4 The Egyptian Nile: Human Transformation of an Ancient River

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Summary

The Nile, the longest river of the world, connects Northeast Africa from its headwaters near Lake Victoria to the Mediterranean Sea. This chapter focuses on the Nile in Egypt, where the river's annual inundation (until the building of the two modern dams at Aswan) was the source of the country's fecundity and guarantor of its civilization since the 6th millennium BCE. While the historical population of Egypt remained at a maximum of c. four million people until the mid-19th century when Vice-Roy Muhammad Ali modernized the country, in 2019 the number passed the threshold of 100 million people. Increased demographic pressure, the alteration of the country's ecology through the mega-impact of the construction of the Aswan High Dam, and industrialization have led to a massive transformation of the Nile River system. One of the consequences has been an almost complete extinction of the country's native fauna and flora. The overuse of the water (rice and cotton irrigation projects) and the absence of the river's historical natural sedimentation have had irreversible effects on Egypt's agriculture and heritage (salination; disappearance of archaeological sites) and caused land loss to rising sea levels in the delta. In view of the environmental degradation in the Nile valley, and the dangers to Egypt's water security posed by overpopulation and the construction of the Merowe dams in Sudan and the Renaissance dam in Ethiopia, sustainable water management is of critical importance.

4.1 Introduction

The Nile was considered a wonder of nature in Classical antiquity, represented in literature and art such as the famous Nile mosaic from Praeneste (Schrijvers 2007, Manolaraki 2013, fig. 4.1). The ancient Egyptians worshipped the annual flood of the Nile in the form of the god Hapy. Their life and economy depended so exclusively on it that the Nile River system has been more recently described as a social cage for its inhabitants (see for an explanation 4.3.1). The description of Egypt as the *gift of the Nile* by the Greek historian, Herodotos, refers to the fact that the Nile Delta and a part of the river valley were progressively sedimented up by the river (see 4.6); a natural process stopped – like the annual flooding – by human intervention in the 20th century. A corridor throughout northeast Africa, the Nile is the lifeline particularly for the Sudan and Egypt and has nurtured human civilization here from the beginning of a perennial flood regime 8,000 years ago, to the present. At the same time, the modern history of the Nile in Egypt is a key paradigm for overuse and degradation of the

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Fig. 4.1 Graphical summary of Nilotic history in Ancient Egypt. ***Top Left***: Image of a shadoof (Carleton H. Graves 1904, Gelatin silver print, 84.XC.979.3996, The J. Paul Getty Museum, Los Angeles, Gift of Weston J. and Mary M. Naef). Photo: Getty's Open Content Program. ***Center top left***: Cairo Nilometer, Rhoda Island (Photo: Baldiri, CC BY 3.0.). https://en.wikipedia.org/wiki/Nilometer#/media/File:Cairo_Nilometer_2.jpg. ***Center top right***: Zangaki, Water Buffalo in the Nile 19th century, albumen print (Detroit Institute of Arts, Collection of The Detroit Institute of Arts, 1988.89). Photo: The Detroit Institute of Arts. https://www.dia.org/art/collection/object/water-buffalo-nile-65801. ***Center***: Crocodile god Sobek, Book of the Fayum, 1st century BCE – 2nd century CE (The Walters Art Museum, W.738, Museum purchase 1949 and Gift of The Morgan Library & Museum, 2012, CC0 1.0). ***Top Right***: Old Aswan Dam 1910–19150 (Library of Congress, Prints & Photographs Division, LC-DIG-ggbain-12415, George Grantham Bain Collection). http://hdl.loc.gov/loc.pnp/ggbain.12415. ***Bottom Left***: Image of fishing and fowling, Tomb of Menna (TT 69), north wall (Metropolitan Museum of Art 30.4.48. Painting: Norman de Garis Davies, CC0 1.0). ***Bottom Center***: The Flooded Courtyard of Amenhotep III in the Luxor Temple (Photo: Antonio Beato, Getty Collection Object 84.XM.1382.9). Photo: The Getty's Open Content Program. ***Bottom right***: Unification iconography featuring the inundation god Hapy, statue base of Ramesses II, Luxor (Photo: Christine Johnston)

natural habitat, and the threat to the country's cultural heritage. With a growth in population from three to 100 million people in Egypt since the mid-19th century within an inhabitable area (Nile valley and delta) that is the size of Belgium (32,000 km^2) and a modest average annual discharge equivalent to that of the Rhine, the Nile represents a most vulnerable resource. An ancient river turned progressively into a 'giant irrigation canal' (Dumont 2009, pp. 1–2), the quickly rising demands of agriculture, industry, and households, on the river have only exacerbated the social cage situation from which the building of the Aswan High Dam was to liberate Egypt.

4.2 Geophysical setting

The Nile is one of the world's largest river systems. Credited with being 6,695 km long (Times Atlas 2018), it has two main tributary systems, the White Nile and the Blue Nile (fig. 4.2). Meeting at Khartoum in Sudan, they form the mainstem Nile that flows northwards through Egypt into the eastern Mediterranean Sea. The White Nile rises from the Lake Victoria basin on the equator in Uganda at an elevation of 1,135 m above sea level. As it reaches Southern Sudan, it flows into a wetland about 57,000 km^2, known as the Sudd. From the Sudd, it traverses a variety of tropical, sub-tropical and increasingly arid habitats until it is joined by the Blue Nile at Khartoum. Emerging from Lake Tana in the Ethiopian Highlands, at an elevation of 1,890 m, the Blue Nile is shorter than the White, but contributes 80% of the total average annual discharge of the Nile River.

The White Nile has a fairly steady discharge of around 580 $m^3 s^{-1}$ rising to around 1200 $m^3 s^{-1}$ during the winter rains (Murakami 1995; fig. 4.2). The downstream impact of this increased discharge is moderated by the enormous wetland of the Sudd. The sediment transported by the river comprises mainly quartz and feldspar (Woodward 2007) which, being white, give the river its name. The Blue Nile and the other main tributary, the Atbara River, rise in Ethiopia. They receive monsoon rain in their catchments during

July, August, and September when their discharge rises dramatically from less than 200 to more than 8000 $m^3 s^{-1}$. The eroded basalts of the Ethiopian Highlands contribute dark clay minerals to the river sediment load that create the fertile soils of Egypt. The color of the Blue Nile at Khartoum is normally blue but changes to red during the flood, contrasting strongly with the White Nile at the confluence. From Khartoum, the Nile travels into the Sahara Desert in northern Sudan before being captured by the large reservoir of Lake Nasser (3,262 km^2) that straddles the Sudanese-Egyptian border.

The river channel is around 500 m wide and 10 m deep at its deepest point (except when in flood). This is roughly consistent from Khartoum to Cairo, where the Nile system starts to form the distributary channels of the delta. Although the channel is of fairly consistent size, the floodplain varies depending upon the local topography, from almost no floodplain in northern Sudan in the area of the cataracts, to 10 km or more width of floodplain in Middle Egypt. Before the construction of the Aswan High Dam (initiated in the late 19th century) river floodwaters rose naturally to inundate the Nile Valley in Egypt for four months of the year (late June to late September). An ideal flood rise was considered to be around 6 m and the fertile silt that was deposited by the receding floodwaters. Since the construction of dams (see below), the floodwaters (and sediment) have been trapped in Lake Nasser and water is released at an approximately constant rate, meaning that the river level now fluctuates little in Egypt. The absence of nutrient-laden

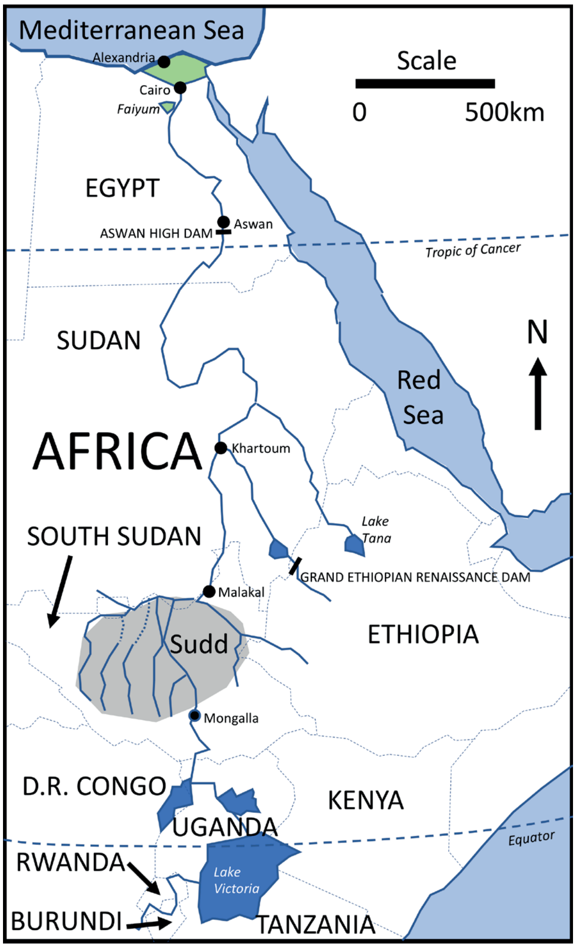


Fig. 4.2 Map of the Nile Basin including the Blue and White Nile tributaries. Map: compiled from GoogleEarth and the Times Atlas of the World (2018), with permission

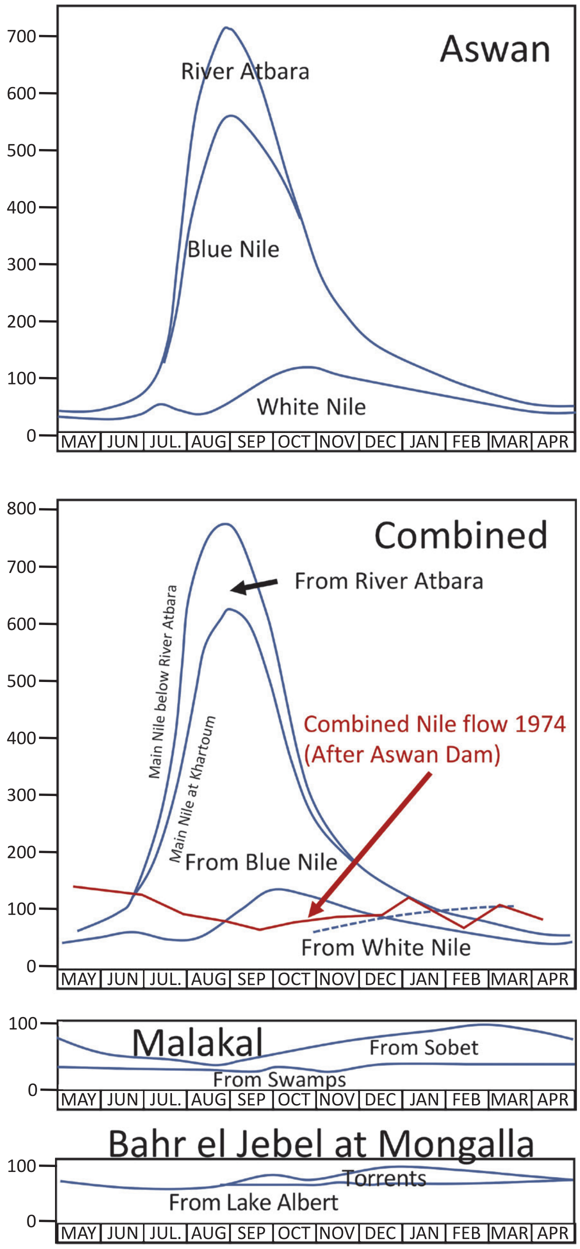


Fig. 4.3 Hydrographs for the Nile River system and stations (million $m^3 d^{-1}$), monthly averages of 1871–1965 before the construction of the Aswan High Dam, at the most prominent gauging stations that are shown on the accompanying map. Graphs: after Murakami (1995), based on Hurst (1952), with permission

Table 4.1 Main characteristics of the Nile River basin in Egypt – Areas upstream of the Egypt/ Sudan border have been omitted for simplicity

Nile in Egypt	
Countries in the catchment	Nile in Egypt downstream of the cataracts at Aswan
Catchment size (km^2)	3,007,000
Length (km)	1,000
Mean (min/max) annual discharge (m^3 s^{-1})	2,800 million at Aswan, peak discharge in September of 8,240 million. No further tributaries in Egypt
Hydrological pattern	Combined flow regime of the flows of the Blue and the White Nile regulated by the artificial Lake Nasser; maximum flood levels in July–August
Degree of naturalness	Intensively agriculturally managed and urbanizing floodplain controlled by discharge from Lake Nasser
Natural landscape types	From Aswan, cultivated floodplain of sandy bed river confined within a rocky canyon through the Sahara Desert; coastal delta downstream of Cairo that flows into the Mediterranean Sea through multiple distributary mouths
Impact types	Aswan high dam completed during 1960s created Lake Nasser, below this multiple canalization and irrigation schemes feed western branch of the Nile known variously as Bahr Libeini and Bahr Yusuf. This channel feeds the Faiyum Oasis. North of Cairo the anabranches of the main river bed channels are channelized.
Largest cities (inhabitants)	Cairo (21 million), Alexandria (5.3 million)
Urbanization	100% developed, including irrigation agriculture, villages, towns and cities since around 1500 BC
Protected areas	Lake Qarun Protected Area (a Ramsar site and nature reserve in the Faiyum Oasis) 250 km^2; Saluga and Ghazal protected areas
Prevailing use form in the catchment	Cultivated Nile Floodplain, fisheries in delta
Famous elements of biodiversity	Many migratory birds on the Black Sea-Mediterranean and East Asia-East Africa flyways visit Nile floodplain in winter; waterbirds and several IUCN Red Data species
Famous elements of culture	Pyramids, Sphinx, Valley of the Kings and other material culture of the ancient Egyptian Civilisation, Christian and Islamic Empires, Nubian cultures (ancient and modern), tourism industry

sediment in this water has led to a drop in fertility of the Nile Valley, while the absence of the flood water has led to problems with salination. An increasing number of dams and hydroelectric schemes south of Egypt are being constructed leading to conflict with Sudan and Ethiopia. From Cairo northwards to the sea, the modern Nile divides into two main distributaries. However, Herodotus (Dewald 1998) and the investigations of Stanley and Warne (1994) show that from the early Holocene (10,500–4,000 BP), there were a considerably larger number of delta distributaries, the number of which has reduced through time due to canalization and other modifications (Cooper 2014). The shape of the seaward end of the Nile Delta is controlled by longshore currents in the Mediterranean Sea that have created a series of longshore bars enclosing lagoons. These natural lagoons, with the exception of Lake Manzala, have gradually shrunk through time (Stanley 1988). They are being further reduced in size through the introduction of fish farming (Alison Gascoigne and Ben Pennington, personal communication). The Delta is also at risk of drowning through sea-level rise (Frihy et al. 2010, https://www.grida.no/resources/6366).

