

- sustainability of the traditional Sami lifestyle—reindeer herding and inland fisheries in the area;
- sustainability of the salmon fisheries on the Alta River.

In these respects, the final solution satisfies the sustainability criterion: no significant, irreversible adverse effects have emerged so far. The other questions that were raised were, to a large extent, conservation issues: whether there were rare species in the submerged areas, and whether unique prehistoric sites would be destroyed. As far as the current investigations can tell, no such damage has been identified, but of course the question always remains whether such investigations are thorough enough. The main irreversible element is of course the dam itself, and the change from an unregulated river to a regulated one.

An interesting observation is that the modifications of the plans came about as a result of the ordinary planning process, and political decisions under the influence of the public debate. The Alta actions and the civil disobedience did not have any influence on the realization of the power plant, except for delaying it by a couple of years. The actions may, however, have had other, long-term effects on public opinion and attitudes.

5.3 ASWAN HIGH DAM

5.3.1 Introduction to the Aswan case study

Egypt's hydrogeopolitical situation is unique. The Nile River constitutes the only significant water resource for the entire country. Few other insignificant water resources are available such as groundwater in the desert, and scarce rainfall at the northern boundaries of the country. As the most downstream country in the Nile basin, Egypt has no direct control on its main water resource. Egypt's land resources are no better than its water resources. About 4% of its territory is arable while 96% is barren desert. Population growth and the quest for economic development put these two crucial resources, water and land, under great stress.

Since the early years of the 20th century, several development plans for the Nile River have been suggested. These plans included different seasonal storage, over-year storage, and channelization schemes that involved more than one country in the basin. In 1952, Egypt adopted the idea of building one large over-year storage reservoir within its borders to face its critical present and future hydrogeopolitical situation. The suggested location for the Aswan High Dam (AHD) was upstream from Aswan cities and the Old Aswan Dam (OAD). The annual storage of OAD after its second heightening in 1933 was five billion cubic metres (bcm), but this storage capacity could

not secure the increasing needs of socio-economic development of the country.

The AHD was built not only to meet Egypt's agriculture expansion plans, but also to achieve other objectives such as satisfying industrial power demand, flood control, and navigation improvement. Shalaby (1993) summarizes the main objectives of the AHD as follows:

- optimizing and rationalizing the Nile flow at Aswan;
- regulating and controlling the daily, monthly and yearly discharge downstream of the dam to match the actual water needs;
- protecting the Nile Valley and Delta from hazards of high floods and perils of droughts;
- generating cheap and clean hydroelectric power, sorely needed for development;
- increasing the limited cultivated area by horizontal land expansion and reclaiming new lands;
- changing the system of basin irrigation (one crop per year) to perennial irrigation (two or more crops yearly);
- expanding rice and sugarcane cultivable areas;
- improving navigation through the Nile and navigable canals;
- creating a greater flexibility in agricultural planning and crop patterns.

Construction work on the AHD started in 1960 and finished in 1970. At that time the dam was considered, and maybe still is, one of the most sophisticated monumental civil engineering works. The impounded reservoir upstream of the AHD is one of the largest manmade lakes. At the level of 182 m a.m.s.l., which corresponds to the maximum storage capacity (162.3 bcm), the surface area of the lake is 6540 km². The ratio between storage capacity and the corresponding surface area or the storage mean depth for the AHD is 24.82 m. The AHD Lake has a length of 500 km and an average width of 12 km at the maximum storage level. About 300 km of its length lie within the Egyptian borders, while 200 km are within Sudanese territory. The total storage capacity of the reservoir is allocated as follows: 90 bcm as live storage capacity between levels 147 m and 175 m a.m.s.l.; 31 bcm as dead storage for sediment deposition; and 41 bcm as a flood control buffer between the levels of 175 m and 182 m a.m.s.l.

The hydroelectric power station consists of 12 units with a capacity of 175 MW each, i.e. a total capacity of 2100 MW, producing on average 7 billion kWh of energy annually. After the heightening of the OAD a hydropower plant (Aswan-I) was constructed to utilize the head potential at the dam site. Since Aswan-I could not accommodate all the AHD releases for power production, a new hydropower house (Aswan-II) was added. It has four

turbines, 67.5 MW each, which brings the total AHD capacity of power generation up to 2370 MW.

