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Nile Floods and the Irrigation System in Fifteenth-Century Egypt

Of all of the chronicles that survive from the Mamluk period, al-Maqrīzī′s *Khiṭaṭ* is no doubt the most renowned and familiar source for historians. Yet near the beginning of his text, he voices concern about an issue that has thus far remained unexplained and unaccounted for. ″The people used to say,″ al-Maqrīzī writes, ″′God save us from a finger from twenty,′″ meaning ′please, God, don′t let the Nile flood reach the height of twenty cubits on the Nilometer!′″ For, he explains, this dangerously high flood level would drown the agricultural lands and ruin the harvest. Yet in our time, the chronicler bemoans, the Nile flood approaches twenty cubits and this high flood level—far from drowning Egypt′s arable land—doesn′t even suffice to supply them with water.[1] Al-Maqrīzī associates this phenomenon with various problems in the social structure and the economy—including the breakdown of the irrigation system.[2]

The story behind this tale of misery, echoed by other chroniclers, is both more complicated and more revealing than appears at first sight. For not only is al-Maqrīzī correct in his assertion, but—as a seemingly strange coincidence—the Nile floods during his time are in fact much higher than they had ever been before. Was nature conspiring with the economic woes of this period to create this bizarre situation?

I would like to offer a theory that will explain this puzzling coincidence, link it to the catastrophic period of bubonic and pneumonic plague epidemics that started with the Black Death in 1348-49,[3] and give us a sense of the quantitative scale of the breakdown in the irrigation system.

Egypt′s basin irrigation system was the mechanism by which the Nile′s annual flood provided for the winter harvest. As the summer monsoon in Ethiopia swelled

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[1]Al-Maqrīzī, *Kitāb al-Mawā'iẓ wa-al-I'tibār fī Dhikr al-Khiṭaṭ wa-al-Āthār* (hereafter *Khiṭaṭ*) (Cairo, 1270/1853-54), 1:60.

[2]Ibid.

[3]The Black Death actually began in Egypt in late 1347, when a ship arrived in Alexandria with all but a few of its crew and passengers dead—the few survivors died shortly thereafter. The plague then spread rapidly throughout the city (this story of corpse-ridden ships arriving from ports in the Black Sea and Constantinople is repeated by various sources throughout the Mediterranean world). But the main years for mortality from the Black Death were 1348 and 1349.

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the level of the Blue Nile and Atbara rivers, the Nile in Egypt would rise by an average of some 6.4 meters. The system used canals of various sizes to draw this water off the Nile into basins along the Nile Valley and in the Delta. Dikes were then employed to trap the water and allow moisture to sink into the basins (Fig. 1). The alluvium washed down from Ethiopian topsoil also settled on the fields and provided a rich fertilization that guaranteed annual seed-to-yield ratios of up to 1 to 10 for the winter crop.[4]

Yet the irrigation system was very maintenance-intensive. It required constant dredging of canals and shoring up of dikes in order to work efficiently. Failure to do so would mean that the Nile flood would wash in and out of the basins without providing enough moisture or fertilizer.[5]

Before discussing the hydraulic dynamics of the basins, we need to look at the Nilometer itself and the dynamics of measurement and sedimentation (Fig. 2). The Nile was at its minimum around the beginning of June and would rise and then reach its maximum level around the end of September. Over the course of centuries—from the time of the construction of the Roda Nilometer to the early Mamluk period—the levels of the minimum and maximum increased at a steady rate. This was because the Nile alluvium from the Ethiopian topsoil left a small amount of sediment on the bed of the Nile each fall (as it had done since the end of the last ice age). So as the river bed rose—at the rate of about 10 centimeters per century—so did the June minimum and September maximum.[6]

Between 750 and 1260, the rising layer of sediment pushed up the level of the river bed, the June minimum, and the September maximum. All three rose at

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[4]Ibn Mammātī, *Kitāb Qawānīn al-Dawāwīn,* ed. A. S. ʻAṭīyah (Cairo, 1943), 259.

[5]Khalīl ibn Shāhīn, *Kitāb Zubdat Kashf al-Mamālik wa-Bayyān al-Ṭuruq wa-al-Masālik,* ed. Paul Ravaisse (Paris, 1894), 128-29; al-Qalqashandī, *Ṣubḥ al-Aʻshá fī Ṣināʻat al-Inshā',* ed. M. Ḥusayn al-Dīn (Beirut, 1987), 3:515-16 (hereafter *Ṣubḥ*). For a discussion of irrigation repairs in a wider context, see Hassanein Rabie, ″Some Technical Aspects of Agriculture in Medieval Egypt,″ in *The Islamic Middle East, 700-1900: Studies in Social and Economic History,* ed. Abraham Udovitch (Princeton, 1981), 59-90. For data on irrigation repairs during the Ottoman period that demonstrates the expenditure needed to maintain the system, see Stanford Shaw, *The Budget of Ottoman Egypt 1005-1006/1596-1597* (The Hague, 1968), 124, and idem, *The Financial and Administrative Organization and Development of Ottoman Egypt 1517-1798* (Princeton, 1962), 61-63.

[6]Rushdī Saʻīd, *The River Nile* (New York, 1993), 162-88; Barbara Bell, ″The Oldest Records of Nile Floods,″ *Geographical Journal* 136 (1970): 569-73; Karl W. Butzer, *Early Hydraulic Civilization in Egypt: A Study in Cultural Ecology* (Chicago, 1976), 28; John Waterbury, *Hydropolitics of the Nile Valley* (Syracuse, N.Y., 1979), 25; John Ball, *Contributions to the Geography of Egypt* (Cairo, 1939), 176.