4.3 Historical introduction

4.3.1 6th millennium BCE to Roman Egypt

A permanent settlement of the Egyptian Nile Valley was possible in the 6th millennium when the Nile's hydrological regime had become perennial and offered people relatively stable and beneficial conditions of subsistence (Said 1993, p. 185, with an overview of the transition to a perennial hydrological regime). The availability of the Nile water and the ensuing very high level of agricultural productivity were the key sources for Egypt's economic, political, and cultural development from the later 4th millennium BCE until the present time.

After the climate optimum (6900–5550 BCE), the increasing desiccation of the areas west of the Nile Valley and retreat of the monsoon regime to the south forced population groups into refuge zones – the Sudan, the oases, as well as the Nile delta and valley (see Clarke et al. 2016, p. 151, Riemer 2011, pp. 19–20). The culture of the Nile Valley Neolithic (c. 5500–4000 BCE) is first attested in the Fayyum oasis west of the Nile by the Fayyum A culture (c. 5500–4500 BCE), in the Nile Delta, by the regional cultures of Merimde Beni-Salame (c. 4750–4250 BCE) and el-Omari (c. 4600–4400 BCE), and in Middle Egypt, by the Badari culture (c. 4500–4000 BCE) (Wengrow 2006). Cereals were introduced from the Near East from c. 5200 BCE onward and constituted a significant component of human subsistence after 5000 BCE (Haaland and Haaland 2013, p. 541, Riemer and Kindermann 2019, pp. 210–211). By 3400 BCE, crop agriculture had become the dominant form of subsistence and the basis of the country's economy (Moeller 2016, p. 45). Increased desertification caused the movement of settlements from the desert edge and the mouths of wadis (their locations from 3800 to 3400 BCE) into the floodplain (3400–3200 BCE). The floodplain had become more habitable because of lower and more predictable floods (Bunbury 2018, p. 48, Moeller 2016, pp. 44–45). Proto-states during the early Naqada-III period display the development of administration and urban society, including a writing system (Moeller 2016, pp. 108–109). By the 33rd century BCE, a cultural unification of Egypt is visible in the spread of the Naqada material culture across the country, with a political unity achieved around 3000 BCE.

With the establishment of a centralized state around 3000 BCE, the management of land, water and agriculture became a key concern of Egyptian politics; state success was correlated to the Nile flooding regime (Manning 2010, p. 68, for the Egyptian records documenting historical flood levels, see Seidlmayer 2001). Recent scholarship has described the Nile River as creating a social cage for the valley's inhabitants, and Egyptian kingship as more dirigiste (overseeing the state institutions) than authoritarian (Manning 2010, pp. 62–72). As Manning explains (2018, p. 103): "*The 'social cage' of the river did allow the central state to dominate the economy, in distribution and in trade, and the elites were synonymous with the 'state'. The state faced no internal rivals; there were no powerful city-states as in Mesopotamia to serve as counterweight to royal power. The Nile flood regime itself acted as the real despot, the main forcing mechanism created by the rich soil of the flood plain juxtaposed to the harsh desert environment on either side of it. The state, its institutions and individual farmers had to respond and to adjust to the basic forces of the annual flood and its recession. The flood could not be altered, only contained, and the population was quite effectively 'caged', and therefore easily taxed, in the river corridor.*"

The state, represented across the country in the form of the local elites and temples that administered labor, agriculture, and taxes, would thus have been primarily a fiscal institution coordinating local production centers and maintaining an equilibrium within the country's highly fractured topography and society (Manning 2018, p. 103). Adding to the fragmentation in the Nile valley was a system of artificial basin irrigation (Willems 2013, pp. 346–352). In the delta, the alluvial land was divided by as many as 35 Nile branches as late as the Ramesside Period. This number decreased to seven in Classical antiquity and just two – those of Rosetta and Damietta – in modern times. In antiquity, the delta was also strewn with hundreds of settlement mounds, most of which have disappeared as a result of modern demographic pressure, reuse, and changes in agriculture (Tassie et al. 2015).

Upstream of ancient Memphis (south of modern Cairo), the corridor shape of the highly fertile valley within a naturally hyperarid environment was another determinant of Egypt's historical development. The habitable territory of the Egyptian state (Nile delta, Nile valley, and the desert oases) was comparatively small (c. 32,000 km^2, roughly equal to the surface area of modern Belgium), while the population may have amounted to as many as c. four million people in the New Kingdom (for the debate, Kraus 2004). Finally, the hydroclimatic conditions of the Egyptian Nile valley also gave rise to a number of seasonal diseases (Scheidel 2012, p. 313).

In the early 3rd millennium, the Egyptian state developed a central economy and established a political center in the area of Memphis. This was where the pyramid complexes of the kings of the Old Kingdom (2670–2170 BCE), the extensive cemeteries of the state officials, and subsidiary settlements were located (Moeller 2016, pp. 117–158). From the 4th Dynasty on, the administrative system aimed at territorial control of the countryside, with provinces under the control of local administrators, and two viziers (the highest state administrators) in charge of the Nile Valley and the delta, respectively (Moreno García 2013, pp. 111–113). This period also initiated the systematic foundation of economic domains and towns, although the fact that many of these sites in the floodplain and the delta have become sedimented or built over, leaves little archaeological evidence (Moeller 2016, pp. 113–117). Taxation and conscription to state labor were the main forms of state intervention (Kóthay 2013).

The climate-induced desertification continued throughout the Old Kingdom and probably contributed to its demise (for a discussion, Schneider 2017); the level of the Mediterranean Sea fell by about 5 m between 3000 and 2000 BCE while the flow of the Nile increased only at the beginning of the First Intermediate Period (2170–2040 BCE). Settlements of this time were thus located on much lower-lying ground than in the Archaic Period. With the collapse of the Old Kingdom and the decentralization after 2200 BCE, urbanization was on the rise in the provinces (Moeller 2016, pp. 116–117).

The Middle Kingdom (c. 2050–1650 BCE), the classic period of Egyptian literature and culture, placed a focus on the expansion of the state's political capacity. In a concerted effort, the state initiated town planning across the country, including a new residence city south of the old capital Memphis (Moeller 2016, pp. 249–334). Egypt's largest oasis, the Fayyum, which includes Lake Moëris/Birket Qarun (then a large, ancient freshwater lake, today a smaller saline lake) – connected to the Nile valley by *the Great Canal* (today Bahr Yussuf) – was partially drained and urbanized in the late 19th and early 18th century BCE. An imperial policy was implemented in the Nubian Nile valley south of Egypt's border. Here, the Middle Kingdom established a colonial empire, protected and exploited by a long chain of forts on the 2nd cataract (rapids) of the Nile and a system of colonial administration (Morris 2018, pp. 67–88). In addition to the wealth resulting from agriculture, massive revenues for the Egyptian state came from extensive trade relations abroad as well as access to the gold mines in Nubia (modern-day Northern Sudan and the southernmost part of Egypt) and raw materials from the Sinai Desert and the Red Sea mountains. In the Second Intermediate Period (1650–1540 BCE), the 15th Dynasty of the *Hyksos* – rulers of Levantine descent who assumed power in the Eastern delta (Mourad 2015) – initiated a historical paradigm shift when they made their city of residence Avaris, on the Pelusiac branch of the Nile delta, a capital city of Northern Egypt (Snape 2014).

The kings/leaders of the New Kingdom (1550–1070 BCE; Agut and Moreno García 2016) controlled an empire that stretched at the time of its largest extension, under Thutmose III, from the river Euphrates in Syria to the 4th cataract of the Nile in the Sudan (Morris 2018, chapters 5–8). Political stability and demographic increase resulted in a significant resettlement of the country. In the larger cities, there was a massive expansion of temples (most importantly that of Amun at Karnak) that also became large landowners (Wilkinson 2017). The early 19th Dynasty established a new capital city in the eastern Nile delta, along the Pelusiac branch of the Nile: Piramses. This initiated a change in Egypt's geopolitical orientation towards the Mediterranean Sea and the countries bordering it. The delta then became Egypt's economic and innovative hub. A gigantic architectural program, also benefiting the ancient sacred cities of Abydos and Thebes, spanned Egypt and Nubia, ensuring political and religious consolidation.

Around 1050 BCE, the capital city of Piramses had to be abandoned due to the silting up of the Nile's Pelusiac branch; a new city was built at Tanis (Snape 2014) on the next Nile distributary to the north, and became the Northern cultic center and royal burial place of the Third Intermediate Period (1080–664 BCE, Bennett 2019). Major centers of power in the centuries up to the time of Alexander the Great were delta cities: Tanis (21st/22nd Dynasty), Bubastis (22nd Dynasty), Leontopolis (23rd Dynasty), Saïs (24th, 26th and 28th Dynasties), Mendes (29th Dynasty), and Sebennytos (30th Dynasty) (Snape 2014). In 724 BCE, the 25th, so-called *Kushite* (Nubian), Dynasty conquered Egypt from its capital city Napata at the 4th cataract; this resulted in the most extensive territorial rule over the Nile valley in Egypt's history (see Pope 2014, for a *Nilo-Sahelian* interpretation of the dynasty's foreign policy). In the 6th century BCE, Nekaw II of the 26th Dynasty was the first to initiate the digging of a canal between the Nile Valley (and thus, the Mediterranean Sea) and the Red Sea (completed by the Persian king, Darius I). This shows the change in trade priorities and the shift of Egypt from a mainly riverine civilization to one with a more maritime outlook.

Ptolemaic Egypt (332–30 BCE, Manning 2010, Hölbl 2001) by and large continued the existing administrative practices regarding the country's economy, which was overseen by the *dioketes*, the highest state official in charge of the country's economy. Similar to the pre-Hellenistic situation, and given the fact that less than 50% of the land was owned by the state, the state balanced the interests and practices of different institutions and social groups (von Reden 2006, p. 175). Agriculture and water management changed significantly through the systematic expansion of the irrigation system to create more arable land, the introduction of new crops, and the industrial-scale cultivation of wine and olive oil. The level of the Mediterranean Sea sank by 2.60 m during the Ptolemaic Period (332–30 BCE), enabling settlement in the northern delta; the remaining natural marshland of the Fayyum Oasis was reclaimed for agriculture. The wealth generated was spent on massive expenditures in the wars with the Seleucid Empire and the self-representation of the state.

A vast building policy climaxed in royal projects in the new capital city of Alexandria and some of the largest Egyptian temples ever built in the Nile valley (notably, the Isis temple of Philae at the first cataract of the Nile and the temple of Horus at Edfu). Alexandria was Egypt's first political center in 3,000 years not to be located on the main course of the Nile or one of its distributaries in the delta, but on the Mediterranean coast. The economic policies led to a dramatic impoverishment of the Egyptian population, most of whom were agricultural laborers and tenant farmers – civil war led to a near collapse of the Ptolemaic state in the *Revolt of the Egyptians* (207–185 BCE) when parts of the delta and Upper Egypt seceded from the central state (Veïsse 2004).

The Roman conquest of Egypt in 30 BCE meant the end of the country's autonomy; however, as a province, it received special political status under the governance of a prefect (Derda 2019, Riggs 2012). Socio-economic inequality did not improve. Rather, upward mobility was more limited than in Ptolemaic or pharaonic Egypt and the gap between urban centers and the countryside magnified. The vast majority of Egypt's population – consisting of Egyptian peasants, a Greek and Hellenized Egyptian upper class – and an Egyptian priestly class (which had no political rights) – was subject to the poll tax and compulsory services for the state. In the 2nd and 3rd centuries, repetitive economic crises, revolts, and a plague (probably smallpox; 167–179 CE) affected Egypt; several attempts to reform the country's administration, fiscal system, and agriculture failed. A comprehensive administrative reform implemented in 284 CE by emperor Diocletian (284–305 CE) marked the end of *Roman Egypt* and the beginning of *Byzantine Egypt*, with the partition of the Roman Empire into eastern and western sections; Constantinople was founded as the capital of East Rome in 330 CE. Egypt's role as the grain basket for the region remained significant during the Byzantine empire, with the country being subdivided into smaller provinces, with intensified water use for irrigation agriculture being a feature of the times, together with a heavier system of taxation.

4.3.2 Islamic Egypt to the present

The Arab-Islamic conquest of Egypt between 639–642 CE was, in effect, a highly effective decapitation of a Byzantine provincial regime by a relatively small military force under the Arab general 'Amr Ibn al-'Āṣ. Byzantine rule had been weakened in its last three decades, by the Heraclian rebellion, by Sassianian-Persian invasion, and by sustained internal resistance by native Egyptians articulated in part through religion (Bulter 1978 (1902), pp. 8–32, 42–53, 193, Frend 1982, 1984). It was not a settler-colonial venture, but an excursion by Amr's small army of about 3,500 men, seeking new conquest and the spoils that came with it (Shaaban 1971, p. 36, Kennedy 2007, p. 139).

