No. 8

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)
FEDERAL COMMISSION OF ELECTRICITY
THE UNITED MEXICAN STATES

FEASIBILITY STUDY ON REHABILITATION OF MAZATEPEC HYDROELECTRIC POWER STATION

FINAL REPORT

EXECUTIVE SUMMARY

NOVEMBER 1993

NIPPON KOEI CO., LTD.
TOKYO, JAPAN

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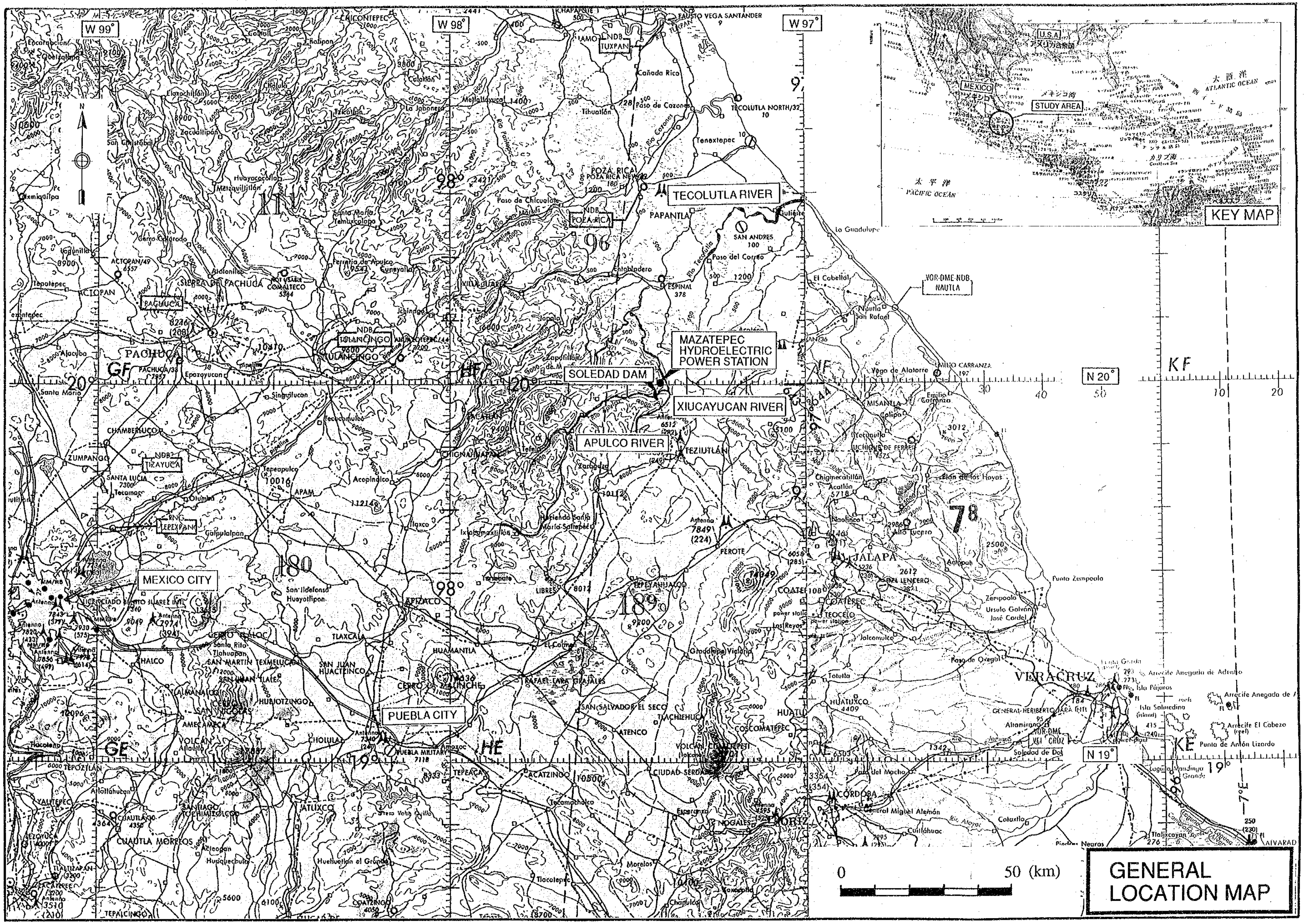

