Chapter 11
Lake Nasser: Alleviating the Impacts of Climate Fluctuations and Change

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Abstract Egypt as a country may not have existed without the Nile River. Its population was 84 million in 2015 and is estimated to reach 124 million by 2050. It is already the largest global importer of wheat. Even after Lake Nasser became operational in 1970, its arable land is still less than 4 % of its land area. The major constraint to expand agriculture is water, not land. Agriculture currently accounts for more than 80 % of total water use. Throughout history, Egypt has suffered from frequent droughts and floods. Construction of a storage reservoir at Aswan allowed it to stabilize significant interannual and intra-annual fluctuations of the Nile. Lake Nasser enabled Egypt to increase its cultivable land by 30 % and allowed cropping intensities to reach 180–200 % in old lands. When it became operational in 1970, it accounted for over half the country's electricity generation. While this reservoir has effectively taken care of climatic fluctuations, a main issue now is how to seamlessly integrate future climate change considerations with climatic fluctuations. At the present state of knowledge, it is impossible to predict even what will be the direction of river flow changes, let alone their real magnitudes. Three well-respected global circulation models indicate flow increases of 12 and 18 % and catastrophic decline of 77 %. Under such uncertainties, Egypt needs to increase all types of water storage, improve significantly water use efficiencies in all sectors, and monitor river flow changes over years very carefully.

Keywords Egypt · Lake Nasser · High Aswan Dam · Climate fluctuations · Climate change · Benefits of storage reservoirs · Climate change adaptation

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11.1 Background

"Egypt," observed the Greek historian Herodotus as early as the 5th century BC, "is the gift of the Nile." Nearly two-and-a-half millennia after his visit, and in spite of extensive technological and economic developments, it is still not an overstatement. Life and human activities in Egypt would be impossible without the waters of the Nile River.

Napoleon invaded Egypt in 1798. He shared the view of Herodotus on the importance of the Nile for the country's survival. He observed, "If I was to rule a country like Egypt, not even a single drop of water would be allowed to flow to the Mediterranean Sea." While Napoleon was not aware of the environmental and ecological roles the river waters play, his concept of using all the water available for human uses in a desert has some merit.

The situation is not very different at present. In fact, overall dependence of Egypt on the Nile waters has risen many times because its population has risen—from an estimated 3.8 million in 1800, around the time of Napoleon's invasion, to 72.7 million, according to the last census in 2006. The increase is more than 18-fold in a period of little over two centuries. The current projection is that the population will reach 124 million by 2050—a further increase of nearly 40 million people over the latest 2015 estimate.

For Egypt, which is the largest importer of wheat in the world, the major constraint to agricultural development is water, not land. Even after completion of the High Aswan Dam in 1970, the country's total arable land was still less than 4 % of its total land area. Currently, the rural population accounts for about 57 % of the total population, and their livelihoods primarily depend upon agriculture.

Like the entire developing world, Egypt is witnessing rapid urbanization. Because of the needs of a rapidly increasing urban population and consistently poor land-use planning, the country has been progressively losing productive agricultural land. This makes the country dependent on imported food. The area of Egypt's highly productive land (Class 1 soil) declined from 683.2 km^2 in 1992 to 618.5 km^2 in 2009. During the same period, the area of moderately productive (Class 2) land declined from 100.5 km^2 to 93.8 km^2 and marginally productive land (Class 3) from 209.1 km^2 to 198.3 km^2 (Shalaby et al. 2012). In 2006, it was estimated that an average Egyptian had to depend on 504 m^2 of arable land for food production. Fortunately, the decline in productive areas has been compensated by steadily increasing agricultural yields and improvements in management practices. With an ever-increasing population, a decreasing agricultural area, a serious water constraint, and rising expectations of the people for a better standard of living, the country has no choice but to improve its agricultural management practices and water-use efficiencies continually and significantly in the coming decades. This is an even more daunting task when the political turmoil of the recent years are considered. These factors will make it extremely difficult to improve the efficiencies of land and water management practices in the coming years.

The most challenging issues facing Egypt up to the year 2050 will be how to provide enough food, energy, housing, employment, a clean environment, and basic services, such as a water supply, wastewater treatment, education, health, transportation, and communication, to its current 84 million people, as well as to another estimated 40 million expected by that time. Furthermore, it should be noted that a very substantial middle class has emerged in recent decades. They are educated and affluent. Their number is likely to increase significantly in the coming decades. As in other parts of the world, the growing middle class will most certainly demand steady improvements in their standards of living and quality of life. If their expectations are not met, most probably there will be significant social unrest, which may have serious social, economic, and political repercussions for the country, including on land and water management practices.

The present and future expectations of Egyptians cannot be sustainably met without the efficient harnessing and use of the Nile waters. This is because water is a cross-cutting issue, essential for basic human needs such as drinking, agricultural production, energy generation, and employment creation through industrial, commercial, and agricultural developments, as well as for maintaining good health and a clean environment. Unquestionably, the Achilles heel of current and future development of the country is, and will continue to be, good water management processes and practices. Efficient and equitable water management is needed to contribute to steadily improving social and economic conditions. For an arid country like Egypt with only one primary source of water, the River Nile, the only option is water storage. Water can be stored in flood years and then used during drought years.