In most respects, Egypt's new rulers did little at first to disrupt the organization and day-to-day running of the state, including administration of the Nile River and irrigation-based agriculture, as well as the taxation arising from it (Spuler 1960, p. 25, Kirk 1964, p. 16, Shaaban 1971, p. 39, Hourani 1991, p. 23). Large-scale Islamisation of the Egyptian population took some three centuries to achieve following the conquest (O'Sullivan 2006) and, as a result, the ritual ownership of the core functions of the river remained in Christian hands for a further two centuries; indeed, even Egypt's administrative languages remained Coptic and Greek for some time after centralizing administrative and linguistic reforms initiated by the Umayyad Caliph 'Abd al-Malik (r. 685–705 CE, Kirk 1964, pp. 22–23). At the heart of the management of the Nile's waters, and the ceremonial attending it, was the nilometer (Arabic: *miqyās*), a measuring device by which the level of the river was monitored. At the time of the conquest, it took the form of a portable measure housed in a church in Memphis. In 715 CE, however, the nilometer and its attendant administration were relocated to Rawḍa (Roda) Island, alongside the new Islamic capital of Egypt, Fusṭāṭ, thus establishing it at the heart of Muslim rule. However, the key moment of transition from Christian to Muslim control of the nilometer and its ritual came more than a century later, in 247 A.H. (861 CE), when the Abbasid Caliph al-Mutawakkil (r. 822–861 CE) ordered the construction of a replacement nilometer and associated structure at Rawḍa. This new building was specifically Islamic in character, not least in it incorporated inscriptions of relevant passages from the Qur'an and one crediting the Caliph with its foundation (Popper 1951, pp. 19–20). That said, the lunar basis of the Islamic calendar made it ill-suited for river management, and even after the Muslim takeover of these functions, the key moments of the Nilotic cycle continued to be marked until the modern era with reference to Christian festivals – which in turn had been overlain onto the ancient Egyptian solar calendar (Lane 1908, pp. 494–505, Ludwig 1937, pp. 498–502, Popper 1951, pp. 64–73, 82–88, Cooper 2014, pp. 117–123). These moments included the moment at which the river was expected to begin its rise, celebrated on St Michael's Day, the 12th day of the Coptic month of Paoni (19 June), and the opening of the seasonal Cairo Canal on the first day of the Festival of the Cross, the 17th day of Thout (27 September), after which all the major seasonal canals of Egypt were opened progressively (Popper 1951, pp. 68, 85, 87, Cooper 2014, pp. 117–123).

What the Islamic conquest did do was fundamentally disrupt the pre-conquest relationship of Egypt and its Nile with the Mediterranean, oriented as it had been towards that sea and its political-cultural world (Bulter 1978, pp. 359–399, Bagnall 1993, pp. 77, 156, 290). Pirenne's thesis (Pirenne 1939, pp. 284–285) might have overstated the degree of decoupling of the sea's Byzantine north from the newly Islamic south (Hodges and Whitehouse 1983). It is nevertheless true, however, that Egypt found itself no longer sending grain and other tribute north to Constantinople, but rather across the Red Sea to the Hejaz, and the Arab-Islamic capital, Medina. This reality occasioned two major political reconfigurations of the Nilotic landscape of Egypt. The first was the establishment of Fusṭāṭ as the country's new administrative capital on the edge of the Byzantine fort of Babylon, today's Old Cairo (Sheehan 2010): Arabic tradition has it that the Caliph wished there to be no water between him and the new Egyptian capital (Ibn 'Abd al-Ḥakam 1922, p. 91). Thus was established the kernel around which Egypt's capital city has grown ever since, albeit by different names. Unlike Mediterranean Alexandria – Egypt's capital before the conquest – Fusṭāṭ sat at the Egyptian Nile's major pinch-point, controlling river traffic between the delta and the Nile valley, as well as land traffic over pontoon bridges linking the river's east and west banks (Shaaban 1971, p. 31, Cooper 2014, pp. 187–194).

Fusṭāṭ soon also found itself at the mouth of a newly restored canal linking the Nile to the Red Sea at modern Suez – the second early Islamic reconfiguration of the Nilotic landscape (Cooper 2009, Trombley 2009, Sheehan 2010, pp. 51–53). Excavated in the year 643 CE at the behest of the Caliph 'Umar (r. 634–644 CE) the canal largely followed the course of an earlier Roman canal that had been built by the Roman emperor Trajan at the end of the 1st century. It did, however, have a new connection to the river, some 3 km further downstream from the original at Babylon, at what is today Cairo's Sayyida Zaynab Square (Sheehan 2010, pp. 48–51, Cooper 2009, pp. 199–200). This major work turned Egypt's agricultural bounty to the task of ensuring the food security of the Islamic capital: the 9th century CE historian al-Balādhurī (1959, p. 3.269) reports that it was blocked during the reign of the Abbasid Caliph Abū Ja'far al-Manṣūr (r. 754–775 CE) in order to prevent the same agricultural supplies from reaching a rebellious Hijaz. Nevertheless, its foreshortened remnant continued to supply water to Cairo and the agricultural lands of the eastern delta until the late 19th century (Cooper 2009, p. 200).

By the time the first detailed cartography of the Islamic-era Nile appears in the 10th century CE, it is clear that Egypt's Nilotic geography had altered substantially since the Roman era. Works by the 10th century CE geographer Ibn Ḥawqal (1938–1939, 132–145) and the geographer al-Idrīsī (1970–1984, 3.329–343) in the 12th century reveal a delta that was by this time dominated by the Rosetta (*Rashīd*) and Damietta (*Dumyāṭ*) branches: geological investigations confirm the disappearance of the former Pelusiac distributary in the 8th century CE (Goodfriend and Stanley 1999) and the Canopic distributary in the ninth (Stanley et al. 2001, Stanley et al. 2004). Turbulent navigational conditions at the remaining Rosetta and Damietta mouths were pivotal in the emergence of the island city of Tinnis in Lake Manzala as the dominant Nile-sea port of the eastern delta until the onset of the Crusades (Cooper 2012, 2014, pp. 143–150, Gascoigne and Cooper 2019); so too was the maintenance of a canal to the excellent harbors of Alexandria that sustained it as Egypt's principal western port (Cooper 2014, pp. 48–68).

The establishment of the Fatimid Dynasty in Egypt and the foundation of Cairo as its capital in 969 CE marked a turning point in the political economy of the Egyptian Nile. For the first time since the Ptolemies, Egypt was unequivocally a dynastic center. The emergence of Cairo as a nexus of power and courtly culture established it also as the heart of a trade network linking the Indian Ocean world with that of the Mediterranean (Chaudhuri 1985, p. 37, Hourani 1991, p. 41). Commerce via the Red Sea was at first conducted through al-Qulzum (modern Suez), and from there by land to Cairo (Cooper 2014, pp. 235–236). However, the emergence of the Crusader threat in the 11th century CE prompted a refocusing of trade and pilgrimage routes through the Nile Valley and the Eastern Desert, with the remote harbor at 'Aydhāb (in the modern Ḥalayib Triangle) constituting the main Red Sea entrepôt (Peacock and Peacock 2007, Cooper 2014, pp. 235–236).

The middle Fatimid period – the latter part of the 11th century CE – is characterized by the multiple failures of the Nile to rise annually as normal. The resulting failure of the irrigation system sparked famine and exacerbating ethnic tensions within the military to the point of conflict. The weakened Egyptian body politic that emerged from this period of *shidda* (hardship) became the object of intensifying Crusader aggression – first by Baldwin I, King of Jerusalem, in 1118 CE, and later, under Ayyubid rule, by the armies of the 5th and 7th Crusades (1217–1221 CE and 1248–1254 CE respectively). The focus of the last two was the heavily defended entrance to the Nile's Damietta branch. In both cases, the Egyptians' superior knowledge of the river was pivotal in repelling the invaders: during the 5th Crusade, the Sultan al-Kāmil forced the surrender of the advancing Crusader army by flooding the land around it (Runciman 1954, pp. 168–169, Van Cleve 1969, pp. 424–428); during the 7th Crusade, Baybars – later a Mamluk Sultan (r. 1260–1270 CE) – was able to cut off King Louis' supply lines from the coast by sending boats along canals unknown to the Crusaders (Strayer 1969, pp. 501–504).

The post-Crusade order established in Egypt under the new Mamluk Dynasty in the late 13th century CE facilitated the growth of trans-Mediterranean trade in local and eastern goods, particularly with the Italian city states. Baybars invested in the excavation of a new seasonal canal to Alexandria in 662 and 664 AH (1263/4 and 1265/6 CE) to support this trade and also established Bulaq as Cairo's new river port serving the delta-bound trade (al-Maqrīzī 2002, 1.463–464, Hanna 1983, 1–4, Cooper 2014, 63–65). Subsequent sultans al-Naṣir Muḥammad Ibn Qalawūn (r. 1293–1294, 1299–1309, and 1310–1341) and al-Ashraf Barsbay (r. 1422–1438) also sought to improve Alexandria's vital canal connections from the river's major Rosetta branch, each attempting a new route in a bid to keep this seasonal waterway open for as long a period as possible each year (al-Qalqashandī 1913–1922, 3.304–305, al-Maqrīzī 2002, p. 1464). All had limited, and certainly temporary, success, as repeated excavations and multiple changes of route demonstrate (Cooper 2014, pp. 63–68).

The arrival of bubonic plague in Egypt in the mid-14th century had a devastating effect on the Nilotic landscape that lasted well over a century: the loss of so much of the population to disease caused Egypt's dirigiste, community-dependent agricultural system to collapse in many areas: deaths due to the plague rendered unsustainable collective public works using corvee labor, such as the maintenance of irrigation basins, and canal and ditch clearing; uncommonly high annual floods recorded during this period did not, as a result, translate into ample irrigation (Borsch 2000, 2015).

Following the Ottoman conquest of Mamluk Egypt in 1517 CE, Egypt found itself once more the most profitable province of an external empire, and once more ruled from Constantinople/Istanbul. The Ottoman state moved quickly to secure Egypt's main asset – its productive land – by placing almost all of it under state ownership. Cairo, Rosetta, Alexandria, and Suez hosted major grain storage facilities (Mikhail 2012, p. 83). The land was divided into small units (*muqāta'āt*) that were managed locally, with a legal obligation to maintain irrigation canals and ditches. By the early 17th century, however, the rights to most of these had been sold to local peasant leaders who were entitled to take a personal profit after paying their dues to the state, a system that was intended to incentivise good local irrigation management (Mikhail 2012, pp. 7–11).

With Egypt's focus of imperial tribute reinstated as Istanbul, and Alexandria, the Mediterranean ports of Rosetta, and the Nile routes that served them became particularly important for commerce. The favored canal to Alexandria from the Rosetta branch before the late 17th century CE was the al-Nasiriya canal, lending new importance for a time to Fuwa, the town on the Rosetta branch near its head (Cooper 2014, pp. 206–207). Thereafter – apparently due to poor maintenance of the already seasonal Alexandria canals – the connection with Alexandria's harbors was either by land or by the sea in coasting vessels from Rosetta, despite the notoriety of the Rosetta mouth as a difficult and dangerous place for navigation (Cooper 2014, pp. 143–150). That situation did not change until the coming of Muḥammad 'Alī at the turn of the 19th century.

The conquest of Egypt, as well as the *Ḥijāz*, also extended Ottoman control over – and certainly access to – much of the Red Sea, and placed the Nile as the principal conduit of Ottoman trade via that sea. Key commodities included coffee and Chinese ceramics traded via al-Mukhā (Mocha) in Yemen (Um 2009, pp. 16–35, Ward 2001). Another aspect of Ottoman rule was control over the Hajj pilgrimage – for the Nile, that meant the emergence of a new fluvial and maritime route (in addition to the land route via Sinai) that passed up the Nile valley to *Qūṣ*, and thence to Qusayr on the Red Sea coast (Le Quesne 2006).

Muḥammad 'Alī's rise to power in 1805 as *Wālī* (Viceroy) of Egypt in the wake of the brief French occupation marks a turning point in the country's ambitions to control the Nile's waters. His programme to establish Egypt as a modern, autonomous state entailed extensive administrative, tax and land reforms. This included the establishment of the first, perennial irrigation systems, with a view to developing cotton as Egypt's principal cash crop and export earner. His Maḥmūdiyya canal (1917–1929), excavated from al-'Aṭf on Nile's Rosetta branch to Alexandria, extended irrigation across Baḥriyya province and instated a reliable water supply to Alexandria in support of its urban development (Hairy and Sennoune 2006, pp. 251–252, Mikhail 2012, pp. 242–287). It also allowed for year-round river navigation between the city and Cairo. It was also under Muḥammad' Alī that the first project to set an irrigation barrage at the apex of the Nile delta, running across the heads of the Damietta and Rosetta branches, was conceived and attempted. Work began in 1833 and was completed in 1862: however weakened foundations prompted safety fears, and the structure was largely abandoned, apart from as a river crossing (Tvedt 2004, pp. 20, 23).

The British occupation of Egypt from 1882 spans a period of extensive major engineering work aimed at extending the cultivable area and agricultural output of the Nile river valley and delta, not least for cotton production (Tvedt 2004). Remedial work on the delta barrage in the 1880s restored it to function in boosting delta irrigation; a further major project to raise the head of water behind the barrage followed in the 1930s. The first entirely new project under the British was, however, the Aswan Low Dam (1899–1902 CE), which was designed to store enough annual flood water to offset dry-season lows; its height was subsequently raised twice, in 1907–1912 and 1929–1933. Further irrigation barrages followed. One was built at Zifta on the delta's Damietta branch between 1901–1903; others were built in the Nile valley at Assyūṭ (1902), serving the Ibrahīmiyya canal; at Isnā (Esna, 1906–1908); and at Nag 'Ḥammādī (1927–1930) (Tvedt 2004, pp. 75, 90, 147).

Proposals developed by Greek-Egyptian engineer Adrien Daninos for a new High Dam at Aswan found favor with Egypt's new nationalist government under Gamāl 'Abd al-Nāsir (Nasser) following the 1952 revolution (Tvedt 2004, pp. 260–261). Nasser regarded the dam as a means of boosting agriculture and electricity production, and ensuring Egypt's water security: it would for the first time allow Egyptians to complete control of the flow of Nile water through the country and enable the storage of annual flood waters against the effects of failure or excess. Its immense scope also secured for its prominence in national and international politics, with the major engineering works ultimately carried out by Soviet contractors. Negative consequences have included increased erosion along the Mediterranean coast as the result of the trapping behind the dam of river sediment that would previously have found its way to the delta and the sea. The quantity of sediment debouching into the sea is no longer sufficient to compensate for the erosional effect of Mediterranean longshore drift currents along the Delta shore, resulting in coastal retreat (Frihy and Lawrence 2004).