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roughly the same rate—between .5 and .6 meters total, or an average of slightly more than 10 centimeters per century.[7]

Contemporary observers knew about the buildup of alluvium on the Nile river bed and they report that the ideal level of the September maximum in the thirteenth and early fourteenth centuries was about 17 cubits. A level of 14 or 15 was too low and would leave many of the basins dry, while 19 or 20 cubits was too high and would flood the basins with too much water and damage the harvest.[8]

Over the course of the next two and a half centuries—from 1260 to 1502—the June minima oscillated but on average continued to rise at the same rate as before: roughly 10 centimeters per century.

Fig. 3 shows the increase in the June minimum between 750 and 1502. Note that the minimum has increased by 34 centimeters between 1260 and 1502: over the course of these two and a half centuries it rose at a fairly normal rate of 14 centimeters per century.[9]

However, in the fifteenth century, the records of the maximum flood in September begin to tell us a dramatically different story—a story that brings us back to our introduction and al-Maqrīzī´s concern about the changing impact of high flood levels. Ibn Iyās, al-Qalqashandī, and al-Maqrīzī all report that the Nile flood was reaching abnormally high levels as measured at the Cairo Nilometer. They also report that the very high level of 20 cubits, previously considered a dangerous overflood that would ruin the crop, was now leaving many of the basins dry.[10] They all mention this phenomenon while discussing problems in the Mamluk economy and polity, including the extensive decay of the irrigation system.[11]

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[7]The data for the Nile levels are from William Popper, *The Cairo Nilometer* (Berkeley and Los Angeles, 1951), 221-23 (hereafter Popper, *Nilometer*).

[8]Al-Maqrīzī, *Kitāb al-Sulūk li-Ma'rifat Duwal al-Mulūk,* ed. Sa'īd 'Abd al-Fattāḥ 'Āshūr (Cairo, 1934-73) (hereafter *Sulūk*), 2:753 in 748/1347, 2:769 in 749/1348; *Ṣubḥ* (referring to the fourteenth century), 4:516; Ibn Iyās, *Nuzhat al-Umam fī al-Ajā'ib wa-al-Ḥikam,* ed. M. Zaynahum Muḥammad 'Azab (Cairo, 1995), 88-89 (referring to the fourteenth century); *Khiṭaṭ* (referring to the fourteenth century), 1:60; 'Abd al-Laṭīf al-Baghdādī, *Kitāb al-Ifādah wa-al-I'tibār,* ed. and trans. K. H. Zand, John Videan, and Ivy Videan (London, 1965); Zakariyā' ibn Muḥammad al-Qazwīnī, *Āthār al-Bilād wa-Akhbār al-'Ibād,* ed. Wüstenfeld (Gottingen, 1848-49), 1:175, as cited in Popper, *Nilometer;* Ibn Baṭṭūṭah, *Tuḥfat al-Nuẓẓār,* ed. and trans. C. Defremery and B. R. Sanguinetti as *Voyages d'Ibn Batoutah* (Paris, 1914-22), 1:78-79, as cited in Popper, *Nilometer,* 81.

[9]Data from Popper, *Nilometer*, 221-23.

[10]*Ṣubḥ,* 3:515.; Ibn Iyās, *Nuzhah*, 88-89; *Khiṭat,* 1:60.

[11]*Ṣubḥ,* 3:516; *Sulūk,* 4:564 in 824/1421, 4:618 in 825/1422, 4:646 in 826/1423, 4:678 in 828/1425, 4:709-10 in 829/1426, 4:750-53 in 830/1427, 4:806-9 in 832/1429, 4:834 in 833/1430, 4:863, 874 in 835/1432, 4:903-4 in 837/1434, 4:831, 950 in 838/1435. *Khiṭaṭ,* 1:101. Muḥammad ibn Khalīl al-Asadī, *Kitāb al-Taysīr wa-al-I'tibār,* ed. Aḥmad Ṭulaymat (Cairo, 1968), 92-93. Ibn Taghrībirdī, *Ḥawādith al-Duhūr fī Madá al-Ayyām wa-al-Shuhūr,* ed. William Popper (Berkeley and Los

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Indeed if we compare flood records for the Nile minima (Fig. 3) and Nile maxima (Fig. 4), we see that while the June minimum rose at its regular rate, the September maximum increased dramatically over the course of these two and a half centuries, rising by almost twice as much as it had increased in the previous five centuries. Furthermore, 90% of this increase occurred in the 150 years following the arrival of the Black Death and the onset of repeated plague epidemics.[12]

Why did the September maximum jump by such an unprecedented amount over the course of 150 years? An intensification of the Indian Ocean monsoon would be a possible cause, and yet there are no accounts of a dramatic increase in rainfall for this period in Yemen, East Africa, or the Indian subcontinent.[13] The Nile flood variations at this time are also normal compared to earlier periods in Egypt´s history; again indicating that environmental factors are not to blame.[14] Shifts in the course of the Nile also occurred over time, but shifts in the river that affected the Nilometer bedrock would also appear as an aberration in the Nile minima data; they do not. William Popper briefly addressed this issue, but failed to note the true significance of the data for this period.[15]

My explanation rests upon quantitative data drawn up by a nineteenth-century hydraulic engineer who observed the Upper Egyptian basins before they had converted to perennial irrigation.[16] The Upper Egyptian basins would be filled from August 12 to the 21st of September. Each basin would be filled to an average level of one meter and the water and sediment would settle in the basin for an average of 40-50 days before being drained back into the Nile in October. Willcocks calculated the average volume of water drawn into the Upper Egyptian basins and the average loss due to evaporation before being drained back into the Nile.[17]

Now, if we take a total of some 2 million feddans (of 4200m^2 each) of basins in Upper Egypt (based on a rough computation from the 1315 Rawk al-Nāṣirī)[18] then the total volume of water drawn from the Nile in Upper Egypt from August

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Angeles, 1930-31), 4:673. Ibn Iyās, *Nuzhah,* 182. Ibn Iyās´s testimony from *Badā'i' al-Zuhūr fī Waqā'i' al-Duhūr,* ed. Muḥammad Muṣṭafá (Wiesbaden-Cairo, 1961-75), as cited and quoted in Carl F. Petry, *Protectors or Praetorians?* (Albany, 1994), 114-15, 124-25.