11.2 Water, Climate, and Development

The main source of water in the desert climate of Egypt is the River Nile. Rainfall is scanty. Only a small part of the country, the Mediterranean coastal strip, receives a comparatively higher average annual rainfall—100 to 200 mm—than the rest of the country. For example, annual rainfall south of Cairo is about 25–50 mm a year. In Central and Southern Egypt, several years may pass without any noteworthy rainfall. Throughout the country, rainfall is insufficient to grow most food crops in any year.

In the absence of significant, regular rainfall, Egypt, not surprisingly, does not have much renewable groundwater. Thus, human survival, agriculture, and the country's socioeconomic development depend on the flow of the River Nile. The river is shared by 10 countries, of which Egypt is the last downstream country. This geographical fact contributes to many complexities and uncertainties in terms of assuring water security in the future, which is essential for planning the country's future sustainable social and economic development. Fortunately for Egypt, in recent decades, two of its immediate upstream countries, Ethiopia and Sudan, did not use much water because of political and social turmoil, which constrained their economic and social development processes (Biswas 2011).

The hydropolitics behind the management of the Nile were complicated throughout the latter part of the 20th century. This has become even more complex in recent years (Biswas 1994; Biswas et al. 1997). The hydropolitics in the region have changed rapidly and significantly, especially in Ethiopia, which is currently constructing the Grand Ethiopian Renaissance Dam. Egypt is concerned that the construction and operation of this dam may reduce water availability for its steadily increasing future water needs (Abdelhady et al. 2015). Accordingly, the dispute between Egypt and Ethiopia on the construction of this new storage structure has become a contentious political issue. Egypt, not surprisingly, is concerned about its future water security and, thus, its economic development and political stability. Ethiopia also has similar concerns.

Irrespective of what happens in the future because of new storage structures that may be constructed in Ethiopia and Sudan, unless water management processes and practices in Egypt become significantly more efficient than they have been historically, the country will face major problems during the post-2020 period, both in terms of water quantity and quality. The time for incremental changes is now long over. The country needs significant and major structural changes in water management practices, which will be difficult to implement because of sociopolitical reasons, vested interests, and institutional inertia. However, the country has no alternative. It does not have the luxury of enough time to implement these long-needed structural changes, which have been mostly inconspicuous in the past by their absence.

Agriculture currently accounts for more than 80 % of total water use. Farming is by far the largest sector from where most Egyptians earn their livelihoods. Accordingly, the changes needed will be politically difficult to implement because a very large number of farmers are poor, illiterate, and barely eke out a living at present. Thus, making changes that may adversely affect their current lifestyles, at least over the short to medium terms, will be a very difficult process politically. Another major constraint facing Egypt is that even though water is a critical resource, data on its availability, demand, quality, and water-use efficiency by sectors and major users are not reliable and often could be contradictory. Without reliable, adequate data, proper planning and management of water will be a very difficult process, even under the best of circumstances.

11.3 Reservoirs and Climate Fluctuations

While the Nile has been a lifeline for Egypt for thousands of years, its annual flow has often fluctuated significantly from year to year, as well as within years. The Nile is one of the few rivers in both the developed and developing world for which reasonably accurate flow records have been available for several centuries. These

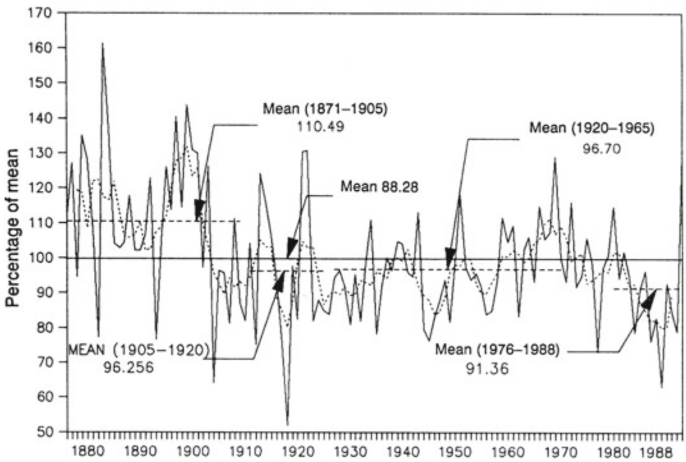

Fig. 11.1 Annualized Nile flow at Aswan (Abu-Zeid and Biswas 1992)

records show that the average yearly flow in the river has varied significantly, depending upon the periods over which average flow is estimated.

Figure 11.1 shows annualized Nile flow at Aswan as a percentage of the long-term mean flow over nearly 120 years. In hydro-meteorology, it is often assumed that the mean can be reasonably defined with around 30 years of data. Figure 11.1 shows that, depending on the period selected, the mean can be very different. For example, if a major storage structure had been designed in 1900 based on the previous 30 years of data or in 1950 based on the previous 50 years of data, the project design for the same location would have had significant differences. This means that the benefits and costs of a water infrastructure in the same location could be very different, depending on the period of data used by the planners and designers.

The problem is not limited to the Nile flow in Egypt. Similar problems would have been encountered at the White Nile at Mogren (Fig. 11.2) or the Blue Nile in Khartoum (Fig. 11.3) because of interannual and intra-annual river flow fluctuations. The flow records at Mogren can be easily divided into two distinct periods: 1912–1961 and 1962–1985. The mean annual flow during the period 1912–1961 was 25.6 billion m^3. For 1962–1985, it was 33.3 billion m^3, which is nearly one-third higher than during the previous 50-year period.