Population growth and shifting Nile Basin hydro politics have continued to drive Egypt's Nile policies. In 1997, the government launched the controversial New Valley Project to divert some of the waters of Lake Nasser – the reservoir behind the High Dam – along a 310 km canal into areas of the Western Desert in order to irrigate new areas and create habitable zones (Waterbury and Whittington 1998, Warner 2013). The project was abandoned under the Islamist government of Muḥammad Morsī (2012–2013) and its future remains uncertain. More recently, dam-building projects on the Nile in Sudan and Ethiopia have led to increased tensions between these riparian states, leading in 2015 to a tentative agreement on Nile water-sharing that modified previous agreements reached in 1929 and 1959 between Egypt and Sudan (see 4.7, for more recent developments in transboundary water sharing).

4.4 Key elements of biotic diversity

4.4.1 Biocultural overview

The Egyptian Nile is one of the longest continually inhabited places on Earth. The current biome is largely result of that impact and interaction over more than five millennia. Many of the street flora, garden plants, and current agricultural crops are almost entirely non-native. Most of the domestic animals were introduced during the Neolithic, and some, such as the camel and chicken, at the end of the 1st millennium BCE. Much of the native fauna, less so the flora, has almost completely disappeared (Brewer and Friedman 1989, Osborn and Osbornova 1998, Osborn and Helmy 1980, Täckholm and Drar 1956). The most recent mega-impact construction is the Aswan High Dam. It has changed the topography dramatically by creating the massive Lake Nasser that flooded the Nile Valley south of Aswan, displacing human and wildlife populations and monuments. This also affected the rhythm of the agricultural cycle and system, affected the diversity and abundance of fish species not only in the Nile, but also in the Mediterranean (Nixon 2004), isolated the crocodile (*Crocodylus niloticus*) population of Egypt to reaches downstream of the dam, and affected Egypt's natural and cultural heritage by either inundating it or creating a situation whereby salt has a deleterious effect on it, as is seen in many temples, including those of Luxor and Karnak. Changes in the ecosystem have been exacerbated by rapidly rising population, the intensification of agriculture (almost all the vegetation near the Nile is agricultural), the use of agrochemicals, and industrialisation along the riverbank, with wastewater and toxins draining into the river. There is one remaining area of original Nilotic vegetation, the Saluga and Ghazal Protected Areas, comprising two islands in the Nile, 3 km north of Aswan.

4.4.2 Historic overview

Evidence for human presence in what is known now as Egypt dates to c. 600,000 years ago, with a concentration of settlement along the Nile Valley occurring probably before the early Neolithic, integrating Near Eastern domesticates (sheep, goat, possibly cattle and donkey), with herding becoming an extant foraging strategy. An African origin for the domestication of these animals is also argued – it is noteworthy that rock art from Qurta, along the Nile, features images of cattle that have been dated to 15,000 BCE using Optically Stimulated Luminescence dating (Huyge et al. 2007). Much of our understanding of the flora and fauna of Egypt from the Neolithic onward relies on faunal material as well as images on artifacts and on tomb and temple walls, with the caveat that some images became canonical, and thus might not accurately depict the environment at a particular period, but rather, as a timeless ideal.

Early human artifacts show images of hippopotami (*Hippopotamus amphibius*), crocodiles, Nile softshell turtles (*Trionyx triunguis*), various fish, greater flamingo (*Phoenicopterus roseus*), unidentifiable waterbirds birds, and plants – imagery that is supported by excavated faunal remains. There is no way of calculating the precise number of species of birds, fish and other fauna inhabiting the Nile Valley at any one time, as prior to the 19th century data are too limited. Also, avian presence fluctuated naturally due to the migration of many species, particularly between Africa and Europe, with the largest numbers in any year present in Autumn (October–November) and Spring (March–April). Several of these species were kept in captivity and could have been bred (Ikram 1995, Houlihan 1988). Indeed, today Egypt is signatory to the Convention on the Conservation of Migratory Species of Animals (CMS) as well as the Ramsar Convention (Baha El Din 1999). It is worth noting that thus far 211 bird species have been provisionally identified in Egypt (not just waterfowl) from 4000 BCE to 395 CE (Wyatt 2012). Some species, such as the Sacred Ibis (*Threskiornis aethiopicus*), once so plentiful in Egypt and identified with the Egyptian god, Thoth, had become locally extinct sometime between 1876 and 1886, with only occasional stray birds recorded subsequently (Nicoll 1919, p. 68, Goodman and Meininger 1989, pp. 106, 149). It is unclear if this was due to overexploitation by hunting, disease, or for some other reason. In the late 1990s and into the 21st century, there have been discussions about re-introducing the bird to Egypt.

In the case of fish, at least 46 species were known to exist (Gaillard 1923, pp. 101–103); the number is most probably far higher, as images are limited, as are faunal remains, with fish remains easily overlooked in archaeological deposits. Certainly, a 1907 publication lists 74 fish species in the Egyptian Nile, in the reach from Aswan to the Mediterranean Sea (Boulenger 1907, pp. xii–xviii), and current lists indicate 95 species present (Froese and Pauly 2020).

Despite another climatic shift around c. 2000 BCE (Macklin et al. 2015), the flora and fauna seem to have been relatively stable. Scenes of fishing and fowling in papyrus marshes are a standard image in tomb art, and persist into the New Kingdom. By the end of this time, tomb art changed its focus to images of deities and the hereafter. Common animals in these scenes include hippopotami, crocodiles, fish (selections from 42 species were chosen, depending on the tomb, see Gaillard 1923, Brewer and Friedman 1989) birds, frogs, locusts, swamp cats (*Felis chaus*), butterflies, and ichneumon (*Herpestes ichneumon*) climbing amongst the papyrus (*Cyperus papyrus*) thickets. The other plants depicted are more limited in diversity, including sedges, reeds (such as the reed, *Arundo donax*, *Phragmites* spp.), and the blue water lily (*Nymphaea caerulea*). The different reeds were used to fabricate baskets, shoes, and mats, and in architecture (elements of fences, roofs, walls, pillars, and walls), while lilies provided raw material for perfumes and medicines, and might have been used as mild hallucinogens (Harer 1985) for religious and recreational purposes. Willows are known from the archaeological record, but are rare in art.

Papyrus thickets, once so plentiful due to both nature and cultivation for reed boats, baskets, and paper, greatly declined by the 9th century CE with the introduction of mulberry and other new sources for paper production. Papyrus persisted in pockets in the Delta, however, according to 19th century travellers' accounts (Minutoli 1827), though it is unclear if it persisted into the 20th century. It was reintroduced in the Cairo area for scientific, touristic, and commercial purposes by Dr. Hassan Ragab, a history and botany enthusiast, in the 1960s (Smith 1973). The water lilies, too, almost died out, with a few pockets still existing in the delta. This loss of habitat, together with an increasing human population, no doubt negatively affected native biodiversity.

While plants and animals were imported during the pharaonic period, few seem to have influenced the Nile ecosystem. The water buffalo (*Bubalus bubalis*) was introduced into Egypt at some time after 30 BCE and before 1581 CE (Alpin 2007, p. 228). The majority of introduced species that have affected Egypt and the Nile riverine ecosystem were imported during the 19th century. One of the most destructive to the Nile is the invasive water hyacinth (*Eichhornia crassipes*) that was introduced in the last decades of the 19th century as an ornamental plant (Gopal 1987).

The number of fish species found in the Nile has decreased since the second half of the 20th century, due to the construction of the Aswan High dam (flow regulation and river fragmentation), increases in population, agriculture, tourism, and industrialization, with industrial and agrochemical wastes being deposited into the Nile. This situation is now changing, with more fish, though fewer species, such as Cichlidae, *Lates niloticus*, and *Schilbe* spp., once again inhabiting the Nile, thriving on human waste (Nixon 2004). The same forces also have contributed to the loss of habitat for several types of birds. Softshell freshwater turtles, once extant in the Nile, have not been recorded in the river reaches downstream (north) of the Aswan High Dam, and their survival in the Egyptian Nile is now uncertain. The Nile monitor (*Varanus niloticus*) continues to survive, despite habitat loss and its hunting as an ingredient for folk medicine and as an apotropaic animal to avert evil and bring good luck.

The Nile's irrigation canals and areas where basin irrigation is practiced and in areas where water is slow-moving have also been home to parasites, notably of the genus *Schistosoma*, transmitted via *Bulinus snails*. Schistosomiasis (bilharzia) was endemic in ancient Egypt, found in several mummies, referred to in medical texts, and with sufferers depicted in art (Nunn 1996, pp. 63, 68–71). The effects of the High Dam on the epidemiology of schistosomiasis are disputed. Some scientists have argued that the increase in basin irrigation would increase incidences, and the decrease in water current velocity and absence of silt, particularly in the Lower Nile, would provide a better habitat for the snails that transmit the parasite. In contrast, some studies in Upper Egypt reported a decrease in the disease (Barakat 2013), though this might be linked to changing life styles and decreased association with the river. Nowadays, the incidence of infections has decreased due to new drugs and their availability, dissemination of information about the disease, and various control programs implemented by the Ministry of Health, including exterminating the snails that serve as hosts (Barakat 2013).

Today, very little remains of the original Nilotic flora and fauna (see table 4.3), with only a few areas of natural vegetation persisting below the Old Aswan Dam, on Saluga and Ghazal Islands, declared a Conservation Area in 1986 and full protection under Law No. 1969/1998 (Baha El Din 1999). With 120 native plants recorded, including five species of *Acacia*, these river islands are home to unique assemblages of native species typical of the Nile's aquatic life (Ali et al. 2011). They also support important populations of waterbirds including the locally decreasing Egyptian Goose (*Alopochen aegyptiaca*) listed by the International Union of Conservation of Nature (IUCN) (Baha El Din 1999, https://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22679993A131910647.en). Interestingly, the fauna found in Lake Nasser, created by the High Dam, is more diverse than what is found in the river below the High Dam, including fish, birds, amphibians, mollusks, crustaceans, annelids, a single cnidarian species, and a bryozoan (Abdel-Meguid 2016).

4.4.3 Telling tales: some Nilotic fauna

Certain Nilotic animals, such as hippopotami, present throughout Egypt for most of its history, were almost extinct in the Egyptian Nile by 1819, save for some rogue individuals (Burckhardt 1819, p. 67). These creatures had regularly been hunted to protect crops and people, as well as to supply meat and ivory. Their extinction in Egypt was primarily due to the increased availability of firearms and the presence of western game hunters and military personnel.

Crocodiles, associated with fertility, inundation, and the sun by the ancient Egyptians, and also exploited for their skin and bones (Ikram 2010), have been the major predators in the Egyptian Nile from time immemorial, and still exist in Egypt, although only below the Aswan High Dam (see fig. 4.11 first column for iconic example of biological elements). From mummified remains, it is posited that two species of crocodiles were known to the ancient Egyptians: *Crocodylus niloticus* (Nile crocodile) and *C. suchus* (West African or desert crocodile) (Hekkala et al. 2011). The latter species might have been imports, or a small population of these animals that now are better known from West Africa once might have existed in Egypt (Hekkala et al. 2020), although have not been recorded here in the 20th century.

By 1891, Nile crocodiles were extremely rare in the lower river downstream of Aswan. After 1891, anecdotal records such as that of Amr Sharawi's (pers comm.) from the 1960s, most probably relate to Nile monitor lizards or to rejects from the pet trade. Nowadays Nile crocodiles flourish in Lake Nasser, together with large (often over 1 m long) Nile Perch (*Lates niloticus*), a native Nile fish. There are reports of adults and children being snatched by crocodiles in the area, and recent attempts at establishing legal touristic hunting of these animals is under discussion as tourism based on sport fishing (particularly of Nile Perch) has proved very popular. However, due to the economic (tourism) decline, following the Arab Spring (2011, 2013), sport fishing no longer provides economic support locally. Moreover, there has been a marked rise in illegal poaching of crocodiles for meat, skin, teeth and bone, which is contributing to declining numbers of these animals (Schwarzstein 2017).

The High Dam is responsible for creating artificially flooded wadis known as *khors*, some of which are permanently flooded. These have provided fresh habitats for a range of species not noted in modern Egypt previously: the African Pied Wagtail (*Motacilla aguimp*), Pink-backed Pelican (*Pelecanus rufescens*), Yellow-billed Stork (*Mycteria ibis*), African Skimmer (*Rhynchops flavirostris*), and Namaqua Dove (*Oena capensis*) are all now regularly recorded. Two species historically intrinsically linked with Egypt may also return. The Egyptian Plover was famously recorded by Herodotus as the 'running bird' for picking parasites from the gaping jaws of crocodiles (Herodotus 1998, p. 2.68). It was last sighted in Egypt in 1932 (Goodman and Meininger 1989) but the creation of new habitats may tempt it back. There have also been discussions about the reintroduction of the Sacred Ibis. In 2009, Nature Conservation Egypt (NCE) working with the French NGO Ligue pour la Protection des Oiseaux (LPO), under the auspices of BirdLife International, was looking towards re-introducing the Sacred Ibis into Egypt. This is not without some controversy, as elsewhere, accidentally introduced/escaped Sacred Ibis populations have proved problematic (Yesou and Clergeau 2006). The project stopped in 2011 (Viney 2011) due to the Arab Spring and negotiations have not recommenced till now (2021).

