

1. SUMMARY

This Volume presents the results and conclusions of CYJV's technical review of the Three Gorges Project as outlined in the YVPO 1985 Preliminary Design Report and presents the CYJV Recommended Project.

1.1 Site Selection and Project Arrangement

From 1956 to 1959 YVPO investigated sites in two regions: the Nanjingguan region with limestone bedrock and the Meirentuo region with granite bedrock (Plate 4.2). The granite sites generally were wider and favoured surface powerplants while the limestone sites were in narrow gorges and favoured underground powerplants. Ease of access, availability of space for construction plant and activities, greater ease of construction for surface type power plants and superior foundation conditions led to selection of the Meirentuo region for the site of the Three Gorges Project. Within the Meirentuo Region the Sandouping site was selected over the Taipingxi site due to better site access, more suitable space for construction plant and more favourable topography for management of the river diversions.

The layout selected by YVPO for the Sandouping site comprised a concrete gravity dam having a spillway centred over the main river channel with intakes and powerhouses on both sides. The flight locks for navigation were located on the left bank. This layout appears optimum for the Sandouping site.

1.2 Geology

The granite bedrock at the Sandouping site is excellent. It is very strong, impervious and has only a few minor shears. The dam axis was selected so that the dam will be founded where the rock has weathered the least, resulting in the least foundation excavation and concrete backfill.

1.3 Seismicity

The Sandouping site is in an area of low tectonic and seismic activity. Review of seismic data and design criteria using "Design Basis" and "Maximum Credible Earthquake" (MCE) concepts yield slightly higher ground acceleration values than those adopted by YVPO. For safety evaluation purposes a horizontal peak ground acceleration of 0.17 g is recommended for use in the stress-stability analyses of the main structures. With reference to induced seismicity and the effects of reservoir impoundment, a slight increase in seismic activity is anticipated in the area upstream of the damsite where the Xingshan-Qianjiang and Zigui-Yuyuanguan fault systems cross the reservoir valley. Further upstream the seismic activity would be expected to remain at the same low level.

1.4 Reservoir Slope Stability

Extensive studies have been made of the main Yangtze valley between Sandouping and Chongqing to identify and classify landslide hazards to the local population, to navigation and to future project structures. A total of 82 large scale features (larger than $1 \times 10^6 \text{ m}^3$) have been identified. Of this total, 60 slide masses are expected to be stable under all cases of reservoir operation. Sixteen slide masses are considered potentially unstable and six are presently in a developing or active condition. Under future reservoir conditions, debris from potential slide zones is not expected to pose major problems for navigation, to reduce the useable storage in the reservoir or to endanger resettled population.

1.5 Hydrology

Daily streamflow records at Yichang, downstream from the dam site are available for the period from 1877 to the present. These are adequate for carrying out energy and power studies as well as for determining flood-frequency relationships for the design of hydraulic structures. Daily streamflows available at Luoshan and other downstream stations for the period 1951–1984 are adequate for evaluating the flood control benefits of the project.

1.6 Energy Studies

The monthly flows for the 44-year period from July 1939 to June of 1983 were used for the energy simulations. The natural inflow hydrology was modified to account for the regulation provided by projects on upstream tributaries. The usable upstream storage and its regulating effect is planned to be increased in the future as shown below:

<u>Year</u>	<u>Upstream Storage</u> km ³	<u>Increase in</u> <u>Average Winter</u> <u>Flows</u> %	<u>Decrease in</u> <u>Average Summer</u> <u>Flows</u> %
2005	9.8	12	2
2010	19.7	28	5
2020	27.7	40	7