From the perspective of social and economic development in very arid areas of Egypt or Sudan, such annual variations in high and low river flow result in feast or famine without the construction of large storage reservoirs. Such reservoirs, by storing enormous quantities of water, smooth out downstream water availability and substantially reduce the adverse impacts of potential high floods or prolonged droughts.

Hydrologists and climatologists have often assumed that 30 years of continuously observed data can reliably define long-term rainfall and runoff patterns and

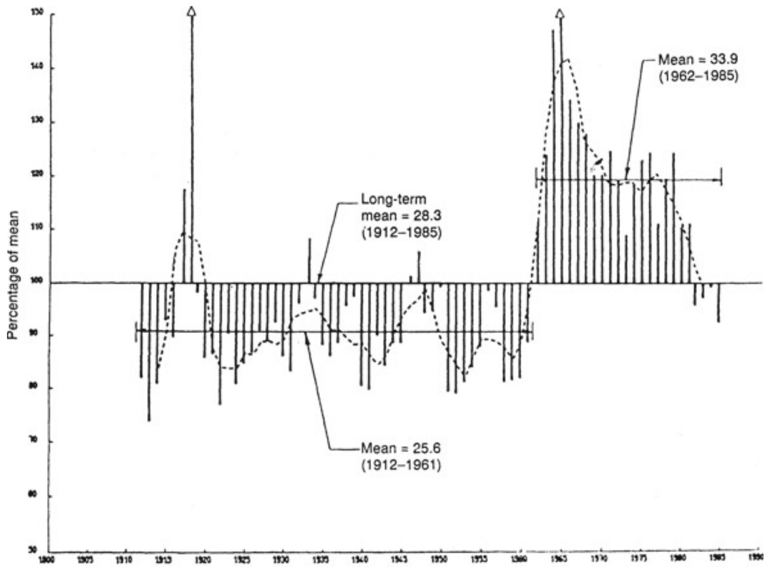

Fig. 11.2 Annual flow of White Nile at Mogren (Abu-Zeid and Biswas 1992)

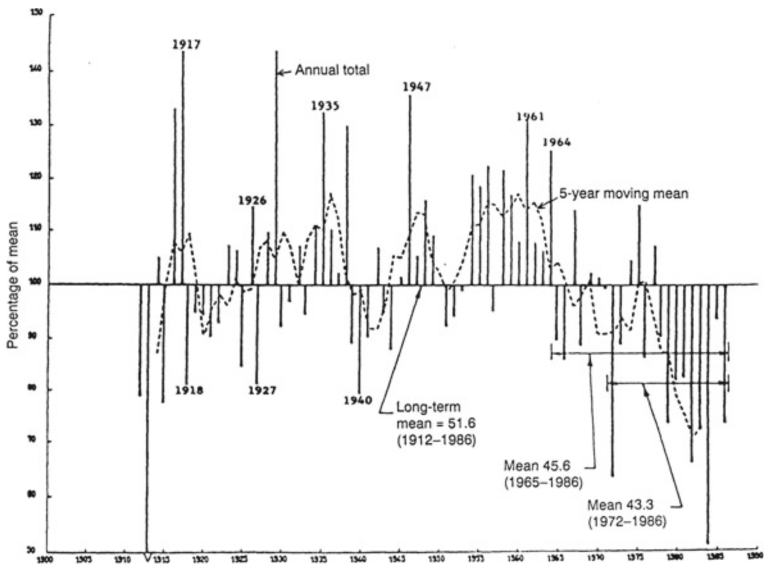

Fig. 11.3 Annual flow in Blue Nile at Khartoum (Abu-Zeid and Biswas 1992)

mean. The analyses of such data on the Nile, at three different places, clearly indicate that the interannual fluctuations in the Nile flow are often so different that this assumption is not valid, at least for this particular river.

11.4 High Aswan Dam and Lake Nasser: Hydro-political Developments

To stabilize the significant fluctuations in annual Nile flow, on which Egypt has been forever dependent for survival, Adrian Daninos, an Egyptian of Greek origin, first proposed in 1948 to construct a high dam at Aswan. The idea was that such a dam could control and manage the uneven flow regime of the river and, by doing so, would benefit the entire Egyptian population and contribute to economic growth. The proposed dam would also ensure that the Egyptians would have an assured supply of water, year after year, in perpetuity. The dam would further ensure that the periodic floods and droughts that have ravaged the country from prehistoric times could be successfully managed by creating a major storage reservoir. This reservoir is now known as Lake Nasser or the High Dam Lake.

In 1952, the Egyptian Government approved the proposed dam project and planning started. It was initially expected that the World Bank and the governments of the United States and the United Kingdom would finance the construction of the dam. However, the US Secretary of State, John Foster Dulles, unfairly and unilaterally decided in 1956 not to provide any funding for the construction of the dam for political reasons. Without the American funding, the British Government and the World Bank withdrew their offers to finance the project (Biswas and Tortajada 2012).

The dam was an important sociopolitical issue for President Nasser. Not only it was essential for Egypt to construct it to protect the country from regular floods and droughts, but also it was essential to smooth the Nile flow so that the country would have a reliable supply of water for agricultural production, hydropower generation, land reclamation, industrial and commercial development, and overall social and economic progress.