While the Nile Crocodile is prevalent in Lake Nasser, it was worshipped throughout the *oasis* of Fayoum from Old Kingdom through to Roman times. There is evidence for crocodiles being reared and revered at the ancient site of Crocodilopolis (Bresciani 2005, p. 202) as well as at other sites in the Fayoum, such as Karanis and Qasr Qarun (Ikram 2015). The crocodiles have long since disappeared from the Fayoum, and the landscape has changed dramatically. Not a true oasis, the Fayoum is rather a cul-de-sac of the Nile, the water used extensively for irrigation running off into the newly created lakes at Wadi Rayan and into the naturally created Lake Qarun. With no outlet, water is today only lost through evaporation and Lake Qarun has become steadily more saline, now at an estimated 40 $g\,L^{-1}$ salinity which is higher than most sea water (Baha El Din 1999, Hassan 2018). Whereas freshwater species historically formed the mainstay for the local fisheries, today the species caught are those that also thrive in saltwater, such as Bolti (*Tilapia zilli*) and Bouri (*Mugil cephalus*) (El-Sherif 2017), though few are now found in the lake; rather, net fishing in the lake yields small catches of whitebait. Several fish farms of various sizes, ranging between 0.25 and 1.68 ha, in general, have been established beside the lake (Konsowa 2007), together with salt extraction centers, with a large salt extraction plant having being established at Shakshuk that extracts sodium chloride as well as other salts. The lake also plays a significant economic role in the Fayum as it is a draw for local tourists, with cafés, restaurants, and hotels proliferating along its southern edge – the northern edge is currently relatively devoid of human exploitation as it is a protected area, although this might soon change as one tourist camp has been established there and there are ongoing discussions concerning more development (N. Hewison, H. Saleh, pers. comm.).

Although their fish species composition has changed, Lake Qarun and the two lakes of Wadi Rayan remain important overwintering grounds for waterfowl, including waders, and a variety of other birds, to the extent that they were declared Protected Areas in 1989 (Baha El Din 2004). Flocks of several hundred Greater Flamingos (*Phoenicopterus roseus*) are regularly recorded and also the enigmatic Demoiselle Crane (*Anthropoides virgo*). The latter, recorded in tomb carvings, such as that of Ti at Saqqara, in mixed flocks with semi-domesticated Common Cranes (*Grus grus*), is rare in modern Egypt, but has been sighted recently at Lake Qarun by ornithological enthusiasts (N. Hewison, pers. comm.).

The Egyptian Nile supports a number of African animal species that just reach the Western Palearctic faunal zone in Egypt's Nile Delta and Valley. These include the Senegal Coucal (*Centropus senegalensis*), Kittlitz's Plover (*Charadrius pecurius*), Painted Snipe (*Rostratula benghalensis*) and Senegal Thick-knee (*Buhurinus senegalensis*). To these, the Egyptian Mongoose may also be added, though its present range extends into southern Europe and the Near East.

Egypt is the only foothold in Africa for the predominantly Asian Swamp Cat (*Felis chaus*). It has been reported from much of the Nile Valley until Aswan, across the North Coast west to Mersa Matruh and from some of the Western Desert oases, excluding Siwa. Curiously for a species whose range extends over much of South Asia through to the Middle East, there are no confirmed records from North Sinai, the Egyptian subspecies *nilotica* being an isolate (Anderson 1902, Hoath 2009, p. 98). In modern Egypt, the Swamp Cat seems to have largely substituted its natural habitat of dense reed beds, marshes, and bushy cover for sugarcane and cotton fields in the Valley, barley fields along the North Coast, and other agricultural land and its periphery elsewhere. Of all Egypt's beleaguered wild cat species, it seems to have adapted best to areas of intensive human activity and is still regularly recorded. Indeed, there are several recent records of kittens from the vicinity of Luxor (Hoath 2009) where sugar cane fields have become surrogate habitat replacing the ancient swampland. A further predominantly Asiatic species, Short-tailed Bandicoot Rat (*Nesokia indica*) shows a similar distribution, with an isolated African population in the western Nile Delta, Fayoum, and Bahariya (Osborn and Helmy 1980).

One of the species that appears regularly in tombs from the Old Kingdom to the Middle Kingdom is the Pied Kingfisher (*Ceryle rudis*) (Houlihan 1996). Readily distinguished by its bold patterning in black and white, a shaggy crest, and distinctive hunting technique, the portrayals are so accurate in the tomb depictions that male and female can be readily distinguished. By the mid-20th century its population had declined significantly, and it was absent from large portions of the Nile, notably south of Cairo to Luxor. Since then, there has been a resurgence, possibly due to the construction of the High Dam. Much of the silt that formerly fertilized the Valley and Delta was held behind the dam, creating a number of environmental problems, but possibly the clearer water has made hunting easier for the Pied Kingfisher (Goodman and Meininger 1989). Other kingfisher species have also extended their range in Egypt. In the 1970s the White-throated Kingfisher (*Halcyon smyrnensis*) was noted in northern Sinai, and by the 1980s it had reached the Nile Delta (Goodman and Meininger 1989). Today it is a common bird in the Delta and Nile Valley having advanced south at least to Minya (Richard Hoath, pers. obs.) and with recent unconfirmed reports from Luxor. Less tied to open water than the Pied Kingfisher, the White-throated Kingfisher may have benefitted from changing agricultural practices and expansion of potential breeding sites.

Despite its density of population and millennia of human activity, the fauna of the Nile Delta is relatively poorly studied and surprising discoveries still occur. In 1993, for instance, a new species of toad, the Nile Delta Toad (*Amietophrynus kassasii*), was described from the Nile south of Damietta (Baha el Din 1993) showing clear affinities to *A. vittatus*, a species known only from the vicinity of Lake Victoria. The race of weasel (*Mustela nivalis subpalmata*) largely confined to the southern Delta and Cairo has recently been subject to a detailed genetic study and may yet prove to be a full species (Rodrigues et al. 2016). It has been proposed that the Egyptian race of Yellow Wagtail (*Motacilla flava pygmaea*), largely confined to the Nile Delta and Valley, may be a full species. Other species recently recorded from the Delta are deliberate or accidental introductions that have now established self-sustaining populations. Amongst these are the Streaked Weaver (*Ploceus manyar*), Rose-ringed Parakeet (*Psittacula krameri*), Red Avadavat (*Amandava amandava*), and Indian Silverbill (*Lonchura malacca*), and it seems that the Common Myna (*Acridotheres tristis*) may soon follow.

The above shows that the Nile in Egypt has undergone unprecedented human influence over many millennia. Much of the original Nilotic flo-

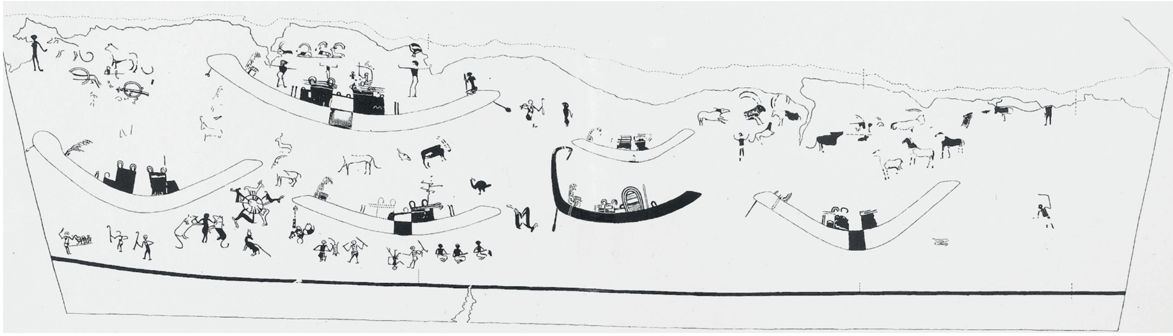


Fig. 4.4 Nilotic scene, Tomb 100, or "*The Painted Tomb*", at Hierakonpolis. Graph: modified after Quibell and Green (1902, pl. LXXV)

ra and fauna has disappeared, other elements cling on in a much-changed ecosystem and are challenged by recent introductions, either intentional or accidental, of wild and domestic species, while yet others have adapted with some success. Perhaps the Egyptian Nile's greatest test, and certainly the most dramatic one, since the construction of the Aswan High Dam, may be the upcoming completion of the huge Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile (see subchapter on trends, below). Its impacts, political, economic, cultural, industrial, agrarian, and of course environmental, cannot yet be fully understood, but they will no doubt change the face of the Egyptian Nile irrevocably. They may be the biggest challenges the Egyptian Nile has yet faced, even after thousands of years of human intervention.

4.5 Key elements of cultural diversity

4.5.1 Cultural diversity from the 5th millennium BCE to Roman Egypt

4.5.1.1 Historical influence of the Nile on Egyptian Culture

Human occupation became concentrated along the Nile Delta, River Valley, and desert oases during the 5th and especially 4th millennium BCE when seasonal rains decreased, lessening the habitability of the desert (see historical overview in section 4.3; for discussion of soil erosion and decreasing habitability of the wadis, see Bunbury 2019). With this shift towards the Nile River came the adoption of more permanent and densely settled communities, as well as changes in subsistence livelihoods, such as the development of irrigation strategies and the adoption of flood recession agriculture (Bunbury 2020). In these new Nile Valley settlements, cooperative construction projects emerged such as the South Building at Naqada and religious spaces like the Horus Precinct at Hierakonpolis (known as *Nekhen*). Communal activity is also shown by the shared beer production facilities at Hierakonpolis (Hierakonplis HK 24A and 24B). Along with these changes there is also evidence for increasing social hierarchy and wealth inequality, demonstrated by significant stratification of mortuary wealth at southern burial sites like Hierakonpolis, Abydos, and Naqada (Bard 2007, pp. 94–101).

From these early predynastic sites, particularly in Upper Egypt, we find evidence of traditional Egyptian cultural practices such as the provisioning of the dead in burials and early attempts at body preservation (Shaw 2012, pp. 80–82), as well as iconography that would remain popular in ancient Egyptian art. Important among the early artistic motifs of predynastic Egypt are Nilotic images such as the fleet of boats depicted in

Fig. 4.5 Irrigation Scene, Mace head of King Scorpion, recovered from the early Horus precinct at Hierakonpolis (AN1896-1908.E.3632, Ashmolean Museum, University of Oxford). Photo: modified after image by akhenatenator, CC0 1.0. https://upload.wikimedia.org/wikipedia/commons/e/eb/Ceremonial_mace-head_of_King_Scorpion.jpg

Table 4.2 Key elements of biodiversity and protected sites at the Egyptian Nile

Key elements	Distribution	Ecosystem services	Human use and threats
Nile Crocodile (*Crocodylus niloticus*)	Now only found in Lake Nasser and south	Last remaining top predator along the Egyptian Nile	Persecuted almost to extinction in Egypt. Now under pressure due to conflicts with fishermen and possibly sport hunting, being captured for tourism, and leather/skin trade
Migratory birds. The Egyptian Nile is a major migration corridor for many species of migratory birds including the White Stork (*Ciconia ciconia*), Common Crane (*Grus grus*), and large raptors such as eagles (*Aquila* spp.)	Intense passage in Spring and Autumn providing a corridor parallel to the Red Sea coast; also a major migration highway with a significant convergence east of the Nile at Gebel Zeit and Suez	Major migration highway for many species breeding in Europe and wintering in sub-Saharan Africa. Records include such species as (Greater) Spotted Eagle (*Aquila clanga*) now increasingly threatened in Europe.	Threats posed include pollution, illegal hunting and habitat destruction.
Wintering birds: The Egyptian Nile is an important wintering ground for many wintering species of waterbirds and waterfowl including the Ferruginous Duck (*Aythya nyroca*) and a number of Aythya and Anas species. Marbled Teal (*Marmaronetta angustirostris*) probably locally extirpated.	Historically recorded along the length of the Egyptian Nile and widely portrayed in ancient tomb paintings and friezes. Lake Nasser and the reservoir created between the Old Dam and the High Dam have provided important new habitat.	Important wintering ground for many species breeding in northern Europe and hence covered under the CMS	Threats include pollution, habitat disturbance, and illegal hunting from areas such as Fayoum. The islands of the Upper Nile and numerous Delta and northern lakes are Important Bird Areas (IBAs) identified by BirdLife International.
Fish: number of species possibly diminishing, particularly in the Cairo to Beni Suef region. Common species: Bolti (*Tilapia zilli*) and Bouri (*Mugil cephalus*)	Since the building of the dams, throughout the Nile, more common in Lake Nasser	Important position in the foodweb	Fishing; pollution
Nile tilapia, bulti (*Oreochromis niloticus*)	Throughout the Nile	Can eat insect larvae, useful against malaria; can eat detritus	Aquaculture, food fishing
Many types of catfish (Siluroidea)	Throughout the Nile and canals	Detritivore and predatory	Food fishing
Some species of Mormyridae, Cyprinidae, few Mugilidae	Throughout the Nile, but most plentiful in the south	Biotic diversity	Food fishing

Table 4.2 (continued)

Key elements	Distribution	Ecosystem services	Human use and threats
African elements of the Nile Valley in Egypt: Nile Delta Toad (*Amietophrynus kassasii*), Senegal Coucal (*Centropus senegalensis*), Kittlitz's Plover (*Charadrius pecurius*) and Senegal Thick-knee (*Buhurinus senegalensis*)	Most closely related to a species confined to the environs of Lake Victoria emphasizes the Afro-tropical elements of Egypt's fauna.	Diverse	Status unclear but changing salinity in the Delta, pollution and habitat destruction with increasing agricultural and on marshy soils represents a threat
Nile softshell turtle (*Trionyx triunguis*)	Now only found occasionally in Lake Nasser.	Omnivorous	Hunted for meat and carapace; habitat loss; pollution
Papyrus (*Cyperus papyrus*)	River edge and delta; cultivated for tourism	Cleansing of habitat; habitat creation; tubers as food for various species	Cultivated for multiple purposes
Reeds, such as *Arundo donax*	River edge, canals, delta (invasive species in Mediterranean countries)	Water filtration, habitat for small fry, insects, small mammals	Overexploitation for basket and mat making; habitat loss, pollution
Water hyacinth (*Eichhornia crassipes*)	Introduced species	Problematic as it clogs river and canals, impeding passage of boats, collects garbage, reduces oxygen levels	Potentially removes heavy metal from waste water (Shafy et al. 2016)
Saluga and Ghazal Protected Area. Status due to being one of the last areas of native Nilotic vegetation in Egypt. 5 species of *Acacia*. Important for bird species such as *Ardea* spp, *Egretta* spp, Black-crowned Night Heron (Nycticorax nycticorax), and Purple Swamphen (*P. porphyrio madagascariensis*).	Sandwiched between the Old and Aswan High Dam and the Lower Nile Valley, which is now completely dominated by human activity and pollution	Ancient once natural ecosystem. No longer influenced by the natural flow of the river, as in modern Egypt the flow regime is now highly regulated by dams, etc.	Increasingly used but also threatened by tourism and related development

Tomb 100 or "The Painted Tomb" at Hierakonpolis (fig. 4.4), as well as images of early waterworks, such as the so-called *Irrigation Scene* on the Mace head of King Scorpion, recovered from the early religious precinct of the god Horus at Hierakonpolis (fig. 4.5). These early forms of artistic expression demonstrate the central role of the Nile River in Egyptian ideology from its earliest inception.