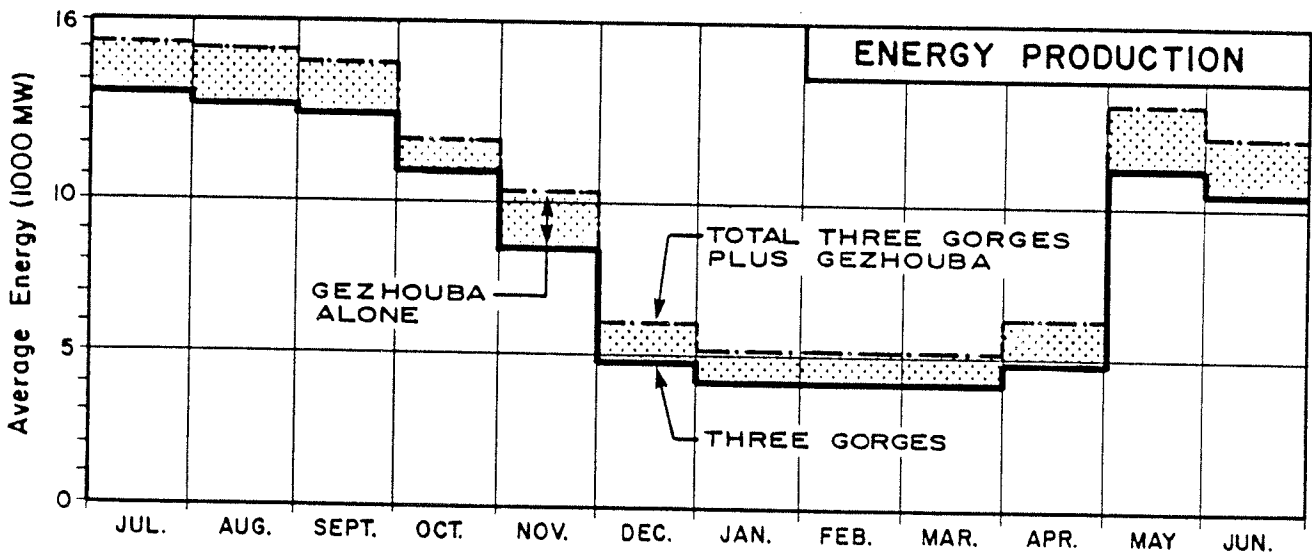
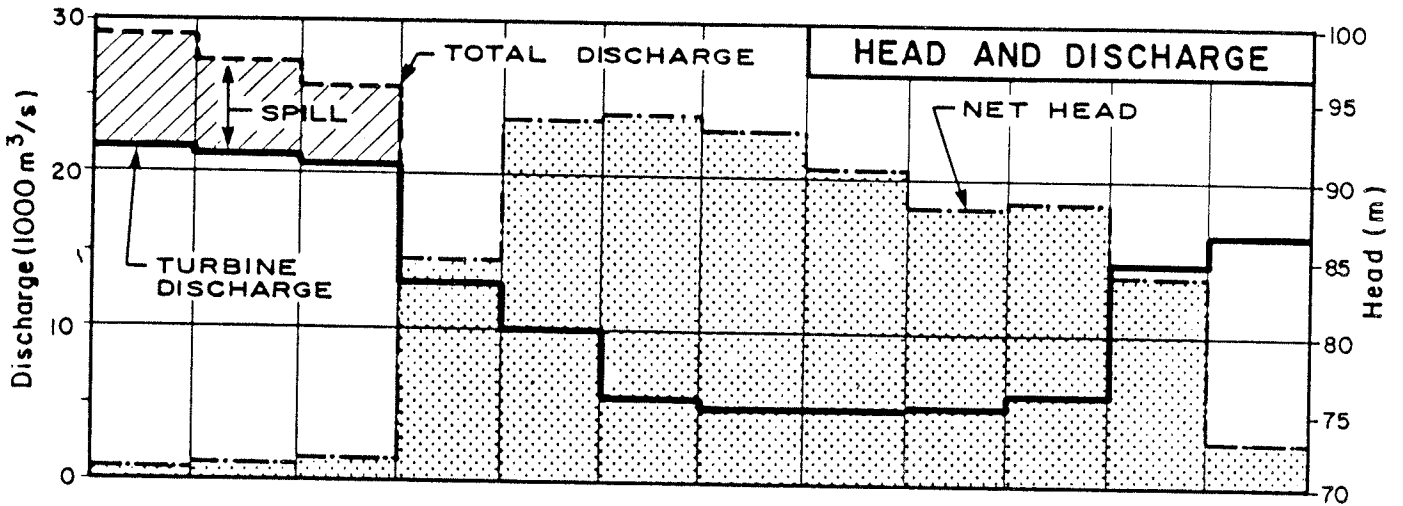
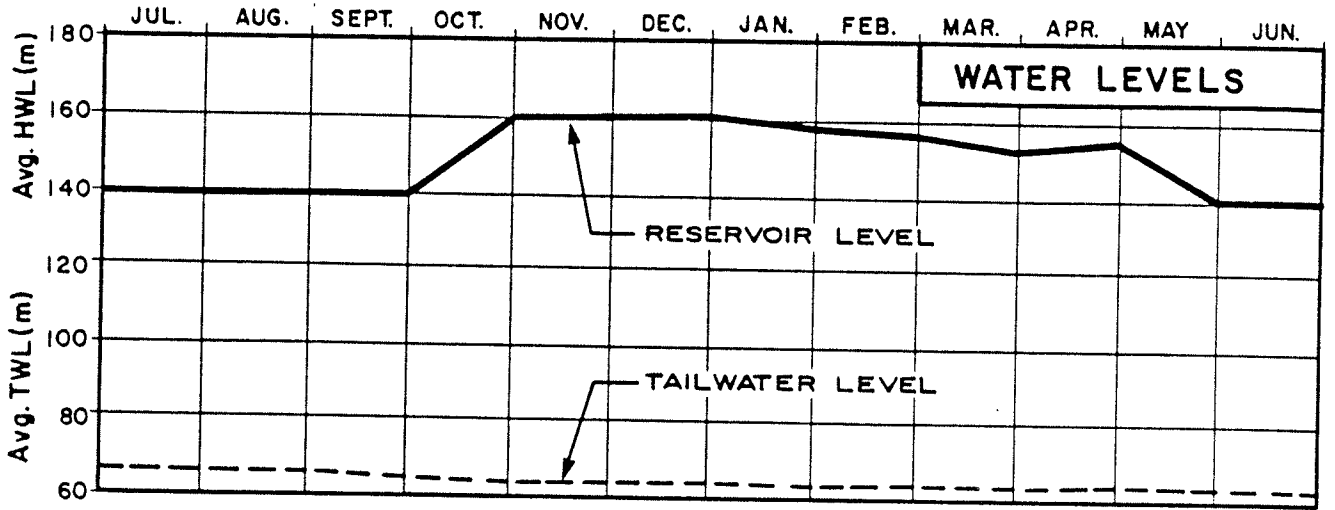
The mean of these monthly inflows for the 44-year period under various amounts of upstream regulation are tabulated below:

Flows in m ³ /s				
	<u>Historic</u>	<u>2005 Regulation</u>	<u>2010 Regulation</u>	<u>2020 Regulation</u>
January	4 180	4 680	5 500	6 040
February	3 750	4 520	5 470	6 060
March	4 180	4 990	5 930	6 590
April	6 370	7 020	7 710	8 460
May	11 600	11 600	11 100	11 600
June	17 800	17 000	15 200	14 000
July	29 500	29 300	29 100	28 900
August	27 900	27 600	27 400	27 300
September	26 400	26 000	25 200	25 500
October	18 500	17 500	16 900	15 600
November	10 200	10 200	10 200	10 200
December	5 860	5 920	6 100	6 190
Annual	13 900	13 900	13 900	13 900

Energy production was simulated by routing the monthly inflows through the reservoir and powerplants, spillway and navigation facilities of both the Three Gorges and Gezhouba Projects. Navigation was assumed to consume 100 m³/s at Three Gorges and 50 m³/s at Gezhouba. As shown in **Figure 1.1**, the reservoir was operated at NPL during the months of November through March except when drawdown is required for flow regulation. During these months, the reservoir was lowered as required to regulate flows for firm energy production and for navigation downstream. During May it was lowered uniformly from the NPL to the FCL. From June through September, during the flood season, the reservoir was held at the FCL to flush sediments through the reservoir, except when it was filled above the FCL in the process of regulating flood inflows to provide flood protection downstream. During October the reservoir was filled uniformly from the FCL to the NPL.

The energy studies determined the firm and total annual energy that could be produced for a variety of projects having various combinations of FCL and NPL. The same turbine efficiency curve was used for all project combinations with appropriate adjustments to the turbine head so that it matched the required operating range. In computing the net head, the variations of tailwater levels and head losses were accounted for.

