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Independent Review

of the Environmental Impact Assessment

for the Merowe Dam Project

(Nile River, Sudan)

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1. Executive summary

The Merowe Dam, presently under construction 800 km downstream of Khartoum on the Nile River in Sudan, will submerge the fourth cataract of the Nile and form a 200 km long artificial lake. With a surface area of 800 km^2, the lake will inundate 55 km^2 of irrigated land and 11 km^2 of farmland used for flood recession agriculture. Merowe represents the current largest hydropower project in Africa. The main purpose of the 67 m high Merowe Dam is hydropower production. The capacity of 1’250 MW will be almost twice the current hydropower capacity in Sudan. The project includes an irrigation component but there are still uncertainties as to whether it will be implemented.

The total cost of the Merowe Dam Project is estimated to reach $1.2 billion. Beside the Sudanese Government, the project is financially supported by the China Export Import Bank, the Arab Fund for Economic and Social Development, and the Development Funds of Saudi Arabia, Kuwait, Abu Dhabi, and the Sultanate of Oman. The dam and the transmission lines are mainly being constructed by Chinese companies. Sudanese contractors are involved in building the dam and the resettlement sites. Several European companies are participating in the project: Lahmeyer International (Germany) manages the construction of the project; Alstom (France) is supplying electro-mechanic equipment; and ABB (Switzerland) is building transmission substations.

At the planning stage of dam constructions on major rivers, a full consideration of the environmental impacts is required according to international standards. The project participants are therefore required to prepare or contract an environmental impact assessment report (EIAR) in accordance with specific guidelines that address three major topics:

- **Social issues -** consequences of people resettlement from future flooded area;
- **Archeological issues -** resulting from destruction or submerging important archeological sites or places of high cultural value;
- **Environmental issues -** effect of large scale hydrological alteration of the natural river system with major impacts on the environment and water quality.

In April 2002, Lahmeyer International prepared the EIAR for the Merowe Dam Project. The document focuses on the complex resettlement issues involving about 7’500 families. Among the environmental impacts it discusses are the hydrological changes, the erosion of the river bed and its banks, greenhouse gas emissions and changes in the aquatic ecosystem. The 150 page report was far from meeting European or international standards, such as the guidelines of the World Commission on Dams (WCD, 2000). No serious attempt was made to use the vast scientific knowledge base on environmental effects of large dams, although four decades of research on the Aswan High Dam (Lake Nasser in Egypt, Lake Nubia in Sudan) have revealed a dramatic sediment accumulation in the upper part of the reservoir, problematic water quality issues and detrimental downstream effects such as river bed erosion or water level fluctuations.

This independent review of the Lahmeyer EIAR (2002) was motivated by the mission of Eawag to use our competence in the assessment of surface water systems and their management in relevant contexts. In addition, Eawag has an intrinsic interest as man-made alterations of aquatic system are part of its core business. International Rivers Network (IRN) encouraged Eawag to carry out this review, and provided inputs by sharing documents and other information. IRN did not influence the contents nor the topics addressed in this review in any way. In preparing this review we worked towards achieving three objectives:

- to **review the relevant literature** concerning the environmental effects of the Aswan High Dam as a suitable reference system for large dam projects on the main reach of the Nile River,
- to **identify and quantify possible environmental changes** induced by the Merowe Dam,
- to **provide a constructive critique** of the Merowe EIAR including recommendations for further study and for developing mitigation measures.

The expertise of the authors covers the fields of aquatic physics, chemistry and sedimentology. Additionally, we obtained input from other specialists. The review was deliberately focused on natural science issues, where the authors follow an active research agenda (Friedl and Wüest, 2002; Friedl et al., 2004; Teodoru and Wehrli, 2005; Bratrich et al., 2004). Health aspects were covered only marginally and socioeconomic topics such as the resettlements and economic valuation were not addressed as they are outside our field of competence. Our report was written for the experts in Sudan, for the project parties and the interested stakeholders. With this case study we hope to intensify the scientific exchange and debate concerning environmental impact assessments for large dam projects.

1.1 General results

The following conclusions can be drawn for EIAR of large dam projects in general.

- The scientific analysis of environmental effects of river impoundments is vast and growing fast. The ISI database lists more than 200 publications under key words “Nile” and “dam”. Relevant scientific results should be used explicitly in preparing an EIAR. The past experience with existing dams in the same river system proved particularly valuable for predicting the impact of a new dam.
- The practice of “peer review” as it is used for improving scientific publications could well add credibility to an EIAR, particularly if the original report is prepared by a company with close ties to the project.