The Dynastic Period of ancient Egypt represents one of the longest extant states in world history. Centering on the Nile Valley from the Mediterranean Sea to the cataracts in the south (fig. 4.2), and bounded by deserts on the east and west, the ancient Egypt state survived for over three millennia. The Nile played an integral role in mobility and trade, and in facilitating the production of grain surplus used to fund state enterprise. Institutional power is evidenced by the construction of monumental pyramids, including those on the Giza Plateau in the mid-3rd millennium BCE. Though the cores were constructed of locally quarried limestone, finer Tura limestone, sourced to the south of Cairo, was used for the external pyramid facing. This Tura limestone was brought to the Giza plateau along the Nile, as were the high-quality finishes like the red granite used for sarcophagi and lining burial chambers, which was brought from Aswan in the south. Images of boats towing large blocks of stones and obelisks appear in relief art, including scenes at the Old Kingdom Pyramid of King Unas, and at the New Kingdom mortuary temple of the ruler Hatshepsut at Deir el-Bahri (fig. 4.6). Early state power and its monumental expression depended on the Nile – both for the production and mobilization of vast resources of staple goods like grain grown in the Nile floodplain and delta (which fed the laborers of state-building projects) and for the acquisition and transportation of luxury materials sourced throughout Egypt.

Through the subsequent millennia Egypt grew in size and prosperity, expanding at times to occupy regions to the north into modern Syria-Palestine, and to the south beyond the First Cataract into Nubia. These expansions – driven primarily by imperial ambition and the acquisition of precious resources like gold and copper – brought Egypt into contact with other Nilotic cultures, such as the Kushite Kingdom to the south. Though complex cultures in Nubia have traditionally received less attention by historians and the broader public, the excavation of the Kushite centers of Napata and Meroe have revealed evidence of complex and powerful polities, undercutting the once perceived exceptionalism of the ancient Egyptian state (van Pelt 2013, Spencer et al. 2017, for an example of Nubian-Egyptian cultural entanglement, see Ashby 2018).

From the First Dynasty to the time of the defeat of Cleopatra VII by the Roman leader Octavian (soon to be Emperor Augustus; see historical overview in 4.4), the power of centralized kingship waxed and waned, however the Nile maintained a principal place in ancient Egyptian religion and economic prosperity. Though the Nile remained centrally important, the landscape and environment of Egypt were not static through this period. As the overall North African climate fluctuated and the Nile River migrated across the valley (Lutley and Bunbury 2008, Graham 2020), the physical and cultural landscapes of ancient Egypt were modified (Willems and Dahm 2017, Bunbury 2019, Schneider and Johnston 2020). The form and mouth of the delta were altered (Bunbury et al. 2017, Rowlands 2020), while islands rose and sank within the river channel (Wilson 2012, 2018, Ginau et al. 2017, Bunbury 2019, Moreno García 2020). The naturally dynamic, shifting Nile course led to changes in settlement and harbor locations (Graham 2010a, Boraik et al. 2017) and the landscape around religious architecture (Graham 2010a,

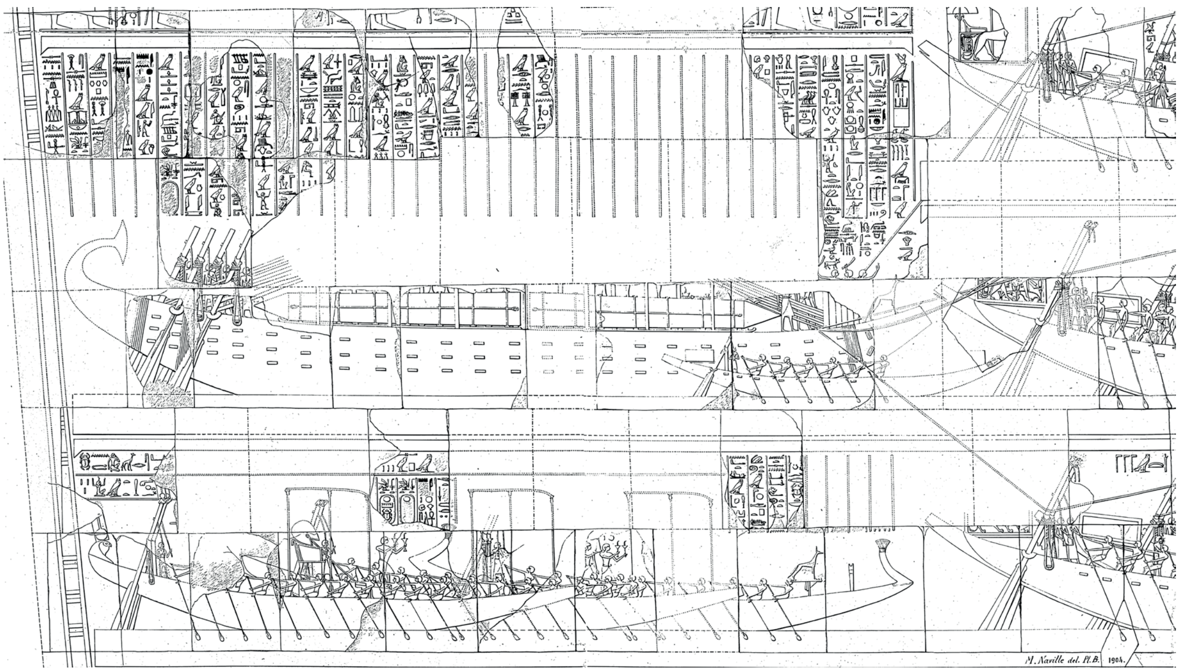


Fig. 4.6 Scene of obelisks being transported by barge, mortuary temple of Hatshepsut at Deir el-Bahri. Photo: Stephen Vinson, with permission

Gabolde 2013). Examples include the abandonment of the site of Piramesses in the 11th century BCE following the blocking of the Pelusiac Branch of the Nile through sedimentation (Bietak 2017, p. 63), and the development of the Temple of Karnak in Thebes upon a newly formed island and infilled channels (Bunbury 2019, pp. 88–92, Graham 2010b).

The connection between climatic and environmental shifts and political change is a continuous field of study in the history of Egypt, especially for Mediterranean-wide incidents such as the so-called *4.2 ka BP event* – an important episode of climate fluctuation connected to political collapse in neighboring Mediterranean cultures (Finné et al. 2011, Höflmayer 2017, Bini et al. 2019). In the last few decades, historians of ancient Egypt have been shifting their approach to the study of the environment. This broadened perspective focuses not only on human inhabitants as "*the main agents of history*" (Schneider 2020), but views the landscape and environment as active agents influencing Egyptian political and cultural history through the opportunities afforded and limitations imposed (see discussion in 4.3.1, also Manning 2012, 2018, p. 103, Moreno García 2020, Schneider 2020).

Along with political and environmental fluctuations, a profound social and cultural change occurred throughout Egyptian history, particularly following the conquest of Egypt by neighboring states in the 1st millennium BCE (see 4.3). This included more extractive production policies, such as the intensification of agrarian production and export under Rome (Manning 2012). Further significant changes occurred in late antiquity with the introduction of first Christianity and then Islam. Centers of traditional Egyptian polytheistic worship were officially shuttered by the Roman emperor Theodosius in 392 CE, bringing to an end nearly four thousand years of relative continuity of belief and religious observance.

In more recent history, the construction of dams through the 19th and 20th centuries, particularly the building of the Aswan High Dam in the 1960s, led to significant subsistence changes, particularly for rural settlements along the Nile valley. The dams regulated the natural floodplain inundation cycle of the Nile, which no longer overflowed its riverbanks. Farming became more industrialized and water and input-intensive, with new technologies introduced as part of the global Green Revolution (Ramzi 2012, p. 51). These changes have led to exponential population growth. Though the population of ancient Egypt has been estimated to be as high as eight million in late antiquity (Scheidel 2001, pp. 183–186), it had decreased to only roughly 2.5 million by the time of the first modern census in 1800 (the decline was in part a result of the Black Death and early modern diseases, among them cholera and smallpox; Scheidel 2001, Ramzi 2012). By the census of 1960, the population had increased to around 26 million (Central Agency for Public Mobilization and Statistics Statistical Yearbook 1960), after which point growth accelerated, with a population roughly quadrupling to over 100 million in the six decades since dam construction (Central Agency for Public Mobilization and Statistics Population Clock, July 2020).

4.5.1.2 Interactions between the river and spiritual activities

As famously articulated by the 5th century Greek historian Herodotus, the Ancient Egyptian state was perceived (by non-Egyptians) to be the 'gift' of the Nile River (Herodotus Histories, 2.5.1; similar sentiments are also presented by Pliny, Naturalis Historia, 18.47). The rich alluvial soil deposited on the river banks and floodplain, known as the "Black Land" (*kemet*), was the home of Ancient Egypt and the domain of the falcon-headed god, Horus. This fertile land adjacent to the Nile was governed by Ma'at (justice and order) and contrasted with the "Red Lands" (*deshret*) of the desert, ideologically framed as the source of chaos, danger, and foreigners (these ideological distinctions did not preclude nomadism or transhumance; Quirke 2014, pp. 12–14). The Nile was known in Egyptian literature simply as *iteru* (the river), from which the Greek *Neilos* may have derived (from the plural na iteru, 'the rivers', perhaps reflecting the numerous Delta branches, Quirke 2014, 13).

With deserts flanking the Nile valley to the east and west, cataracts in the south, and the Mediterranean Sea in the north, the land of Egypt was geographically circumscribed by natural barriers. Though these barriers were highly permeable, they formed ideological boundaries between the land of Egypt and the adjacent foreign territories. Geographic orientation was based on the Nile and its northerly flow. Sailing upstream, enabled by the prevailing wind direction, meant travelling south. In accordance, the Egyptian word *pḥwy* could mean both backwards and north, while *ḫnt(y)* meant both front and south (Faulkner 1991, pp. 92, 194). Similarly, navigating upstream, or southwards, put the eastern bank on the left side and the western bank on the right. The term *i by* meant both left and east, while the term *imn* meant both right and west (Faulkner 1991, pp. 8, 21). Religious monuments were also oriented towards the river (as well as stellar and solar phenomena; Shaw 2012, p. 164).

The Nile and its annual floodplain inundation articulated the passage of time and the seasons (see fig. 4.3). The new year began with the inundation (*akhet*) from roughly late July/August to November; followed by the growing season (*peret*) from December to March, and the harvest (*shemu*) from April to July (Shaw 2012, pp. 160–162). Many religious festivals were held in observance of important times within the inundation and agricultural calendar. For example, the Festivals of Khoiak for the god Osiris marked the receding of the Nile flood and the sowing and sprouting of crops, reflecting Osiris' own physical resurrection after death (Teeter 2011, pp. 58–66). An ideological connection between time and the growing season can also be seen in the use of the plant symbol (*rnpt*) as the sign for the year (Shaw 2012, p. 160).

Though not all festivals were tied directly to the agriculture cycle, most incorporated the Nile River directly or indirectly. During these festivals, some of which were known as *khenet* ('sailings'; Quirke 2014, p. 98), the images of the gods were transported in sacred barques along processional routes, stopping at different temples and shrines along the way (fig. 4.7). These processions allowed for greater proximity to the divine for ancient Egyptians, both in life and after death; many dedicatory inscriptions note that the builder placed their statue or shrine in close proximity to the processional route, in order that they may be in the god's company for eternity (Teeter 2011, pp. 23–24). Nautical journeys also played an important figurative role in religion, with the sun god Ra depicted as traveling through the sky each day in a solar bark. Similarly, the final journey to the afterlife incorporated travel by boat, as the mummy of the deceased (in the case of the Egyptian elite) was transported from the place of mummification to the place of burial in a ceremonial boat (fig. 4.8); ceremonially buried boats have been recovered from a number of royal funerary complexes. This represented the transition from the land of the living on the east bank, to the land of the dead on the west bank (Teeter 2011, p. 138).

Though the river itself was not worshiped as a deity, the floodwaters or inundation of the Nile was manifest in the fertility god Hapy (fig. 4.9). The vital importance of this god is reflected in the surviving texts, including the Great Hymn to Hapy, the Pyramid Texts, and the Coffin Texts. These documents describe Hapy as the god "who fills the storerooms and enlarges the granaries" (Hymn to Hapy, IV.9; translation after van der Plas 1986, 29), and for whom "the land prospers to the extent of [his] desire" (Coffin Texts, Spell 318, trans. Faulkner 1973, 4:142). Hapy's role as a provisioner of Egypt is explicit in his many epithets, which characterize him as the god "who brings vegetation" (Coffin Texts, Spell 317, trans. Faulkner 1973, 4:115), and who "provides food … and makes herbage grow" (Coffin Texts, Spell 320, trans. Faulkner 1973, 4:144). Egyptian kings were responsible for propitiating the god in order to ensure agricultural bounty – a relationship that they acknowledged in their texts: "*Hapy gave me honor on every field, / So that none hungered during*

Fig. 4.7 Festival Barques of the gods Hathor (*above*) and Horus (*below*), Temple of Hathor, Dendera. Photos: Christine Johnston

Fig. 4.8 Model Sailing Boat transporting the mummy of the deceased, Tomb of Djehuty, Lisht South, Tomb B. Photo: Metropolitan Museum of Art 32.1.124a, Met's Open Access Program, CC0 1.0

Fig. 4.9 Androgynous inundation god Hapy follows the King of Egypt bearing gifts of lotus flowers and tall vases of flood water, Temple of Hathor, Dendera. Photo: Christine Johnston

my years, / none thirsted therein." (Teaching of King Amenemhet I, trans. by V.A. Tobin in Simpson 2003, p. 169).