Psychologically, it was also important for Nasser to use the construction of what, at that time, was the largest dam in Africa as an important contribution to nation-building. This was especially relevant since, in 1952, King Farouk was dethroned and a new government of military officers took over the national leadership. Nasser felt that the construction of a large dam would give the newly independent nation confidence and pride. Successful construction of the dam would make the Egyptians proud of their country, instill confidence in the new political regime, and also contribute significantly its socioeconomic development. Thus, for both Nasser and Egypt, building the dam was more than a construction of a large infrastructure project: its symbolic and real contributions to Egypt's social and economic development pride and national unity should not be underestimated.

When western support for financing the dam was withdrawn in July 1956, a month after Nasser officially became the president, he promptly nationalized the Suez Canal. In his famous Alexandria speech of 26 July 1956, Nasser said, "The annual income of the Suez Canal Company was USD 100 million. Why not take it ourselves? We shall build the High Dam we desire." Accordingly, nationalization of the Suez Canal was a direct consequence of the withdrawal of the western offer to finance the construction of the High Aswan Dam. It resulted in the British, French, and Israeli invasion of Egypt. The war was an attempt to regain control of the Suez Canal and also to remove President Nasser from power. The United States publicly condemned the invasion and voted for the UN resolution to establish a peacekeeping force. No other dam in the entire history of the humankind has ever played such a major geopolitical role.

Nasser's view of the importance of the dam to the psyche of Egypt was outlined later in a speech in 1960: "We shall build the High Dam, but before building the High Dam, we have to first build the dam of dignity, the dam of integrity, the dam of liberty, and when we have built the dam of dignity, integrity and liberty, we shall have realized our hopes and we shall then surely build the High Dam."

The dam was eventually constructed with funding and technical assistance from the then Soviet Union. By all accounts, the dam has been remarkably successful. It has delivered much more than even its strongest supporters may have expected when it was first proposed in 1956. However, because of the then Cold War rivalry of the two superpowers and because the High Aswan Dam was the first successful foray by the Soviets into Africa, much false information was spread, often deliberately, by the western powers, intelligence authorities, media, and academics on the social and environmental costs of the dam. Regrettably, to a certain extent, this false information persists even today (Biswas and Tortajada 2012; Tortajada and Biswas 2017).

11.5 Role of Lake Nasser in Managing Climatic Fluctuations

When the High Aswan Dam was being planned, the overall concept was relatively simple and straightforward. Agriculture has never been possible in Egypt with only rainfall. The principal source of water is the Nile, which, historically, has had fluctuating interannual and intra-annual flows that have resulted in regular floods and droughts. The nature and extent of the roles of the dam in moderating the flow can be appreciated by the following facts. Before Lake Nasser became operational, the natural flow of the Nile fluctuated between 600 and 13,000 m^3/s, and the mean annual discharge to the Mediterranean Sea was 32 km^3/s (Abu-Zeid and El-Shibini 1997). After the construction of the dam, the discharge downstream varied from 700 to 2800 m^3/s. The variation between minimum and maximum discharge of the Nile was four-fold after the reservoir became operational, compared to nearly 22 times before its construction.

The differences in high and low water levels in the Nile, beyond Aswan, prior to the construction of the reservoir have been equally remarkable. These were around 7–8 m without the dam. After the reservoir was built, the difference has been around 2–3 m. Thus, downstream of Aswan, since the reservoir became operational, there has not been even a minor flood and, hence, no loss of life or damage to property.

In addition, the water flowing into the Mediterranean is now restricted to about 300 million m^3 in the winter season, only sufficient enough to provide the navigational requirements for the tourist boats. This is because during the winter, the irrigation water requirements in Egypt are at their lowest because the irrigation system is closed for annual maintenance. However, while irrigation water requirements are at their lowest during the winter, navigational water requirements for tourist boats during this period are at their highest. This is because tourism in Egypt during the winter is at its peak because numerous Europeans and North Americans like to take a break from their cold weather. The climate in Egypt during this period, especially in Aswan and Luxor, is very pleasant. In summer, the temperature in this region is very high and is not a pleasant time for tourism. Thus, the peak tourist arrivals in Egypt in this area are during November to January. Tourism has been a major source of income for Egypt, ranking only after the income from the tolls of the Suez Canal.

Without an adequate flow in the Nile, income from tourist boats would decline significantly. The tourist boats operating on the Nile are designed and constructed to require only a shallow depth of water. Thus, water released from the dam during the winter closure can be kept to a minimum, consistent with satisfying only the navigational water requirements of the boats.

Egypt's population in the 1950s was increasing rapidly. The majority of the households depended on agricultural activities for a living. Thus, a large reservoir was needed to store water in flood years so that it could be used during drought years. The High Aswan Dam provided the necessary storage to decrease the variations between high and low flows, eliminate flood damages, and ensure enough water was available during drought years for domestic needs, agriculture, and industrial uses.

The dam and reservoir system was completed in 1970. However, impoundment of Lake Nasser started in 1964. Figure 11.4 shows the variations in water level and the volume of water stored in Lake Nasser during 1964–2003. By storing a very large volume of water and significantly reducing the effects of climate fluctuations, Lake Nasser started playing an important role in Egypt's social and economic development. As President Nasser had anticipated, for an overwhelming majority of Egyptians, the High Aswan Dam became a source of national pride and joy. It has brought tremendous benefits to the country, both directly and indirectly, as well as political stability to the region.

