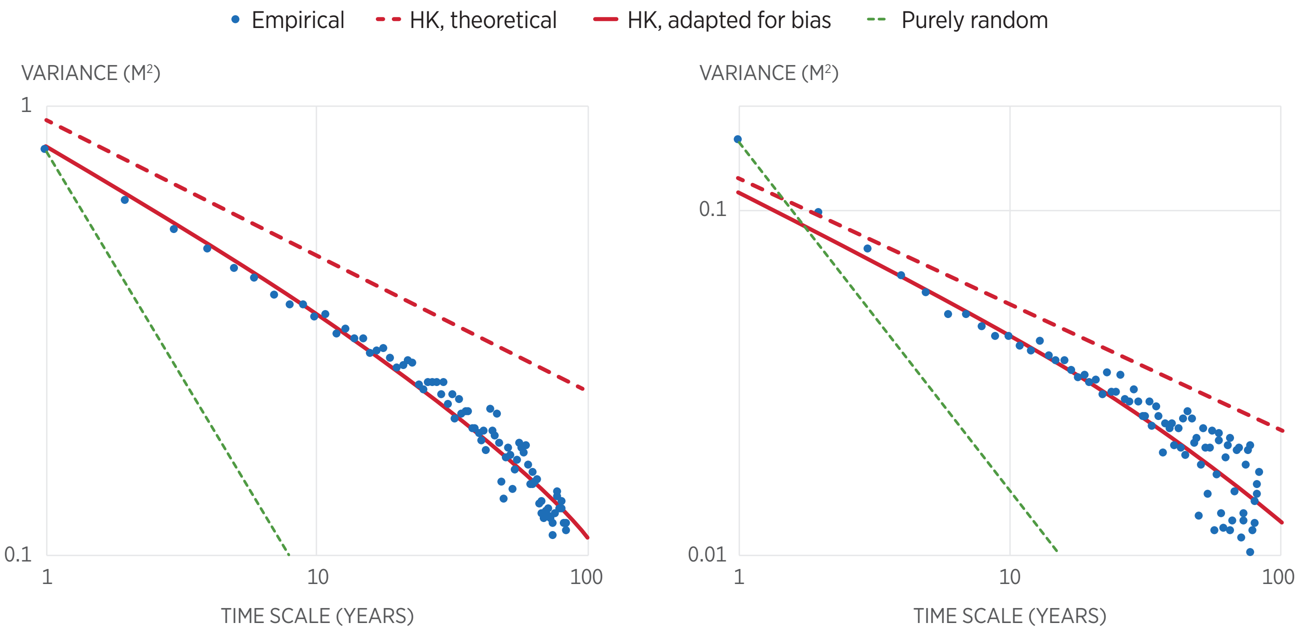
In real world processes, the slope is different from –1, designated as $2H - 2$ and describing the scaling law:

$$\gamma(k) = \frac{\gamma(1)}{k^{2-2H}} \tag{4}$$

Equation (4) defines the Hurst-Kolmogorov (HK) process. The parameter H is called the Hurst parameter and is restricted in the interval (0,1). H is a measure of entropy production, which is closely related to change.[83] If $H = 1/2$, then equation (4) switches to (3), and hence, the value $H = 1/2$ signifies a purely random process. In most natural processes, the Hurst parameter is in the interval $1/2 \leq H < 1$. High values of H, particularly those approaching 1, indicate *enhanced change* and *enhanced uncertainty* at large scales or strong *clustering* (grouping) of similar values, elsewise known as *long-term persistence* or *long-range dependence*. Some texts interpreted it as *long-term memory* or *infinite memory,* but this is an incorrect and misleading

CHART 13

Climacograms of the Nilometer Series



Empirical climacograms (plots of the variance γ(k) vs. scale k) of the nilometer series of annual minimum and maximum water depths (left and right, respectively), along with the fitted HK models.

SOURCE: Authors' research.

SR301 heritage.org

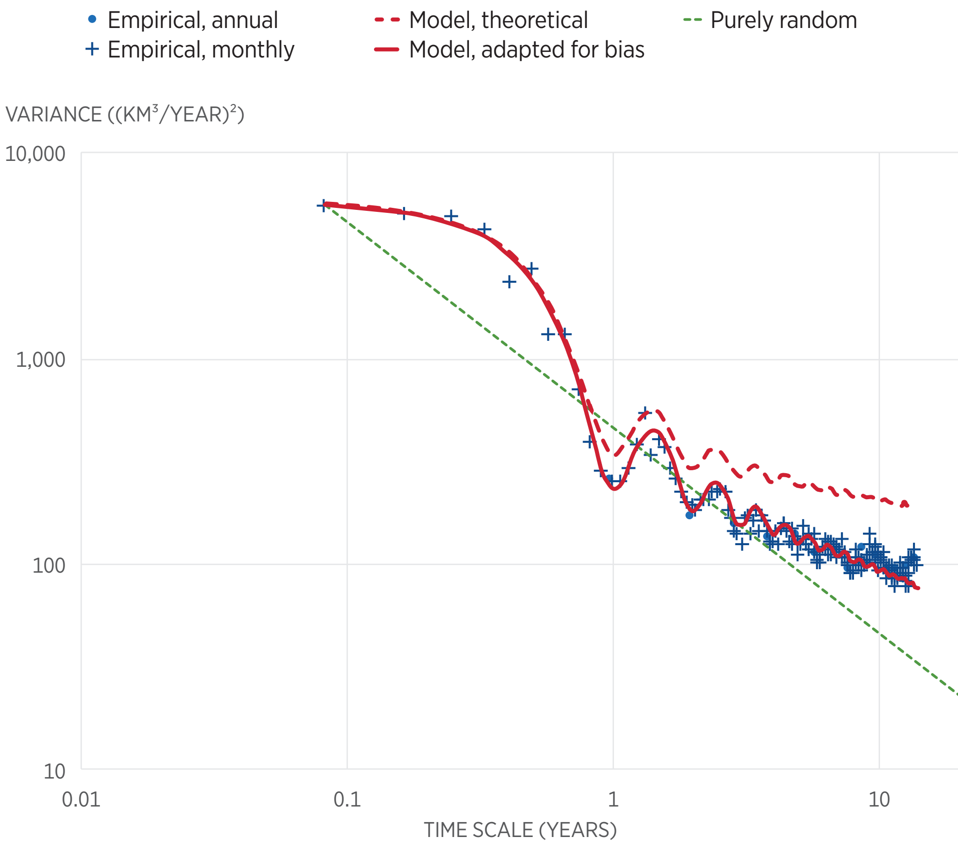
interpretation.[84] Values of *H* in the interval $0 \leq H < 1/2$ suggest *antipersistence*, sometimes misinterpreted as quasi-periodical oscillation.

It was the investigation of the Nile records by Hurst (for dam design and other water resource development studies), and the observation of the huge climatic variability in them at large time scales, that triggered the discovery of the HK behavior, initially called the "Hurst phenomenon," a rather unfortunate name as the behavior proved to be quite common—not phenomenal.

Chart 13, in addition to the empirical climacograms of the Nilometer, estimated from the time series for time scales one to 84 years, also shows the theoretical HK model and its fitting to the empirical climacogram. This fitting is not made by matching the two, but by also considering the estimation bias, which is high, equal to $-\gamma(n)$, where n is the length of the time series.[85] Thus, the fitting error is measured as that between the empirical climacogram and the theoretical model plus bias (marked as "HK adapted for bias" in Chart 13). In fitting the HK model to the case of maxima, the

CHART 14

Climacograms of the Modern Nile Flow Series



Empirical climacogram of the Nile flows at Aswan along with the fitted HK model plus an annual harmonic.

SOURCE: Authors' research.

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first two time scales were not considered as they are severely affected by the extraordinary flood of a single year, in 1360, as discussed in "3. The Nile as a Trigger of Metrology" above. The empirical climacograms of both minimum and maximum water depths at the nilometer are consistent with the HK behavior with fitted $H = 0.85$ and 0.82, respectively.

The modern data of Nile flows at Aswan have been processed in a similar manner and their climacogram is shown in Chart 14.

