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SEDIMENT, FLOOD-CONTROL AND NAVIGATION ASPECTS OF THE THREE GORGES PROJECT, YANGTZE RIVER, CHINA

Sediment-, Hochwasserregulierungs- und Schiffahrtsaspekte des Drei-Schluchten-Projektes am Yangtze Fluß in China

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Abstract
The Three Gorges Project on China's Yangtze River has been under investigation since it was first proposed, by Dr. Sun-Yat San, in 1922. The rapid economic development of China, and the steadily increasing population and investment that are at risk from flooding of the Yangtze River, have given new impetus to investigation of the project. The Chinese governments' continuing investigation of the project, and design of its various components, recently has been complemented by an extensive feasibility study sponsored by World Bank. Several aspects of the project are reviewed in this paper. The proposed project would produce the world's largest hydroelectric plant. It appears to be technically feasible, and economically very attractive. The principal problems surrounding it relate to the population relocation it would require, its possible environmental impacts, and the tremendous drain it would place on China's resources at a time when these resources are needed also for other types of development. This paper reviews principally the sediment, flood-control and navigation aspects of the project.

Inhalt
Das Drei-Schluchten-Projekt an Chinas Yangtze Fluß wird untersucht, seit es von Dr. Sun-Yat San im Jahr 1922 erstmals vorgeschlagen wurde. Die schnelle wirtschaftliche Entwicklung Chinas, die weiterhin zunehmende Bevölkerung und Investitionen, die durch Hochwasser des Yangtze Flusses gefährdet sind, haben einen neuen Anstoß zur Untersuchung dieses Projektes gegeben. Die fortgesetzten Untersuchungen des Projektes durch die chinesische Regierung und die Planung der verschiedenen Bereiche wurden kürzlich durch eine umfassende Durchführbarkeitsstudie der Weltbank abgeschlossen. Verschiedene Aspekte dieses Projektes werden in diesem Beitrag besprochen. Das vorgeschlagene Projekt würde zur größten Wasserkraftanlage der Welt führen. Es erscheint technisch durchführbar und wirtschaftlich äußerst vorteilhaft. Die Hauptprobleme beinhalten die erforderliche Umsiedlung der Bevölkerung, mögliche Umweltaspekte und die gewaltige Bindung von Ressourcen Chinas zu einer Zeit, da diese ebenfalls für andere Entwicklungsprojekte benötigt werden. Dieser Beitrag geht vorwiegend auf Aspekte der Sedimente, der Hochwasserregulierung und der Schiffahrt ein.

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1 Introduction

Many benefits accrue to large-scale dam-reservoir systems (hydroprojects), including flood control, improved navigation, power generation, and recreation and tourism. However, large hydroprojects invariably carry with them some associated, not wholly quantifiable costs, including environmental impacts, submergence of archeologically and anthropologically significant sites, and population displacement. In view of the tremendous benefits they produce and the sensitivity of the problems which accompany them, it is not surprising, therefore, that planning for major hydroprojects is attended by often shrill controversy, some of which frequently tends to mask the issues which should be key to the decision-making processes involved in project planning.

There are some almost purely technical aspects of large hydroprojects about which there can be little sensible disagreement. First, there is no equally effective alternative available, at any reasonable price, for protection of downstream areas against the ravages of large floods, or for water conservation. Second, they are practically unequalled as sources of renewable, low-cost electric power. Third, many ancillary often unanticipated, benefits arise after the projects are placed in operation. Fourth, suitably designed hydroprojects are an invaluable aid to navigation, because of the enlarged, low-velocity waterways they produce upstream of the dam, and of the control they exert on the downstream discharges. Finally, at many dam sites the sediment-management strategy is one of the most challenging engineering aspects of the project. This paper is concerned principally with the first and last of these questions.

2 Rivers: Flows of Water and Sediment

To the casual observer, rivers appear to be flows of water, but in fact they are flows of water and of sediment. One of the fundamental laws of geomorphology is that the mountains are moving into the oceans. It is the things that happen along the way that form the basis for sedimentation engineering.