THREE GORGES PROJECT FEASIBILITY REPORT



**RECOMMENDED PROJECT
TYPICAL OPERATION AND ENERGY GENERATION**

To evaluate the full effect of Three Gorges the energy produced by Three Gorges and Gezhouba was compared with the energy produced by Gezhouba without the flow regulation of Three Gorges.

The turbine and generator capacities were made consistent between the various combinations of FCL and NPL by holding the turbine discharge capacity constant. For all FCLs, the total discharge capacity from the turbines was 22 180 m³/s. Thus, the portion of the total flow that could be utilized to produce energy when the reservoir was at FCL was the same for all alternatives.

The generator capacity selection was based on the NPL. Generally generator capacity was 10 to 20% larger than the output of the turbines at FCL in order to utilize part of the additional turbine capacity at heads higher than at FCL. This also permits the turbine to operate at higher efficiencies at the NPL. However, in order to utilize the capacity for peaking operation in the winter, Gezhouba reservoir must re-regulate the Three Gorges discharges so that downstream navigation is not affected adversely.

CYJV found that the generating capacity proposed by YVPO in their 1985 Feasibility Report could just be re-regulated by Gezhouba. This study assumed that four of the 26 units would be out of service for maintenance during the winter. The discharge of the remaining 22 units at NPL when using their full generating capacity would be 17 160 m³/s for all alternatives. This peaking discharge is near the limit that could be re-regulated by Gezhouba and was selected for all alternatives as the limit of peaking discharge.

The generating capacity and output for Three Gorges and Gezhouba for the inflow conditions of the year 2005 are shown in **Table 1.1**. These estimates were made with the PDL equal to the FCL for producing firm energy during the winter.

By lowering the PDL, firm energy will increase significantly while average total energy will decrease very little. In general the average energy is reduced only 0.2% for each 5 m that the PDL is set below the FCL while the firm energy is increased by 2 or 3%. For example, the effect of various PDLs on the energy production of the 160 NPL, 140 FCL alternative is tabulated below:

<u>NPL</u> <u>m</u>	<u>FCL</u> <u>m</u>	<u>PDL</u> <u>m</u>	<u>Average</u> <u>Energy</u> <u>MW</u>	<u>Firm</u> <u>Energy</u> <u>MW</u>
160	140	145	10 265	5 170
160	140	140	10 240	5 321
160	140	135	10 217	5 427
160	140	130	10 195	5 516

THREE GORGES PROJECT FEASIBILITY REPORT

TABLE 1.1 - CAPACITY AND ENERGY OUTPUT FOR THREE GORGES PROJECT PLUS GEZHOUBA FLOW CONDITIONS OF 2005

CAPACITY IN MW							
NPL	150	155	160	165	170	175	180
All FCLs	15 000	15 900	16 750	17 600	18 500	19 400	20 300
FIRM ENERGY IN MW							
FCL & PDL m							
130	4 662	5 081	5 516	6 027	6 124	6 124	6 124
135	4 561	5 000	5 427	5 965	6 336	6 343	6 343
140	4 425	4 890	5 321	5 852	6 385	6 567	6 567
145	4 204	4 730	5 158	5 695	6 268	6 785	6 789
150	3 770	4 511	5 009	5 550	6 100	6 768	7 000
155	-	3 963	4 718	5 334	5 885	6 500	7 220
AVERAGE TOTAL ENERGY IN MW							
FCL & PDL m							
130	9 137	9 317	9 503	9 695	9 880	10 022	10 104
135	9 492	9 684	9 878	10 044	10 221	10 408	10 501
140	9 826	10 056	10 240	10 414	10 569	10 749	10 880
145	10 133	10 389	10 585	10 768	10 959	11 121	11 261
150	10 283	10 669	10 927	11 127	11 307	11 475	11 637
155		10 805	11 189	11 489	11 673	11 830	12 000

Firm energy from Gezhouba without regulation from the Three Gorges Project would be 825 MW and the average total energy would be 1 536 MW.

On the other hand, lowering both the FCL and PDL provides no more firm energy than lowering only the PDL, but it decreases the average energy by almost 3% per 5 m as shown below:

<u>NPL</u> m	<u>FCL</u> m	<u>PDL</u> m	<u>Average Energy</u> MW	<u>Firm Energy</u> MW
160	145	145	10 585	5 170
160	140	140	10 240	5 321
160	135	135	9 878	5 427
160	130	130	9 503	5 516

To determine if it would be economic to increase or decrease the installed capacity, the energy production with various installed capacities was determined for the NPL 160 and FCL 140 alternative for the year 2005 inflow conditions. Only average energy increases with capacity as shown below:

<u>Capacity</u> MW	<u>Average Energy</u>	<u>Firm Energy</u>
15 460	10 000	5 170
16 750	10 240	5 170
18 040	10 435	5 170
19 330	10 610	5 170

These energy values and others for other NPL/FCL/PDL combinations were used for evaluations of economic generating capacity for various combinations of NPL, FCL and PDL.

1.7 River Diversion

During Phases I and II, the river will be diverted first to the left side and then to the right in open channels. During Phase III the river will be diverted through the diversion outlets and spillway bays in the dam (Plate 4.13).

1.7.1 Phase I Diversion

No unusual problems are expected during the Phase I diversion. In this phase the river will be restricted to its main channel on the left side by a 40 m high cofferdam which runs from the right bank across to Zhongbao Island, along the island and back to the right bank. This cofferdam will be constructed of earth and rockfill with a concrete cutoff wall from bedrock to El 72 and a clay core from El 70 to El 79.5. The crest of the cofferdam along Zhongbao Island and upstream will be at El 80.5. It is designed to withstand a 1:20-year flood under normal conditions and a 1:50-year flood under emergency conditions.

A diversion channel will be excavated inside the cofferdam during Phase I for use in Phase II. A longitudinal concrete cofferdam will also be constructed during Phase I to a crest level of El 90 initially and ultimately to El 135 upstream of the main dam axis and El 82 downstream of the axis.

1.7.2 Phase II Diversion

During Phase II, the river will be diverted through the 350 m wide channel excavated in Phase I on the right side of the river.