Because the basic time scale is now monthly, the annual periodicity is apparent in the empirical climacogram. The theoretical climacogram should also take periodicity into account. The simplest way to do this is by adding a single harmonic of the form $\lambda \cos(2\pi\, i/12)$ to the signal, where i is

TABLE 1

Hurst Parameter Estimates

Assumption	Case	Period	H
Elevating zero point by 53 mm/century	Nilometer minima	622–1470	0.85
	Nilometer maxima	622–1469	0.82
Constant zero point	Nilometer minima	622–1470	0.87
	Nilometer maxima	622–1469	0.83
Constant zero point	Nilometer minima	622–1300	0.90
	Nilometer maxima	622–1300	0.84
Elevating zero point by 100 mm/century	Nilometer minima	622–1470	0.87
	Nilometer maxima	622–1469	0.89
None	Modern flow record	1871–2018	0.87
	Modern flow record	1901–2018	0.67

Estimated Hurst parameters (H) for the nilometer and Aswan time series using different fitting periods and assumptions. The first two values and the penultimate value correspond to the assumptions adopted in this study and are consistent with Charts 13 and 14 in the text.

SOURCE: Authors' research.

SR301 heritage.org

a month counter and λ is a parameter. This results in a climacogram expression $\gamma_p(k) = \lambda^2 \operatorname{sinc}^2(\pi k)$ where the time scale k is measured in years[86] (this expression is valid for $k \neq m + 1/2$, where m is any integer). The component $\gamma_p(k)$ is added to that of the HK process in equation (4). The fitted Hurst parameter in this case is $H = 0.87$.

To strengthen the credibility on the consistency between the HK model and the Nile time series, a sensitivity analysis is also performed using different fitting periods and assumptions. Specifically, for the nilometer data: (a) the fitting time period is restricted to 622 to 1300 in order to delimit the inhomogeneities; (b) a constant zero point of the nilometer is assumed to determine the water depth from the water level; (c) an elevating zero point of 100 mm per century (instead of 53 mm per century documented above) is assumed, which has been a common rate used in the literature (such as in Said[87]). As seen in Table 1, in all cases of alternative assumptions, the resulting Hurst parameter values are higher than in the basic case, reaching even 0.90.

For the modern data set (Aswan monthly streamflow series), for an alternative estimate of the Hurst parameter, the period from 1871 to 1900 is excluded. In this case the Hurst parameter has substantially decreased to 0.67, consistently to the value reported recently by Enda O'Connell, Greg O'Donnell, and Demetris Koutsoyiannis,[88] who also found for the same period a similar value for the rainfall over the Nile basin. However, as discussed in "4. Lessons Still Unlearned: The Nile and Climatology," the data from 1871 to 1900 are deemed reliable; hence, the value $H = 0.87$ is reasonable and also consistent with the estimates from the nilometer for much longer data sets.

In brief, all records suggest the omnipresence of the HK behavior, which manifests that long-term changes are much more frequent and intense than commonly perceived and, simultaneously, that the future states are much more uncertain and unpredictable on long time horizons (because the standard deviation is larger) than implied by pure randomness. Ignoring or neglecting this behavior for the past undermines the understanding of climate. Ignoring or neglecting it for future planning increases the risk substantially. For the latter, the scientific community has invested on the alternative of climatic model projections, even though they fail to describe the known past. It is very likely that the use of climate model results underestimates climate risk, compared to the use of measurement data combined with stochastic HK dynamics,[89] and misspecifies the source of the risk as if it was human-caused, while it has been largely natural.

6. Discussion and Conclusions

While the discussion here has focused on the water flows in the Nile and their connection to rainfall variations in the Nile headwaters of central Africa, these historical changes were necessarily related to atmospheric changes on much larger scales. For example, the dry Saharan region, and other subtropical dry regions, are due to large-scale sinking of air masses which are directly connected to the strength of rising air and precipitation production in the deep tropics.

The Nile has given material gifts to humanity, related to the prosperity not only of Egypt, which according to Herodotus is itself a Nile's gift, but in a wide area expanding into the Mediterranean, Europe, and western Asia. Its intellectual gifts, related to science and technology, are equally important. Today, the development of technology follows that of science and data acquisition. However, the history of the Nile shows that technological development preceded, followed by measurement of the environment as a measure to increase productivity, while the development of science was the latest part in this coevolution.

The study of the Nile is inseparable from the birth of science, in particular geoscience, as the first geophysical problem in history was about the Nile. Also, the first in history scientific expedition was made to confirm Aristotle's hypothesis that rainfall in Ethiopia was the prime determinant of the Nile's flow. However, there still remains much to learn from the Nile's behavior, particularly in climatology and hydrology.

The fact that climate always changes is well established, but seldom appreciated in the modern era that generally relates all environmental change to human causation (such as increasing atmospheric carbon dioxide). The historical evidence is commonly provided by proxy data. The Nile is a unique case that provides such evidence by uninterrupted instrumental records of many centuries, complemented by interrupted records going back five millennia. The instrumental records also serve to reveal the stochastic dynamics of change and quantify the change in terms of the HK dynamics.

Additional information from archaeological, documentary, and proxy studies confirm the large climatic changes. A graph summarizing many sources of related information can be seen in Said[90] and additional information is provided by other researchers.[91] These climatic changes were often combined with tectonic changes in geomorphology to produce cosmogonic results. Said[92] describes how the Lake Plateau drained west toward the Congo before the formation of the African Rift led to the presence of Lake Victoria. The age of Lake Victoria is currently estimated to be less than 500,000 years, which could imply a similarly young age for the White Nile.[93] Both Lake Victoria and the Sudd basin of the southern Sudan were closed basins until they overflowed toward the Nile some 12,500 years ago.[94] Amazingly, Lake Victoria seems to have dried twice in the relatively recent past, some 14,000 and 16,000 years ago.[95] A big increase (about 3 meters) in the water level of the lake occurred as recently as 60 years ago,[96] around 1960. As per the Blue Nile, calibrated radiocarbon ages for its high flows indicate very high flood levels toward 13.9–13.2 thousand, 8.6 thousand, 7.7 thousand, and 6.3 thousand years before present.[97]

For the more recent period, the changes observed have been registered in instrumental records, by far the longest in history. With respect to future prediction, observed data of the past, particularly quantified ones, are a better determinate than any speculations or outputs of poorly performing models for an imaginary future, as has been the rule for climate change, anthropogenic or not. In the Nile case, the instrumental data are also confirmed or complemented by written documentation in the form of hieroglyphic inscriptions in rocks or steles, papyruses, and books in Greek, Latin, or Arabic. In this respect, archaeologists have offered great assistance in understanding the changes. Some of these sources contain information on the intensity and consequences of famines in Egypt resulting from droughts or floods in the Nile (Hassan[98]). And, indeed, the consequences in some cases triggered horrific social behaviors.

Many researchers attributed several discontinuities (declines or even collapses) in Egyptian civilizations to bad climatic conditions that caused famines. Such explanations, relying on what has been called environmental determinism, may be true up to some point. However, the social dynamics, including prudent and visionary administration (exemplified in several texts relevant to Egypt), public involvement (exemplified by the wide use of nilometers in Egypt to guide agricultural activities of the population), and adaptation readiness may mitigate natural calamities. Hence, study of the social dynamics may often provide better guidance than environmental determinism.[99]

Changing climate has always been a potential threat to human societies and civilization. Human intelligence, resourcefulness, and adaptability have been weapons against this and other threats. Panic never helped to confront threats. The recently cultivated climate panic is a speculative manifestation of weakness and decadence. The current decadence, mostly seen in the intellectual decline and departure from reason, is the real and most dangerous threat.