Egypt has devoted an entire research institute to monitor and study the impacts of the AHD. This institute is the Nile Research Institute (NRI). During the last three decades a lot of information and knowledge about the AHD reservoir and its effect on the downstream system have been accumulated. It should be noted that the scope of this case study is not intended to address all the impacts due to the construction of the AHD. Only some of the issues discussed in the previous chapters will be addressed with the focus on two topics:

- inundation of populated areas; and
- sedimentation problems.

5.3.2 Inundation of populated areas

Nubia is the name of the area that was subject to inundation due to the construction of the AHD. As shown in Fig. 5.4 it extended from the north near Aswan cities in Egypt down to the third cataract of the Nile in the south of Sudan. The maximum inundated area by the AHD reservoir inside the Egyptian borders is about 0.4% of the total area of Egypt.

More than 100 000 Nubians occupied this inundated area before the construction of the AHD; some of them lived inside the Egyptian borders while others were settled in Sudan (Said, 1993a). Although the Nubians lived in two different states, demographically, they are considered as one community. Their unique cultural heritage distinguished them from both the Egyptians and the Sudanese (Berg, 1976). Their economic activities were limited to agriculture, herding, and fishing. They used to live in small scattered communities that yearned for services regarding health, roads, social care, and schooling. The Nile played a major communication role among these communities. At the time of the AHD construction, northern parts of Nubia had already suffered from the inundation of their land and properties due to the increase in height of the OAD.

In 1963 the entire Nubian population (Egyptian and Sudanese) that was subjected to resettlement represented about 0.4% of the Egyptian population. The Nubians resettlement plan was very successful according to Said (1993b), Shalaby (1993) and Abu El-Wafa (1962). About 55 000 Egyptian Nubians were resettled in the vast fertile plain of Kom Ombo 60 km downstream of the AHD, called New Nubia. In the Kom Ombo area, 28 000 acres were reclaimed and provided with the required irrigation infrastructure. The resettlement plan included more than 25 000 houses in 33 villages that combined both modern public utilities and Nubian architecture in their design.

Nearly 53 000 Sudanese Nubians were resettled in Khashm el Girba, in the east of Sudan. A new irrigation scheme called new Halfa was developed for them. Although migration to the north was very well planned, the immigrants to the south were luckier in terms of the compensation they received and services provided during the transportation and early phases of the immigration process.

The Egyptian Government in 1962 estimated the Egyptian Nubians loss of property to be six million Egyptian Pounds (L.E.). Nearly 50% of indemnities were paid in advance to help the Nubians move to their new settlements. The other 50% were used to pay part of the cost of land, infrastructure and houses. The rest of the cost is being paid in 40 annual instalments without any interest (Abu El-Wafa, 1962). According to the 1959 agreement between Egypt and Sudan, resettlement of the Sudanese Nubians was the responsibility of the Sudan Government. Nubians, as a distinctive community, being deeply attached to their lands, lost something they cannot be compensated for and suffered psychologically. "After 25 years, the social impacts of migrants have been remarkable. They were mixed with people of Aswan and Qena provinces and got used to their culture and traditions and were thus leading normal happy life" (Shalaby, 1993).

Nubia had monuments, temples, tombs, fortresses and other remains from Pharaonic, Ptolemaic and Roman ages. Most of these treasures were already seasonally submerged due to the heightening of the OAD. Only during low storage seasons of the OAD did these historical assets re-emerge from the water. The AHD threatened these ancient sites, including the rock-cut temples