The Stage II cofferdams which effect the Phase II diversion will be constructed between the left bank of the river and the longitudinal concrete cofferdam to divert the river through the right bank channel. Cofferdams are required both upstream and downstream to isolate the dam foundation area from the river. The upstream cofferdam will be constructed to El 90 and the downstream cofferdams to El 81. They will be constructed with dumped rockfill and weathered sand to about El 72 for the upstream cofferdam and to El 68 for the downstream cofferdam. A single concrete cutoff wall will be constructed to bedrock from platforms at these levels. Above these levels the cutoff wall will be tied into an impervious clay blanket and core extending to El 88 for the upstream cofferdam and El 79 for the downstream cofferdam. These cofferdams will require about $13 \times 10^6 \text{ m}^3$ of fill and about $60\,000 \text{ m}^3$ of concrete for the cutoff walls of 0.8 and 1.2 m thicknesses. The Stage II cofferdams are designed for a 1:50-year flood under normal conditions and could withstand a 1:100-year flood under emergency conditions.

The Stage II cofferdams are very large requiring underwater construction for the most part. CYJV recommends a single plastic concrete cutoff wall rather than 2 walls of rigid concrete.

1.7.3 Phase III Diversion

During Phase III the river will be diverted first through outlets in the concrete spillway dam and later, after the diversion outlets are closed, through the spillway bays and powerplant. Three cofferdams will be constructed for the Phase III diversion. First, during the months of November to January when the flows are low, upstream and downstream earth and rockfill cofferdams will be constructed from the right bank to the longitudinal concrete cofferdam. The upstream cofferdam would be 40 m high with a crest level at El 90 and the downstream cofferdam 43 m high with a crest level at El 81. These cofferdams would require about $3.35 \times 10^6 \text{ m}^3$ of fill.

Once the working area between the two fill cofferdams is unwatered at the beginning of February, the third cofferdam will be constructed of roller compacted concrete (RCC) to El 135. This cofferdam is required to allow the reservoir to be raised to El 130 and permit the operation of the left bank powerplant while the right bank powerplant is being

constructed. The RCC cofferdam must be completed by the end of June to provide protection against the 1:100-year flood. Thus, only five months are available to construct this 85 m high, 962 000 m³ RCC gravity dam. This is an extremely tight schedule for the placement of such a large volume of RCC in a constricted area.

The downstream cofferdam is designed for a 1:50-year flood under normal levels and for a 1:100-year flood under emergency conditions. The upstream cofferdam, which is needed for about 6 months for construction of the RCC cofferdam, is designed for only a 1:20-year May flood. The RCC cofferdam is designed for a 1:100-year flood under normal conditions and a 1:200-year flood under emergency conditions.

1.8 Hydraulic Structures

1.8.1 Foundation Excavation

YVPO had considered in previous studies that foundation excavation should remove all rock above the top of the slightly weathered granite. This would provide an excellent foundation and satisfy the Chinese national design code for concrete gravity dams (SDJ 21-78). However, a review of the available information on rock characteristics indicates that most rock classified as weakly weathered would also provide a suitable foundation for the Three Gorges Project concrete gravity dam. CYJV considers that excavation to a foundation level in the weakly weathered rock would be appropriate.

Adopting a higher bed rock level would result in a saving in excavation and backfill concrete costs.

1.8.2 Foundation Treatment

The YVPO design provides for grout curtains upstream and downstream of the dam with several rows of foundation drains in between. While the downstream grout curtain represents only a small portion of the curtain grouting, it is not required for stability and is not in accordance with normal international practice. Therefore, CYJV recommends that the downstream grout curtain be eliminated and that the downstream drainage curtain be located as far downstream as practical, under the powerhouse and spillway bucket. The consolidation grouting and foundation drainage systems proposed are appropriate for a foundation in weakly weathered rock.

1.8.3 Structural Review

The concrete gravity dam, intake, spillway and non-over flow sections are of conventional design and would be founded on excellent rock. Based both on Chinese and International standards, the factors of safety against sliding (shear friction factors) are adequate. Longitudinal joints in the gravity dam would not be required if suitable temperature control measures are taken. The powerhouse has adequate factors of safety against uplift.

1.9 Navigation Facilities

1.9.1 Permanent Shiplocks

Two basic arrangements, both on the left bank, have been considered for the permanent shiplocks to permit vessels to pass the dam:

1. multi-stage flight locks adjacent to the river; and
2. multiple separate locks joined by intermediate navigation channels.

The lift for individual locks in each of the various lock arrangements should be limited by the hydraulic head across the filling valves. CYJV recommends this head not exceed world experience by more than 30% or a maximum of 45 m. Thus for NPLs of El 150 or lower, four-stage flight locks or two-stage separate locks could be considered. For the range of NPLs between El 155 and 175 m, five-stage flight locks or three-stage separate locks would be necessary.

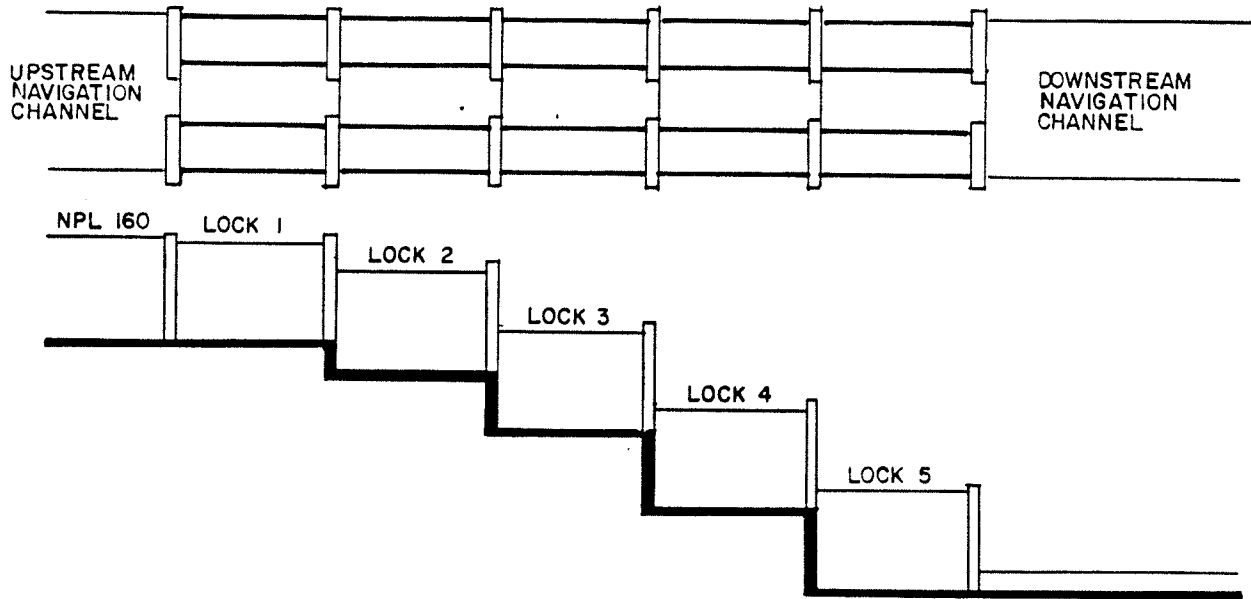
These alternatives have about the same capacity. The cost of the separate locks in series would be about 21% higher. If low demand occurs for the first 10 to 15 years of operation the separate locks are economic with staged construction. Single locks could be constructed initially and twinned later as the demand grows. If flight locks are used, staging is not feasible as each flight must be operated in one direction only to achieve reasonable efficiency. Therefore flight locks must be twinned from the outset.