Appendix A: Ancient Texts References

A1. The Bible, Genesis 41[100]

Greek text[101]

Ἀποστείλας δὲ Φαραὼ ἐκάλεσε τὸν Ἰωσήφ· καὶ ἐξήγαγον αὐτὸν ἀπὸ τοῦ ὀχυρώματος, καὶ ἐξύρησαν αὐτὸν, καὶ ἤλλαξαν τὴν στολὴν αὐτοῦ· καὶ ἦλθε πρὸς Φαραώ. Εἶπε δὲ Φαραὼ πρὸς Ἰωσὴφ, ἐνύπνιον ἑώρακα, καὶ ὁ συγκρίνων οὐκ ἔστιν αὐτό· ἐγὼ δὲ ἀκήκοα περὶ σοῦ λεγόντων, ἀκούσαντά σε ἐνύπνια, συγκρῖναι αὐτά. Ἀποκριθεὶς δὲ Ἰωσὴφ τῷ Φαραὼ εἶπεν, ἄνευ τοῦ Θεοῦ οὐκ ἀποκριθήσεται τὸ σωτήριον Φαραώ. Ἐλάλησε δὲ Φαραὼ τῷ Ἰωσὴφ, λέγων, ἐν τῷ ὕπνῳ μου ᾤμην ἑστάναι παρὰ τὸ χεῖλος τοῦ ποταμοῦ. Καὶ ὥσπερ ἐκ τοῦ ποταμοῦ ἀνέβαινον ἑπτὰ βόες καλαὶ τῷ εἴδει καὶ ἐκλεκταὶ ταῖς σαρξὶ, καὶ ἐνέμοντο ἐν τῷ Ἄχει. Καὶ ἰδοὺ ἑπτὰ βόες ἕτεραι ἀνέβαινον ὀπίσω αὐτῶν ἐκ τοῦ ποταμοῦ, πονηραὶ καὶ αἰσχραὶ τῷ εἴδει, καὶ λεπταὶ ταῖς σαρξὶν, οἵας οὐκ εἶδον τοιαύτας ἐν ὅλῃ γῇ Αἰγύπτου αἰσχροτέρας. Καὶ κατέφαγον αἱ ἑπτὰ βόες αἱ αἰσχραὶ καὶ λεπταὶ τὰς ἑπτὰ βόας τὰς πρώτας τὰς καλὰς καὶ τὰς ἐκλεκτάς. Καὶ εἰσῆλθον εἰς τὰς κοιλίας αὐτῶν· καὶ οὐ διάδηλοι ἐγένοντο, ὅτι εἰσῆλθον εἰς τὰς κοιλίας αὐτῶν· καὶ αἱ ὄψεις αὐτῶν αἰσχραὶ, καθὰ καὶ τὴν ἀρχήν· ἐξεγερθεὶς δὲ ἐκοιμήθην. Καὶ εἶδον πάλιν ἐν τῷ ὕπνῳ μου, καὶ ὥσπερ ἑπτὰ στάχυες ἀνέβαινον ἐν πυθμένι ἑνὶ πλήρεις καὶ καλοί· Ἄλλοι δὲ ἑπτὰ στάχυες λεπτοὶ καὶ ἀνεμόφθοροι ἀνεφύοντο ἐχόμενοι αὐτῶν. Καὶ κατέπιον οἱ ἑπτὰ στάχυες οἱ λεπτοὶ καὶ ἀνεμόφθοροι τοὺς ἑπτὰ στάχυας τοὺς καλοὺς καὶ τοὺς πλήρεις· εἶπα οὖν τοῖς ἐξηγηταῖς, καὶ οὐκ ἦν ὁ ἀπαγγέλλων μοι αὐτό.

Καὶ εἶπεν Ἰωσὴφ τῷ Φαραὼ, τὸ ἐνύπνιον Φαραὼ ἕν ἐστιν· ὅσα ὁ Θεὸς ποιεῖ, ἔδειξε τῷ

English text[102]

The king sent for Joseph, who was quickly brought out of jail. He shaved, changed his clothes, and went to the king. The king said to him, "I had a dream, yet no one can explain what it means. I am told that you can interpret dreams." "Your Majesty," Joseph answered, "I can't do it myself, but God can give a good meaning to your dreams." The king told Joseph: I dreamed I was standing on the bank of the Nile River. I saw seven fat, healthy cows come up out of the river, and they began feeding on the grass. Next, seven skinny, bony cows came up out of the river. I have never seen such terrible looking cows anywhere in Egypt. The skinny cows ate the fat ones. But you couldn't tell it, because these skinny cows were just as skinny as they were before. At once, I woke up. I also dreamed that I saw seven heads of grain growing on one stalk. The heads were full and ripe. Then seven other heads of grain came up. They were thin and scorched by a wind from the desert. These heads of grain swallowed the full ones. I told my dreams to the magicians, but none of them could tell me the meaning of the dreams.

Joseph replied: Your Majesty, both of your dreams mean the same thing, and in them God has shown what he is going to do. The seven good cows stand for seven years, and so do the seven good heads of grain. The seven skinny, ugly cows that came up later also stand for seven years, as do the seven bad heads of grain that were scorched by the desert wind. The dreams mean there will be seven years

A1. The Bible, Genesis 41 continued

Greek text continued

Φαραώ. Αἱ ἑπτὰ βόες αἱ καλαὶ, ἑπτὰ ἔτη ἐστί· καὶ οἱ ἑπτὰ στάχυες οἱ καλοὶ, ἑπτὰ ἔτη ἐστί· τὸ ἐνύπνιον Φαραὼ ἕν ἐστι. Καὶ αἱ ἑπτὰ βόες αἱ λεπταὶ, αἱ ἀναβαίνουσαι ὀπίσω αὐτῶν, ἑπτὰ ἔτη ἐστί· καὶ οἱ ἑπτὰ στάχυες οἱ λεπτοὶ καὶ ἀνεμόφθοροι, ἑπτὰ ἔτη ἐστί· ἔσονται ἑπτὰ ἔτη λιμοῦ. Τὸ δὲ ῥῆμα ὃ εἴρηκα Φαραὼ, ὅσα ὁ Θεὸς ποιεῖ, ἔδειξε τῷ Φαραώ.᾽Ιδοὺ ἑπτὰ ἔτη ἔρχεται εὐθηνία πολλὴ ἐν πάσῃ γῇ Αἰγύπτου. Ἥξει δὲ ἑπτὰ ἔτη λιμοῦ μετὰ ταῦτα· καὶ ἐπιλήσονται τῆς πλησμονῆς τῆς ἐσομένης ἐν ὅλῃ Αἰγύπτῳ· καὶ ἀναλώσει ὁ λιμὸς τῆν γῆν. Καὶ οὐκ ἐπιγνωσθήσεται ἡ εὐθηνία ἐπὶ τῆς γῆς ἀπὸ τοῦ λιμοῦ τοῦ ἐσομένου μετὰ ταῦτα· ἰσχυρὸς γὰρ ἔσται σφόδρα. Περὶ δὲ τοῦ δευτερῶσαι τὸ ἐνύπνιον Φαραὼ δὶς, ὅτι ἀληθὲς ἔσται τὸ ῥῆμα τὸ παρὰ τοῦ Θεοῦ· καὶ ταχυνεῖ ὁ Θεὸς τοῦ ποιῆσαι αὐτό. Νῦν οὖν σκέψαι ἄνθρωπον φρόνιμον καὶ συνετὸν, καὶ κατάστησον αὐτὸν ἐπὶ γῆς Αἰγύπτου. Καὶ ποιησάτω Φαραὼ καὶ καταστησάτω τοπάρχας ἐπὶ τῆς γῆς· καὶ ἀποπεμπτωσάτωσαν πάντα τὰ γεννήματα τῆς γῆς Αἰγύπτου τῶν ἑπτὰ ἐτῶν τῆς εὐθηνίας, καὶ συναγαγέτωσαν πάντα τὰ βρώματα τῶν ἑπτὰ ἐτῶν τῶν ἐρχομένων τῶν καλῶν τούτων· καὶ συναχθήτω ὁ σῖτος ὑπὸ χεῖρα Φαραώ· βρώματα ἐν ταῖς πόλεσι φυλαχθήτω. Καὶ ἔσται τὰ βρώματα τὰ πεφυλαγμένα τῇ γῇ εἰς τὰ ἑπτὰ ἔτη τοῦ λιμοῦ, ἃ ἔσονται ἐν γῇ Αἰγύπτου, καὶ οὐκ ἐκτριβήσεται ἡ γῆ ἐν τῷ λιμῷ.᾽Ηρεσε δὲ τὸ ῥῆμα ἐναντίον Φαραὼ, καὶ ἐναντίον πάντων τῶν παίδων αὐτοῦ....