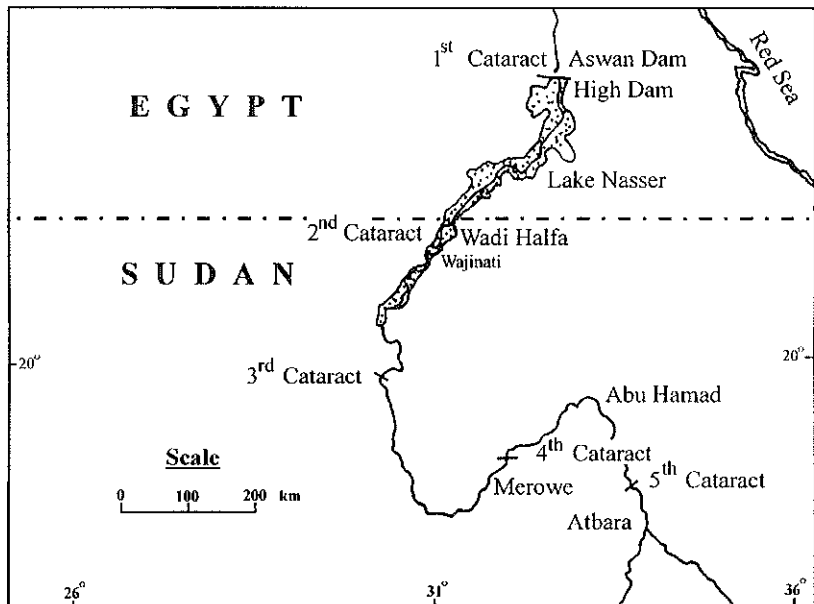


Fig. 5.4 Map of the AHD Lake and Nubian land.

of Abu Simbel, with permanent loss. In response to this threat an unprecedented international campaign to salvage the Nubian legacy was set up by UNESCO. More than 25 countries including the USA, Germany and The Netherlands contributed to the salvage effort either through funds or experts. The Egyptian Government, in its appeal to UNESCO to preserve one of the most important human legacies, promised to give 50% of the duplicated discovered antiquities to the participating foreign expeditions. Also five Nubian temples were given to countries who contributed to the large-scale salvage programme (Said, 1993b).

Most of the monuments and temples were preserved by dismantling and reconstructing them on higher grounds or islands. Special attention was given to the Abu Simbel temples because they were cut in solid rock. Dismantling and reconstructing these two temples are still considered one of the contemporary engineering miracles. This miracle cost about \$40 million. Moving Philae temples was another monumental accomplishment.

The salvage campaign of the Nubian legacy can be considered without doubt a milestone in history of international cooperation. Many archaeological surveys and discoveries would not have been made, had the site not been subject to development, and they were in fact made and shared with other countries. Present and future generations are and will be enjoying the Nubian legacy for a long time, and inter-generational equity will in this context probably be achieved.

Inundation of large areas after construction of a dam is considered one of the indications of the environmental destruction. Section 1.2 compares the largest 10 dams in the world with two Russian dams on the Volga River, and 2575 dams in Japan. If the mean storage depth is applied as a criterion to measure the storage efficiency of a specific dam location, then the storage efficiency of the AHD corresponds with most of the other large dams in the world. The AHD follows the average relation $V = 9.2A^{1.1}$, where A is inundated area and V is storage volume, obtained by analysing 7936 reservoirs distributed worldwide.

Goodland *et al.* (1992) justify the loss of tropical forest by inundation due to dam construction if the rate of power production per area flooded is 100 kW ha^{-1} . They suggest lower rates if the flooded area is used for agriculture or degraded land. In the case of the AHD, the ratio between maximum power production in kW and the maximum surface area in ha is 3.63 kW ha^{-1} . It is a very low ratio, but it should be noted that power generation is not the single purpose of the AHD. Moreover, the percent of the hydropower generated from the AHD and the OAD (Aswan complex) to the total national power production is declining. It has declined from 70% in 1975/1976 to 24% in 1990/1991. Currently, hydropower generation from Aswan complex is a by-product, which does not influence the reservoir operation.