[12]Data from Popper, *Nilometer,* 221-23.

[13]H. H. Lamb, *Climate, History, and the Modern World* (London and New York, 1995), 185, 208-9; Robert I. Rotberg and Theodore K. Rabb, *Climate and History: Studies in Interdisciplinary History* (Princeton, 1981), 12-13.

[14]Popper, *Nilometer,* 180.

[15]Ibid., 242-43.

[16]W. Willcocks, *Egyptian Irrigation* (London, 1889) (hereafter Willcocks, *Irrigation*).

[17]Ibid., 61-65.

[18]Ibn al-Jī'ān, *Kitāb al-Tuḥfah al-Sanīyah*, ed. Mortiz (Cairo, 1898).

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12 to September 21st is 8.4 billion cubic meters over this period, or 2,430 m^3/sec. Let us assume that from 1355 to 1502, the Upper Egyptian irrigation system decayed and many of the basins were no longer functioning. Most of the water formerly trapped in these basins is now being swept down to Cairo.[19] What does this do to the September maximum flood level? We have the following graph based on a table by Willcocks that allows us to correlate volumetric discharge with the maximum Nile levels based on a gauge at Cairo (Fig. 5).[20]

Note in the following table that if we take the .88 meter jump in the maximum from 1355 to 1502 and subtract 15 centimeters for normal alluvium buildup on the river bed, we have a .73 meter rise to account for. If we look at the table of volumetric discharge versus flood height we see that the difference in volumetric discharge for 1 meter (between meter 8 and meter 7 on Willcocks′ gauge) is 2200 m^3/sec. If we then multiply 2200 m^3/sec by .73 meters we end up with an additional 1600 m^3/sec (1606 m^3/sec exact) of flood water coming from Upper Egypt. This suggests that 1600 m^3/sec of Nile water out of the normal 2,430 m^3/sec is no longer being drawn off into the basins in Upper Egypt. Taken at face value, this would suggest that 1600/2430, or some 2/3, of the basins in Upper Egypt were no longer operational: all of this in the 150 years following the onset of the plagues.

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[19]Abd al-Laṭīf al-Baghdādī′s observations for an earlier period demonstrate this phenomenon. In 596/1200 there was an unprecedented and disastrous Nile maximum of only 12 cubits and 21 fingers. The famine that followed caused the peasants to flee their villages in large numbers (this seemingly contradictory tendency of peasants to flee to urban centers during famines was due to the grain storage facilities located there—this type of rural flight was also witnessed immediately following the Black Death, although the reasons were more complex). Al-Baghdādī reports that the floods washed in and out of unmanned and uncontrolled irrigation channels and basins. This in turn led to another short and disastrous flood, although the level should have been more than enough to water all of the agricultural lands. According to his account, in the two years following the devastatingly low flood, the flood waters ″receded without the country having been sufficiently watered, and before the convenient time, because there was no one to arrest the waters and keep them on the land,″ al-Baghdādī, *Kitāb al-Ifādah wa-al-I′tibār,* 253-54. Al-Maqrīzī reports that the same phenomenon occurred following the first and most devastating outbreak of the new, mutant strain of *Pasteurella pestis* (i.e., the Black Death, 1348-1349). In 751/1350, the Nile flood ″reached 17 cubits—but then dropped down: much of the land was left dry. This ′drought′ lasted for three years and matters became grievous for the people because of the lack of peasants (*fallāḥīn*),″ *Sulūk,* 2:832-33.

[20]Willcocks, *Irrigation*, 66.

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Table: Volume Discharge vs. Height of Nile

Volumetric Discharge of Water at Cairo	Height of Nile (19th Century gauge)	Difference in m^3/sec between 1m on gauge
9800 m^3/sec	8m	2200 m^3/sec
7600 m^3/sec	7m	1750 m^3/sec
5850 m^3/sec	6m	1500 m^3/sec
4350 m^3/sec	5m	1250 m^3/sec
3100 m^3/sec	4m	970 m^3/sec
2130 m^3/sec	3m	

Volume of water in 1 ″modern″ feddan square = 4200 m^3
Total number basin feddans in Upper Egypt = 2 million ″modern″ feddans
Total volume of water taken by basins in Upper Egypt over 12 Aug - 21 Sep 4200 m^3 x 2 million ″modern″ feddans = 8.4 billion m^3
Total volume of water taken per second from the Nile from 12 Aug to 21 Sep 8.4 billion m^3/(40 x 24 x 60 x 60) = 2430 m^3/sec

Let us examine another piece of this puzzle that may illuminate this linkage more clearly. Again relying on a graph drawn by Willcocks, we can observe the ordinary difference between the autumn flood profile as measured at Aswan and that measured at Cairo (Fig. 6).[21]

We can see on this graph that the flood reaches a higher peak at Aswan and then drops to a lower level much more quickly than the flood at Cairo. The peak is initially lower at Cairo because the upstream basins are being filled. The flood level then drops more slowly at Cairo as the basins are sequentially emptied. There is additionally a secondary peak at Cairo which appears in the late autumn as the last of the upstream basins are emptied at the same time. If a large percentage of the upstream basins had ceased functioning, their effect on the Nile level at Cairo would diminish and we would see the two flood profiles—Aswan and Cairo—slowly converge.

In fact we have already been looking at this process in the data above: the ″jump″ in the Nile maxima brings the Cairo flood peak up closer to Aswan´s.

[21]Ibid.