KEY MAP
U.S.A
MEXICO
STUDY AREA
ATLANTIC OCEAN
PACIFIC OCEAN
TECOLUTLA RIVER
MAZATEPEC
HYDROELECTRIC
POWER STATION
SOLEDAD DAM
XIUCAYUCAN RIVER
APULCO RIVER
MEXICO CITY
PUEBLA CITY
PACHUCA
TULANCINGO
TEZIUTLAN
JALAPA
VERACRUZ
POZA RICA
PAPANTLA
CORDOBA
W 99°
W 98°
W 97°
N 20°
N 19°
0
50 (km)
GENERAL
LOCATION MAP

Table of Contents

LIST OF TABLES

LIST OF FIGURES

SUMMARY

1. Mazatepec Hydroelectric Power Project :

The Mazatepec Hydroelectric Power Project is located on the Apulco River about 170 km northeast of Mexico City. The Project has supplied electric energy to the national and regional power systems for 30 years since it was commissioned in 1962. The Project has four units of 54.86 MW turbine-generator each (220 MW in total) and has produced 500 to 800 GWh of energy annually (621 GWh on average for 28 years). The Project includes a reservoir called Soledad created by a 92 m high arch dam, spillway, power intake and low level outlet, power tunnel, surge shaft, penstock, power house and outdoor switch yard. The Project is expected to continuously play a key role as a hydro power plant in the power system not only for energy production but also for voltage control. [Figure 1, 2 and 3]

2. Sediment Volume in the Soleded Reservoir :

Since Soledad Reservoir commenced operation after impounding, it has lost its storage capacity by sedimentation. The gross storage volume originally designed was 58.8×10^6 m^3 below EL. 804.5 m. The total deposits in the reservoir below El. 804.5 m were surveyed at 40.3×10^6 m^3 in 1992, which is equivalent to an annual mean deposit of about 1.3×10^6 m^3 on average for the past 30 years. This sedimentation progress is rather high, since it is usually recommended that storage dam schemes be designed to afford sediment inflow for 100 years.

Assuming an trap efficiency of 65 % based on the inflow-capacity relationship, the total annual sediment inflow into the reservoir is estimated at 2.0×10^6 m^3. This rate is equivalent to 1.4 mm in terms of annual sheet erosion rate over the catchment area. [Table 1]

The sedimentation survey conducted by CFE reveals that the sedimentation occurred at a higher rate for the initial 15 years for 1962 to 1977, and this rate decreased significantly during the period from 1977 to 1990 and again increased for the recent two years. The low rate of deposition is too low to be attributable to the either effects of check dams built in the upper catchment and/or relatively low rainfall during the period. It appears that the 1977 sedimentation survey might not give an accurate value. [Figure 4]

3. Sedimentation Profile and Particle Size in the Soledad Reservoir :

Sedimentation in the reservoir has progressed vertically and horizontally. It is observed from the sediment survey data that the foreset (front of deposition) of sedimentation is approaching to the dam and power intake area. At present, the top layer of deposits near the dam is at around El. 775 m, about 55 m higher than the original river bed, while within a distance of 40 m upstream of the power intake it drops to El. 769 m, almost equal of the intake sill. [Figure 5 and 6]

The low level outlet installed on the arch dam at El. 750 m has been buried under the deposits and is not operational. This outlet was presumably been affected by sedimentation between 1970 and 1977. [Figure 5 and 6]

At present the top layer of reservoir deposits near the power intake mostly consist of fine particles of less than 0.062 mm in size with little quantity of fine sand. However, the movement of the foreset will eventually bring coarser materials towards the power intake, which may accelerate wear of the turbine runners as well as needles and seats of the needle valves.

4. Adverse Effects by Reservoir Sedimentation :

Reservoir sedimentation occurs as a result of change in hydraulic characteristics of river flow when storage dam is built across the river. The reservoir sedimentation usually results in adverse effects such as:

- loss of reservoir storage capacity for flow regulation, leading to decrease or shutdown of energy production
- increase of flood water levels upstream of the reservoir headwater due to coarse deposits
- clogging by sediment in various waterways
- scouring/erosion in downstream sections due to lack of sediment supply from upstream
- over-loading to structures by earth pressure of accumulated sediment
- erosion of hydraulic equipment by sand abbraision effect

5. Source of Sediment Yield :

Dominant factors which affect reservoir sedimentation are :

- Area of catchment
- Basin geology and soil condition
- Topographic conditions
- Vegetation cover
- Rainfall characteristics
- Hydraulic characteristics of river channel
- Various human activities in the catchment such as deforestation, cultivation, road construction, etc.