Goodland (1996) suggested two ratios to judge the sustainability of several reservoir sites. One of them is the inverse of the previously suggested ratio

and the second ratio is the number of persons involuntarily resettled per output of electricity (oustees MW^{-1}). He used the normal reservoir operating area in his analysis rather than the maximum inundated area. Accordingly, the ratio of maximum power production to the normal operating area of the AHD will improve to 5.93 kW ha^{-1} . Although he noted, in his analysis, the difference between multipurpose reservoirs and reservoirs built mainly for power generation, he did not include that in his evaluation of the sustainability. He also ignored the nature of the inundated land as he pointed out in an earlier publication (Goodland *et al.*, 1992). However, AHD sustainability cannot be simplified and evaluated by such ratios. Since Nubia was basically a desert with few small scattered patches of seasonal agriculture, the low ratio of 5.93 kW ha^{-1} may be justified. On the other hand, inundation of Nubia as an extremely valuable archaeological site may not be justified even at a higher ratio than 100 kW ha^{-1} .

5.3.3 Sedimentation problems

The sedimentation problem of the AHD has many dimensions. The annual flood of the Nile used to convey on average about 134 million tonnes, equivalent to 92.4 million cubic metres (mcm) of silt to Egypt (Abu El-Atta, 1978). This silt was assumed to be the main contributor to Egyptian land fertility, a source of building material, and a carrier of nourishment for sardine fish in the Mediterranean near the Nile estuaries. It was considered also a source of instability of the Egyptian irrigation canals. Silt sedimentation in the irrigation canals was a costly problem which the system operators used to face every year. A sudden prevention of the annual silt flow to the Nile Delta and Valley brought forward all these issues, besides reservoir siltation, downstream morphological instability, and coastal erosion. Many pre-design and post-operation studies have focused on the sedimentation problems of the AHD. Reservoir sedimentation is a significant factor in determining the reservoir lifetime which is related to sustainability. As the reservoir lifetime increases, the reservoir is considered to be in a more sustainable way of development. Evidently human needs of future generations can be met if the reservoir lifetime is very long or can be prolonged. Most of the studies for the AHD reservoir in this regard, and also the field measurements concluded that the dead storage (31 bcm) of the AHD reservoir will take 400 years or more to fill. All of the sediment received up till now has accumulated at the upper part of AHD Lake (200 km upstream of the dam) as shown in Fig. 5.5 (NRI, 1993). Specifically, Makary (1982) expected it to take 408 years to fill the AHD dead storage. Field measurements by the High Dam Public Authority from 1978 to 1990 showed that the sediment is accumulating at an average rate of 109 mcm per

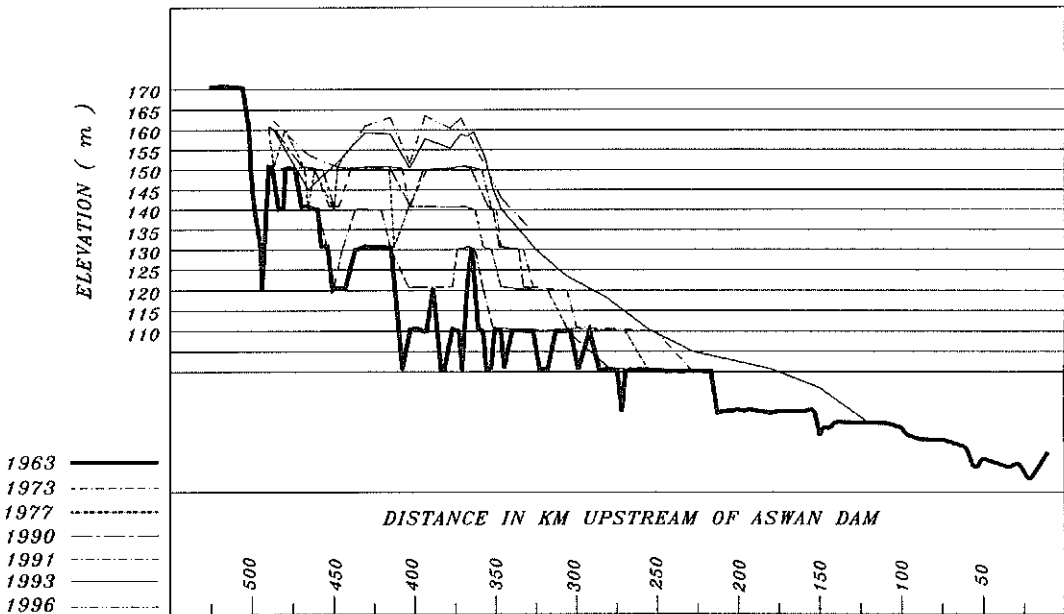


Fig. 5.5 Longitudinal section in AHD Lake showing deposited sediment progress (NRI, 1993).

year (Said, 1993b). If the lifetime is the only criterion for dam sustainability, AHD would rank very high among the world dams.