Similarly, rulers who governed over times of prosperity could be conceptualized as fertility deities, as was the case with Amenhotep III of the 18th Dynasty (Kozloff and Bryan 1992, pp. 103, 204–6, No. 23). The creative powers of the inundation were also harnessed by the ram-headed god Khnum, who was responsible for fashioning people out of clay on his potter's wheel (Quirke 2014, p. 55). In some traditions, Khnum was also responsible for releasing the inundation each year from caverns located under his temple at Elephantine (seen, for example, in the Famine Stele of the Ptolemaic period, trans. R.K. Ritner in Simpson 2003, pp. 386–391).

The precariousness of life in Egypt and dependence of Egyptian prosperity on the inundation is reflected in prayers and invocations of the Nile flood, as well as in didactic literature. One example, the *Teachings of Any* (21st or 22nd Dynasty; roughly the early 1st millennium BCE), expresses anxieties over the river's naturally fluctuating nature: "*... last year's watercourse is gone, / Another river is here today; / Great lakes become dry places, / Sandbanks turn into depths. Man does not have a single way, / The lord of life confounds him.*" (Teaching of Any, trans. Lichtheim 2006, p. 142)

In addition to the variability of the inundation, the power of the Nile was also manifest in the danger posed by its waters. Drowning was a particularly dire fate, as it left the deceased unburied and therefore unable to navigate to the afterlife – those who perished by drowning were often depicted in Afterlife Books as suffering in the underworld, drifting in the water, sometimes upside down, and awaiting rescue by the god Horus (e.g., Amduat, Book of Gates, Hornung 1994, 1999). By the Greco-Roman period, drowning became associated with religious rejuvenation (e.g., the "Ritual of the Cat", Greek Magical

Table 4.3 Key elements of cultural diversity of the Nile in Egypt

Key element	Link to the natural flow regime	Ecosystem services	Threats and recovery
Worship of the Nile flood as the god Hapy	Flood unpredictability and river migration led to an Ideology of risk and impermanence, and the deification of the flood.	Connection between fate and the will of the gods supported religious institutions.	Modern water management has reduced Nile variability. Scientific advancement allows for climate forecasting.
Nilotic images in art	Artwork shows nautical scenes from daily life and religion (sun's journey through the sky; passage to the afterlife). Images of Nilotic flora and fauna reflect the fertility of the river.	Artistic representations guarantee that the depicted scenes are realized – there is a magical permanence created by images.	Religious change through late antiquity with the introduction of Christianity and Islam transformed the meaning of nautical scenes. Pagan deification of the flood and the sun are abandoned.
Subsistence (farming, fishing, fowling)	Risk mitigation strategies include canals, catchment pools, and dams, which managed the flood and increased arable land. Exploitation of marine resources through fishing and fowling	Farming (cereals, fruit, vegetables) relied on the Nile inundation. Fishing and fowling provided important sources of protein. Taxation (calculated with census data and flood heights) supported religious and political institutions.	Population loss as a result of the plague threatened the community-dependent agricultural system. Dams built in the 19th and 20th centuries have largely eliminated the flood. The Green Revolution introduced new technologies and industrialized farming. Pollution and commercialization have impacted marine resources.
Marine transportation and trade	Transport of goods and people throughout the land. Travel facilitated by northerly flow and southerly winds. Geographic orientation was based on the northerly river flow.	Transportation barriers created ideological boundaries between Egypt and its neighbors. Mobilization of resources like stone for use in monumental construction reflected the power of the state.	The canal linking the Nile to the Red Sea reoriented riverine trade and travel in the Islamic Period. Combustion engines have eliminated the dependency on wind and current for river navigation. Aviation and automobiles have reduced reliance on riverine transport.
Health and medicine	River threats included predators and water and insect-born diseases. These threats are often personified by deities who are placated through worship. Water is associated with purification and rejuvenation.	Preventative health focused on the gods and ritual. Treatment included magic and medicine, both linked to religious institutions (sanitoria, healing practitioners).	Advances in science and medicine have improved treatment of certain diseases and gastrointestinal disorders. Evolution of pathogens and post-antique introduction of new diseases (plague, cholera, smallpox) have added new threats.

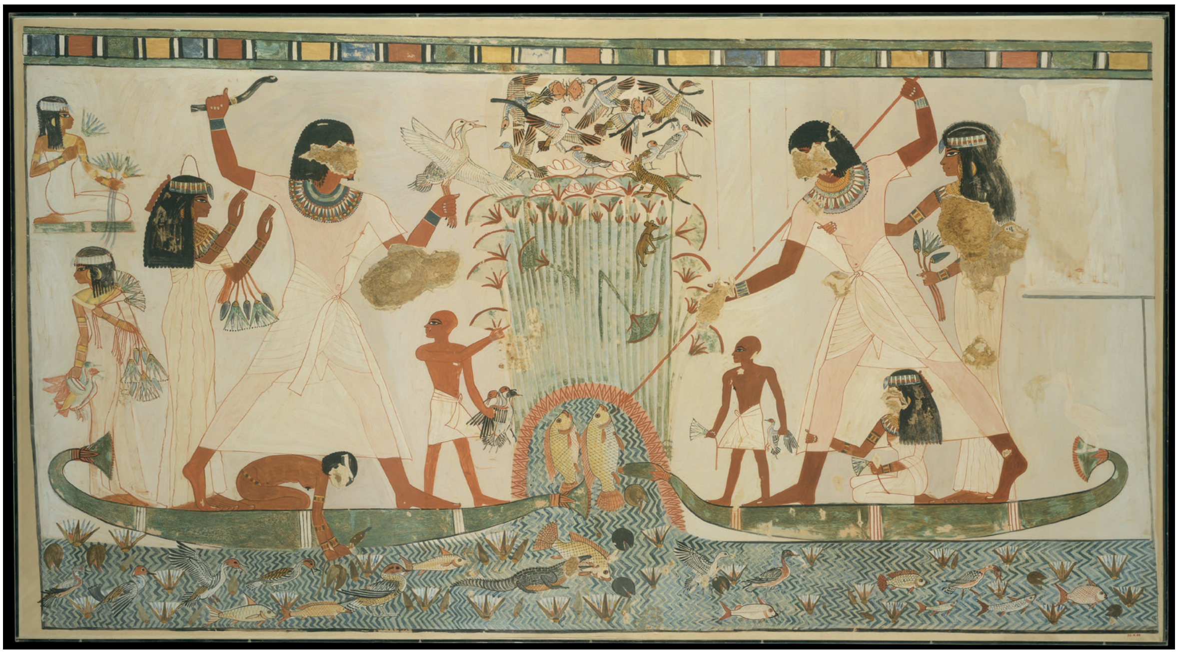


Fig. 4.10 Image of fishing and fowling, Tomb of Menna (TT 69), north wall. Metropolitan Museum of Art 30.4.48. Painting: Norman de Garis Davies, Met's Open Access Program, CC0 1.0

Papyrus III 1–164), most famously seen in the deification of Antinoos, the lover of the emperor Hadrian, who drowned in the Nile in the early 2nd century CE. The river was also home to threats such as crocodiles and hippopotami. According to the 3rd century Ptolemaic historian, Manetho, the reign of Menes the first king of Egypt was ended when he "carried off" by a hippopotamus (Manetho, according to Africanus fragment 6, translated by Waddell 1940, pp. 26–29).

4.5.1.3 Resource use and risk avoidance

As a central vein running through the land of Egypt, the Nile River acted as a conduit for the mobilization of goods and people both within and beyond the traditional boundaries of the Egyptian State. It provided food and facilitated agricultural production – especially cereals (barley – *Hordeum vulgare* and emmer wheat – *Triticum dicoccum*), but also legumes (lentils, peas, and chickpeas), vegetables (onions, lettuce, radishes, garlic, cucumbers, leeks, and gourds), and fruits (dates, pomegranate, melons, berries, and figs). Grapes were also grown as foodstuffs and to make wine. Although cereal production and animal husbandry were central agricultural pursuits, the varied ecology of the Nile valley offered numerous resources and supported a variety of subsistence strategies (Moreno García 2020). For example, the low settlement density and the marshy humid environment of Middle Egypt encouraged pastoralism over sedentary cattle ranches (Moreno García 2017, 2018, 2020). Fishing and fowling served as important subsistence strategies (fig. 4.10), while resources like flax and papyrus were used for the production of linen and paper. Nile silt was used in the manufacture of pottery, figurines, and mud bricks – the main building material of ancient Egypt (Bard 2007, pp. 61–62). Human and goods mobility continued to rely on riverine transport until the introduction of automobiles and aviation.

The specific role of the ancient Egyptian government in economic production and risk mitigation varied considerably through time and is challenging to reconstruct due to the exaggerated role played by the state in the surviving textual sources, which document the interests and activities of state institutions (Muhs 2016, pp. 6–7). The centralized administration of production and redistribution is evidenced in part by the management of grain collection and storage. In addition to the physical storage facilities, many of which were housed in temple complexes, administrative titles, biographical records of officials, and census data document the system of taxation that funded religious institutions and state-sponsored programs of construction and conquest. Corporate irrigation in the form of canals, basins, and dykes is also attested from as early as the Old Kingdom, though the development of a comprehensive national water management strategy appears to have happened later (Willems et al. 2017, pp. 259–261, Manning 2018, pp. 99–103, Moreno García 2020). The reclamation of arable land along the Bahr Yusuf during the Middle

Nile Crocodile (*Crocodylus niloticus*). Photo: Bernard Gagnon, Wikimedia Commons, CC BY-SA 3.0

Nile perch (*Lates niloticus*). Photo: Daiju Azuma, Wikimedia Commons, CC BY-SA 4.0

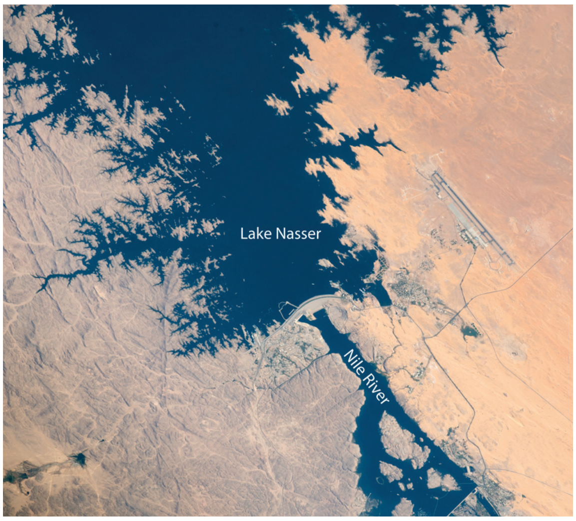
Blue water lily (*Nymphaea caerulea*). Photo: Salima Ikram

The Flooded Courtyard of Amenhotep III in the Luxor Temple. Photo: Antonio Beato, Getty Collection Object 84.XM.1382.9. Getty's Open Content Program

The Nilometer, Island of Rhoda. Photo: David Roberts, Library of Congress, hdl.loc.gov/loc.pnp/cph.3g04040, with permission

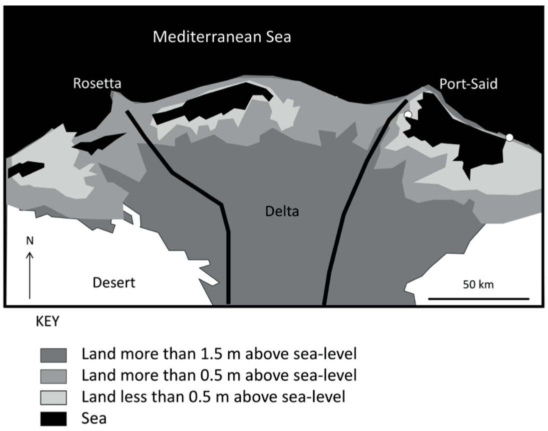
Example of a cippus depicting the god Horus as a child, subduing dangerous animals with surrounding text, ca. 300 BCE, unprovenanced). Photo: Metropolitan Museum of Art 29.2.15, acquired 1929, Rogers Fund, 1928, Met's Open Access Program, CC0 1.0

Fig. 4.11 Left column: iconic examples of biological diversity, right column: iconic examples of cultural diversity



Aswan High Dam. Graph: Christine Johnston, adapted from NASA Earth Observatory photo with captions by Justine Wilkinson

Urban expansion in Cairo. Graph: Christine Johnston, adapted from NASA Earth Observatory photo with captions by Lauren Dauphin



Delta erosion, and sustainable management solutions and conservation actions. Graph: Judith Bunbury, based on UNP forecast data

Field drainage water reuse. Photo: François Molle, Flickr, CC BY 2.0

Drip irrigation in New Lands, Egypt. Photo: François Molle, Flickr, CC BY 2.0

Sugar beet. USDA. Photo: Bob Nichols, Flickr, Public Domain

Fig. 4.11 (continued) Left column: iconic examples of threats, right column: iconic examples of sustainable management

Kingdom is an excellent example of ancient Egyptian water management (see section 4.6 for description).

Risk avoidance strategies were necessitated by the variability of annual inundation levels, as severe effects could result from even moderate fluctuations in flood heights (Butzer 1976, p. 5156). Extreme weather and irregular rainfall could also exacerbate flooding and threaten agricultural stability, with evidence for such episodes appearing in the textual record (e.g., the New Kingdom Tempest Stela of Ahmose, Ritner and Moeller 2014). The flooding of temple complexes located along the Nile also occurred during extreme inundations, both in the ancient world (Krauss 2006, pp. 372–373) and in more recent history (fig. 4.11, second column top). Documented Nile levels from medieval and early modern records demonstrate the high variability of interannual inundation heights (Seidlmayer 2001), which made longer-term forecasting challenging. Risk mitigation was achieved through strategies of water management reliant in part on the recording of inundation levels using Nilometers (from the *Greek neiloskopeion*, "Nile observers", fig. 4.11, second column middle). These instruments were attended to by temple personnel, and were established at strategic points along the Nile, the most important of which was the First Cataract where the inundation first reached Egypt. Long-term data on both flood heights and subsequent harvests were recorded. As described by the 1st century BCE Greek historian Diodorus Siculus, records of the Nilometer measurements were dispatched around Egypt to inform residents of the expected inundation height, when the floodwaters were projected to recede, and how large the upcoming harvest would be (Bibliotheca Historica, 1.36.11–12, see section 4.4.2 for the use of Nilometers in the Islamic period).