Table 1 presents a summary, compiled from data presented by Jansen, et al. (1), of certain characteristics of 17 of the world's rivers that are significant in one sense or another. A river may pose major problems because of its large water discharge, its large sediment discharge, or its high sediment concentration. Noteworthy in the last category are the Waipapa and the Murray-Darling Rivers (in New Zealand and Australia, respectively), which have very small water discharges but sediment concentrations that are so high as to make them difficult to manage.

The Yangtze River, on which the Three Gorges Project (TGP) will be installed, is one of the world's major rivers both in terms of water discharge (number 4) and sediment discharge (number 5). With a length of 6,300 kilometers, the Yangtze River is the longest river in Asia, and the third longest in the world (after the Nile and Amazon). Table 2 (2) shows that of the total of about 13.5 billion tonnes (annual average) of sediment reaching the world's oceans, approximately three-fourths comes from Asia and the large Pacific Ocean islands. It is especially noteworthy that more than 25 percent of the sediment reaching the world's oceans is delivered by China alone.

Table 1
Rankings of the World's Major Rivers (1)
(Data correspond to river mouths)

River	Catchment Area (10^6 km²)	Water Discharge (m³/s)	Sediment Discharge (10^6Te/Yr)	Sediment Concentration (mg/l)
Amazon (South America)	7.0	100,000 (1)	900 (3)	290
Congo (Africa)	3.7	44,000 (2)	70	50
Orinoco (South America)	0.95	25.000 (3)	90	110
Yangtze (China)	1.8	22,000 (4)	500 (5)	1,400
Brahmaputra	0.64	19,000 (5)	730 (4)	1,200
Yellow (China)	0.77	4,000	1,900 (1)	15,000 (1)
Waipapa (New Zealand)	0.0016	46	11	7,500 (2)
Ganges (India)	1.0	14,000	1,500 (2)	3,600 (3)
Missouri (USA)	1.4	2,000	200	3,200 (4)
Murray-Darling (Australia)	1.1	400	30	2,500 (5)
Mississippi (USA)	3.9	18,000	300	530
Rhine (Europe)	0.36	2,200	0.72	10
Danube (Europe)	0.82	6,400	67	330
Nile (Africa)	2.9	3,000	80	630
Indus (Pakistan)	0.96	6,400	400	2,000
Yenisey (USSR)	2.6	17,000 (6)	11	20
Irrawaddi (Burma)	0,41	13,000 (12)	300	750

The fact that China's proportional contribution to the world's sediment budget is roughly the same as its fraction of the world's population is by no means a spurious correlation; intensive land use increases overland erosion, the sediment loads imposed on rivers, and consequently the rate of sediment delivery to the oceans. Even though it is one of China's major rivers, the sediment discharge of the Yangtze River is quite modest in relation to its water discharge, and the sediment concentration is surprisingly low when compared to that of other major rivers of China and other parts of Asia.

Table 2
World Sediment Budget by Geographical Region (2)

	Drainage area (10^6 km²)	Sediment Yield (t km^{-2} yr^{-1})	Sediment Discharge (10^6t yr^{-1})
N. & C. America	17.50	84	1462
S. America	17.90	97	1788
Europe	4.61	50	230
Eurasian Arctic	11.17	8	84
Asia	16.88	380	6349
Africa	15.34	35	530
Australia	2.20	28	62
Large Pacific Islands	3.00	1000	3000
Totals	88.60	150	13,505

Note: Northern Africa, Saudi Arabian peninsula and western Australia are primarily desert, and assumed to have little annual discharge of river sediment. Total land area is 11.40 km² x 10^6.

At the site of the TGP dam, Sanduoping, the annual-average water flow in the Yangtze River is about 453 billion cubic meters, and the average water discharge at the proposed site of the dam is 14,300 m³/s. The dry season discharges about 3,000 m³/s at Sanduoping (3). The average annual sediment discharge at the dam site is about 523 million tonnes, and the corresponding concentration amounts to only 1.19 kilogram per cubic meter (4). All but a few million tonnes per year of this sediment is very fine, and is transported in the so-called wash-load mode. Most of the annual sediment load is transported during periods of high water-discharge, as is the case in practically all rivers.

3 Flooding and Flood Protection of the Valley of the Middle Reach of the Yangtze River

The proposed siting of TGP dam is shown in figure 1 (5). In the Three Gorges reach of the Yangtze River, between Chongqing and Yichang, there are 158 dangerous rapids, and 140 km of the river is restricted to one-way traffic (5).