Total agriculture land at the construction time was estimated to be six million feddans (one feddan = 4200 m²). Arable land being a limited resource (4% of Egypt's area), agriculture productivity and sustainability have been major concerns before and after the AHD construction. Therefore, the effect of silt deprivation on the fertility of the agricultural land was thoroughly investigated and monitored. Most of the silt was received by only 700 thousand feddans that were under basin irrigation out of the six million feddans. The rest of the cultivated area was under perennial irrigation that allows for minimum sedimentation of the silt. This fact and the fact that the plant usable nutrients load of Nile silt is very low (0.04% of the total silt load) made the effect of silt deprivation insignificant. Replacing this small amount of nutrients by artificial fertilizers, which for a long time had been used in Egyptian agriculture practice, solved the problem.

The real threat to agriculture sustainability emerges indirectly from withholding silt upstream of the AHD reservoir. Although the silt deposited in irrigation canals before building the AHD constituted a costly problem, it was the source of raw material for brick manufacturing. All other alternative raw materials such as clay, sand, limestone, and cement, were not commonly used in the brick industry. The sudden loss of silt forced the brick manufacturers to find other sources of material. The obvious and easiest solution was the removal of agricultural topsoil and destruction of the Nile banks. Successful

legislative measures were taken against this destructive process and incentives were provided to the manufacturers for a transfer to other raw materials. The prediction of Abu El-Atta (1978): "we will be able to overcome this problem very soon" became true.

The most evident adverse impact of the AHD on ecological sustainability is the disappearance of sardine in the Mediterranean near Rosetta and Damietta Nile estuaries. Most of the silt carried by the Nile flood was flushed to the Mediterranean through the Rosetta and Damietta branches. The total annual catch of sardine diminished from about 18 000 tonnes before the AHD to 500 tonnes in 1966, and never recovered (ASRT, 1990). The flushed sediment obviously was loaded with attractive nourishment for the sardine species. Although the increase of fish production due to the creation of the AHD lake may counter this loss economically, it may not justify the resulting ecological destruction.

The condition of ecological sustainability that requires preservation of the minimum number of individuals to ensure the natural evaluation of each species is totally violated in the case of the sardine species. On the other hand, 20 years after the construction of the AHD, the total number of fish species has increased in the Nile and its estuaries (Biswas, 1992).

One of the major environmental concerns of retaining the sediment upstream of the AHD is the degradation and erosion that might be caused downstream of the dam. Estimates were made at several locations; at Gaafra and at three regulating barrages located downstream of the OAD. The assumptions and approaches used to obtain these estimates differed significantly as well as the estimates themselves. It is very hard to compare them to each other or to the actually observed drop in water elevation at the different monitoring locations. In Table 5.1 El-Moattassem & Abdelbary (1993) showed the drop in water levels compared with 1963-observed levels, as an indication of the downstream degradation caused by building the AHD.

Their general conclusion was that the Nile bed degradation after the construction of the AHD was limited due to the controlled discharge and the existence of intermediate barrages. The replacement and rehabilitation of the

Table 5.1 Water level drops (cm) at different stations for different discharges downstream of the Nile barrages from 1963 to 1990.

Station	Distance downstream AHD (km)	Discharge (mcm day ⁻¹):						
		80	90	100	120	150	200	250
Gaafra	34	80	76	73	72	60	50	37
Esna	167	73	75	77	77	73	47	-
Nag Hammadi	359	84	88	90	85	75	-	-
Assiut	539	60	63	62	57	56	-	-

old barrages due to ageing may eliminate most of the degradation impacts and the effects of the drop in water levels on navigation.