The costs for these alternatives with NPL 160 would be as shown on **Figure 1.2**. If distances greater than shown on **Plate 4.23** are required between the separate locks, the cost of the separate lock alternative would increase above those shown on **Figure 1.2**.

As there is uncertainty concerning the MOC criteria for separate locks and the demand forecast during the first few years of operation, the five-stage flight lock alternative has been selected.

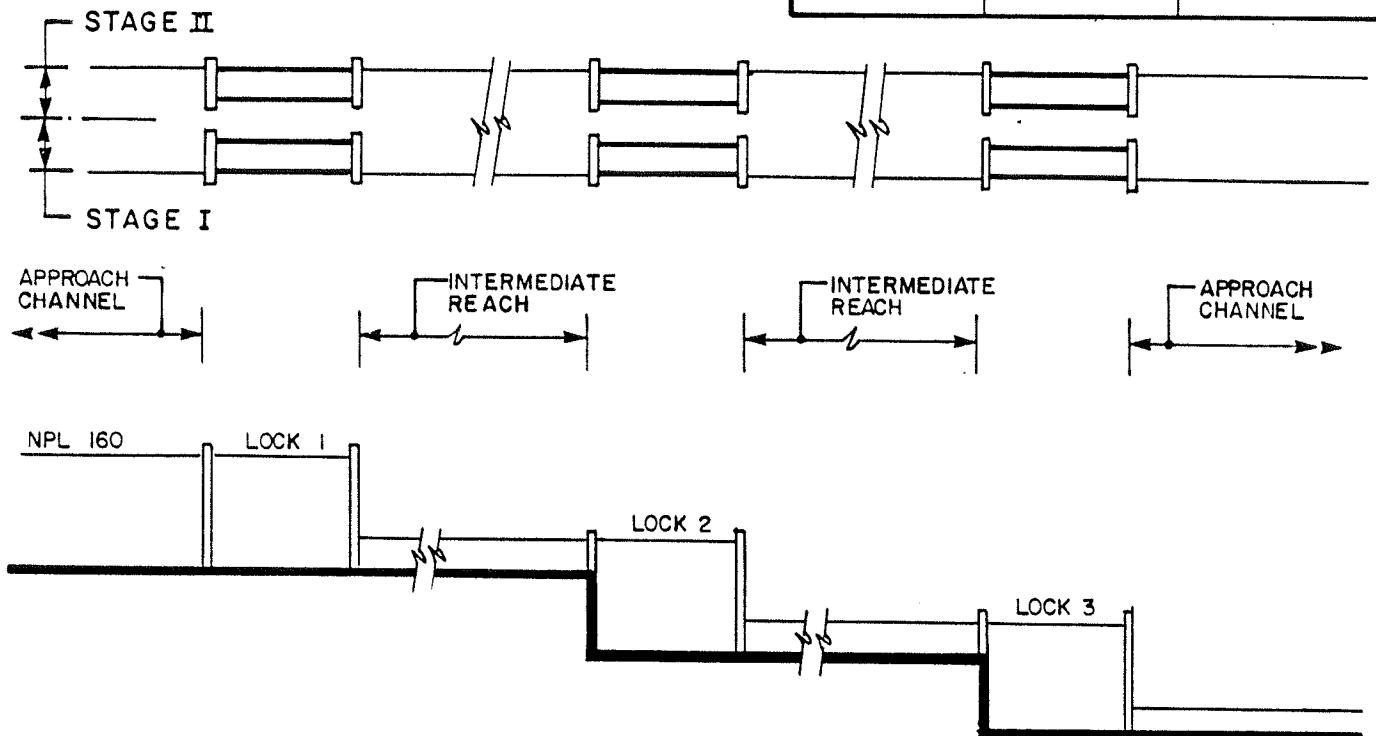
A) FIVE STAGE FLIGHT LOCKS

TOTAL COST ¥ x 10 ⁶	2 230
-----------------------------------	-------



B) THREE STAGE SEPARATE LOCKS

STAGE	COST ¥ x 10 ⁶	% OF FLIGHT LOCKS COST
STAGE I	1 625	73
STAGE II	1 075	48
TOTAL	2 700	121



THREE GORGES PROJECT FEASIBILITY REPORT COMPARISON OF ALTERNATIVE LOCK ARRANGEMENTS

1.9.2 Temporary Shiplock

The temporary shiplock proposed by YVPO would operate between tailwater and a headwater at El 76. CYJV recommends that the height of the walls and gates of the temporary shiplock be increased so that it can operate for head water levels up to El 96. This would reduce the period of time that navigation would have to be suspended during reservoir filling. It would also permit navigation during the first flood season of Stage III diversion if the diversion outlets in the dam should not be closed as scheduled.