According to 1978 statistics, the total population of the Yangtze River Basin is 342 million persons, of which 293 million are engaged in the tillage of 25 million hectares of land. About 40 percent of the country's grain, including 70 percent of its rice, and more than one-third of its cotton are produced in the basin (6).

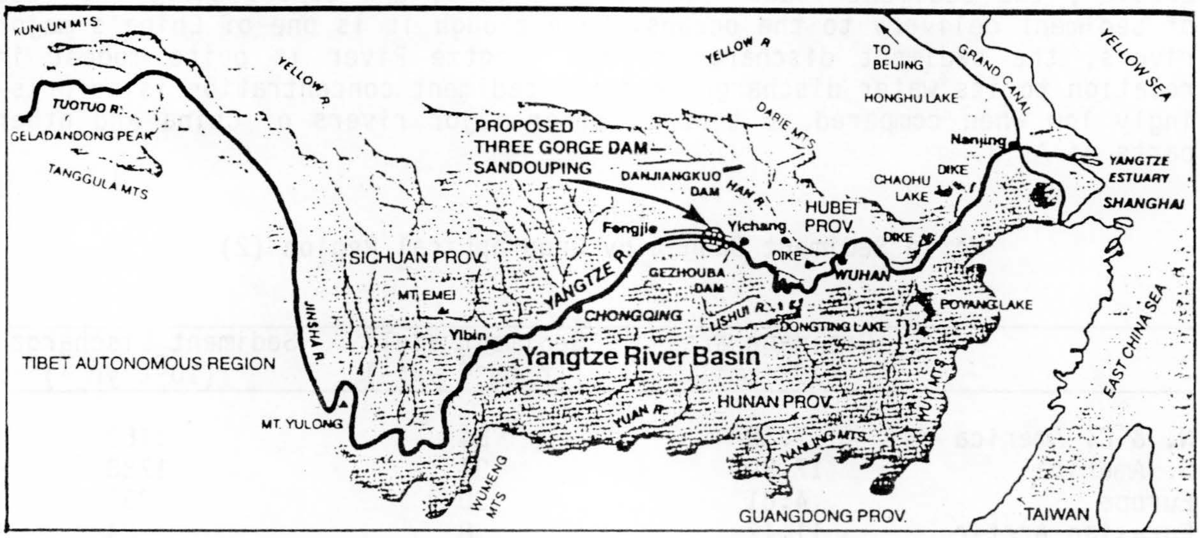


Figure 1: Site of the Three Gorges Project (5)

Flooding of the Yangtze River has ravaged its basin from time to time since the beginning of Chinese civilization. The major problem is insufficient channel capacity to handle flood flows. Records show that more than 214 disastrous floods occurred between 185 BC and 1911 AD. During the 1931 flood, 8.333 million acres of cultivated land was inundated and more than 30 million persons were displaced, with casualties numbering an estimated 145,000. The city of Wuhan was flooded, and nearly ice laded, for about three months (5).