1.2 Specific results

Our analysis has identified the following topics of major concern regarding the Merowe Dam project

- The Merowe dam will act as a major **sediment sink** for the suspended load of the Nile River. Because the reservoir is much smaller in volume compared to the Aswan High Dam Reservoir, it is likely to lose more than 30% of its capacity over the next 50 years. A concept of management for the 130 Mio. tons of sediment accumulating every year in the Merowe Reservoir is lacking at present and deserves a high priority for a sustainable hydropower generation.

- Since about 90 % of the suspended load of the Nile water will be retained in the Merowe Reservoir, the outflow will have a large carrying capacity for particles and produce **erosion of the river bed and the side banks**. The Lahmeyer EIAR recommends monitoring of river cross sections to plan countermeasures for the cities and settlements downstream. Because bed and bank erosion is well documented after closure of the Aswan High Dam, geomorphological studies should be started immediately to identify key areas of concern.
- The Merowe Reservoir will become stratified during the hot season and settling algae can produce **anoxic conditions** in the bottom waters close to the dam. This will reduce the available habitat for fish species and increase the emission rates for the greenhouses gas methane and carbon dioxide.
- The total mass of organic matter contributing to **greenhouse gas emissions** will be an order of magnitude larger than estimated by the EIAR. In addition to the primary production within the reservoir, the suspended load of the Nile River will also carry organic material, which can be degraded to carbon dioxide and methane in the reservoir sediments at rates on the order of 200’000 - 300’000 tons of carbon per year.
- The effects of disrupting the river continuum on **aquatic biodiversity** have not been addressed adequately. The available species lists in the EIAR are inadequate and incomplete. Several species have migratory life cycles and spend time in both the tributaries and the main river. Such life cycles of important fish species should be analyzed in detail before a general assessment of the impacts of a large dam project on biodiversity can be made. Together with the Aswan High Dam, the Merowe Dam will genetically isolate an important reach of the Nile River.
- The dam and the hydropower station are designed for peak operation during a few hours per day. The resulting **hydropeaking** downstream is expected to produce water level fluctuations of about 4 m per day. Such intense fluctuations will have detrimental effects on aquatic ecosystems because the riparian zone of a river provides crucial habitat for aquatic life. The EIAR considers mainly economic

effects such as upgrading of necessary pumping stations and ferry landing sites, but neglects the effects on daily life of the riparian population. A retention dam at the outlet of the power station could mitigate such negative side effects.

- The design of the dam allows for water abstraction for **irrigation**. No planning details are available in the EIAR as the decision for or against irrigation was postponed. An overview by the World Commission on Dams (WCD, 2000) revealed a high failure rate for irrigation schemes in arid areas. Open planning and communication of the goals and the implementation of irrigation schemes at Merowe is a key factor for their success, and should be included in the EIAR.

1.3 Critical issues

In summary, the EIAR for the Merowe Dam Project provided a detailed overview of the technical, hydraulic and hydrologic framework, and discussed issues of resettlement and ecological and economical side effects. The EIAR failed

- to base its assessment on the available scientific literature,
- to develop a plausible sediment management concept,
- to critically assess the ecological functioning of the reservoir ecosystem including its greenhouse gas production and the effects on fish biodiversity,
- to offer strategies for mitigating the downstream effects of hydropeaking.

We hope that the following review can partially close these gaps and provide some concepts for improving future EIA reports.

2. The Lahmeyer report

2.1 International standards

The environmental impact assessment report should be seen as guidance, identifying at the beginning the environmental issues resulting from the project implementation, estimating their extent and providing a basis for deciding whether or not a project should be carried out. Among the goals of the EIAR, the report should contribute to the sustainability and viability of such projects by foreseeing conflicts and deficiencies as well as reparation and mitigation costs. Such a report should propose at the end a few tools to help the decision makers to minimize negative impacts. There are several published guidelines such as the report by the World Commission on Dams (WCD, 2000) or the Operational Policies of the World Bank (www.worldbank.org), which provide specific requirements for establishing an EIAR for a large dam project. No reference is made, however, to such international standards in the Merowe Dam report.

2.2 Important deficiencies

The EIAR (2002) was not made available for public review. Therefore a chance was missed for involving major stakeholders and the general public in a discussion of the quality of the information and the assessments of the report. In addition, it seems that no formal peer review of the report was carried out by qualified environmental assessment specialists, prior to the submission to the Sudanese Government.

It does not appear that Lahmeyer have carried out any specific technical studies for evaluating potential impacts. No reference is made in the report to such studies.

Key environmental issues such as reservoir sedimentation, irrigation, water quality, downstream ecological impacts resulting from hydropeaking were not addressed adequately, as specified below.