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But there is more here: the flood profiles following the Nile maximum—in October and November—also appear to converge. In the fifteenth century there are abundant references to floods which are ″too short,″ or ″receded too quickly,″ or fell ″too soon.″ Al-Maqrīzī makes numerous references to this trend in the 1420s and 1430s, often during years in which the Nile maximum was between 19 and 20 cubits.[22]

Carl Petry quotes what may be a colorful illustration of this phenomenon from Ibn Iyās in 916/1510, when a woman´s dream about the coming flood was widely reported in Cairo: ″It was said that she beheld in a vision two angels descending from Heaven. They proceeded to the river, and after one of them touched its surface with his foot, it sank rapidly. The angel then addressed his companion: ′Truly, God the All-High did order the Nile to reach a level of twenty cubits. But when tyranny prevailed in Egypt, he caused its sinkage after only eighteen!′ Upon the woman´s awakening the next morning, the Nile had indeed fallen over the night by the foretold measure.″[23]

The data for the late autumn flood profile are far from comprehensive. Yet if they are taken together with the convergence in the Aswan/Cairo maxima—and the rest of the quantitative data—basin decay seems to be the only probable cause for the flood variations in this period.

But why did the Upper Egyptian basins decay? Was it due to rural depopulation from the plague or were there other elements involved?

It is beyond the scope of this article to go into a full analysis of the economic dynamics of the plague´s impact, but I would like to discuss one crucial development that played a major role in Upper Egypt. Here there was a seemingly paradoxical reaction to the plagues´ decimation of the rural population: as settled agriculture decayed, the power and even the population of bedouin tribes grew in tandem.[24] There were two reasons for this; both had to do with an ecological niche that was opened by *Pasteurella pestis*. The first of these was the environmental product of basin decay. The breakdown of the basin system—accelerated by the bedouin

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[22]*Sulūk,* 4:646 in 826/1423, 4:678 in 828/1425, 4:709-10 in 829/1426, 4:750-52 in 830/1427, 4:806 in 832/1429, 4:834 in 833/1430, 4:903-4 in 837/1434, 4:931, 950 in 838/1435.

[23]Petry, *Protectors*, 105.

[24]Among the many studies which highlight this problem, see J. C. Garcin´s study of bedouin incursions in Qūṣ in Upper Egypt: Garcin, *Un centre musulman de la Haute-Egypte médiévale, Qūs* (Cairo, 1976), 468-507; Sa'īd 'Abd al-Fattāḥ 'Āshūr, *Al-Mujtama' al Miṣrī fī 'Aṣr Salāṭīn al-Mamālīk* (Cairo, 1993), 59-63; idem, *Al-'Aṣr al-Mamlūkī fī Miṣr wa-al-Shām* (Cairo, 1994); Petry, *Protectors*, 106-13. Stanford Shaw notes that it took the Ottomans over a century to subdue bedouin tribes in Upper Egypt, a task that was never fully realized; see Shaw, *Ottoman Egypt 1517-1798,* 12-13, 19.

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tribes themselves[25]—did not lead to desertification. The product of breakdown was rather the emergence of wasteland that was no longer suitable for grain agriculture. With the Nile flood no longer under control and water sweeping in and out of the basins, the effect was an expansion in the category of land known as *khirs*. *Khirs* was the category applied to areas not suitable for agriculture due to the proliferation of weeds and lack of proper maintenance. It was the most extreme of the three land-clearing categories (the other two being *al-wisikh al-muzdara'* and *al-wisikh al-ghālib*). It was also associated with the categories of *sharāqī* (unirrigated) and *mustabḥar* (flooded).[26] It was the natural product of any area of the flood basin which was no longer controlled by dikes and canals. It was not suitable for agriculture—not unless the irrigation system were restored and the land arduously weeded and plowed.

Yet *khirs* was quite well suited to the bedouin economy. Nomadic pastoralists, leading their grazing livestock over marginal scrub areas, could ask for no better terrain than the weedy product of Egypt′s collapsing irrigation system. Their arrival in these areas, and their use of *khirs,* went hand in hand with Egypt′s post-plague irrigation problems. The bedouin spread because the land was becoming increasingly suitable for their way of life, just as it had become wasteland for agriculturalists.[27]

The second contribution to the growth of bedouin powers and numbers came from another environmental factor that was just as important: the bedouin had a relative ″immunity″ to the plague. This was by no means an immunity in the ordinary biological sense. If any part of Egypt′s population were to develop a hereditary biological immunity, it would have been the more densely populated agrarian communities and urban centers,[28] but modern medical studies have shown no evidence that human populations develop hereditary adaptive immunities to *Pasteurella pestis.*[29]

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[25]It was often the practice of the bedouins to deliberately break the dikes as a means of taking over and adapting the land for their use. See, for example, *Sulūk,* 2:832-33; Petry, *Protectors*, 124-25.

[26]*Khiṭaṭ*, 1:100-101.

[27]This was not universally the case. When bedouin shaykhs assumed the role of *muqṭa'* for the land they controlled, some of them did oversee agrarian production. See 'Āshūr, *Al-Mujtama',* 59.

[28]Had that been the case, the bedouin would have been more vulnerable to the plague over time, not less (as was the case for other communicable diseases that appeared earlier, such as smallpox and measles).

[29]It is theoretically possible that a population of Homo sapiens, under continual and prolonged pressure from one particular strain of *Pasteurella pestis*, could develop a hereditary resistance. However, if this is the case, the mutual adaptation period must be in the range of hundreds of years. Lawrence I. Conrad stresses that twentieth century medical studies have shown no evidence

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The bedouin tribes were less vulnerable because of their primary mode of subsistence. Living in less densely crowded conditions, pursuing a more autarchic economy, and engaging only tangentially in agrarian production, the bedouin were far less susceptible to the deadly locus of rat and flea concentration that devastated other population groups in Egypt.[30] This ″immunity″ allowed them to thrive during the devastating plague years. These two environmental factors thus opened a large ecological niche which allowed the bedouin to turn many areas of organized basin agriculture into pastoral land upon which they flourished.