1.9.3 Shiplift

As described in detail in Volume 6, Sections 5.4.4 and 7.7.1, CYJV was unable to confirm economic justification for including the shiplift as part of the Recommended Project. Never the less CYJV evaluated information on the reliability of such a structure. While the shiplift proposed by YVPO would be substantially larger than any existing shiplift, it is based on proven technology. Thus, the Three Gorges Project shiplift could be expected to be as reliable as similar smaller structures.

1.10 Recommended Project

The project recommended by CYJV comprises a dam with crest at El 185, two 11-unit powerplants with a combined capacity of about 16 750 MW, a spillway with 26 gated overflow bays and 27 submerged bays and a five-stage twin flight lock. The recommended NPL is El 160 and both FCL and PDL are El 140. The reservoir would be operated at FCL 140 during the wet season and would be allowed to rise as required to control downstream flooding. The maximum level permitted in the reservoir when operating to control downstream flooding is El 181 and when this level is reached the spillway must be fully opened.

1.10.1 Dam Crest Level

Dam crest levels of El 175 and El 185 were considered. The additional storage provided by a 10 m increase in dam height could be used to reduce flood damage downstream of the project. The discounted value of this increased flood control benefit is in the order of 500×10^6 yuan while the discounted cost of the increased dam height is in the order of 50×10^6 yuan. This suggests that a level higher than El 185 would be optimum. However, the calculated increase in flood control benefits is small for increases in flood control storage capacities greater than the 31 km^3 provided by the Recommended Project, and the problems of constructing a higher dam within the allowable time increase rapidly. Accordingly, a DCL of El 185 is recommended.

1.10.2 Powerplants

Two powerplants of 11 units each are recommended. The use of 22-761 MW units to provide a plant capacity of about 16 750 MW is about 180×10^6 yuan less expensive than the use of 26-644 MW units. The left bank powerhouse with 11-761 MW units is about 80 m shorter than one with 14-644 MW units. This 80 m was utilized to enlarge the spillway.

Other features of the powerplants for the Recommended Project are:

1. The use of two 1000 t bridge cranes in each power house to reduce cost and increase flexibility and handling capability for smaller loads.
2. The provision of a service road around the end of the powerhouses for access into the unloading bay at El 76.8 on the upstream side. This will permit the service bays and unloading bays to be at one level for their full length and will provide more usable floor space for the critical unit erection activities.
3. The location of electrical equipment and the control building close to the upstream side of the powerhouse with the gas insulated switchgear located in a building above the transformers to leave more room between the dam and powerhouse for access, especially during construction.

1.10.3 Intake Dam

CYJV recommends two intake gates per penstock with a central pier between gates. For units 1-6 on the left bank it is recommended that slots be excavated in rock for the penstocks and that the rock pillars between the slots be extended as far downstream towards the powerhouse as practical to improve the sliding stability of the rock foundation under the intake dam and to reduce costs. The silt discharge trench in the rock foundation just upstream of these units should be eliminated as it would introduce water into the foundation at high pressure.

1.10.4 Spillway

CYJV recommend that the spillway be extended to utilize the 80 m of reduced powerhouse length to permit the use of more of the reservoir for controlling downstream flooding. This would involve the addition of four more spillway blocks at a cost of about 70×10^6 yuan. This cost discounted to 1987 at 10% would be about 22×10^6 yuan compared to increased flood control benefits with a discounted value of 65×10^6 yuan as illustrated below:

	<u>23 Spillway Blocks</u>	<u>27 Spillway Blocks</u>
Maximum flood control operating level	El 178.1	El 180.7
Available flood control storage – km ³	27.8	30.8
Increase in discounted flood control benefits – Yuan x 10 ⁶	–	68.0
Increase in discounted construction costs – Yuan x 10 ⁶	–	22.0
Increase in discounted net benefits – Yuan x 10 ⁶	–	46.0

The spillway would have 26 gated overflow bays with an ogee crest level of El 158 and 27 submerged bays with sill invert El 85 controlled by 7 m wide by 8.5 m high radial gates.

The 1982 shape for the YVPO check flood could be routed through the reservoir starting from FCL 140 and following the rules for providing downstream flood control benefits until the reservoir reaches its maximum flood control operating level of El 181. At that time all spill facilities would be opened and the powerplants are assumed to be out of service. The reservoir would continue to rise to the PMF level of about El 183. The maximum spill would be 116 000 m³/s.

2. SITE SELECTION AND PROJECT ARRANGEMENT

Chinese water resources engineers began studying the improvement for navigation and power potential of the Three Gorges region of the Yangtze River in the 1930s. Construction of the first dam on the main stem of the river, at Gezhouba, began in 1970. Power was first generated at the Gezhouba Project in 1981 and completion of the second powerhouse is currently scheduled for 1988.

A Feasibility Report on the Three Gorges Project was produced by YVPO in 1983 and a Preliminary Design Report in 1985. This section summarizes the basis for selection of the Sandouping site for the Three Gorges Project and the development of the project general arrangement.

2.1 Cascade Developments

Cascade developments between Yichang and Cuntan were considered briefly. However, the cost of two to four projects to develop the same head for electric power would not be economic because the spillway capacity and powerhouse size would be about the same for projects with 25 to 50% of the head, as for projects with spillways and powerhouses with 100% of the head. Only the dam costs might be smaller for cascade projects and the dam is a small part of construction costs. Resettlement costs could be significantly less but they would not balance increased construction costs. Moreover, downstream flood control benefits would not be significant for cascade projects designed to minimize resettlement.

2.2 Site Selection

From 1956 to 1959, YVPO investigated two regions suitable for the construction of a high dam project (**Plate 4.1**). In the 13 km long Nan Jing Guan region, located at the downstream end of the Three Gorges, the bedrock is mostly limestone, with narrow valleys and steep slopes. In the 25 km long Mei Ren Tuo region, the bedrock is mostly granitic and the valley is generally wider than in the limestone region. Bank slopes vary in steepness depending on the extent of rock weathering.

2.2.1 Regional Comparison

In all, 14 dam sites were identified and investigated by YVPO, five in the Nan Jing Guan region and nine in the Mei Ren Tuo region. A comparison was made between representative sites in each region on the basis of geology, project layout and cost.

