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Mr. Martin Kamarck
Acting President
The Export-Import Bank of the United States
811 Vermont Avenue, N.W.
Washington, DC 20571

Dear Mr. Kamarck,

I am a scientist and professor long interested in problems of rivers and reservoirs. A particular concern has been sedimentation of rivers. The Three Gorges Dam Project involves many complex problems, of which sedimentation is one. The attached discussion examines sedimentation and the inherent risks it poses to the viability of the Three Gorges project. I find these problems sufficiently serious to call them to your attention because their final resolution will greatly influence the project's fiscal effectiveness and the scale of environmental degradation.

In view of these questions, there is strong reason to refrain from providing United States support for such a project.

Sincerely,

Luna B. Leopold

Luna B. Leopold
PhD, PE, PG, PH

Enclosure

Sediment Problems at Three Gorges Dam

Luna B. Leopold[1]

The Three Gorges Dam is designed to operate under conditions practically untested in the world and never before tested in such a large structure. Projections of controlling sedimentation within the reservoir are subject to significant uncertainties. China has about 83,000 reservoirs built for various purposes, of which 330 are major in size. Sediment deposition in 230 of them has become a significant problem, resulting in a combined loss of 14 percent of the total storage capacity. In some, more than 50 percent of the storage capacity has been lost.(1)

The proposed operating procedure at Three Gorges is as follows: during the flood season (May through September), the reservoir level would be held at a low pool elevation, called the Flood Control Level (FCL). During this period inflows are used for power generation. After the flood season, the lower flows with lower sediment concentration will be impounded, and the reservoir pool level will rise to the Normal Pool Level (NPL).

It is proposed that in time, sediment will be deposited in the reservoir until a uniform slope of the bed will be established that can just transport the annual sediment load through the reservoir. It is estimated that this condition will be reached between 70 and 150 years after construction, depending on the choice of the elevation for the Flood Control Level (FCL).

There are an estimated seventeen reservoirs in the world that operate in this manner, seven of which are in China and one in the United States.(2) All of these except one are small in size. That exception is Sanmenxia in China, which has only eighteen percent the storage capacity of Three Gorges — in other words, very much smaller. Thus the world's experience with this type of operation is very meager.

These uncertainties lead to the conclusion that significant fiscal forecasts that presume to support the financial benefits expected may be in error and that investing in the project would be unwise. There are several sources of such error in dredging costs, resettlement costs, flood control benefits, and other areas, but the present discussion deals with the problems only in the subject of sedimentation.

The sedimentation conditions at various times during the first 100 years of operation have been forecast by use of mathematical models and physical analogues that involve many assumptions of

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unverified reliability. Any difference between the forecast and on-the-ground performance has large financial, environmental, and humanistic implications. Therefore, it is necessary to specify some of the most important possible sources of error in the forecasts.

The largest dam construction projects in the United States — Hoover, Glen Canyon, Bonneville, Ft. Peck, Tennessee Valley, to name a few — do not utilize the principal of sediment flushing or sluicing contemplated for Three Gorges, but some of the same uncertainties were present in their design. The American experience gives some direct insight into possible future uncertainties. Perhaps the most important lesson gleaned from direct experience is that conditions 50 years in the future are usually quite different from any forecast, and 100 years in the future are simply not forecastable.

One problem is in the ability of designers to forecast the rate of sediment accumulation in a reservoir. Even when the records of sediment inflow are reliable, the deposit rate is often quite unanticipated. For the multi-purpose reservoirs in India, Murty states that the "annual loss rates of siltation in most reservoirs are 145 percent to 875 percent of the figures assumed at the time of construction."[3]

The Canadian Yangtze Joint Venture (CYJV) estimates that the equilibrium would be reached when the 90 to 95 percent of the sediment entering is flushed through the reservoir. This would be in about 100 years (CYJV, pp. 1-4). A forecast of an approximate condition 100 years ahead is hardly a fiscal surety.

A most important problem involves the actual management of the facility. Between May 1 and September 30, sediment-laden large flows of water will be discharged in order to carry away its sediment. But those same large flows of water cannot be used to fill the reservoir to provide for the winter needs. Moreover, the large flows that carry the sediment can also be the cause of floods. Because the high sediment inflow corresponds closely with the high water inflow, the needs of flood storage and sediment removal are antithetical.

In the case of a possible flood condition upstream of Three Gorges, the prudent course of action would be to close or partially close the discharge gates so that potentially destructive floods would be prevented by storage of the incoming water. But the incoming high flood flow also carries the most sediment and could not be flushed through the reservoir. The sediment so held as a deposit in the reservoir settles on the bed, and requires more force to dislodge it than was necessary to keep it flowing to the outlet gates.