2.2.1 Sedimentation

We predict that an annual sediment volume of approximately $84x10^6$ m^3 yr^{-1} will be accumulated in the Merowe Reservoir. As this value is extremely high compared to the total storage of $12.4x10^9$ m^3, the reservoir is expected to lose its total capacity (dead and active) in less than 150 yr. For comparison, the dead storage capacity (20 % of the total reservoir volume) of the AHD will be lost in 360 yr whereas it will take another 1'000 yr until the reservoir will lose its active capacity (55 % of the total volume). Therefore, sedimentation represents a major issue for the Merowe Dam Project and more detailed information should be acquired.

On page 4-6, the EIAR (2002) made the following statement: "…*the future reservoir will trap 100 % of the river bed load and much of its suspended load*". On page 2-2, the EIAR specifies potential mitigation strategies: "*The dam design incorporates special sluices and particular operation rules to reduce the reservoir sedimentation and to reduce the capacity losses over 50 yr period to 17 % of the original active capacity (83 % will still remain active)*".

The proportion of bed load to suspended load varies from river to river. In general, large rivers at lower elevations are less steep and therefore the proportion attributable to bed load is small (Meade et al., 1990). This is the case for the Nile River for which the bed load transport does not represent an issue. The issue here is represented by the suspended load.

According to EIAR (2002), the volume of sediment annually retained in the reservoir will correspond to $28x10^6$ m^3 yr^{-1}. Using the conversion factor of 1.56, this annual volume is equivalent to a sediment mass of $44x10^6$ t yr^{-1}. Compared to the inflow load of $143x10^6$ t

TSS yr^{-1} calculated from a water flow of 84 km^3 yr^{-1} and a TSS concentration of 1.7 kg l^{-1}, the sediment retention capacity of the reservoir would correspond to only 30 % of the incoming sediment load.

Compared to our estimated retention of 90 % of the incoming load for a residence time of approximately two months, the EAIR (2002) assumption is based on unknown or unshared data and represents a factor of 3 lower retention. This low retention contradicts existing experience with large dams such as the Iron Gates Reservoir (Teodoru and Wehrli, 2005) and the AHD. No technical information is given to sustain the claim that "*special sluices*" and "*particular operation rules*" can indeed ensure the transport of the suspended load for 200 km along the Merowe Reservoir.

2.2.2 Hydrology

Long hydrological time series and their interpretation is often a matter of controversy. The EIAR (2002) does not specify the source of the hydrological data on which the average annual runoff and its variability were based.

Peak operation of the hydropower scheme will create daily water level fluctuations between 2.6 and 4.9 m below the dam. This hydropeaking will have significant impacts on small-scale irrigation pumps and ferry landing sites expected to occur over a small distance of only 20 km downstream the dam. Further consequences for the local population and the riparian morphology and ecology are not discussed in any detail. Good practice in large dam design would require a serious evaluation of mitigation measures such as a small dam to limit the amplitude of these daily level fluctuations.

2.2.3 Irrigation

The Merowe Dam is described as a multi-purpose project for hydropower production and irrigation. At the completion of the EIAR in April 2002, the irrigation component was still studied at pre-feasibility level "although two irrigation intakes on the right and left bank of the river (2x150 m^3 s^{-1}) have been incorporated in the dam structure design" (EIAR, 2002; page 2-1).

According to our calculations, the proposed irrigation scheme would lead to an annual abstraction of up to 7.4 km^3 yr^{-1}. As this diversion would represent 9 % of the river flow, the irrigation scheme should be assessed in the report together with the operation rules, a plan for limiting salinization of irrigated land, and total water allocation within Sudan. Such an important aspect should not be ignored simply due to the fact that the plans are still in limbo.

2.2.4 Water quality

No database on water quality parameters was presented by the EIAR (2002). The general prediction that "*no significant change of water quality is expected to occur, neither immediately after impounding nor in the long term*" disregards long-term observations on reservoirs in arid areas. The optimistic assessment was based on the following assumptions (EIAR, 2002; page 4-4)

(1) "*Remarkable very little biomass exists within the reservoir area – 25,000 t of readily degradable and 9,000 t of slowly degradable biomass*";
(2) "*Very short residence time of only two months*";
(3) "*Annual draw-down of the reservoir which will tremendously reduce reservoir depth, length and volume*";
(4) "*Operation of bottom outlet and low water intake level*".

Based on the water residence time and the local climate, we demonstrate that strong water column stratification, with temperature differences between the surface and the deep waters of several °C will occur during the summer period.

Moreover, it seems that the Lahmeyer report disregards *in-situ* reservoir production. Low primary production rates will produce between 320'000 and 750'000 t of organic matter per year, which is one to two orders of magnitudes more than the existing biomass in the reservoir area before flooding. In addition, inflow organic matter will be degraded within the reservoir.