The interaction between agrarian plague depopulation and the bedouin mode of subsistence thus offers a likely explanation for the decay of the Upper Egyptian basins. The decay of these basins further explains the ″puzzling coincidence″ between the high floods of the fifteenth century and the failure of these floods to irrigate agricultural areas in both the Nile Valley and the Delta. Finally, the hydraulic calculations allow us to estimate the scale of this phenomenon in Upper Egypt: probably half or more of the basins there were no longer functioning.

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of adaptive immunities in exposed populations: see ″The Plague in the Early Medieval Near East,″ Ph.D. diss., Princeton University, 1981, 32-33.

[30]This pattern, and the contagious nature of *Pasteurella pestis*, was first recognized by Ibn Khaṭīb, a fourteenth century Andalusian doctor and observer of the Black Death′s impact on different segments of the population. See Michael Dols, *The Black Death in the Middle East* (Princeton, 1977), 65. For a good analysis of the bedouins′ environmental resistance to *Pasteurella pestis*, see Conrad, ″The Plague in the Early Medieval Near East,″ 466 f.

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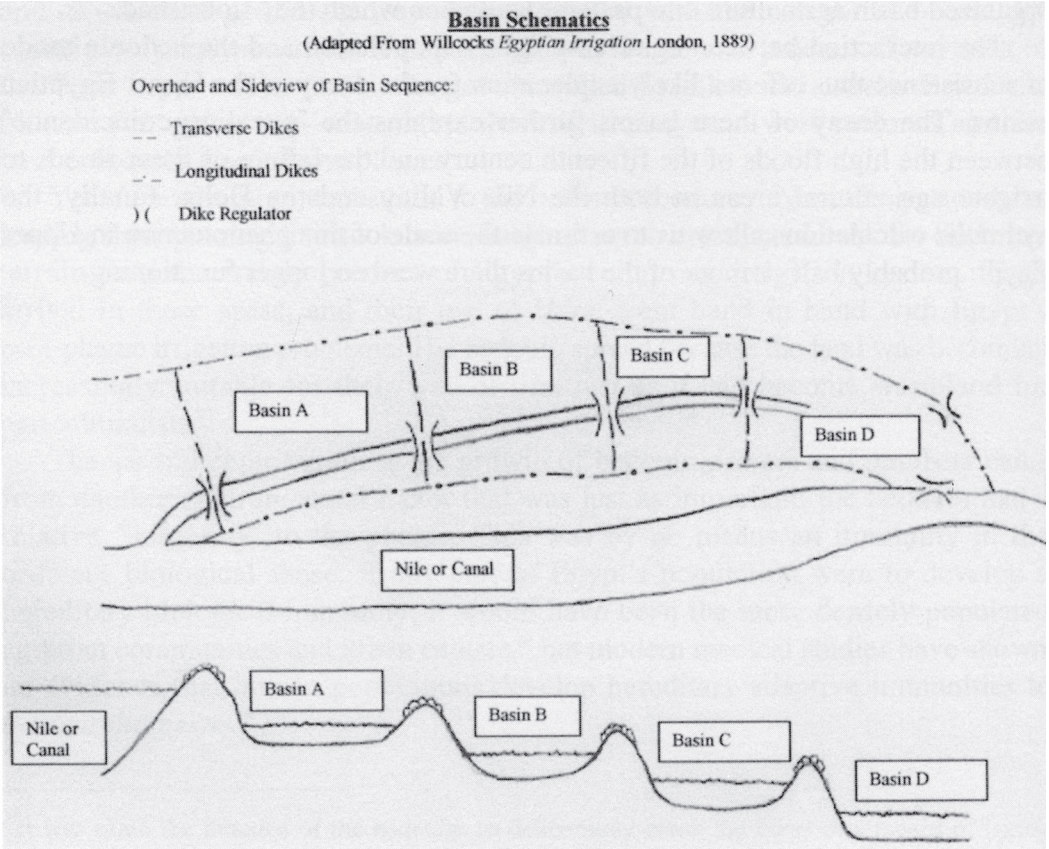

Figure 1. Basin Schematics

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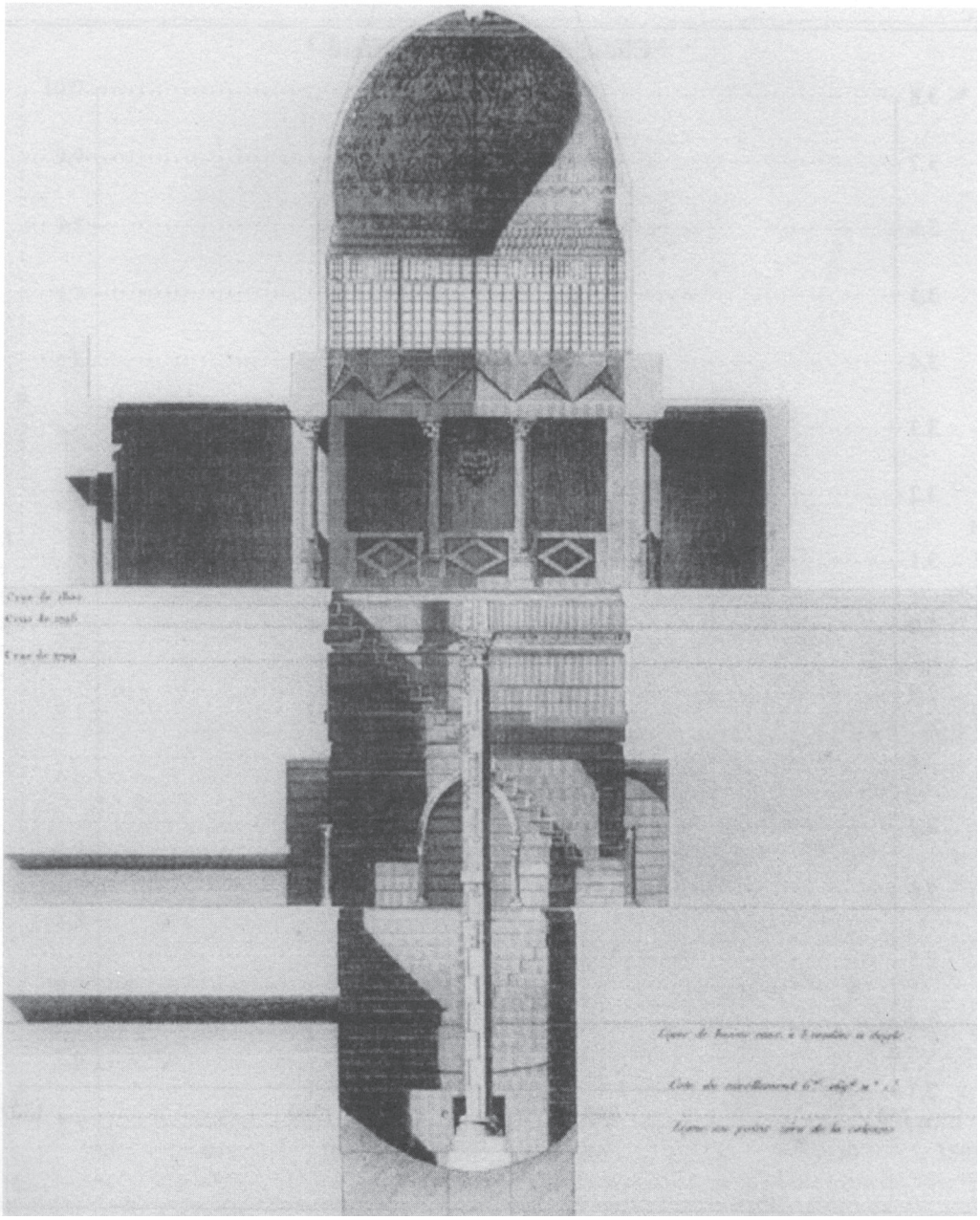