ἐξῆλθε δὲ᾽Ιωσὴφ ἀπὸ προσώπου Φαραὼ, καὶ διῆλθε πᾶσαν γῆν Αἰγύπτου. Καὶ ἐποίησεν ἡ γῆ ἐν τοῖς ἑπτὰ ἔτεσι τῆς εὐθηνίας δράγματα. Καὶ συνήγαγε πάντα τὰ βρώματα τῶν ἑπτὰ ἐτῶν, ἐν οἷς ἦν ἡ εὐθηνία ἐν τῇ γῇ Αἰγύπτου· καὶ ἔθηκε τὰ βρώματα ἐν ταῖς πόλεσι·

English text continued

when there won’t be enough grain. It is just as I said—God has shown what he intends to do. For seven years Egypt will have more than enough grain, but that will be followed by seven years when there won’t be enough. The good years of plenty will be forgotten, and everywhere in Egypt people will be starving. The famine will be so bad that no one will remember that once there had been plenty. God has given you two dreams to let you know that he has definitely decided to do this and that he will do it soon. Your Majesty, you should find someone who is wise and will know what to do, so that you can put him in charge of all Egypt. Then appoint some other officials to collect one fifth of every crop harvested in Egypt during the seven years when there is plenty. Give them the power to collect the grain during those good years and to store it in your cities. It can be stored until it is needed during the seven years when there won’t be enough grain in Egypt. This will keep the country from being destroyed because of the lack of food. The king and his officials liked this plan....

For seven years there were big harvests of grain. Joseph collected and stored up the extra grain in the cities of Egypt near the fields where it was harvested. In fact, there was so much grain that they stopped keeping record, because it was like counting the grains of sand along the beach....

Egypt’s seven years of plenty came to an end, and the seven years of famine began, just as Joseph had said. There was not enough food in other countries, but all over Egypt there was plenty. When the famine finally struck Egypt, the people asked the king for food, but he said, “Go to Joseph and do what he tells you to do.”

A1. The Bible, Genesis 41 continued

Greek text continued

βρώματα τῶν πεδίων τῆς πόλεως τῶν κύκλῳ αὐτῆς ἔθηκεν ἐν αὐτῇ. Καὶ συνήγαγεν Ἰωσὴφ σῖτον ὡσεὶ τὴν ἄμμον τῆς θαλάσσης πολὺν σφόδρα, ἕως οὐκ ἠδύνατο ἀριθμηθῆναι, οὐ γὰρ ἦν ἀριθμός….

Παρῆλθον δὲ τὰ ἑπτὰ ἔτη τῆς εὐθηνίας, ἃ ἐγένοντο ἐν τῇ γῇ Αἰγύπτου. Καὶ ἤρξατο τὰ ἑπτὰ ἔτη τοῦ λιμοῦ ἔρχεσθαι, καθὰ εἶπεν Ἰωσήφ· καὶ ἐγένετο λιμὸς ἐν πάσῃ τῇ γῇ· ἐν δὲ πάσῃ τῇ γῇ Αἰγύπτου ἦσαν ἄρτοι. Καὶ ἐπείνασε πᾶσα ἡ γῆ Αἰγύπτου· ἔκραξε δὲ ὁ λαὸς πρὸς Φαραὼ περὶ ἄρτων· εἶπε δὲ Φαραὼ πᾶσι τοῖς Αἰγυπτίοις, πορεύεσθε πρὸς Ἰωσὴφ, καὶ ὃ ἐὰν εἴπῃ ὑμῖν, ποιήσατε. Καὶ ὁ λιμὸς ἦν ἐπὶ προσώπου πάσης τῆς γῆς· ἀνέῳξε δὲ Ἰωσὴφ πάντας τοὺς σιτοβολῶνας, καὶ ἐπώλει πᾶσι τοῖς Αἰγυπτίοις. Καὶ πᾶσαι αἱ χῶραι ἦλθον εἰς Αἴγυπτον, ἀγοράζειν πρὸς Ἰωσήφ· ἐπεκράτησε γὰρ ὁ λιμὸς ἐν πάσῃ τῇ γῇ·

English text continued

The famine became bad everywhere in Egypt, so Joseph opened the storehouses and sold the grain to the Egyptians. People from all over the world came to Egypt to buy grain, because the famine was so severe in their countries.

A2. Herodotus, *The Histories*, Book 2, Chapter 109

Greek original[103]

κατανεῖμαι δὲ τὴν χώρην Αἰγυπτίοισι ἅπασι τοῦτον ἔλεγον τὸν βασιλέα [Σέσωστριν], κλῆρον ἴσον ἑκάστῳ τετράγωνον διδόντα, καὶ ἀπὸ τούτου τὰς προσόδους ποιήσασθαι, ἐπιτάξαντα ἀποφορὴν ἐπιτελέειν κατ᾽ ἐνιαυτόν. εἰ δὲ τινὸς τοῦ κλήρου ὁ ποταμός τι παρέλοιτο, ἐλθὼν ἂν πρὸς αὐτὸν ἐσήμαινε τὸ γεγενημένον: ὁ δὲ ἔπεμπε τοὺς ἐπισκεψομένους καὶ ἀναμετρήσοντας ὅσῳ ἐλάσσων ὁ χῶρος γέγονε, ὅκως τοῦ λοιποῦ κατὰ λόγον τῆς τεταγμένης ἀποφορῆς τελέοι. δοκέει δέ μοι ἐνθεῦτεν γεωμετρίη εὑρεθεῖσα ἐς τὴν Ἑλλάδα ἐπανελθεῖν: πόλον μὲν γὰρ καὶ γνώμονα καὶ τὰ δυώδεκα μέρεα τῆς ἡμέρης παρὰ Βαβυλωνίων ἔμαθον οἱ Ἕλληνες.

English translation by A. D. Godley[104]

This king [Sesostris, c. 2000 BC] also (they said) divided the country among all the Egyptians by giving each an equal parcel of land, and made this his source of revenue, assessing the payment of a yearly tax. And any man who was robbed by the river of part of his land could come to Sesostris and declare what had happened; then the king would send men to look into it and calculate the part by which the land was diminished, so that thereafter it should pay in proportion to the tax originally imposed. From this, in my opinion, the Greeks learned the art of measuring land; the sunclock and the sundial, and the twelve divisions of the day, came to Hellas from Babylonia and not from Egypt.

A3. Aristotle, *Metaphysics*, Book 1, Section 981b

Greek original[105]

τὸ μὲν οὖν πρῶτον εἰκὸς τὸν ὁποιανοῦν εὑρόντα τέχνην παρὰ τὰς κοινὰς αἰσθήσεις θαυμάζεσθαι ὑπὸ τῶν ἀνθρώπων μὴ μόνον διὰ τὸ χρήσιμον εἶναί τι τῶν εὑρεθέντων ἀλλ᾽ ὡς σοφὸν καὶ διαφέροντα τῶν ἄλλων: πλειόνων δ᾽ εὑρισκομένων τεχνῶν καὶ τῶν μὲν πρὸς τἀναγκαῖα τῶν δὲ πρὸς διαγωγὴν οὐσῶν, ἀεὶ σοφωτέρους τοὺς τοιούτους ἐκείνων ὑπολαμβάνεσθαι διὰ τὸ μὴ πρὸς χρῆσιν εἶναι τὰς ἐπιστήμας αὐτῶν. ὅθεν ἤδη πάντων τῶν τοιούτων κατεσκευασμένων αἱ μὴ πρὸς ἡδονὴν μηδὲ πρὸς τἀναγκαῖα τῶν ἐπιστημῶν εὑρέθησαν, καὶ πρῶτον ἐν τούτοις τοῖς τόποις οὗ πρῶτον ἐσχόλασαν: διὸ περὶ Αἴγυπτον αἱ μαθηματικαὶ πρῶτον τέχναι συνέστησαν, ἐκεῖ γὰρ ἀφείθη σχολάζειν τὸ τῶν ἱερέων ἔθνος.

English translation by A. D. Godley[106]

It is therefore probable that at first the inventor of any art which went further than the ordinary sensations was admired by his fellowmen, not merely because some of his inventions were useful, but as being a wise and superior person. And as more and more arts were discovered, some relating to the necessities and some to the pastimes of life, the inventors of the latter were always considered wiser than those of the former, because their branches of knowledge did not aim at utility. Hence when all the discoveries of this kind were fully developed, the sciences which relate neither to pleasure nor yet to the necessities of life were invented, and first in those places where men had leisure. Thus the mathematical sciences originated in the neighborhood of Egypt, because there the priestly class was allowed leisure.