Year to year, this simultaneous need to pass sediment through the reservoir and the need to store water for power or flood control requires a neat and sophisticated day-to-day forecast of inflow of water and sediment. The hope is that a slight lack of simultaneity of water and sediment inflows could be used to move sediment just ahead of or behind the greatest flow of water. Experience in dam operation in the United States shows that such delicate management is uncommon. The delicacy of such an operation is emphasized by the fact that the sediment rating curves do not show the common lack of coincidence of maximum water flow and maximum sediment flow. Usually the sediment is greatest in the early or rising limb of the annual hydrograph, but at Three Gorges, the rating curves are not looped (vol. 5, pp. 5-16, 5-18, 5-19). Therefore, dependence on a lack of coincidence is a poor procedure on which simultaneous flood control and sediment flushing must rest.

Another aspect of possible trouble is in the forecast, 90 to 100 years in the future, of the final slope of the deposited sediment in the reservoir. If the slope is greater than forecast, the deposition in the channel at the head of the reservoir would be much steeper than forecast, leading to unanticipated flooding. The analyses of this important matter were done by computation and models, with no detailed analyses of experience in other reservoirs of the world. Only one page in the CYJV report was devoted to another example – that of Sanmenxia Reservoir in China – but no statement was made concerning the depositional slope. The one example is hardly reassuring because after two years of operation, 1960-62, the sediment deposition was so large that the operation of the reservoir was completely altered. "New tunnels were driven...and some penstocks were converted to spillways" (CYJV, vol. 5, pp. 7-20). The rate of deposition had been grossly underestimated and remedial action was needed after only two years.

Another possible problem is in the assumptions regarding bedload, the coarse material that will eventually accumulate at the head of the reservoir. The gravel component in the sediment was deemed so small that it was "not considered in reservoir sedimentation calculations" (CYJV vol. 5, pp. 1-2). The gravel's portion is of great importance at the head of the reservoir. The report suggests that "gravel bedload amounting to perhaps 200,000 m^3 per year may need to be dredged for the Chongquing reach" for the chosen elevation of the FCL.

The bulk of the sediment that will be deposited in the reservoir will be the sand portion. The gravel- and cobble-size material will be the first to drop out of the flow and will accumulate near the head of the reservoir. The slope of this coarse deposit will determine how far upstream it will extend and thus the extent to which it will result in flooding nearby Chongquing and harm the navigation channel and facilities. The project plan apparently expects that as the final condition is reached in 100 years, all the incoming gravel will have to be dredged, each year, into the indefinite future. If the incoming load is underestimated, these costs could be so financially burdensome that the original benefit-cost relationship is quite discredited.

The effect of sediment storage in the reservoir on the channels downstream is given little importance. The report implies that until equilibrium is established, about 100 years hence, water with little sediment will be discharged and "there will be degradation below Gezhouba and the alluvial reaches of the middle and lower Yangtze" (CYJV vol. 5 pp. 1-10). But the report says "some degradation may be beneficial."

Experience in the United States of degradation by clear water below a dam hardly justifies such optimism. Below Hoover Dam on the Colorado River, the degradation was some 35 feet. Below Fort Peck on the Missouri, there was serious bank erosion. Discharge of water with a low sediment content for 100 years is not likely to be insignificant in its effect on downstream channels. If degradation is great, diversion works could be destroyed. If bank erosion is serious, the extensive levees may be in jeopardy – levees critical to the flood management system of the river's lower reaches.

Downstream of Three Gorges, the alluvial plain is settled by several millions of people who all depend on diversion works for irrigation water and on massive levies to confine floodwaters. The morphology and stability of the channels on this alluvial plain are conditioned by the combination of water and sediment that has characterized the river for hundreds of years. If clear water from Three Gorges flows into such a channel part of each year for many decades, the channel will react.[5] Experience in many countries demonstrates that the reaction will be some combination of bed erosion and bank erosion.

Downcutting could leave diversion works and canals high above the river level and thus require new engineering facilities to correct the problem. Bank erosion would tend to undermine the flood control levees and thus demand levee rehabilitation.

The analysis of the CYJV says that the effect of sediment on the discharge tubes in the dam would be minimal. It speaks only of abrasion to the penstocks and turbines. But the experience in the United States is that the discharge of large volumes of water through tunnels, pipes and penstocks results in serious cavitation, due to local below-atmospheric pressure resulting in pieces of rock and concrete blown off the walls of the tunnels, especially at the entrance. This created a maintenance problem as well as decision to refrain from extended discharge at high rates for long periods. This potential problem deserves more attention than has been given in the analyses at Three Gorges.

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