Figure 2. The Nilometer

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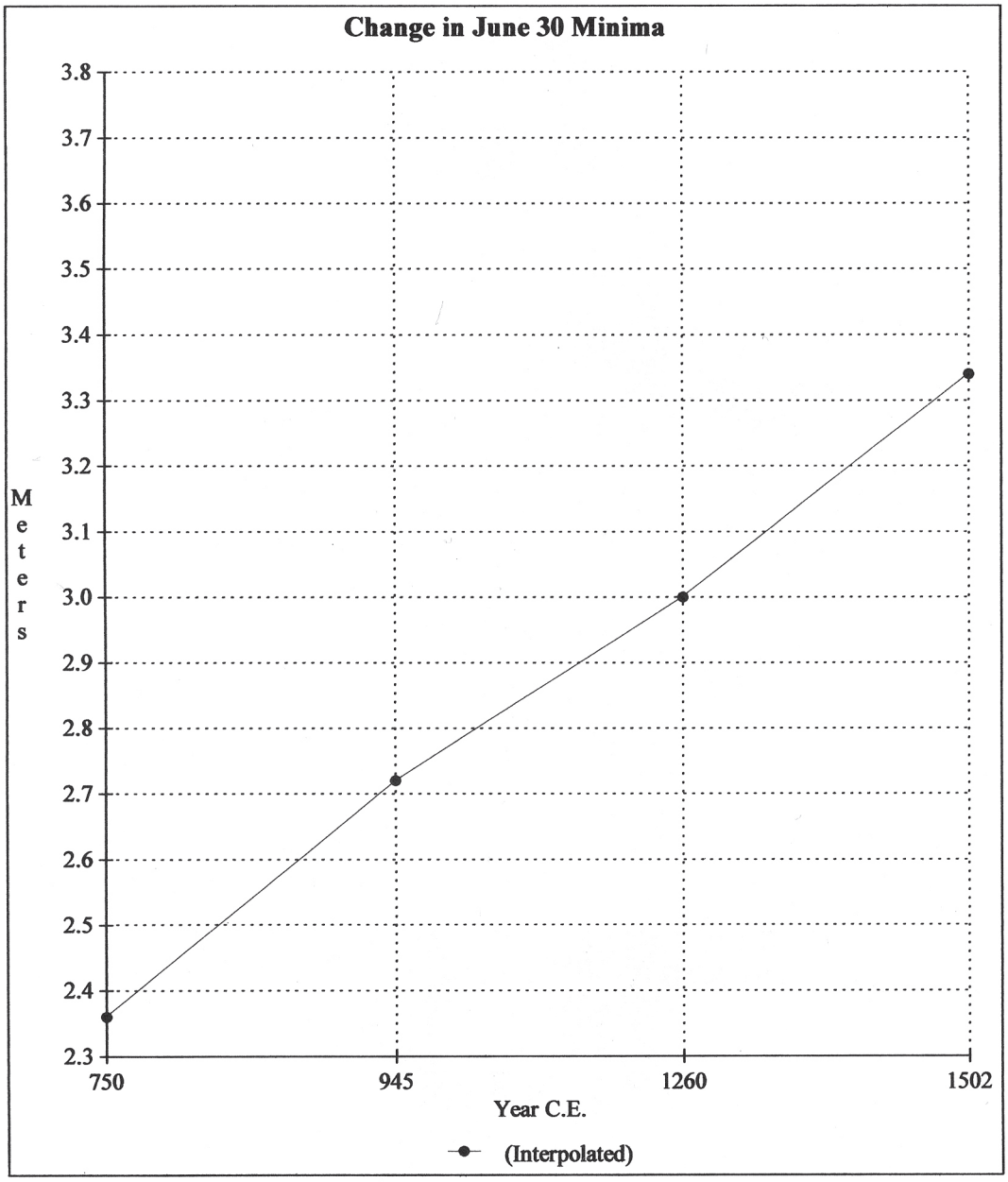