A4. Diodorus Siculus, *Bibliotheca Historica*, Book 1, Chapter 36, Section 11

Greek original[107]

διὰ δὲ τὴν ἀγωνίαν τὴν ἐκ τῆς ἀναβάσεως τοῦ ποταμοῦ γινομένην κατεσκεύασται Νειλοσκοπεῖον ὑπὸ τῶν βασιλέων ἐν τῇ Μέμφει: ἐν τούτῳ δὲ τὴν ἀνάβασιν ἀκριβῶς ἐκμετροῦντες οἱ τὴν τούτου διοίκησιν ἔχοντες ἐξαποστέλλουσιν εἰς τὰς πόλεις ἐπιστολάς, διασαφοῦντες πόσους πήχεις ἢ δακτύλους ἀναβέβηκεν ὁ ποταμὸς καὶ πότε τὴν ἀρχὴν πεποίηται τῆς ἐλαττώσεως. διὰ δὲ τοῦ τοιούτου τρόπου τῆς μὲν ἀγωνίας ἀπολύεται πᾶς ὁ λαός, πυθόμενος τὴν τῆς αὐξήσεως εἰς τοὐναντίον μεταβολήν, τὸ δὲ πλῆθος τῶν ἐσομένων καρπῶν εὐθὺς ἅπαντες προεπεγνώκασιν, ἐκ πολλῶν χρόνων τῆς παρατηρήσεως ταύτης παρὰ τοῖς Αἰγυπτίοις ἀκριβῶς ἀναγεγραμμένης.

English translation by A. D. Godley[108]

And because of the anxiety occasioned by the rise of the river the kings have constructed a nilometer at Memphis, where those who are charged with the administration of it accurately measure the rise and despatch [sic] messages to the cities, and inform them exactly how many cubits or fingers the river has risen and when it has commenced to fall. In this manner the entire nation, when it has learned that the river has ceased rising and begun to fall, is relieved of its anxiety, while at the same time all immediately know in advance how large the next harvest will be, since the Egyptians have kept an accurate record of their observations of this kind over a long period of terms.

A5. Strabo, *Geography*, Book 17, Chapter 1, Section 48

Greek original[109]

ἡ δὲ Συήνη καὶ ἡ Ἐλεφαντίνη ἡ μὲν ἐπὶ τῶν ὅρων τῆς Αἰθιοπίας καὶ τῆς Αἰγύπτου πόλις, ἡ δ᾽ ἐν τῷ Νείλῳ προκειμένη τῆς Συήνης νῆσος ἐν ἡμισταδίῳ καὶ ἐν ταύτῃ πόλις ἔχουσα ἱερὸν Κνούφιδος καὶ νειλομέτριον, καθάπερ Μέμφις. ἔστι δὲ τὸ νειλομέτριον συννόμῳ λίθῳ κατεσκευασμένον ἐπὶ τῇ ὄχθῃ τοῦ Νείλου φρέαρ, ἐν ᾧ τὰς ἀναβάσεις τοῦ Νείλου σημειοῦνται τὰς μεγίστας τε καὶ ἐλαχίστας καὶ τὰς μέσας: συναναβαίνει γὰρ καὶ συνταπεινοῦται τῷ ποταμῷ τὸ ἐν τῷ φρέατι ὕδωρ. εἰσὶν οὖν ἐν τῷ τοίχῳ τοῦ φρέατος παραγραφαί, μέτρα τῶν τελείων καὶ τῶν ἄλλων ἀναβάσεων: ἐπισκοποῦντες οὖν ταύτας διασημαίνουσι τοῖς ἄλλοις, ὅπως εἰδεῖεν: πρὸ πολλοῦ γὰρ ἴσασιν ἐκ τῶν τοιούτων σημείων καὶ τῶν ἡμερῶν τὴν ἐσομένην ἀνάβασιν καὶ προδηλοῦσι. τοῦτο δὲ καὶ τοῖς γεωργοῖς χρήσιμον τῆς τῶν ὑδάτων ταμιείας χάριν καὶ παραχωμάτων καὶ διωρύγων καὶ ἄλλων τοιούτων, καὶ τοῖς ἡγεμόσι τῶν προσόδων χάριν: αἱ γὰρ μείζους ἀναβάσεις μείζους καὶ τὰς προσόδους ὑπαγορεύουσιν.

English translation by H. C. Hamilton and W. Falconer[110]

Syene is a city situated on the borders of Ethiopia and Egypt. Elephantina is an island in the Nile, at the distance of half a stadium in front of Syene; in this island is a city with a temple of Cnuphis, and a nilometer like that at Memphis. The nilometer is a well upon the banks of the Nile, constructed of close-fitting stones, on which are marked the greatest, least, and mean risings of the Nile; for the water in the well and in the river rises and subsides simultaneously. Upon the wall of the well are lines, which indicate the complete rise of the river, and other degrees of its rising. Those who examine these marks communicate the result to the public for their information. For it is known long before, by these marks, and by the time elapsed from the commencement, what the future rise of the river will be, and notice is given of it. This information is of service to the husbandmen with reference to the distribution of the water; for the purpose also of attending to the embankments, canals, and other things of this kind. It is of use also to the governors, who fix the revenue; for the greater the rise of the river, the greater it is expected will be the revenue.

A6. Arrian of Nicomedia, *Anabasis of Alexander*, Book 5, Chapter 6, Section 5

Greek original[111]

Αἴγυπτόν τε Ἡρόδοτός τε καὶ Ἑκαταῖος οἱ λογοποιοί, ἢ εἰ δή του ἄλλου ἢ Ἑκαταίου ἐστὶ τὰ ἀμφὶ τῇ γῇ τῇ Αἰγυπτίᾳ ποιήματα, δῶρόν τε τοῦ ποταμοῦ ἀμφότεροι ὡσαύτως ὀνομάζουσιν καὶ οὐκ ἀμαυροῖς τεκμηρίοις ὅτι ταύτῃ ἔχει Ἡροδότῳ ἐπιδέδεικται, ὡς καὶ τὴν γῆν αὐτὴν τυχὸν τοῦ ποταμοῦ εἶναι ἐπώνυμον.

English translation by E. J. Chinnock[112]

Both Herodotus and Hecataeus the historians (unless the work about the Egyptian country is by another person, and not by Hecataeus) in like manner call Egypt a gift of the river; and Herodotus has shown by no uncertain proofs that such is the case; so that even the country itself perhaps received its name from the river.

A7. Pliny the Elder, *The Natural History*, Book 5, Chapter 10, Sections 57–59

Latin original[113]

Incipit crescere luna nova, quaecumque post solstitium est, sensim modiceque cancrum sole transeunte, abundantissime autem leonem, et residit in virgine isdem quibus adcrevit modis. in totum autem revocatur intra ripas in libra, ut tradit Herodotus, centesimo die. cum crescit, reges aut praefectos navigare eo nefas iudicatum est. auctus per puteos mensurae notis deprehenduntur. iustum incrementum est cubitorum XVI.

minores aquae non omnia rigant, ampliores detinent tardius recedendo. hae serendi tempora absumunt solo madente, illae non dant sitiente. utrumque reputat provincia. in XII cubitis famem sentit, in XIII etiamnum esurit, XIIII cubita hilaritatem adferunt, XV securitatem, XVI delicias. maximum incrementum ad hoc aevi fuit cubitorum XVIII Claudio principe, minimum V Pharsalico bello, veluti necem Magni prodigio quodam flumine adversante. cum stetere aquae, apertis molibus admittuntur. ut quaeque liberata est terra, seritur. idem amnis unus omnium nullas exspirat auras.