Soledad Reservoir has a total catchment of 1,860 km^2 consisting of three basins, the Apulco, the Sontalaco and the Xiucayucan basins. Water in the Xiucayucan basin is diverted into the reservoir through a diversion dam and tunnel. The basin characteristics of the Apulco River differ greatly in the upper and lower basins in terms of rainfall intensity and land use pattern. The lower basin of approximately 400 km^2 near the reservoir area is well forested and the annual rainfall reaches to 3,000 mm. On the other hand, the upper basin is poor in vegetation due to extensive human activities and the rainfall is quite low being about 600 mm in the vicinity of Zautla. The upper land is generally susceptible to erosion by water and is judged as a major source of sediment supply into the reservoir. [Figure 7]

6. Countermeasures Taken by CFE :

CFE made great efforts for soil conservation by means of terracing, drain ditches, rock walls, reforestation and construction of check dams on the above sediment production area. [Figure 8]

The CFE's efforts are :

- Terracing on 43,1000 m in length on 100 ha of land
- Rockwall of 5,019 in number
- Drain ditch of 255,000 m in length affecting 640 ha of land
- Reforestation of 450,000 trees on 625 ha of land
- Check dam of 25 in number [Figure 8]

The above soil conservation measures were provided on the relatively small areas. The check dams were built on the tributaries of the basin. Several of those located downstream of Zautla are still serving their intended function. Upstream of Zautla, most of the storage capacity of the dams has been filled with sediment, some in as long as five years or shorter. Although not proven conclusively that the 25 check dams helped in reducing the sedimentation process in Soledad Reservoir, the concept is workable. Probably, the check dams were of small sizes relative to the contributing areas and the low trap efficiencies of the dams might not have proved these to be effective. However, the dams did retain coarser particles which would cause damages for the turbines and also settle in the reservoir.

7. Sensitivity of Storage Capacity to Energy Production :

Storage dam schemes intends to regulate river runoff which varies with season. Soledad Reservoir has lost its storage volume progressively but with a higher rate than initially expected. A long-term trend of energy production of Mazatepec Power Station was reviewed on the double mass curve for annual energy output and reservoir inflow. However, the curve does not indicate any significant decrease in energy output due to decrease of storage volume.

In order to analyze the flow regulating function of Soledad Reservoir, a simulation was made on sensitivities of storage capacity to energy production. For the simulation, a daily runoff series for 29 years from 1963 to 1991 was used and several optional storage capacities and reservoir operating levels were examined. The results of the simulation are as follows.

FSL/MOL (El. m)	Effective storage ($x10^6$ m^3)	Energy production (GWh/yr)
804.5/797.5	10.2	629.2
804.5/797.5	11.3	630.0
804.5/797.5	13.3	631.2
804.5/775	18.4	612.8
804.5/775	22.3	614.8
804.5/775	41.6	620.8

As seen above, the storage capacity apparently does not give any significant influence to the annual energy production. It is noted that the energy output is rather sensitive to

reservoir operating level than storage volume. These results indicate that the effective storage capacity which was initially set at 30 x 10^6 m^3 is too small against the total annual mean inflow of 573 x 10^6 m^3, or 18.19 m^3/s, if the Project was intended to regulate the seasonal fluctuation of river runoff throughout the year.

Also, the maximum plant discharge is rated at 55.2 m^3/s. The river runoff which exceeds this plant discharge occurs about 3 percent of time as indicated on the daily flow duration curve. This means that the power plant could almost utilize potential volume of river water to its maximum extent without any storage function if properly operated. [Figure 9]

8. Available Water for Sediment Flushing :

Alternative measures to flush the sediment loads by water are considered. One is a method to sluice the reservoir deposits/sediments inflow out of the reservoir through spillway or outlet. The other is to intercept the sediment carrying flows before they arrive at the reservoir and to bypass them into another basin. The required amount of water would depends on sediment volume, grain-size distribution, weight and shape of sediment particles, sediment concentration, hydraulic conditions, etc. It is usual that the flushing operation is limited during wet season or flood season when excess water is available and sediment concentration rate is high.

Available water for the flushing operation was examined through a simulation process. However, it was determined that no significant amount of excess water would be available since the maximum plant discharge is rated at 55.2 m^3/s, which is rather high as seen in the flow duration curve. The reservoir inflow which exceeds 55.2 m^3/s occurs only 3 % of time and the total volume of water above 55.2 m^3/s equals about 8 % of the total runoff yield. This means that any flushing operation should be made with a trade-off for loss of energy production.

The results of the simulation are as follows.