The Sandouping site in the granite region and the N-III site in the limestone region were selected as the two best representative sites. The comparison was made for an NPL at El 200. Rock foundations in both regions were found to be competent for a high concrete dam and other major structures. However, the cost and schedule for the Sandouping site were found to be superior by a significant margin. Other major

contributing factors in favour of the Sandouping site were the greater space for access and construction in the wider river valley and the ability to provide surface rather than underground locations for major structures.

This led to a decision in May 1959 to proceed with development of project designs in the Mei Ren Tuo granite region. The two most favoured sites in this region, Taipingxi and Sandouping were then investigated and compared in more detail for an NPL at El 200.

2.2.2 Alternate Sites in the Meirentuo Region – Sandouping and Taipingxi

The Sandouping dam site is located about 40 km upstream from Gezhouba, between Maopingxi and Fenxianggou in the lower section of the Xiling Gorge. The valley at the site is relatively wide, about 2 300 m at El 175. Towards the right bank the river is divided by Zhongbao Island so that the main stream flows to the left side of the island. With the Gezhouba reservoir impounded, the water surface at the site is currently about 1 000 m wide. The river bed is at approximately El 25 and the bedrock averages El 15.

The valley at the Taipingxi site 7 km upstream of Sandouping is narrower than at Sandouping. The valley is approximately 1 400 m wide at El 175 while the river is about 600 m wide. Bedrock exposed in the river bed averages El 10.

Extensive surveys by YVPO have shown that the geological characteristics of the Sandouping and Taipingxi sites are essentially the same. The granitic rocks at each site are of the Huangling anticline that offer strong, essentially impervious foundation conditions for the proposed dam.

These hard igneous rocks have low permeability and compressive strength in the order of 1 000 kg/cm². The distribution and thickness of overburden are also generally the same at each site. Both sites are in a zone of weak earthquakes.

Comparisons of costs of the two sites were made by YVPO for an NPL of El 200. The following common features were assumed:

- Power plant – 25 000 MW, 25 units
- Temporary shiplift and permanent 6–flight twin navigation locks (right bank at Taipingxi, left bank at Sandouping)
- Gated spillway in river channel

The costs of the two sites for the main civil work items were found to be equivalent, as shown in the following tabulation:

Items	Unit	Qty	TAIPINGXI SITE		SANDOUPING SITE		
			Unit Price (Yuan)	Cost (10 ⁶ Yuan)	Qty	Unit Price (Yuan)	Cost (10 ⁶ Yuan)
Excavation	10 ⁶ m ³	81.6	17	1 387	50.5	17	858
Tunnelling	10 ⁶ m ³	0.5	75	37	—	—	—
Concrete	10 ⁶ m ³	25.6	105	2 688	32.1	105	3 370
Reinforcing & Structural Steel	10 ⁶ t	0.58	1 600	928	0.58	1 600	928
TOTAL				<u>5 041</u>			<u>5 156</u>

In this comparison, the total difference of 115 x 10⁶ yuan, representing about 2% of the main civil works cost is considered marginal for a preliminary comparison.

The listed quantities do not include all the structures as only the structures with significant quantity differences have been considered. The total cost of all other components of the project, including resettlement, was found to be similar for both sites.

The Sandouping site was selected because its greater width offered more flexibility for construction and better flow conditions for diversion, navigation and flood discharge.

Although comparisons were not made for the lower DCLs subsequently considered, CYJV agrees that the Sandouping site is superior for the following reasons:

1. lower dam crest elevations will result in greater savings in dam costs at Sandouping where abutment topography is less steep than at Taipingxi;
2. at the Sandouping site, the wider valley will result in a shallower depth of excavation for the diversion channel and allow earlier diversion;
3. Zhongbao Island at Sandouping facilitates river diversion;

4. navigation during construction is unlikely to be possible in the diversion channel at the narrow Taipingxi site since the river velocity would be high, while the diversion channel at the Sandouping site would be wider, permitting its use for navigation during the second stage diversion; and
5. at the Sandouping site the wider valley will provide larger areas near the dam for construction installations and facilities, stockpiling of materials and construction of access roads while at the narrower valley of the Taipingxi site, temporary construction facilities would have to be located as much as 5 km downstream from the site due to lack of suitable terrain.

2.3 Development of Layout

Early studies by YVPO of the Three Gorges Project, were based on NPLs from El 190 to El 200. This was considered to be the appropriate NPL range to maximize flood protection, power generation and navigation benefits. Studies by YVPO since 1958 recognized that these high pool levels would cause problems for the resettlement of people in the reservoir and in Chongqing which could make these levels unacceptable. More recently, investigations have concentrated on lower NPLs and the 1983 Feasibility Report was based on an NPL at El 150.

2.3.1 Feasibility Report Layout

The principal features of the project as presented in the 1983 Feasibility Report are shown in **Table 2.1**.

The spillway was centred in the main river channel with powerhouses on each side. The average annual energy production of the proposed power plant was estimated to be 64.6 TWh with a firm power output of 2940 MW. Power would be transmitted by HVAC or HVDC transmission lines. The number of transmission circuits out of the powerhouse varies between 15 and 17 depending on the scheme envisaged. The unit capacity of the generating equipment was based on a 10 m turbine throat diameter, the limit assumed to be readily manufactured in China.

The proposed permanent navigation facilities were located on the left bank at the end of the dam and consisted of twin three-flight locks. The proposed one-way annual shipping capacity of these facilities was 50×10^6 t. The proposed temporary navigation facilities were located on the left bank 200 m north of the flight locks and consisted of upstream and downstream shiplifts with an interconnecting high level canal. These facilities would have a one-way annual throughput of 4.6×10^6 t.