The total cost of the dam, including subsidiary projects and the extension of power lines, was about EGP 450 million (Abul-Atta 1975, 1979; Biswas 2002). Water Minister Abul-Atta further estimated that the total cost was recovered in only 2 years, making it one of the most economically efficient large dams ever built anywhere in the world. The dam's annual return was estimated in 1975 at EGP 140 million in agricultural production, EGP 100 million in electricity generation, EGP 10 million from flood protection, and EGP 5 million as a consequence of improved navigation.

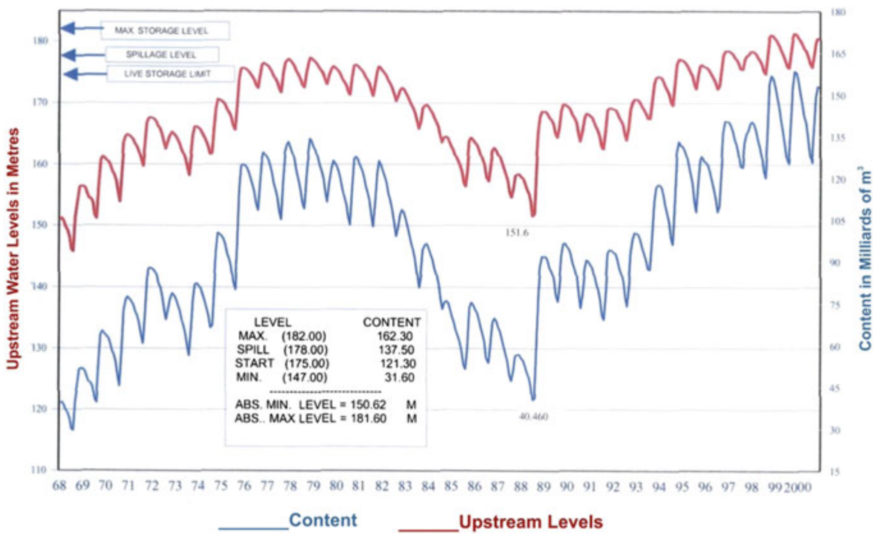

Fig. 11.4 Upstream water levels and volume of water in Lake Nasser (Tortajada and Biswas 2017)

11.5.1 Benefits of Lake Nasser

The overwhelming economic benefits from the construction of Lake Nasser are shown in Fig. 11.4. Egypt suffered from a prolonged drought between 1979 and 1986, followed by a very high summer flood in 1988. In the absence of Lake Nasser, the country would have undoubtedly faced very serious social, economic, and political turmoil because of the occurrences of these extreme hydrological events within a very short period of years. The two events had unprecedented adverse impacts on upstream neighbors like Ethiopia and Sudan. Because of the moderating effects of Lake Nasser, Egyptians did not feel any of the likely adverse impacts of the catastrophic prolonged drought, followed by a serious flood. Even with Lake Nasser, Egypt did come perilously close to feeling the adverse impacts of a prolonged drought. By early 1988, the volume of water available in Lake Nasser had declined to a perilously low level. Had the drought persisted for another two or three years, Egypt would have faced very serious economic hardships, and possibly social and political unrest. Lake Nasser saved the country from serious damages by attenuating the high and low flow of the Nile.

In addition, the dam generated hydroelectricity, which contributed to social, economic, and industrial development. During the 1950s, 1960s, and 1970s, Egypt had not discovered any oil or natural gas within its national jurisdiction. Thus, alternatives to generate electricity were limited. Electricity generated by the dam very significantly reduced the national balance of payment problems during the 1970s, when the country needed significant imports of food and energy for survival. Thus, the economic benefits accrued from Lake Nasser ensured that the Egyptian pound did not devalue as significantly as it might have without it. There is no question that without the reservoir, Egypt would have faced a serious balance of payments crisis.

The reservoir also provided a new water body for fish production, an important source of animal protein. Equally, the city of Aswan became an increasingly important tourist destination. The reservoir further ensured year-round navigation between Cairo and Aswan, which generated additional employments and revenues by boosting tourism and other associated economic and industrial activities.

11.5.2 Lake Nasser and Hydropower Generation

Water stored in Lake Nasser enabled hydropower generation. Originally, the power plant had 12 generating units, each with a capacity of 175 MW. Together they were capable of generating 10 billion kwh of electricity annually. The first two generators were brought online ahead of schedule to compensate for the destruction of thermal power plants during the 1967 Arab-Israeli war. Up to the early 1980s, electricity generated from Lake Nasser accounted for more than half that used by the country. Thus, not only did Lake Nasser ensure that the country did not feel the ravages of droughts and floods, but it also generated enough electricity to sustain more than half the country's domestic, industrial, and commercial needs.