Figure 3. The Nile Minima

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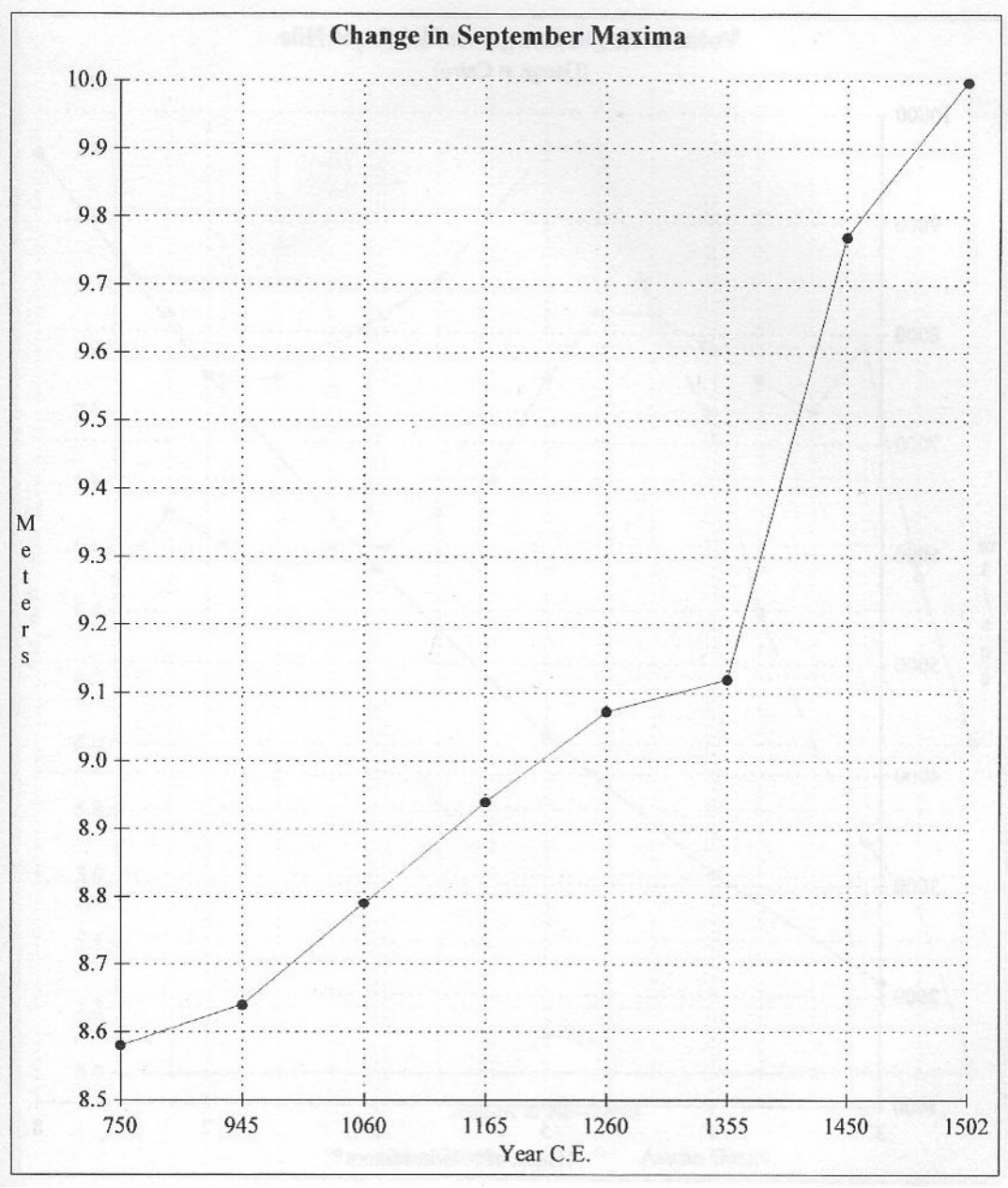

Figure 4. The Nile Maxima

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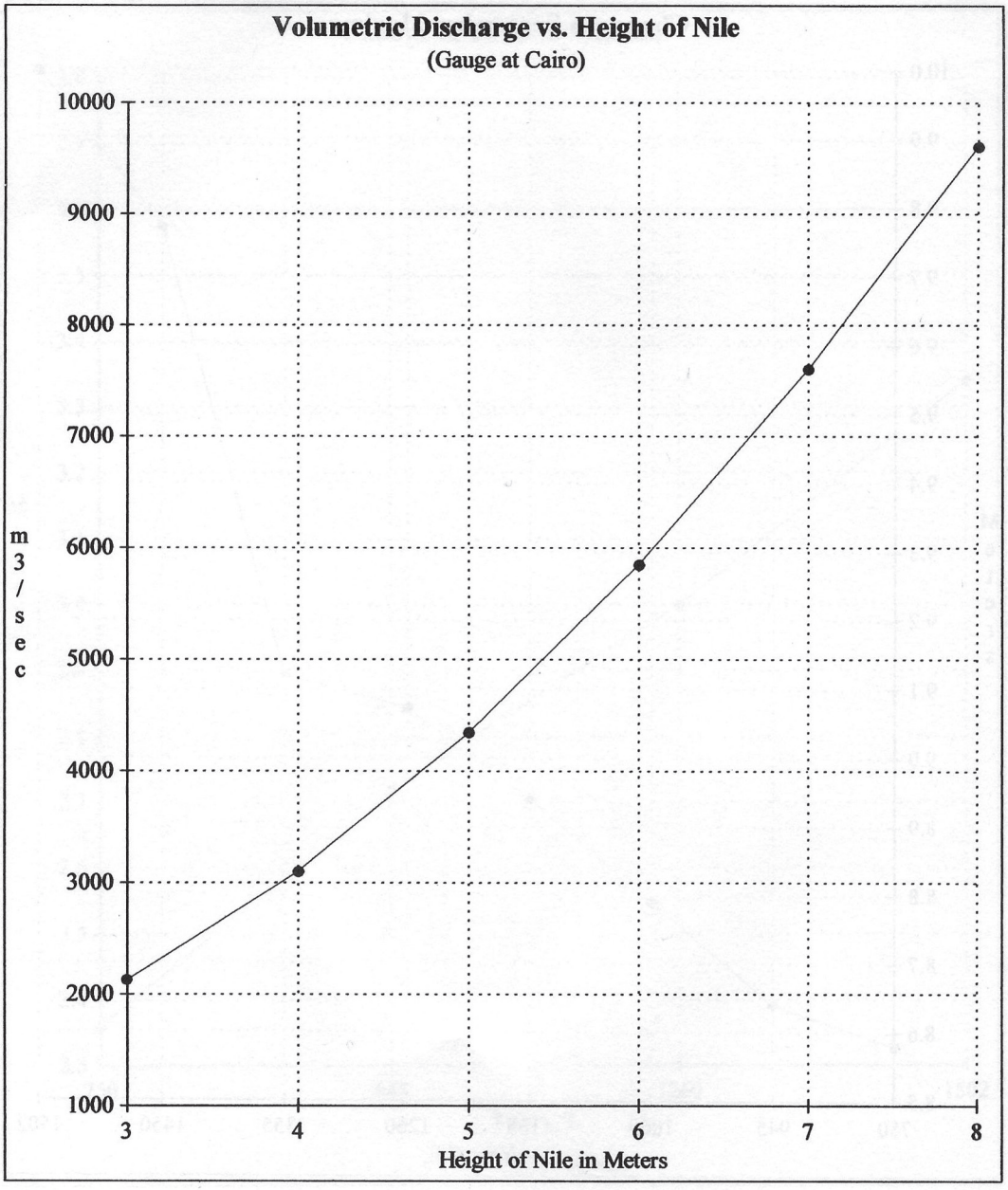