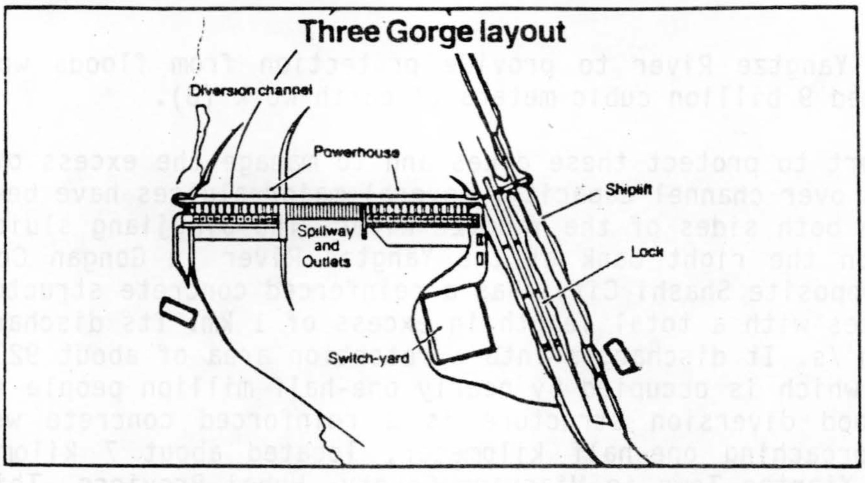
The main flood protection of the Middle Yangtze River valley now is provided by systems of levees, which straddle the river along much of its length downstream from Yichang. When the levees fail, or the flood release gates in them are open, the excess water is stored in lakes and other lowlying areas of the valley. The present system of dikes has a total length of approximately 30,000 km, of which about 3,100 km are along the main stem of the Yangtze River, and some 700 km are along the Hanjiang and other tributaries (6). In many ways, the dikes of the rivers of China are more impressive than its Great Wall. The dikes are nearly as old, involved larger volumes of earth and rock movement, have greater length, serve a peaceful purpose, and are still being used beneficially. The largest of the levees is the Jingjiang, a 182-km-long earth and masonry structure constructed beginning about 325 AD (7). It provides primary flood protection for some 5 million persons around Wuhan. During the past 30 years, the levee has been raised significantly (5), but in its present state still could only protect against water levels no higher than those which accompanied the 1954 flood (6).

The dike is beset by numerous problems, however. These include: a rather unstable sand and gravel foundation; frequent cave-ins; deep pools of water that have built up behind it; and ants that have excavated large caves within the levees (7). Consequently, this levee, like many others along the Yangtze, leaks during floods. Repairing and raising all the levees along the Yangtze River to provide protection from floods would require an estimated 9 billion cubic meters of earth work (6).

In an effort to protect these dikes and to manage the excess of flood flow discharges over channel capacity, several major sluices have been installed in them on both sides of the Yangtze River. The Jingjiang sluice, which is situated on the right bank of the Yangtze River in Gongan County, Hubei Province opposite Shashi City, has a reinforced concrete structure containing 54 gates with a total length in excess of 1 km. Its discharge capacity is 8,000 m^3/s. It discharges into a retention area of about 920 square kilometers, which is occupied by nearly one-half million people (7). The Dujiatai flood diversion structure is a reinforced concrete weir, with a length approaching one-half kilometer, located about 7 kilometers downstream of Xiantao Town in Mianyang County, Hubei Province. This structure includes thirty outlets, each equippped with a tainter gate, and has a total discharge capacity of 4,000 m^3/s (7).

At present, the available flood-carrying capcity of the midlle reach (Yichang to Wuhan) of the Yangtze River is about 60,000 m^3/s, and that of the stretch from Chenglinji to Hankou is about the same. Below Hankou, the flood-carrying capacity of the channel amounts to about 70,000 m^3/s. During the past 100 years, there were 21 floods which have had peak discharges at Yichang exceeding 60,000 m^3/s. Since 1153, eight major floods have had peak flows at Yichang exceeding 80,000 m^3/s, the largest being the 1870 flood with a peak flow of about 110,000 m^3/s (6). These statistics suggest that without further flood-control measures, future flooding can be expected at an average interval of about 5 to 10 years. The dikes have been raised to the point that increasing their size further is very difficult, for the aforementioned reasons. Installation of gates in the levees to alleviate the floods by diversion of flow from the Yangtze River into surrounding areas causes disruption of economic activity and recurring displacement of population that are increasingly unacceptable as China rapidly develops one of its most valuable resources, the Yangtze Valley.

A major dam, Gezhouba Dam, is presently (1986) nearing completion at a site approximately 40 kilometers downstream from the Sanduoping, the proposed site of TGP dam. Figure 2 summarizes the layouts of, and principal data on, Gezhouba Dam and TGP (5). Gezhouba Dam is relatively low, with a reservoir volume of only about 1.5 billion cubic meters. The annual runoff of the Yangtze River is approximately 453 billion cubic meters (3), and therefore Gezhouba Dam can accomplish relatively little in the way of flood control. TGP reservoir, on the other hand, would have a reservoir capacity slightly in excess of 20 billion cubic meters (about 5 percent of the annual runoff), of which approximately one-half would be available for flow regulation and flood control (4). TGP could, therefore, through proper reservoir regulation coupled with modern flow-forecasting techniques, produce significant attenuation of flooding of downstream areas, and result in a marked increase of the average return period between flood events. The required reservoir-regulation strategy would involve lowering the reservoir annually before the onset of the flood season, to provide storage capacity to accommodate the flood flow. This is the ordinary practice for flood-control hydroprojects. Fortunately, this policy is also compatible with the sediment-management strategy for the reservoir.