Dicionis Aegyptiae esse incipit a fine Aethiopiae Syene; ita vocatur paeninsula M passuum ambitu, in qua castra sunt, latere Arabiae, et ex adverso insula est IIII, Philae, DC p. a Nili fissura, unde appellari diximus Delta. hoc spatium edidit Artemidorus et in eo CCL oppida fuisse, Iuba CCCC p., Aristocreon ab Elephantide ad mare DCCL. Elephantis insula intra novissimum catarracten IIII p. et supra Syenen XVI habitatur, navigationis Aegyptiae finis, ab Alexandria DLXXXV p.: in tantum erravere supra

English translation by J. Bostock and H. T. Riley[114]

The Nile begins to increase at the next new moon after the summer solstice, and rises slowly and gradually as the sun passes through the sign of Cancer; it is at its greatest height while the sun is passing through Leo, and it falls as slowly and gradually as it arose while he is passing through the sign of Virgo. It has totally subsided between its banks, as we learn from Herodotus, on the hundredth day, when the sun has entered Libra. While it is rising it has been pronounced criminal for kings or prefects even to sail upon its waters. The measure of its increase is ascertained by means of wells. Its most desirable height is sixteen cubits; if the waters do not attain that height, the overflow is not universal; but if they exceed that measure, by their slowness in receding they tend to retard the process of cultivation. In the latter case the time for sowing is lost, in consequence of the moisture of the soil; in the former, the ground is so parched that the seed-time comes to no purpose. The country has reason to make careful note of either extreme. When the water rises to only twelve cubits, it experiences the horrors of famine; when it attains thirteen, hunger is still the result; a rise of fourteen cubits is productive of gladness; a rise of fifteen sets all anxieties at rest; while an increase of sixteen is productive of unbounded transports of joy. The greatest increase known, up to the present time, is that of eighteen cubits, which took place in the time of the Emperor Claudius; the smallest rise was that of five, in the year of the battle of Pharsalia, the river by this prodigy testifying its horror, as it were, at the murder

A7. Pliny the Elder, *The Natural History*, Book 5, Chapter 10, Sections 57–59 continued

Latin original continued

scripti. ibi Aethiopicae veneunt naves; namque eas plicatiles umeris transferunt, quotiens ad catarractas ventum est.

English translation by J. Bostock and H. T. Riley continued

of Pompeius Magnus. When the waters have reached their greatest height, the people open the embankments and admit them to the lands. As each district is left by the waters, the business of sowing commences. This is the only river in existence that emits no vapours.

A8. Photius, *Myriobiblon or Biblioteheca*, Life of Pythagoras

Greek original[115]

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.

English translation by Koutsoyiannis and Mamassis[116]

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 analyzed 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.

A9. ʿAbd al-Laṭīf al-Baghdādī (also known as Abdallatif)

French text from De Sacy[117]

Evénements de l'an 597.

Dans cet état de choses, l'année 597 s'annonça comme un monstre dont la fureur devoit anéantir toutes les ressources de la vie et tous les moyens de subsistance. On ne conservoit plus aucun espoir de la crue du Nil; et en conséquence, déjà le prix des denrées s'étoit élevé ; les provinces étoient désolées par la sécheresse : les habitans prévirent une disette inévitable et la crainte de la famine excita parmi eux des mouvements tumultueux. Les habitans des villages et des campagnes se retirèrent dans les principales villes des provinces : un grand nombre émigrèrent dans la Syrie, le Magreb, le Hedjaz et le Yémen, où ils se dispersèrent de côté et d'autre, comme autrefois les descendans de Saba. II y en' eut aussi une multitude infinie qui cherchèrent une retraite dans les villes de Misr et du Caire, où ils éprouvèrent une famine épouvantable et une affreuse mortalité : car, lorsque le soleil fut entré dans le signe du belier, l'air se corrompit, la peste et une contagion mortelle commencèrent

Greek text, ʿAbd al-Laṭīf al-Baghdādī[118]

Τὸ τμῆμα τὸ δεύτερον περὶ τῶν συμβάντων κατὰ τὸ ἔτος ἕβδομον καὶ ἐνενηκοστὸν καὶ πεντακοσιοστὸν

Καὶ εἰσῆλθεν τὸ ἔτος ἑπτὰ (τοῦ λέοντος), ἁρπακτικὸν εἰς τὰς ἐκφάνσεις τῆς ζωῆς. Πράγματι ἀπεγοητεύθη ὁ λαὸς ἐκ τῆς αὐξήσεως τοῦ Νείλου καὶ ἀνυψώθησαν αἱ τιμαὶ καὶ ἐστερήθη ὕδατος ἡ χώρα καὶ ᾐσθάνθη ὁ λαὸς αὐτῆς τὴν ἀπόγνωσιν καὶ τοῦτο [ἦτο] ἀτμοσφαῖρα φόβου περὶ τὴν πεῖναν. Καὶ κατέφυγον οἱ κάτοικοι τῶν χωρίων καὶ τῆς ὑπαίθρου πρὸς τὰς μητροπόλεις καὶ μετανάστευσαν πολλοὶ ἐξ αὐτῶν πρὸς τὸ Σσὰμ (Συρίαν) καὶ τὸ Μάγρεμπ καὶ τὸ Χεγγάζ καὶ τὴν Ὑεμένην καὶ διεσπάρησαν εἰς τὴν χώραν ὡς οἱ ἐπίγονοι τοῦ Σαβᾶ καὶ διεσκορπίσθησαν (εἰς) πλήρη διασκορπισμὸν καὶ εἰσῆλθεν εἰς τὸ Κάϊρον καὶ τὴν Μὲσρ (Φωστάτην) ἐξ αυτῶν λαὸς πολυάριθμος. Καὶ ἐνετάθη εἰς αὐτοὺς ἡ πεῖνα καὶ ἐπέπεσεν ἐπ' αὐτῶν ὁ θάνατος καὶ κατὰ τὴν κατάβασιν τοῦ ἡλίου εἰς τὸν Κριὸν ἐμολύνθη ὁ ἀὴρ καὶ ἐπέπεσεν ἡ ἐπιδημία καὶ τὸ

English translation by authors

The second part about the events in the year 597.

And entered the year seven (of the lion), predatory in the manifestations of life. Indeed, the people were disillusioned by the rise of the Nile and the prices were raised and the country was deprived of water and its people felt despair and this [was] an atmosphere of fear about hunger. And the inhabitants of the villages and the countryside fled to the metropolises and many of them migrated to Sham (Syria) and the Maghreb and the Hedjaz and Yemen and they dispersed in the land like the descendants of Saba and were dispersed (in) complete dispersion and a large number of them entered into Cairo and Misr. And famine came upon them, and death fell upon them, and when the sun had entered the sign of Aries, the air was polluted, and epidemy and death fell upon them. And the famine was spread among the poor, so that they would eat the carrion and the dead and the dogs and the excrement and dung of animals.

French text from De Sacy continued

à se faire sentir ; et les pauvres, pressés par la famine qui alloit toujours croissant, mangèrent des charognes, des cadavres, des chiens, les excrémens et la fiente des animaux.

Ils allèrent plus loin, et en vinrent jusqu'à manger de petits enfans. Il n'étoit pas rare de surprendre des gens avec de petits enfans rôtis ou bouillis. Le commandant de la garde de la ville faisoit brûler vifs ceux qui commettoient ce crime, aussi-bien que ceux qui mangeoient d'un tel mets.

J'ai vu moi-même un petit enfant rôti dans un panier. On l'apporta chez le prévôt, et on amena en même temps un homme et une femme qui, disoit-on, étoient le père et la mère de l'enfant : le prévôt les condamna à être brûlés vifs.

Au mois de ramadhan, on trouva à Misr un cadavre dont on avoit enlevé toute la chair pour la manger, et qui étoit resté les jambes liées, comme un mouton que des cuisiniers lient pour le faire cuire.

Greek text, ʿAbd al-Laṭīf al-Baghdādī continued

θανατικόν. Καὶ ἐνετάθη εἰς τοὺς πτωχοὺς ἡ πεῖνα, ὥστε νὰ τρώγουν τοὺς πεθαμένους καὶ τὰ ψοφίμια καὶ τοὺς κύνας καὶ τὴν κοπριὰν καὶ τὰς καβαλίνας.