Figure 5. Volumetric Discharge vs. Height of Nile

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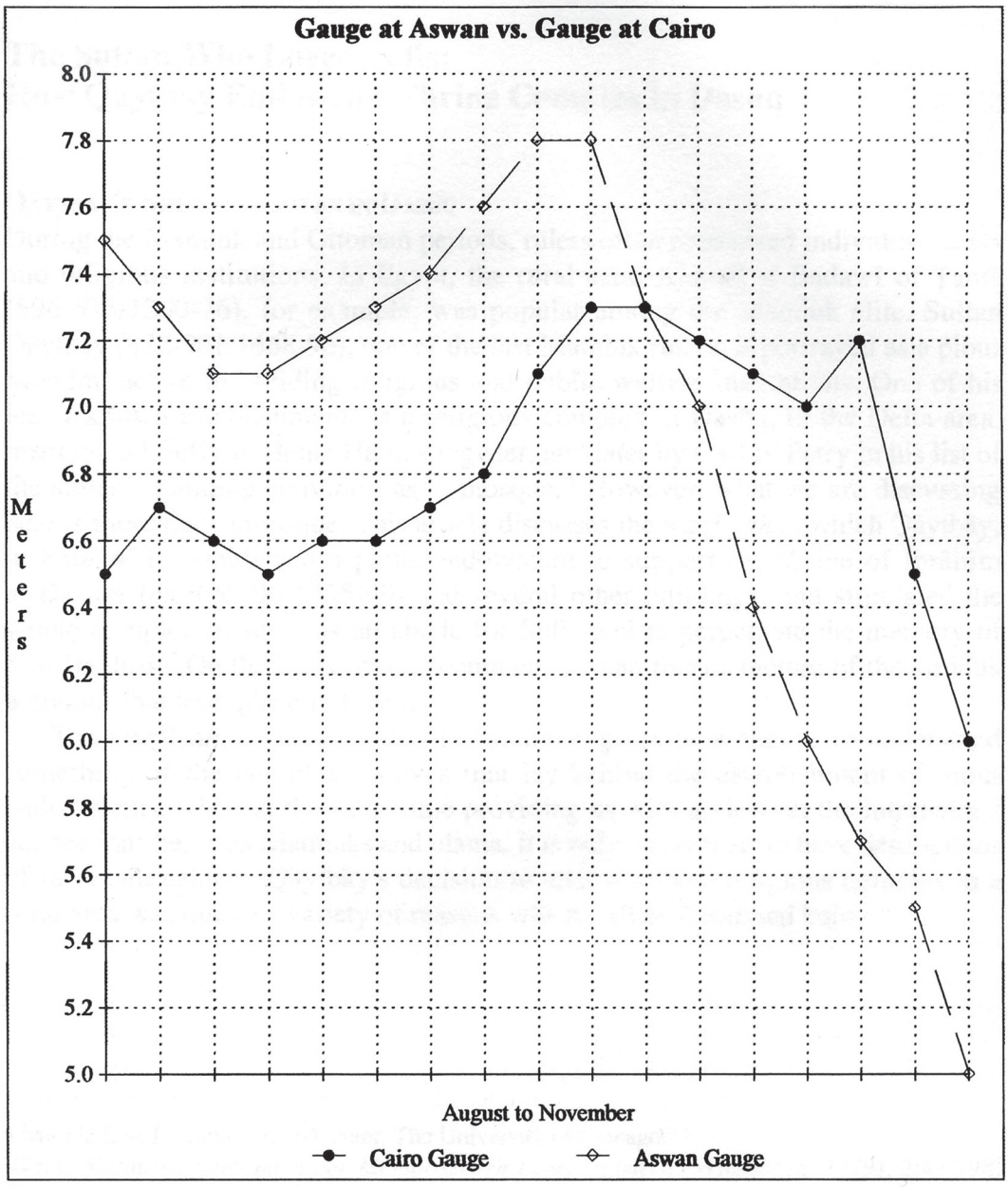

Figure 6. Aswan vs. Cairo Flood Profiles

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