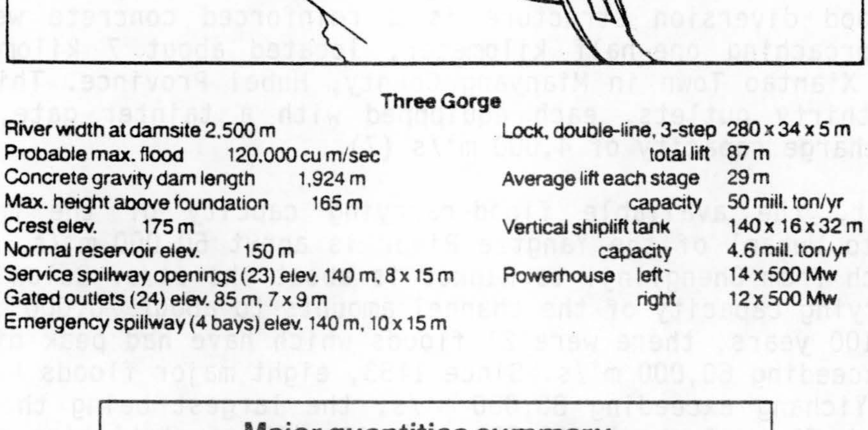


Three Gorge

River width at damsite 2,500 m		Lock, double-line, 3-step	280 x 34 x 5 m
Probable max. flood	120,000 cu m/sec	total lift	87 m
Concrete gravity dam length	1,924 m	Average lift each stage	29 m
Max. height above foundation	165 m	capacity	50 mill. ton/yr
Crest elev.	175 m	Vertical shiplift tank	140 x 16 x 32 m
Normal reservoir elev.	150 m	capacity	4.6 mill. ton/yr
Service spillway openings (23) elev. 140 m, 8 x 15 m		Powerhouse left	14 x 500 Mw
Gated outlets (24) elev. 85 m, 7 x 9 m		right	12 x 500 Mw
Emergency spillway (4 bays) elev. 140 m, 10 x 15 m			

Major quantities summary

	Gezhouba	Three Gorge
Excavation	55.3 mill. cu m	52.4 mill. cu m
Concrete	9.8 mill. cu m	24 mill. cu m
Earth fill	32.2 mill. cu m	22 mill. cu m
Reinf. steel	163,000 ton	207,000 ton
Struct. steel	460,300 ton	191,500 ton



Gezhouba

River width at damsite	2,200 m	Locks, single-step	No. 1 NA
Max. design flood	110,000 cu m/sec		No. 2 280 m long, 34 m wide, 5 m deep
Conc. gravity dam length	2,595 m		
Max. height above foundation	70 m		No. 3 120 m long, 18 m wide, depth NA
Crest elev.	70 m		
Normal reservoir elev.	63-66 m	Total capacity 50 million tons, one way	
Gated spillway bays (27)	12 m wide x 24 m high	Powerhouse, left channel	2 x 170 Mw, 5 x 125 Mw
Left bank silt-sluice cap.	10,500 cu m/sec	Powerhouse, main channel	14 x 125 Mw

Figure 2: Summaries of data on Three Gorges Dam and Gezhouba Dam (5)

4 Sediment and Three Gorges Project

As was discussed above, most rivers are flows not of just water, but of water and sediment. The Yangtze River carries very large sediment discharges, but because of its correspondingly high water discharges the sediment concentration tends to be relatively low. The average annual suspended-load discharge at the Yichang hydrological station is 523 million tonnes, which gives a mean sediment concentration of 1.19 kilograms per cubic meter (4). The total suspended-load discharge during the high-flow months, May to October, amounts to 95.7 percent of the annual total, 72.9 percent of the total annual suspended-sediment discharge occurs just between July and September (8). The annual bed-load discharge is extremely small, the total annual sand discharge amounting to only about 6 million tonnes per year, and the average annual discharge of gravel with a diameter greater than 10 mm amounting to only about 0.758 million tonnes per year (8).