Κατόπιν συνέχισαν τοῦτο μέχρις ὅτου ὡδηγήθησαν πρὸς μικροὺς υἱούς τοῦ Ἀδὰμ (μικροὺς ἀνθρώπους, παιδία). Καὶ συχνάκις αὐτὸ τὸ ὁποῖον ἐτύγχανέν τις ἐπ' αὐτῶν, τὸ νὰ ἔχουν μαζῇ των μικρὰ (παιδία) ἐψημένα ἢ βεβρασμένα. Καὶ διέταξεν ὁ *κτήτωρ τῆς φυλάξεως* τὴν καῦσιν τοῦ πράξαντος τοιοῦτο καὶ τοῦ ἐσθίοντος.

Καὶ εἶδον μικρὸν ἐψημένον εἰς κάλαθον καθ' ὅσον πράγματι ἐπαρουσιάσθη εἰς τὸν οἶκον τοῦ βαλῆ καὶ μετ' αὐτοῦ ἀνὴρ καὶ γυνή.' Ἰσχυρίσθη ὁ κόσμος, ὅτι οἱ δύο [ἦσαν] οἱ γονεῖς του, ὁπότε διέταξεν (ὁ βαλῆς) τὴν καῦσιν ἀμφοτέρων.

Καὶ εὑρέθη κατὰ τὸ ῥαμαζάνιον εἰς τὴν Αἴγυπτον ἄνθρωπος, τοῦ ὁποίου πράγματι ἀπεγυμνώθησαν τὰ ὀστᾶ ἐκ τῆς σαρκὸς καὶ ἐφαγώθη καὶ παρέμεινεν ὁ θώραξ ὡς κάμνουν οἱ μάγειροι μὲ τὸν ἄμνον.

English translation by authors continued

Then they continued this until they went so far as to eat the little sons of Adam (little people, children). And it was frequent that they have with them little (children) baked or boiled. And the *owner of the ward* (commander of the city) ordered the burning of him who committed this and him who ate such a dish.

And I myself saw a little one baked in a basket, as indeed appeared in the house of the wali [governor], along with a man and a woman. The world became convinced that the two [were] his parents, so he (the wali) ordered the burning of both.

And a man was found during Ramadan in Egypt, whose bones were indeed stripped from the flesh which was eaten, and the chest remained as the cooks do with the lamb.

A10. Ancient Information Quoted by Toussoun (1925)

French text by Toussoun[119]

p. 455

En l'an 278 de l'Hégire (891 après J.-C.), le sage et docte Aboul Farag, fils d'El-Djouzi, dit que le Nil d'Égypte se cacha dans la terre, au point qu'il n'en resta rien; ce que l'on n'avait pas encore vu ni avant ni depuis l'Islam.

En l'an 333 de l'Hégire (944 après J.-C.), il ne restait plus d'anciennes eaux dans le bassin du Méqyâs, et l'on ne put prendre la hauteur du fleuve, avant la crue, que sur la rive du côté de Gizeh. Celte année, l'eau monta à 14 coudées 16 doigts; ensuite elle baissa, et pendant neuf années consécutives, la crue ne parvint pas une seule fois à 16 coudées; ensuite elle baissa, et pendant neuf années consécutives, la crue ne parvint pas une seule fois à 16 coudées.

p. 477

En l'an 761 de l'Hégire (1360 après J.-C.), quand on prit la hauteur des anciennes eaux, on trouva 12 coudées, et il y eut ouafâ dès le 6 Misra; selon Maqrizi, dans ses Khitat, la crue, cette année, fut de vingt-quatre coudées, ce que quelques-uns ont contesté; mais le témoignage de Maqrizi est confirmé par le sheikh Djelâl el-Din el-Soyouti, qui, dans son livre intitulé Kaoukeb el-Rodah, atteste que « cette année, le Nil crût d'environ vingt-quatre coudées, comme le dit Maqrizi », et cela, sous le règne d'El-Malik el-Naçer Hassan fils de Mohammed fils de Qalâoun, qui ordonna que l'on cesserait de proclamer la hauteur de la crue, parce que l'on craignait une inondation générale. Les grandes eaux se soutinrent ainsi, sans diminuer, jusqu'au 25 Bâba, ce qui causa une extrême désolation parmi le peuple. La chaussée du

English translation by authors

In the year 278 of the Hegira (891 AD),[120] the wise and learned Aboul Farag, son of El-Djouzi, said that the Nile of Egypt was hidden in the earth, to the point that nothing remained of it; something that had not been seen before or since Islam.

In the year 333 of the Hegira (944 AD),[121] there were no longer any ancient [former] waters[122] left in the basin of the nilometer, and the height of the river could be taken before the flood only on the shore of the Giza side. That year, the water rose 14 cubits 16 fingers; then it fell, and for nine consecutive years the flood never once reached 16 cubits.

In the year 761 of the Hegira (1360 AD),[123] when we took the height of the ancient waters, we found 12 cubits, and there was wafâ[124] from the 6th Misra;[125] according to Maqrizi, in his Khitat, the flood this year was twenty-four cubits, which some have disputed; but Maqrizi's testimony is confirmed by Sheikh Djelâl el-Din el-Soyouti, who, in his book entitled Kaoukeb el-Rodah, attests that "this year, the Nile grew by about twenty-four cubits, as Maqrizi says," and that, under the reign of El-Malik el-Naçer Hassan son of Mohammed son of Qalâoun, who ordered that one would cease to proclaim the height of the flood, because one feared a general flood. The high waters continued thus, without diminishing, until the 25th of Baba,[126] which caused extreme desolation among the people. The Fayoum causeway became impassable, the

French text by Toussoun continued

Fayoum devint impraticable, les jardins de l'ile de l'Éléphant furent submergés, ainsi que les chemins de Shoubra et d'El-Minieh. Les eaux s'étendirent jusqu'aux premières maisons d'El-Husseinieh : elles encombrèrent les puits, s'ouvrirent un passage par le bassin de la mosquée de Hâkem, et détruisirent plusieurs habitations de l'île de Rodah, qui finit par être entièrement submergée. Elles interceptèrent en plusieurs endroits le chemin de Boulaq, et renversèrent un grand nombre de maisons. Cette affreuse inondation subsista dans toute sa force jusqu'à la fin de Bâba; jamais on n'en avait vu de pareille en Égypte ni avant ni depuis l'Islam. Le peuple se rendit au désert et invoqua Dieu pour la diminution des eaux: ce même jour elles diminuèrent, en effet, de quatre doigts. Ces grosses eaux furent suivies de la peste, qui ravagea toute l'Égypte.

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En l'an 807 de l'Hégire (1404 après J.-C.), le Nil fut à sec, si bien qu'on le traversait à gué, et l'on passait ainsi du Caire à Gizeh. La hauteur de anciennes eaux ne fut que de 1 coudée 10 doigts; on la prit du côté de Gizeh; ensuite le fleuve crût et parvint aux termes du ouafâ; mais il ne monta guère an delà. C'était sous le règne d'El-Naçer Farag, fils de Barqouq.

English translation by authors continued

gardens of Elephant Island were submerged, as well as the paths of Shoubra and El-Minieh. The waters spread as far as the first houses of El-Husseinieh: they blocked the wells, opened a passage through the basin of the mosque of Hâkem, and destroyed several dwellings on the island of Rodah, which ended up being completely submerged. They intercepted the road to Boulaq in several places and overthrew a large number of houses. This dreadful inundation continued in full force until the end of Baba; never had the like been seen in Egypt before or since Islam. The people went to the desert and invoked God for the reduction of the waters: that same day they decreased, in fact, by four fingers. These great floods were followed by the plague, which ravaged all of Egypt.

In the year 807 of the Hegira (1404 AD),[127] the Nile was dry, so that one crossed it with ford, and one thus passed from Cairo to Gizeh. The height of ancient waters was only 1 cubit 10 fingers; they took it from the side of Gizeh; then the river grew and reached the limits of the ouafâ; but he scarcely ascended further. It was under the reign of El-Naçer Farag, son of Barqouq.

Appendix B: Additional Chart Sources

Chart 2: The origin of the rainfall data is the NCEP/NCAR Reanalysis 1 by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR), which are publicly available and were retrieved through the climexp platform (http://climexp.knmi.nl/). Also, see E. Kalnay et al., "The NCEP/NCAR 40-Year Reanalysis Project," *Bulletin of the American Meteorological Society*, Vol. 77, (1996), pp. 437–472.