In 1985, a total of 270 MW of additional capacity was added. Even as late as 2000, the hydropower contributed around one-fifth of the nation's electricity requirements. However, as time progressed and as Egypt's population and economic activities increased, the percentage of electricity generated by the reservoir waters started to decline because of increasing contributions from the newly

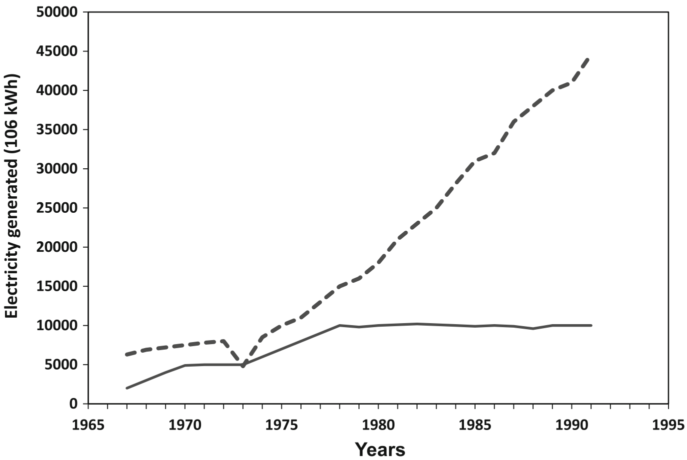

Fig. 11.5 Contribution of High Aswan Dam hydropower to Egypt's total electricity generation, 1967–1993 (Egyptian national statistics)

constructed thermal power plants. Figure 11.5 shows the contributions of Lake Nasser to Egypt's total electricity generation between 1967 and 1993.

It should be noted that when Lake Nasser became operational, Egypt had to import much of its fossil fuel. The hydropower generated from Lake Nasser significantly reduced the energy import bill of the country, and thus significantly reduced balance of payments problems. Even after oil was discovered and the country became self-sufficient and started to export oil, the availability of hydropower has reduced the amount of oil consumed nationally. This has meant that Egypt can export more of the oil it produced, and thus generate additional revenues. Without the reservoir, Egypt would have exported less oil, meaning significantly less revenue for the country.

During the early years of the operation of the High Aswan Dam hydropower plant, it accounted for over half the electricity generated in the country (Fig. 11.5). In 1978, hydropower accounted for 54.3 % of the country's electricity. Even though the total electricity generated by the dam has increased steadily over the decades because of better management and installation of increasingly more efficient machinery, its percentage share of national electricity production has steadily declined because more and more thermal power stations have come onstream.

11.5.3 Lake Nasser and Agricultural Development

The impacts of Lake Nasser on agricultural production have been very substantial for two important reasons. The first is land reclamation. When Lake Nasser became operational in 1970, Egypt's total arable land was estimated at 6 million feddan (1 feddan = 0.42 ha). By 1996, total cultivable land had increased by nearly 30 %, to 7.8 million feddan (Biswas 1995). This expansion was possible by using the water that was stored in Lake Nasser.

The second reason for steadily increasing agricultural production is because of steadily increasing cropping intensification. Before the construction of the reservoir, Egyptian farmers depended on irregular flows of the River Nile for agriculture. They did not have access to a reliable supply of water from Lake Nasser. Accordingly, agricultural yields in the farms were low. Farmers were lucky to get one good crop each year. Not surprisingly, the incomes of farmers were low. More than 90 % of Egyptian farmers are smallholders, with less than 3 feddan of land (Achthoven et al. 2004). Like most small farmers in developing countries, they are poor and their levels of literacy and risk tolerance are equally low. Somehow they manage to survive from these small plots of land.

The main advantage of a reliable supply of irrigation water from Lake Nasser has been that not only have crop yields increased, but cropping intensities have also steadily advanced. In recent decades, cropping intensities have reached around 180–200 %, especially in the old lands. The cropping intensities in the newly reclaimed land are somewhat lower, primarily because water still remains a constraint (Biswas 1993, 1995).

Lake Nasser ensured that Egyptian farmers had access to a reliable supply of irrigation water, year after year. By dampening the efforts of both high and low flows of the Nile through a vast reservoir and by enabling both vertical and horizontal expansion of agriculture, total agricultural production has increased very significantly. Agriculture accounted for 16.6 % of the gross domestic product (GDP) by 2000. It also contributed to 20 % of the country's export earnings. Agriculture further provided employment to more than 5 million workers, representing over 30 % of Egypt's entire labor force.

Lake Nasser not only stabilized the effects of climatic fluctuations that contributed to periodic high and low river flows, but it also ensured that a large number of Egyptian families have higher incomes, better standards of living, and a better quality of life. Our analyses indicate that had Lake Nasser not been constructed, Egyptians would have significantly lower standards of living at present. Without the reservoir, there is no doubt that there would have been serious social and political unrest, especially during the years when extreme hydrological events occurred (Tortajada and Biswas 2017).

11.6 Climate Change Implications

A major issue that the water profession has generally not faced up to now is how future potential climate change considerations can be seamlessly integrated with climate fluctuations factors that have occurred regularly in the past and will continue to occur in the future. Historically, climatic fluctuation has always been a fact of life. To a significant extent, climatic fluctuation considerations can now be adequately incorporated in planning, design, and operational processes of large reservoirs. We now have enough knowledge, technology, and management expertise to handle climatic fluctuation effectively. However, realistically, we are unable to plan, design, and operate new and existing reservoirs like Lake Nasser for both climatic fluctuation and climate change in an efficient, timely, and cost-effective manner. There are many reasons for this. Only the most important reasons for this inability will be discussed here in the context of Lake Nasser.

The first reason is the prevailing disconnect between water and climate change professionals. Climate change experts have been primarily concerned with averages, such as how average temperature may increase or how mean sea level may rise. In contrast, water professionals are interested not in averages but in extreme hydrological events, like prolonged droughts and high floods. Water resource systems are not planned or designed on the basis of average values, but on the basis of the occurrence of extreme events. This disconnect has had many major consequences.