For TGP, as in practically all hydroprojects, a sound sediment-management strategy is essential to the success of the project. The factors which augur well for the development of a successful, practical-management strategy at the site are as follows:

* The sediment concentration in the flow is relatively small, and practically all of the sediment transported by the river is very fine. The discharges of sand- and gravel-size sediments into the reservoir will be very small. Therefore, flushing of deposited sediment from the reservoir will be relatively easy.

* The fact that the river bed along most of the Three Gorges reach of the river is covered with exposed gravel and rock, the sand-, silt-, and clay-size sediment fractions having been scoured away by the flow, demonstrates that the river presently is "sediment starved". That is, it has capacity to transport far more sediment than presently is delivered to it by the contributing watershed.

* The reservoir will be of the elongated, river type. There will be virtually no water storage and attendant sediment deposition in areas far removed from the present main river channel. This greatly facilitates sediment flushing of the reservoir.

* The large annual river-flow volume in relation to the reservoir capacity makes it possible - indeed, very practical - to flush the sediment from the reservoir, by lowering its level annually to return the reservoir to conditions tending toward those of a free-running river.

* The sediment-management strategy which has been proposed for the reservoir appears to be sound. It consists of lowering the reservoir during the months of March and April, before the onset of the high-flow season. The reservoir then will be held at a low level for approximately four months, during the high-flow period, so that the heavily sediment-ladened flows will pass through the reservoir with larger velocities and attendant higher sediment-transport capacities. The reservoir will again be filled during September and October of each year, toward the end of the high-flow period, to maintain larger depths for navigation and higher heads for power generation during the annual low-flow periods. In summary, the overall strategy consists of lowering the reservoir level to permit the passage of large flows transporting high

sediment concentrations through the reservoir, and storage of the relatively sediment-free flows that occur during low-discharge periods.

* Low-level sediment sluices will be installed in the dam, to permit sediment flushing from the reservoir and passage of the sediment through the dam. Therefore, after sediment-equilibrium conditions are reached in the dam, sediment delivery to the downstream river channel will be largely uninterrupted by TGP.

* The experience with sediment flushing at Gezhouba Dam, just downstream of the proposed TGP dam site, has demonstrated that successful sediment flushing can be achieved on the Yangtze River, and has provided valuable experience.

* Very extensive studies, involving the most modern hydraulic-laboratory and numerical-simulation modelling techniques, have been carried out on the sedimentation aspects of TGP. It is doubtful that any previous hydroproject anywhere has had its sediment aspects subjected to such extensive, detailed investigation.

* Modern meteorology and flow-forecasting techniques bring finely tuned, precise reservoir-management execution, and the attendant sediment management, into the realm of practicality.

The engineering challenges in sediment management at TGP remain, nevertheless, formidable. The negative factors include:

* The very large sediment discharge transported by the Yangtze River.

* The requirement that Chongqing Harbor not be subjected to sediment shoaling, which often occurs at the upstream ends of reservoirs.

* The sometimes conflicting demands resulting from the need to maintain high heads for power generation, and to lower the reservoir for flood-flow storage and sediment flushing. However, this incongruity of objectives is by no means unique to TGP, and has been dealt with successfully at many other large hydroprojects.

* Failure of the sediment-management strategy to perform as predicted could have major consequences (as could failure of practically any other designed feature or components of TGP and other hydroprojects).

5 Navigation Aspects

Development of Three Gorges Project will result in a completely new environment for navigation on the upper reach of the Yangtze River. Most of the changes will be decidedly beneficial, as the impounding of a deep reservoir behind the dam will create a more consistent and less restrictive navigation situation. This will result in significant improvements in both the cost of, and the capacity for, movement of water-borne traffic on the river.

The value of these improvements will depend on several factors, including:

* The degree of improvement relative to existing and probable future conditions without Three Gorges Project.

* The amount of future traffic which will benefit from the improved conditions.

Downbound water traffic currently amounts to approximately 4 million tonnes per year. This is projected to grow by a factor of approximately 10 by the year 2050.