2.2.5 Greenhouse gas

The report assumes that greenhouse gas emissions were limited to the degradation of existing biomass in the reservoir area. A "*total emission of some 600,000 t of* CO_2" was predicted by the EIAR (2002) on page 4-4. "*Since anaerobic decomposition would not occur, due to the continual exchange of water within all parts of the reservoir, no methane would be produced*", so that "…*greenhouse gas emissions from the Merowe project are considered to be non-significant*".

These predictions contradict the current scientific knowledge. Even in the absence of anoxic bottom water, high sedimentation rates in the reservoir and therefore high burial efficiencies will result in prevalence of anoxic condition within the sediment. Therefore, during decomposition of organic matter, both CO_2 and CH_4 will be produced within the sediment of the Merowe Reservoir. As the CO_2 and CH_4 fluxes released from the reservoirs depend on a large number of factors, we limited the evaluation to the total carbon available for greenhouse gas production. Our calculations showed that annually, between 40'000 and 90'000 t C yr^{-1} will be available to be converted into CH_4 by organic matter decomposition within the water column and the sediment. Considering the large fraction of organic matter input via total suspended solids, the available carbon will be actually much higher, between 250'000 and 300'000 t C yr^{-1}. These simple estimates show that monitoring of the water column for oxygen and greenhouse gases is of high priority for a sound assessment of reservoir performance.

2.2.6 Fishes

Concerning the fish populations, the EIAR (2002) considered the Merowe Dam Project having no significant impacts on fish fauna, being "…*mainly limited to changes in the* *future reservoir*" (page 4-7) due to the fact that "…*no endangered species have been reported and there is no evidence of fish migration other that local movements in the Main Nile river*" (page 4-7).

The report disregards the fact that the present fish population of Lake Nubia consists of several migratory fish. Several species like *Barbus bynni*, *Barbus perine*, *Labeo coubi*, *Labeo horie* and *Laboe niloticus* which belong to Cyprinidae family are migratory fish. The ecological assessment is based on incomplete species lists and disregards the life cycle of the different species involved. The isolation of a very large fish population on the 700 km river stretch between Aswan and Merowe represents a dramatic fragmentation of one of the largest river systems in the world and requires a much more careful and detailed monitoring and assessment.

2.3 Recommendations for mitigating negative impacts

2.3.1 Recommendation on reservoir level operation

In general, the operation policy of a dam is to "refill" the reservoir volume during the high flow, which in the case of Merowe is represented by the summer period between June and October and to have the reservoir full at the beginning of the following dry season. In the course of autumn, winter and spring, the water levels will usually decrease progressively due to the water release for energy production and/or irrigation demands and evaporation.

The seasonal fluctuation in the Merowe Reservoir of between 800 km^2 at maximum level and 350 km^2 at low stand imply that more than 450 km^2 of reservoir floor will be exposed to aeolian transport and soil-forming conditions. Therefore, it should be considered that, in order to minimize the environmental impacts, the operation policy should be done in such a manner to reduce the exposure of the reservoir sediment. This would represent a substantial advantage in terms of environmental impacts of the aquatic life and landscape as well as the water losses.

Daily operation scheme of the dam will create downstream water level fluctuations ranging between 2.6 and 4.9 m with significant impacts on small-scale irrigation pumps and ferry landing site. A retention dam at the outlet of the power station could mitigate such negative side effects of hydropeaking. Therefore, the feasibility of a small second dam downstream Merowe, to equalize the daily fluctuations, should be included.

2.3.2 Recommendation on sedimentation

Our predicted annual sediment retention of up to 90 % of the river incoming load is expected to accumulate in the upper stretch of the reservoir, where a new delta will form in relatively short period. The simplest appropriate solution for reducing the sediment retention in the Merowe Reservoir is increasing the discharge during the summer period as 80 % of the annual sediment load occurs with the flooding between July and October.

For a precise estimation of the incoming sediment load, TSS measurements over a full annual cycle should be carried out. A detailed sediment management plan should address the problems of reservoir sedimentation and provide detailed measures and operation rules to mitigate the impact on the reservoir lifetime.

2.3.3 Recommendations on water quality

The water quality in the Merowe Reservoir will mainly depend on the inflow and on the pollution in the catchment area, and to a lesser extent on internal processes. Of particular importance are the summer temperature variations, the flood and the return of water from irrigated areas.

Mitigation measures for reservoir water quality generally focus on maintenance of water quality upstream by treating the sewage of large upstream cities and by preventing water stratification and oxygen depletion. This can be done by limiting the water residence time and designing optimal water intakes for the power plant. The position of the intake influences the nutrient content, oxygen conditions and fish population in the reservoir and downstream. An intake located in the hypolimnion will help to minimize the stratification in the reservoir and assist the transport of oxygen to greater depth. Therefore, the intake should be made flexible to “mix” and maintain a minimum O_2 level. A flexible solution will also help in the future to mitigate unforeseen problems.

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