THREE GORGES PROJECT FEASIBILITY REPORT

TABLE 2.1 - PRINCIPAL PROJECT FEATURES

FEATURE	1983 FEASIBILITY REPORT	1985 PRELIMINARY DESIGN REPORT
NPL/FCL Dam Crest Elevation	150 m/135 m 165 m	150 m/135 m 175 m
Overflow Spillway	- no. of bays x width - sill elevation	22 x 8 m 148 m
Spillway outlets	- no. x width x height - sill elevation	23 x 7 m x 9 m 85 m
Sediment outlets	- no. x width x height - sill elevation	2 x 5 m x 7 m 75 m
Powerplant silt outlets	- no. x width x height - sill elevation	5 x 4 m x 5.5 m 65 m
River Diversion	Channel, right bank	Channel, right bank
Powerhouses	- nominal capacity - maximum capacity - maximum unit capacity	13 000 MW 15 000 MW 577 MW
Flight locks	- no. of units, left bank - no. of units, right bank - turbine throat diameter - location	14 12 9.5 m North of shiplift
Temporary navigation facilities	- no. of flights per lane x width x length - total lift	2 4 x 34 m x 280 m 88 m
Energy output	- location - no. of shiplifts - no. of temporary shiplocks - navigation and diversion channel	At end of left bank dam 1 1 350 m wide 67.6 x 109 kWh
Firm Power	2940 MW	3320 MW

2.3.2 Preliminary Design Report Layout

Following issue of the 1983 Feasibility Report, engineering studies and investigations were continued by YVPO, leading to a number of changes in layout of the proposed Three Gorges Project. The Preliminary Design Report layout is shown in **Plate 4.3**. The principal features of the revised project layout are also shown in **Table 2.1** for comparison with the Feasibility Report layout.

Although the proposed NPL remained at El 150 and the main dam axis was unchanged, the crest elevation of the concrete gravity dam was raised by 10 m to El 175. This increase was made to improve flood control benefits downstream without increasing resettlement requirements in the reservoir area.

Other significant changes in layout related to navigation structures. A 350 m wide diversion channel was made available for navigation during construction, the temporary navigation structures were relocated to the end of the left bank dam and the permanent shiplocks moved further north on the left bank and reoriented to improve navigation conditions at the upstream and downstream approaches. The permanent shiplocks were also increased to a twin four-flight system and design improvements were made to the filling and emptying systems. For temporary navigation, the two shiplifts were replaced by a single shiplift and a parallel temporary shiplock both using a common downstream navigation channel. The single shiplock has significantly more capacity than the shiplifts.

The average annual energy production for the 13 000 MW nominal installation was re-estimated as 67.6 TWh, with a firm power output of 3 320 MW. The turbine diameter was reduced to 9.5 m, and a combination of HVAC and HVDC lines were selected for power transmission to central China and eastern Sichuan.

Other minor changes were made in the general arrangement of structures, as indicated in **Table 2.1**. These changes were justified on the basis of design studies, hydraulic model studies and site investigations. The resulting layout is considered to be sound.

2.3.3 Selection of Basic Layout

Prior to the issue of the 1983 Feasibility Report, several types of concrete dam – gravity, hollow gravity, buttress and arch gravity, as well as embankment dam alternatives were investigated. With the dam crest at El 175, it was found that a concrete gravity dam was the least costly alternative and the simplest to construct as an intake for the powerhouses. Also the concrete gravity dam was found to be the most economical to accommodate the necessary overflow and submerged spillway bays as well as the diversion outlets and sediment discharge facilities.

Over the years, several alternative layouts have been studied and compared by YVPO including an arrangement with the spillway on the right bank and a 26-unit powerhouse at the left of the longitudinal cofferdam. The project construction quantities were estimated to be approximately the same for the alternative spillway locations as shown in the following tabulation:

**COMPARISON OF THE MAIN CIVIL WORKS
FOR TWO SPILLWAY ALTERNATIVES**

<u>Item</u>	<u>River Main Units</u>	<u>Channel</u>	<u>Right Bank</u>
Excavation	$m^3 \times 10^6$	72.75	71.08
Tunnelling	$m^3 \times 10^6$	1.07	1.07
Embankment	$m^3 \times 10^6$	25.61	25.88
Concrete	$m^3 \times 10^6$	20.63	20.15
Reinforcing Steel	t x 10	243.9	236.9
Structural Steel	t x 10 ⁶	221.0	230.0

The main features of the YVPO preliminary design layout are as follows:

1. a spillway 483 m long located in the main river channel, with 22 overflow bays with sills at El 148 and 23 submerged bays with sills at El 85;
2. powerhouses on each side of the spillway, one 575 m long on the right bank with 12-500 MW units, and the other 634 m long on the left bank with 14-500 MW units;
3. navigation structures on the left bank adjacent to the dam, with a temporary lock, a shiplift and twin four-flight permanent locks; and
4. a longitudinal concrete cofferdam on Zhongbao Island to facilitate diversion and permit construction in two subsequent stages.

CYJV agrees that the proposed general layout with a central spillway and navigation facilities on the left bank is the optimum scheme for the following reasons:

1. Navigation during construction

The central spillway enables the diversion channel to be used for navigation during the second stage of construction except during high flows. This would not be possible if the spillway were located on the right bank during the first stage diversion. On the other hand, if

the spillway were to be built on the right bank during the third stage diversion, the river would have to be diverted through powerhouse temporary outlets. Either alternative would be more costly and would make navigation during construction more difficult.

2. Energy dissipation

A spillway in the main river channel would provide better energy dissipation because of deeper water and the tendency of the flow to follow the main channel.

3. Downstream bank erosion

Model tests have shown that a spillway on the right bank would cause erosion downstream on the right bank.

4. Sediment flushing

The central spillway location would be more effective in silt flushing than a spillway built on either bank.

5. Excavation and construction facilities

A spillway constructed on either bank would require more excavation in the downstream channel for temporary and permanent low level outlets to enable the discharge to flow back into the main channel. Furthermore certain construction facilities would have to be located further downstream from the dam.

6. Construction schedule

Based on the YVPO schedule, the construction period with a right bank spillway would be 1.5 years longer than with the spillway in the centre of the dam. This would increase costs and delay revenue production.

7. Access to powerhouse

The selected layout would have the advantage of providing access to the powerhouses from each bank, facilitating the installation of the mechanical and electrical equipment.

8. Crossing of spillway by transmission lines

With the spillway located between the power plants, transmission lines would not cross the spillway, which is generally considered undesirable and to be avoided where possible.

9. Navigation lock approach conditions

The location of the navigation locks on the left bank, the inside of the bend in the river, is better as it would provide better channel alignment and approach conditions. Locks located in the main river channel or on the right bank would have more difficult curved approach conditions.

10. Powerhouse sizes

The number of units on each side of the spillway is determined mainly by the location of Zhongbao Island and the excavation involved on each bank. A 14 unit powerhouse on the left bank and 12 unit powerhouse on the right bank are satisfactory.