Shipping through the upper reach of the Yangtze River, which extends from Chongqing to Yichang (about 40 km downstream from Three Gorges Dam), presently is constrained by hazardous conditions and limited channel capacity. High river velocities, narrow channels, shallow depths, and sharp bends limit vessel size, and impose major cost penalties due to restricted operating hours (at times, to daylight hours) and delays in transiting through sections where only one-way traffic can be accommodated. Some reaches are so steep that vessels must be winched upstream through them. As a result, the unit cost of shipping through the upper reach of the River is more than double the cost incurred in the sections below Yichang.

Maintaining and operating the river channel also involves major effort and cost. The expenditures include the operation of winching stations, operation of one-way control stations, maintenance of numerous channel markers and other navigation aids, and an ongoing program of dredging which is required to maintain the required width and depth of navigation.

While it is possible, at least in principle, to improve navigation conditions and reduce costs along the upper reach of the Yangtze River, through better operating procedures, and it is not possible to overcome all of the effects imposed by river morphology. It is difficult to control velocities through narrow gorges and over shallow sections and shoals, while narrow channels and sharp bends can only be remedied by major excavation projects. As a result, future navigation will likely continue to be constrained by high river-flow velocities and one-way channels through many of the narrow sections of the upper reach of the River. It will be difficult to attain a level of cost and capacity which would attract a significantly higher share of traffic to the river away from alternate modes.

During the period of construction of Three Gorges Dam, navigation on the river will be only slightly affected. Conditions along the upper reach of the River will not change in a major way until the reservoir is impounded, which will occur mid-way through the twelfth year of construction. Conditions around the construction site will be affected as sections of the river are cofferdamed. However, facilities are planned to handle navigation during this period. These will include a diversion channel, a temporary lock, and possibly a shiplift.

Three Gorges Project will have major effects on channel operation and maintenance in the upper reach of the River. Most of the costs associated with operating winching stations and one-way control stations will be eliminated, and maintenance and adjustment of channel markers will be greatly reduced. Additionally, there will be a significant reduction in the amount of excavation and dredging work both in the upper reach and downstream from Yichang. However, some of these savings will be offset by the deposition of gravel in the variable backwater reach of the reservoir, and of finer sediment material at the lock approaches. Annual dredging will be required in order to maintain the navigation channel at both these locations.

Coarse material will be deposited along the upstream part of the fluctuating-backwater reach of the reservoir. Therefore, at least initially, most of the deposition will be just downstream from Chongqing. Although deposition in the fluctuating-backwater reach will raise the level of the river bed, it will not necessarily decrease the depth available for navigation. Consequently, only that portion of the deposition which forms bars and shoals will interfere with navigation and require dredging.

The project will also affect the navigation conditions in the middle reach of the river at, and below, Yichang. Positive impacts include increased minimum dry-season flows which will alleviate current problems of insufficient navigation depth. However, this impact will be only partly due to the Three Gorges Projects, as a number of water-control projects will be constructed upstream of Three Gorges Project over the next two decades. These will also provide considerable dry-season flow control.

Another source of concern is that the operation of Three Gorges and Gezhouba Power Plants, to serve daily peaking demand, might lead to low flows and insufficient downstream navigation depths during certain periods each day through the dry season. The variations in water depth resulting from swings in discharge over the 24-hour period should be almost fully attenuated within 50 km downstream from Gezhouba Dam. Because the critical shallow depth sections are located further downstream, these variations should not affect the ability to meet navigation standards. The reduced sediment discharge, because of sediment retention in the Three Gorges Project reservoir, may cause degradation of the river bottom just below Gezhouba Dam, and cause water levels to drop and create depth problems over the sill at Gezhouba locks. It is estimated that the degradation downstream from Gezhouba Dam will not exceed 1 m to 2 m. However, further analysis will be required to reference this estimate.

Future capacity of the navigation facilities in the river channel will depend on the mix of traffic using the river. The future fleet composition, in turn, will depend on the growth in passenger and freight traffic, and on the extent to which new vessel types are adopted in response to changing conditions. On the basis of certain estimates of fleet mixes, it was found that the capacity of the system was limited by the permanent navigation facilities at Three Gorges Dam. One-way annual capacities through the locks range from a low of 27 million tonnes, with a large number of small tows and passenger vessels in fleet, to a high of 36 million tonnes if the traffic is comprised primarily of 9 x 1,000 tonne tows, and if there is no growth in passenger vessel movement. With the locks and shiplift together, the capacity ranged from a low of 33 million tonnes to a high of 40 million tonnes.