5.3.4 Conclusion on the Aswan case study

This case study is a discussion of some ideas introduced in the previous chapters, to derive a set of criteria for reservoirs to be considered as a means of sustainable development. It should be emphasized that the AHD case study, presented here, is not by any means a comprehensive evaluation of its sustainability. The AHD as one of the 10 largest dams in the world has been subjected to a wild campaign of criticism which led to a very wide international debate. Participation of politicians, environmentalists, media, scientists, and technicians added to the controversy, rather than coming up with objective unbiased evaluations.

Nevertheless, there are some simple facts that created a general public sanction of the project at national level and tamed the international criticism. It is undeniable that the AHD saved Egypt from the socio-economic destruction that could have happened due to the persistent nine-year drought from 1979 to 1987. Although destructive impacts were clear in Ethiopia and other African countries, Egypt was not affected except for some reduction in power generation. It also guarded the country from the 1964, 1975, 1988 and 1996 high floods. The role of the AHD in protecting Egypt from these catastrophic events has been highly appreciated by the entire population especially the poor sectors who are the most vulnerable to the consequences of such events.

The AHD has proven to be a very economically efficient project. According to Shalaby (1993), a study for estimating the change in national income due to the presence of the AHD showed that during the first 10 years after construction the national income increased by 10 billion L.E., that is 20 times the AHD cost.

It is obvious, without going into too many details for estimating the economic and social benefits of the AHD, that the intra-generational and inter-generational equity has been very well achieved. It was achieved because most of the benefits of the AHD, as a national project, targeted the majority of the Egyptians. These benefits were oriented towards rural communities where poor people live. The fraction of the resettled population was very marginal with respect to the total population.

In developing a list of criteria for reservoir sustainability the discussion should not be directed to comparing the sustainability of existing reservoirs to each other. The list of sustainability criteria should be chosen and derived carefully to characterize each case individually. The needs for development differ significantly from developed countries to developing countries and from arid zones to wet zones. Nevertheless, evaluation of the sustainability of

existing reservoirs is quite important because it helps in consolidating and formulating the basic rules, principles and concepts of sustainable reservoir operation and management policies that can respond to changes in future human needs and objectives, and advances in technology.

The ratio between power production and inundated area may be used to measure sustainability of a single-purpose reservoir. If the reservoir is a multipurpose reservoir, then a similar criterion for each purpose or another criterion that lumps all the uses together could be derived. The phenomenon of agriculture soil removal resulting from the AHD construction, emphasized that some indirect consequences of reservoir creation can affect sustainability. Therefore, in seeking the objective of developing a comprehensive list of sustainability criteria, the effort should go deeper than the typical direct impacts of reservoir development. The impact of the AHD on fish species in the Nile system shows that positive effects may outweigh negative effects with respect to sustainability.

5.4 MANAGEMENT OF ANNUAL PEAK FLOWS TO RESTORE AQUATIC RESOURCES IN GREEN RIVER, UTAH

5.4.1 Introduction to the Green River case study

The Colorado River is one of the most highly regulated rivers in the world. The total usable reservoir storage capacity exceeds 70 billion m³, or approximately four times the mean annual flow. The four largest reservoirs in the Colorado River basin, each with a usable storage capacity of 2 billion m³ or more, are shown in Fig. 5.6. The relatively large reservoir storage capacity was developed due to significant variations in seasonal and annual runoff, a semiarid climate which necessitates irrigation to raise crops, and a need to meet the legal division of water among the basin states. With the exception of relatively small tributaries, river channels of the Colorado River basin have been extensively altered by the construction and operation of dams. All of the major dams have been completed since 1936, and those upstream from Lees Ferry were only completed in the mid 1960s. The impacts of these impoundments on aquatic and riparian resources of the Colorado River have developed over a period of years and are only now becoming substantial environmental problems (Ward & Stanford, 1989).

A principal hydrological effect of the reservoirs, though by no means the only one, is a decrease in the magnitude and duration of spring flows and an increase of flow during the remainder of the year. A wide variety of physical and ecological effects have been attributed, wholly or in part, to reduced peak