Chart 3: Bell (Fig. I) and Said (Fig. 2.15) after digitization. B. Bell, "The Oldest Records of the Nile Floods," *The Geographical Journal*, Vol. 136, No. 4 (1970), pp. 569–573, and R. Said, *The River Nile: Geology, Hydrology and Utilization* (Oxford, UK, Pergamon Press, 1993).

Chart 4: Said, *The River Nile: Geology, Hydrology and Utilization*, p. 145, and R. Lepsius, *Letters from Egypt, Ethiopia, and the Peninsula of Sinai* (London: Henry G. Bohn, 1853), pp. 509 and 510.

Chart 5: For each measurement, the year of reign of the respective pharaoh was taken from Ventre Pacha, "Crues modernes et crues anciennes du Nil," *Zeitschrift* für Ägyptische *Sprache und Altertumskunde*, Vol. 34, No.1 (1896), pp. 95–107, https://archive.org/details/zeitschriftfr34brug/page/94/ (accessed October 3, 2024). To infer the dating of each measurement (red dot) the years of reign of the kings were taken from Wikipedia. Additional information was taken from G.P.F. Broekman, "The Nile Level Records of the Twenty-Second and Twenty-Third Dynasties in Karnak: A Reconsideration of Their Chronological Order," *The Journal of Egyptian Archaeology*, Vol. 88 (2002), pp. 163–178. The datum of the graph of 72 meters above sea level is the ground level of the temple at about 700 BC (Said, Fig. 2.24).

Chart 6: The origin of the data is O. Toussoun, *Mémoire sur l'Histoire du Nil*, Vol. 2, Imprimerie de L'institut Français D'Archéologie Orientale, Cairo, Egypt, 1925, https://archive.org/details/MIE_9/ (accessed October 3, 2024), while D. Koutsoyiannis, "Hydrology and Change," *Hydrological Sciences Journal*, Vol. 58, No. 6 (2013), pp. 1177–1197, has made the record available online (https://www.itia.ntua.gr/1351/).

Chart 7: Before 1965: Global Runoff Data Centre (GRDC). After 1965: K.G. Wheeler et al., "Understanding and Managing New Risks on the Nile with the Grand Ethiopian Renaissance Dam," *Nature Communications*, Vol. 11, No. 1 (2020), p. 5222, (Fig. 2 after digitization).

Chart 10: Estimated entropic dimensions $d_m(\varepsilon)$ versus length scale ε for embedding dimensions $m = 1$ to 8 calculated from the series of standardized monthly flows of Nile assuming time lag 6. D. Koutsoyiannis and A. Georgakakos, "Lessons from the Long Flow Records of the Nile: Determinism vs. Indeterminism and Maximum Entropy," 20 Years of Nonlinear Dynamics in Geosciences, conference in Rhodes, Greece, June 2006, https://www.researchgate.net/publication/266343449_Lessons_from_the_long_flow_records_of_the_Nile_Determinism_vs_indeterminism_and_maximum_entropy (accessed October 3, 2024).

Endnotes

1. Original Greek text: “Αἴγυπτος ἐς τὴν Ἕλληνες ναυτίλλονται ἐστὶ Αἰγυπτίοισι ἐπίκτητός τε γῆ καὶ δῶρον τοῦ ποταμοῦ.”
2. Aris P. Georgakakos, “Decision Support Systems for Integrated Water Resources Management with an Application to the Nile Basin,” in Andrea Castelletti and Rodolfo Soncini-Sessa, eds., *Topics on System Analysis and Integrated Water Resources Management* (Amsterdam, Netherlands: Elsevier, 2007).
3. Demetris Koutsoyiannis and Nikos Mamassis, “From Mythology to Science: The Development of Scientific Hydrological Concepts in the Greek Antiquity and Its Relevance to Modern Hydrology,” *Hydrology and Earth System Sciences*, Vol. 25 (2021), pp. 2419–2444.
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10. Koutsoyiannis and Mamassis, “From Mythology to Science.”
11. Ibid.
12. James Bruce, *Travels to Discover the Source of the Nile, in the Years 1768, 1769, 1771, 1772, and 1773*, 3rd Ed. (Gregg International Westmead, Eng., 1813), https://archive.org/details/travelstodiscov03brucgoog/ (accessed July 24, 2024).
13. Koutsoyiannis and Mamassis, “From Mythology to Science.”
14. Ibid.
15. Barbara Bell, “The Dark Ages in Ancient History. I. The First Dark Age in Egypt,” *American Journal of Archaeology*, Vol. 75, No. 1 (1971), pp. 1–26, https://www.journals.uchicago.edu/doi/abs/10.2307/503678 (accessed July 22, 2024).
16. A fragment of the Egyptian Royal Annals housed in Palermo, Italy, which, among other information, contains measurements of the height of the annual Nile flood and inundation. An image can be seen in Wikipedia, https://en.wikipedia.org/wiki/Palermo_Stone#/media/File:Abhandlungen_der_K%C3%B6niglich_Preussischen_Akademie_der_Wissenschaften_aus_dem_Jahre_(1902)_(16765759871).jpg (accessed August 28, 2024).
17. Rushdi Said, *The River Nile: Geology, Hydrology and Utilization* (Oxford, U.K.: Pergamon Press, 1993).
18. Herodotus mentions the cubit (πῆχυς) as in use in Egypt and other places, including Persia and Greece, and states that the Egyptian cubit is equal to that used in the Greek island of Samos (*The Histories*, Book 1, Chapter 178, Book 2, Chapter 168, and Book 7, Chapter 117).
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25. Ibid.
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27. Said, *The River Nile: Geology, Hydrology and Utilization*, p. 148.
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36. See, for example, Jürgen von Beckerath, "The Nile Level Records at Karnak and Their Importance for the History of the Libyan Period (Dynasties XXII and XXIII)," *Journal of the American Research Center in Egypt*, Vol. 5 (1966), pp. 43–55; Gerard P. F. Broekman, "The Nile Level Records of the Twenty-Second and Twenty-Third Dynasties in Karnak: A Reconsideration of Their Chronological Order," *The Journal of Egyptian Archaeology*, Vol. 88 (January 2002), pp. 163–178; and Mansour Boraik, Luc Gabolde, and Angus Graham, "Karnak's Quaysides: Evolution of the Embankments from the Eighteenth Dynasty to the Graeco-Roman Period," Proceedings of the International Symposium, Mainz Historical Cultural Sciences, Vol. 36 (2017), pp. 97–144, https://library.oapen.org/bitstream/handle/20.500.12657/31477/627663.pdf (accessed July 24, 2024).
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60. Testimonies of a dry Nile exist also from more ancient times. Thus, in a surviving literary text from the Old Kingdom, dated c. 1990 BC and known as the *Prophecy of Neferti* is read: "The river of Egypt is empty, And the waters may be crossed on foot. Men search for water that the ships may sail, But the watercourse has become a riverbank." See Translations of Papyrus Petersburg 1116B: Prophecy of Neferti or Prediction Relating to King Ameny," ArcheologicalResource.com, http://www.archaeologicalresource.com/Books_and_Articles/Literature/pPetersburg1116B_Neferti.html?i=1 (accessed August 6, 2024).

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121. Probably it means 945 AD as the low-level measurement was taken before June 945, corresponding to the month Dhu al-Qidah of year 333 of the Islamic calendar (see Hijri.Habibur, https://hijri.habibur.com/year/ (accessed August 6, 2024)); the measurement is 2 cubits 12 figures. In 943, it was lower, 1 cubit 6 fingers. The measurement of the flood in this year is 15 cubits 12 fingers (not 14 cubits 16 fingers). In year 943 the recorded minimum level was lower, 1 cubit 6 fingers. In the next few years, indeed, the flood never reached 16 cubits.
122. Ancient waters are those before the start of flooding in each year.
123. This information for the year 1360 AD confirms the nilometer record of that year.
124. *Wafâ* or *ouafâ* is the celebration of the start of the flooding period of the Nile held every year.
125. *Misra* is the month of the Coptic calendar corresponding to August 7–September 5.
126. *Bâba/Baba/Babah* is the month of the Coptic calendar corresponding to October 11–November 9.
127. Probably it means 1405 AD as the low-level measurement was taken before June 1405, corresponding to the month Dhu al-Hijjah in year 807 of the Islamic calendar.

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