Neither of these capacities is sufficient to handle the traffic of the 50 million tonnes per year forecast by the Chinese government. To meet this demand, the average lockage would have to carry between 9,000 and 11,000 tonnes. Achievement of this average would require much greater degree of fleet optimization than has been projected in studies conducted to date. It is doubtful that a major shift to larger, higher capacity barges, and adoption of strong policy steps to limit the number of small vessels on the river, will occur. If these steps could be realized, significantly higher lock capacities could be achieved in the capacity of the upper reach of the Yangtze River which otherwise would become the constraining factor on the system capacity.

The benefits resulting from improved navigation on the river have been calculated by comparing, on a net present value basis, the total cost of moving passengers and freight through the upper Yangtze corridor without Three Gorges Project to the total cost if the project is built. The analysis examined the cost of both water and overland transport, and the probable splits with and without Three Gorges Project. The resultant costs of moving freight and passengers to the region were then compared. The analysis included the cost of maintaining the navigation channel with and without the project.

As a base case, the capacity of the system with Three Gorges was limited by the capacity of the permanent locks assuming twelve passenger vessel transits per day, while the capacity of the natural river without Three Gorges Project was based on a similar number of passenger vessel transits and a fairly optimistic shift toward maximum-size tows in the fleet.

The total savings in transportation costs (passengers and freight) for the base case ranged from 732 million Yuan per year to 810 million Yuan per year, depending on the design reservoir level, for a medium-traffic scenario.

A small saving in channel maintenance costs is expected as a result of the project. While additional dredging will be required in order to remove coarse sediment deposits and to maintain navigation depths, the projected increase in dredging costs is less than the savings accruing to elimination of winching, reductions in the number and length of one-way sections, and reduction in the costs of maintaining navigation aids. The present value of the anticipated savings is 14.3 million Yuan.

Much of the foregoing material related to navigation was obtained from the CIPM Yangtze Joint Venture feasibility report for Three Gorges Project (9).

6 Summary and Conclusions

This paper has considered principally the flood-control, sediment-management, and navigation aspects of the proposed Three Gorges Project. There appears to be no practical, economically achievable alternative to TGP for achieving adequate flood control for the Middle Yangtze River valley. The rapid industrial and agricultural development of this very fertile valley argues strongly for a higher level of flood-control protection than is presently afforded by the existing levees and their diversion tructures. The river channel can handle floods only up to those corresponding to about the ten-year return period without upstream regulation. Raising the dikes is not practical, because of the enormous volumes of earth fill that would be involved, and because of the very high levels of maintenance required by the dikes, as discussed above. Additionally, flooding of surrounding areas, with water diverted from the Yangtze River, during flows that would overtop the dikes without controlled diversion, is becoming increasingly unacceptable, because of the rapid development of the areas which become inundated. TGP will increase the flood-protection of the Middle Yangtze River valley to a much higher level, and promises to keep it free of the devastating effects of all but extreme flooding events. The Project also will have major benefits to navigation.

Sediment management for the TGP reservoir poses some major, unique problems. However, because of the several equally unique features of the site, as discussed above, and because of the experience gained with Gezhouba Dam and other major hydroprojects in the world utilizing sediment management through selected storage of low-sediment-concentration flows and periodic sediment flushing, all indications are that a practical, successful sediment-management strategy can be developed and implemented. Periodic flushing of the sediment from the reservoir through the dam has the added advantage of not depriving the channel downstream of the dam of its sediment discharge. After equilibrium conditions are achieved in the reservoir, the same annual-average total amount of sediment will be passed through the dam as in the natural state. Therefore, the many problems attendant to river-channel deterioration resulting from curtailment of sediment discharges by large reservoirs will be avoided.

Three Gorges Project is by no means the first major hydroproject in the world, and practically all of the problems it poses have been successfully addressed in other large projects. There is no reason to believe that they cannot be handled equally as well--likely better, because of the benefit of experience with these other projects--at TGP.

7 References

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