Despite efforts to monitor the Nile inundation and mitigate risk, numerous literary and figural references to famine and shortage appear. In some cases, these descriptions may be ideological exaggerations in order to express the instability associated with the breakdown of centralized authority during the so-called Intermediate Periods of history. However, documents from New Kingdom Egypt record food shortages and price inflation for commodities like grain (spelt, emmer, and barley) and oil (Janssen 1975), perhaps due to administrative inefficiency or seasonal fluctions (Trigger et al. 1983, pp. 228–229, Antoine 2009). Delays of rations of fish for workers as a result of high floods are also recorded (Antoine 2006, pp. 33–35, 2009). These disruptions in food distribution led to instances of social unrest, the most famous example of which was the Theban workers' strike – the first recorded labor strike in history – which occurred during the reign of Ramesses III (Edgerton 1951). In this event, the artisans employed to build the tombs of the rulers in the Valley of the Kings held a strike demanding the payment of outstanding rations of grain and other foodstuffs, which may have been delayed due to a poor harvest in the preceding year (Antoine 2009, p. 232).

4.5.1.4 Effects of the river on human health

In addition to riverine predators – hippopotami and crocodiles – snakes, scorpions, and waterborne and insect-borne parasites and illnesses posed serious health threats to Egyptian inhabitants. As discussed in section 4.5, parasitic diseases such as schistosomiasis were transmitted by aquatic biota (freshwater snails) and were contracted by humans through contact with contaminated water (Nunn 1996, p. 68, Schistosomiasis is still a cause of chronic illness in Egypt today). The river and canal banks also exposed inhabitants to dangerous mosquito-borne diseases like malaria. Evidence from funerary objects, monuments, and texts reflect a seasonal mortality pattern in which death peaked in ancient Egypt during the spring; this may reflect the increased contamination of canals after the flood had receded, as well as the high number of pathogens, present during this time (Scheidel 2001, pp. 70, 109–117).

Human remains, figural art, and surviving medical papyri document a variety of diseases, as well as common treatments. Healing relied on a combination of observation and diagnosis with both medicinal and religious or magical therapies. Water played a purifying and rejuvenating role. Sanatoria located in temples allowed the sick to be partially or totally immersed in healing water, which could be magically purified by healing statues (Bard 2007, p. 305, an example of a sanitorium survives at the Ptolemaic Temple of Hathor at Dendera). To protect against dangerous creatures and to heal bites and stings water could be applied (or consumed) after first pouring it over a cippus (fig. 4.11, second column bottom), a carved stela depicted the child-god Horus subduing dangerous creatures such as snakes and crocodiles (Shaw 2012, p. 47). Nile mud and dried river sediments were used medicinally for purposes such as the reduction of heat or swelling and the cooling of burns (Nunn 1996, table 7.3, e.g., Papyrus Ebers 482).

4.5.2 Byzantine Egypt to the present

Information on this section is included above in 4.4.2. Relevant examples of cultural diversity relating to the period from the Byzantine to the present have been included in table 4.4.

4.6 Current trends, challenges and threats

The reach of the Nile downstream of the First Cataract at Aswan provides one of the longest-running documented examples of river management. The earliest documentary evidence for the management of the water from the lower river for irrigation appears on the Scorpion Mace Head (c. 3050–3000 BCE, Ashmolean Museum) where the king is depicted wielding a hoe and breaching a dyke (see fig. 4.5). Since this Pre-dynastic example, no doubt pre-dated by earlier attempts of irrigation, there has been an expansion of the scope and impact of river management in Egypt until the present day (Bunbury 2019). Early irrigation was expanded by diversion of the spur channel of the Nile, the Bahr Yusuf, to refill the Faiyum Basin by Amenemhat III (c. 1860–1814) extending agriculture there during the Middle Kingdom. Later, canalization of the main Nile and its distributaries started in the Graeco-Roman period (after 600 BCE). Damming and regulation of the river flow regime on a large scale, began with the construction of the Aswan Dam in the late 19th century and then the High Dam in the late 20th century.

In the Nile Basin, irrigation tends to be managed by the state and historically, in Egypt in particular, has been directed towards increasing the productivity of goods like wheat that can be taxed. In turn, this has led to a marginalization of swamps, marshes and scrub that has reduced the biodiversity, and limited the diet of the farmers (Pennington et al. 2016). At times, perhaps connected to climate stress, these more restricted food webs have led to desertion of the land by farmers who became exiles (Blouin 2014) and may even become enemies of the state and the established irrigation systems in a bid to improve their habitat (Abul-Magd 2013).

All river-management projects, particularly damming, have both advantages and disadvantages. The upsides to dam construction include water storage for supply, control of water to reduce flooding and drought, as well as the production of hydroelectricity. Schemes are in train in many countries within the Nile Basin, particularly in Ethiopia, Uganda, and Sudan, and all share many of the same advantages and disadvantages. In Ethiopia, dam building is seen by many as essential for development, supplying the country's water and electricity needs as well as exporting the latter to neighboring countries. In Egypt, the cessation of the annual flood also liberated large amounts of the floodplain for permanent agriculture and development, but there were also downsides (see fig. 4.11, column three for examples of cultural threats).

Some of the negative impacts of dam construction and the attendant alteration of the natural pattern and timing of flows include the loss of aquatic habitats, critical lifecycle cues for various species, and connectivity, as well as the direct displacement of populations in the flooded areas (Hassan 2007). For example, Lake Nasser flooded Nubia in the late 20th century as the Aswan High Dam came into service and divided the Nubian communities into two geographical areas; some were displaced northwards to Aswan and Kom Ombo in Egypt, while others were displaced to the South into Sudan. This kind of displacement can lead to poverty and also ethnic and political conflict in some areas. The reduction in downstream water supply can also cause hardship for those living downstream.

River processes also cause both short-term and long-term problems arising from dam construction. Reservoirs trap silt causing a corresponding downstream loss of fertilizing sediment, leading to exhaustion of the productivity of agricultural land. Excess chemical fertilizers, used to replace the fertility of the nutrient-rich silt, are washed into waterways and, in extreme cases, algal blooms turn the water red, poisoning the wildlife. In Egypt, this is managed by the control of the water supply, increasing water flow if pollutants are in excess. Low water supply can also lead to rapid salination of the land as evaporation rates are high. This can be mitigated by wicking up salt using desert sand which is disposed of outside the floodplain (pers. obs. and discussion with farmers in the Edfu region). Newer irrigation systems supplying water from boreholes to subsoil irrigation systems are currently being developed in the area around 27° 9'32.48"N, 30°53'6.38"E.

In the longer term, damming the Nile reduces the amount of sediment transported along the river system and reservoir storage, reducing the lifespan of the infrastructure and having dramatic influence on the sediment regime (see chapter on dam legacies, this volume). In the longer term, deltas tend to subside due to the weight of the sediment depressing the crust but this is balanced by aggradation. In the case of the Nile Delta, natural subsidence, sea-level rise by climate change, and the reduction in sediment transport due to the dams coincide, resulting in a possible lowering of the delta by 1 m until 2100 (Stanley and Warne 1998). Since around 2010, there has been noticeable erosion of the Delta front.

In addition to human habitats being fragmented by physical barriers such as dams and reservoir formation, other habitats are also affected. For example, the Nile crocodile and hippopotami no longer survive below the Aswan Dam. Every dam project on the Nile has had similar effects, for example the Meroe Dam lowered the water level downstream in Sudan, impoverishing agriculture. The sandy river flanks that had easy access to the water were unsuitable for agriculture, with the exception of legume crops, while the higher fertile ground that no longer flooded required water to be pumped from around 5 m below the ground surface. These upstream and downstream effects can lead to tension and, unfortunately, the infrastructure for the hydroelectric power that was supplied downstream was rapidly recycled for domestic wiring and the electricity poles used as timber, which is in short supply in that area.

On a basin-wide scale, international negotiations are currently underway to reduce the friction between Egypt and Ethiopia caused by the Grand Ethiopian Renaissance Dam (GERD) project, due to be Africa's biggest hydropower dam (Abtew and Dessu 2018). Construction of the dam, which will be the largest in Africa, began in 2011, but a number of treaties designed to reduce conflict in the catchment area had broken down in 2000. The GERD (Yihdego et al. 2017), on the Blue Nile at the border with Sudan, is designed to alleviate poverty in Ethiopia by supplying water and electricity to the population. Excess electricity may also be supplied to neighboring countries. But, downstream, Egypt fears that a reduction in water flow as the dam fills will affect farmland and reduce around one million people to poverty for every 2% decrease in the water available (Bissada 2021).

4.7 Management suggestions

The Nile river constitutes a limited resource of water for a population of currently 400 million people in the Nile Basin countries (Melesse 2011, Awulachew et al. 2012, Melesse et al. 2014, Kimenyi and Mbaku 2015, Sandstrom et al. 2016, and see https://nilebasin.org/). Further demographic growth, as well as economic and agricultural demands, surpass the river's support capacity, a situation exacerbated by political disputes and climate change. "Water bankruptcy" in the Nile River Basin is a clear possibility for the near future (Degefu and He 2016). While in the past, Egypt was the main beneficiary of the Nile water, as the country is dependent to 95% on the Nile River for its water supply, it will be essential for Egypt to reach an agreement about the distribution of the Nile water with the other riparian states of the Nile Basin, and to maintain a dialogue about an integrated sustainable transboundary management of the Nile in the future (Swain 2011, Zeidan 2015, Degefu and He 2016). Inevitably the new dams from Sudan to Ethiopia have an impact on both the people and the environment. A number of organizations, including the United Nations, are working with the 11 countries in the catchment to mitigate as much as possible the negative effects of the projects. Large supra-national organizations, third-party countries, and intergovernmental processes can help to foster mutual understanding among interested parties along the river. However, the Cooperative Framework Agreement on the Nile River Basin (CFA) which intends to allocate more Nile water to the upstream countries has not been signed (and is not expected to be signed) by Egypt and the Sudan (for the political discussion, Salman 2013, Cascão 2021).

Egypt's annual water shortage was 13.5 billion m^3 in 2016 – compensated for by drainage reuse and groundwater withdrawal – a figure projected to rise to 26 billion m^3 by 2025 (Mohie El Din and Moussa 2016, see fig. 4.11, column four for examples of sustainability strategies). Measures proposed by water management specialists to save water include a more effective application of irrigation methods (including drip irrigation), the removal of aquatic weeds, the substitution of sugarcane plantations by sugar beet, keeping the actual rice area in the traditional agricultural lands, monitoring the withdrawal of deep groundwater, reducing the water losses with in the water distribution network, and increasing water provision by desalination (Mohie El Din and Moussa 2016). In the mid- and long-term, a reduction of Egypt's population growth would be required to prevent a systemic and disastrous situation of water shortage.

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URLs of common license pictures

Fig. 4.5 Irrigation Scene: https://commons.wikimedia.org/wiki/File:Ceremonial_mace-head_of_King_Scorpion.jpg

Fig. 4.8 Model Sailing Boat: https://www.metmuseum.org/art/collection/search/555733

Fig. 4.10 Tomb of Menna: https://www.metmuseum.org/art/collection/search/548437

Fig. 4.11 Nile Crocodile: https://commons.wikimedia.org/wiki/File:Crocodylus_niloticus_in_Lake_Chamo_02.jpg

Fig. 4.11 Nile Perch: https://commons.wikimedia.org/wiki/File:Lates_niloticus_by_DaijuAzuma.jpg?uselang=de

Fig. 4.11 Flooded Courtyard of Amenhotep III: https://www.getty.edu/art/collection/objects/48258/antonio-beato-the-flooded-courtyard-of-amenhotep-iii-in-the-luxor-temple-english-about-1875/?dz=0.5000,0.3634,0.86

Fig. 4.11 Nilometer, Island of Rhoda: http://hdl.loc.gov/loc.pnp/cph.3g04040

Fig. 4.11 Cippus: https://www.metmuseum.org/art/collection/search/550737

Fig. 4.11 Field drainage water reuse: https://www.flickr.com/photos/water_alternatives/36423089134/in/photolist-XuzRrq-2duXd1a-2gFe9Sn-2mygdPi-NuaRb8-2gFc2nL-XuzLq3-YavBhU-oeRH4t-2jZtreg-YvoLWj-YLD49e-2jZxUMy-2jZtrD4-YtNYJL-Zp1QUb-XuESsJ-ZYRgAz-GGTa1k-Yy2k9k-24xTkY2-2gFeat7-XwHkS6-2gFdtiM-2gFdt62-YxZky2-2gFdtQJ-262yQQA-nJraKy-2gFdtYE-2kiP139-YawqXU-2md2izH-23AZXwJ-2gFdtoS-2gFeanL-29wEwmD-Yy3vav-27L2Zcj-2m2wRT5-2mymwx5-2mymwAM-22gXNG7-2m2vLT5-2m2zqbo-27QCLTX-2m2zPGB-Je7KPL-2mykgx5-2mykgyh

Fig. 4.11 Drip irrigation: https://www.flickr.com/photos/water_alternatives/37765585346/in/photolist-ZxduMQ-26LU3GG-2dMMRqC-24tXk31-2b9mRKd-ETGz8k-Q7incd-25dgGDk-2caPTTb-Nu88kt-ETGxiD-24tXkbC-2hroTDT-2caPfpd-26mL6hx-2mypk6N-2md6bNX-Je7CM9-2eTJyN8-23bDQLZ-2cfpAdt-23bDNw8-HER6d1-YaqwB1-YaxbbN-HWov4h-2kV8q9Q-Haa99u-HaiKc8-2kVcnhs-2mJHszq-2aRyexc-23bDMWa-24hh9sP-24ZTMT6-J5vgmP-2myn3k6-HEE3FE-23bDNiT-HaeM43-2m7vxQz-2cfnW9V-YMWwwk-Yy2fNr-2jGftjq-2m7sGKd-2kVe72K-YvrQ7b-29tQb1q-24xTkZV

Fig. 4.11 Sugar beet: https://www.flickr.com/photos/usdagov/7209878018/in/photolist-bZ7vxG