Major storage reservoirs like Lake Nasser, which has a design life of 500 years, are invariably planned to withstand probable maximum floods. Estimating such floods has always been an art rather than a science. The process considers, among other factors, all river flow data that may be available. Then, based on analyses of these historical records, the largest 1-in-1000-year or even 1-in-10,000-year floods are estimated. Naturally, there are considerable uncertainties associated in estimating such large floods of very long return periods based only on short and limited periods of data, usually 20–60 years. In addition, river flows depend on many factors that change with time, such as land-use patterns, levels of urbanization and deforestation, rainfall patterns, groundwater recharge, and quantities of water abstracted upstream—all of which are impossible to predict with any degree of certainty over the long term.

In designing large reservoirs, probable maximum floods are generally estimated by considering the worst hydrological and meteorological conditions that could happen concurrently. These estimates are invariably conservative, and in many instances they are likely to consider both climatic fluctuations and some climate change issues, although how much it is impossible to say at present. The final figures selected often depend on the judgement and experience of the experts concerned.

The second reason is that the global circulation models (GCMs) that are currently available are of limited use for forecasting precipitation at river basin scales, especially over the catchment of a major river like the Nile. The uncertainties increase by several orders of magnitude when such uncertain estimates of precipitation are translated into river flows. Uncertainties increase even further when hydrologists use estimates of precipitation to forecast extreme events, such as high floods. The usefulness of such estimates at our present state of knowledge is dubious at best.

Let us consider the Nile flow at Aswan. Using currently available, well-regarded GCMs do not even give us the direction of river flow changes, let alone the magnitude of such changes. Consider three such GCMs. Two GCMs developed by the Goddard Institute of Space Studies (GISS) and Geophysical Fluid Dynamics Laboratory (GFDL), both well-respected institutions in the United States, give very different results. The GFDL model indicates a decline of 77 % in the River Nile flow. GISS indicates an 18 % increase. The GCM of the UK Meteorological Office, another well-regarded model, estimates a 12 % decrease in the river flow (Strzepek and Smith 1995).

In the face of such extreme uncertainties, not surprisingly, policymakers are reluctant to spend tens, if not hundreds, of millions of dollars to ameliorate the potential impacts of climate change. This is an especially difficult decision for a developing country like Egypt, which has limited financial resources but has many other pressing development priorities over the short, medium, and long terms that are certain, urgent, and real.

Be that as it may, whether climate change affects the Nile flow by an increase of 18 % or a catastrophic decline of 77 %, the storage option continues to remain viable. The country has to consider all forms and types of storage options and also to significantly improve its water use efficiency in all sectors as quickly as possible to assure its water security in the future. The country simply has no other choice.

There are similar uncertainties in other water-related issues as well. For example, take evaporation. The general thinking is that as the climate gets warmer, evaporation from Lake Nasser will increase and thus reduce the amount of water available. This consensus thinking is contradicted by a detailed analysis by Badawy (2009). He concluded that there will be a negligible (0.29 %) increase in evaporation over the entire lake by 2050. The explanation is that while temperature will rise, it will increase humidity and reduce wind speed—the main factors influencing evaporation losses.

With our present state of knowledge, unfortunately we cannot predict what the Nile flow regime may be during the post-2050 period with any certainty. Until it is possible to have actionable knowledge on which new, realistic, and cost-effective policies can be formulated, there is not much that can be recommended to the Egyptian government except to monitor what may happen in the future and to analyze the data as soon as they become available. This may indicate what could be reasonably accurate future trends on the basis of which appropriate policy measures could be considered and operational actions may be taken.

11.7 Lake Nasser and Climate Change

Lake Nasser has become even more important to Egypt than it has been previously because of likely future climate changes, even though their magnitudes are now highly uncertain. New and uncertain conditions have to be superimposed on the "normal" climatic fluctuations that have been witnessed from the Pharaonic times. The evolving uncertainties concerning future climate change have to be effectively superimposed on historical and future fluctuations in river flow attributable to other non-climate-related factors. This will further increase significantly the degrees of uncertainty and risk in terms of reservoir operation and management.

Lake Nasser has released more water in the years of low flows of the Nile (droughts) and stored more water during the years of high flows. Figure 11.6 shows the fluctuations in water level in Lake Nasser because of appropriate discharges from the lake to compensate for the effects of droughts and floods. It also shows the volume of water that remained stored in the lake after these discharges. This diagram alone clearly indicates the effectiveness of large storage reservoirs like Lake Nasser in ameliorating the changes in river flows resulting from climatic fluctuation. Climate change may exacerbate this fluctuation in terms of magnitude, frequency, occurrence, and duration. This means that in the future, storage reservoirs like Lake Nasser will have to play an even more important and critical role to concurrently counter the impacts of both climatic fluctuations and climate change factors. Management practices and operational procedures will have to be steadily and progressively improved as and when the situation warrants.

Accordingly, an effective alternative will be to consider, more and more, all types of water storage practices, big and small, surface and underground, to deal with the two major scourges of floods and droughts in the future. The operational and management practices of water storage structures may have to change over time, depending on the changes observed. The changes in practices have to be complemented with rapidly increasing efficiencies in all types of water uses.

Based on preliminary analyses carried out by the Third World Centre for Water Management, our view is that for a large basin like the Nile, covering 10 countries

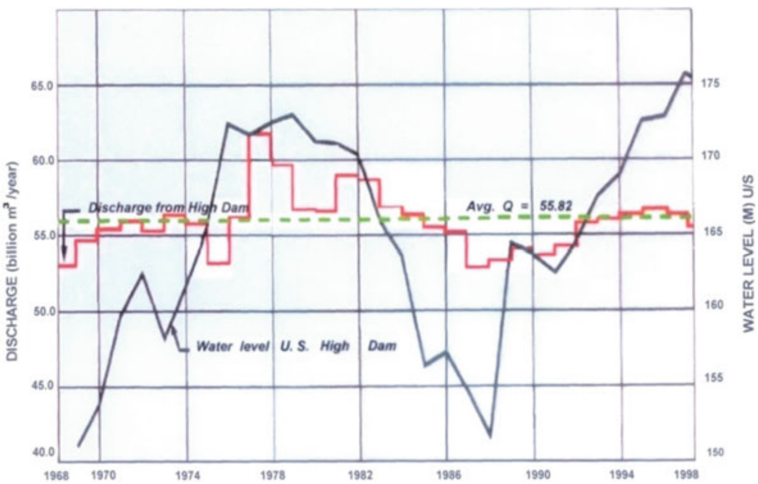

Fig. 11.6 Water levels in Lake Nasser and discharges from High Aswan Dam, 1968–1998 (Tortajada and Biswas 2017)

and spanning some 3,112,370 km^2, the overall impact of future climate change will probably be neutral over the entire river basin. Some parts of the basin may become drier, but other areas may receive more precipitation. An increase in evapotranspiration may contribute to more demand for water because of an increase in demand for supplementary irrigation water. Simultaneously, the water supply may become increasingly uncertain and more unpredictable than has been witnessed in the past.

A country like Egypt, with a desert climate, high temperatures, and an increasing middle class, may further have to meet a surging demand for energy for air conditioning in the warmer months. Because electricity cannot be produced without water, the demand for water for electricity generation may intensify steadily in the coming decades. Thus, total demand for water for agriculture, electricity, and other human and ecosystem needs is likely to increase further, unless the current efficiencies can be improved significantly.

11.8 Concluding Remarks

Lake Nasser has been very beneficial for Egyptians. An objective analysis by Strzepek et al. (2008) indicated that the economic benefits of Lake Nasser added EGP 4.9 billion to the country's GDP in 1997, or about 2 %. Thus, the social, economic, and psychological benefits of Lake Nasser for Egypt have been very substantial.

All three countries in the lower Nile Basin—Egypt, Sudan and Ethiopia—have to negotiate the use of the Nile waters with their neighbors. Populations and economic activities will increase steadily over the next five decades, necessitating more and more water. All Nile Basin countries have to significantly improve water use efficiency in the coming years. There is simply no other alternative. Otherwise, water will increasingly become a major constraint to further development and advances in the standard of living of the Egyptian people. It may also become a serious political issue between the three countries.

To cope with climatic fluctuations and expected climate change, all Nile Basin countries will have to collaborate even more actively and consistently than they have ever done historically. They also must concurrently maximize water-use efficiency by all users and in all sectors. For Egypt, Sudan, and Ethiopia, increasing water-use efficiency must become a national priority. The three countries must consider all means available to improve efficiency, including economic instruments, education, technology, social and cultural behavior change, and institutional strengthening.

In the Nile Basin, all water used in Burundi and Rwanda, and more than half the water used in Uganda, is produced internally. Accordingly, these countries may have more control of their sources of water and, thus, of planning and managing water. However, for both Egypt and Sudan, most of the water they use originates outside their national boundaries. This will make water management progressively more and more difficult and complex for these two tail-end countries of the Nile Basin. Furthermore, both of these countries must consider all cost-effective means available to increase water storage. Simultaneously, they must make water management practices, both in terms of quantity and quality, significantly more efficient than they have ever been in recorded history.

Water demand will increase further because Egypt's population is expected to grow by 40 million by 2050. Egypt does not have other rivers or other suitable locations where another major storage reservoir could be built. Thus, Egypt's most feasible alternative to meeting water demand in the future, and also to meeting the twin challenges of climate change and climatic fluctuation, is to make water management practices and processes progressively more efficient within the coming two to three decades. Water-use efficiency in domestic, industrial, and agricultural sectors can be very significantly improved with existing knowledge, technology, and management practices. Egypt and Sudan must also find new ways of managing agricultural water demand, such as by increasing the use of drought-resistant and pest-tolerant crops, crops that can grow in marginal and saline water, and by keeping abreast of scientific and safety issues concerning genetically modified crops. For domestic and industrial consumption, Egypt must also consider desalination in an aggressive manner.

The current scientific consensus is that extreme hydrological events, such as droughts and floods, are likely to be more intense and frequent in the future. According to the figures quoted by Karl et al. (2009) of the US Global Change Research Programme, for the United States at least, the amount of rain falling during the most intense 1 % of the storms during the past 50 years has increased by almost 20 %. This does not mean that the Nile flow into Lake Nasser has had, or will have, similar changes. Reliable data, as well as the level and quality of research on rainfall and river flow in Egypt and upstream countries, leave much to be desired.

Irrespective of what has happened in recent years and what may likely happen in the coming decades, Egypt has to be prepared to significantly improve management of Lake Nasser, its only major water storage infrastructure. Ensuring water security in Egypt in the coming decades means that the country will have to run ever faster and faster simply to remain in the same place.

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