Flushing operation at reservoir

Target flow to start sediment sluicing (m^3/s)	Available water for flushing ($x\ 10^6 m^3/yr$)	Energy production (GWh/yr)
30	90.6	560.8
40	65.4	588.9
50	50.5	604.9
* w/o flushing	-	629.2

Sediment diversion from upstream section

Target flow to start sediment diversion (m^3/s)	Available water for flushing ($x\ 10^6 m^3/yr$)	Energy production (GWh/yr)
30	20.4	625.8
40	15.1	627.9
50	11.8	628.7
* w/o flushing	-	629.2

9. Measurement of Sediment Load :

Sediment loads have been measured at three locations by CFE using a point sediment sampler capable of sampling probably one to two meters from water surface depending upon the depth and velocity in the river. Use of a depth-integrated sediment sampler is recommended to obtain more accurate data for suspended solids and a reasonable estimate of the total sediment inflow into the reservoir.

The annual sediment load recorded by CFE is as follows.

Location	Sediment load (m^3/yr)	Catchment area (km^2)	Erosion depth (mm/yr)
Apulco river at Buenos Aires	450,000	1,405	0.320
Sontalaco river at Sontalaco	3,130	25	0.125
Canal No. 1	31,600	370	0.085

From the above, it is clear that the major part of sediment load comes from the Apulco basin, in particular, from its upper basin where vegetation cover is poor. Approximately 90 % of the total sediment load comes from the upper Apulco basin.

However, the above values obtained are judged too low compared with the values derived from the reservoir sedimentation survey. Probably this might have been caused by use of improper instrument, analysis and calculation, absence of measurement in flood season, etc. [Table 1]

10. Prediction of Reservoir Sedimentation :

The future sedimentation conditions were predicted by using the simulation method based on the following basic assumptions.

- Sediment deposit rate will be about 1.4 x 10^6 m^3 per year based on the incremental deposit rate estimated from the sedimentation surveys of 1990 and 1992.

- Sediment inflows will be represented by a discharge-sediment transport relationships based on 1988-89 sampling and improved if necessary.

- Particle size distributions of suspended sediment and bed material were used with proper modification to the available data which are not adequate.

For the simulation, the Empirical Area-Reduction Method and the HEC-6 Model were used. By the Area-Reduction Method, it was estimated that in around year 2000, the reservoir will be practically filled. The sediment level near the dam will be about El. 796 m compared to the El. 775 m in 1992. This level is judged to be on the high side. The

HEC-6 Model, which is developed as a one-dimensional continuous simulation model, predicted that the foreset would move towards the intake by about 900 meters in about 8 years and the sediment level near the non-overflow section of arch dam would be about El. 788.5 m.

The two approaches provide a reasonable indication of the reservoir bed level around the year 2000. A level of El. 796 m established by the Empirical Area-Reduction Method may be on the high side because of simplified assumptions in the method. The HEC-6 prediction of El. 788.5 m may on the low side because the model dose not consider the storage effect. A mean elevation, about El. 792 m, averaged on the predictions made by two methods is judged to be reasonable at about 100 meters upstream from the dam. It is noted that sedimentation level at the spillway will not exceed the crest elevation of El. 789.5 m and that at the power intake will be lower because of flow through the intake. [Figures 6 and 10]

11. Necessity of Countermeasures against Sedimentation :

The simulation study indicates that in about 8 years the reservoir will be practically filled with sediment unless any measure is provided. It should be realized that the predicted level is indicative of the average sediment inflow conditions for the reservoir and should not be interpreted in absolute terms. It is, therefore, quite important to take appropriate measures immediately against the progressive sedimentation.

12. Alternative Countermeasures :

Several alternative countermeasures were identified as follows, which would be proposed independently or in combination, if judged feasible.

(I) Rehabilitation of Low level Outlet:

1) Alternative A :	Rehabilitation of existing low level outlet in arch dam
2) Alternative B :	Construction of new low level outlet at a higher elevation through arch dam
3) Alternative C :	Conversion of the existing power intake into a low level outlet

(II) Construction of New Power Intake

1) Alternative D : Construction of new power intake adjacent to the existing power intake

2) Alternative E : Construction of new power intake just upstream of existing power intake

3) Alternative F : Construction of new power intake just upstream of existing power intake

(III) Construction of New Facilities

1) Alternative G : Construction of new settling basin

2) Alternative H : Channel improvements upstream of spillway

3) Alternative I : Construction of new large check dam

4) Alternative J : Construction of sediment diversion tunnel

(IV) Removal of Reservoir Sediment Deposit

1) Alternative K : Removal of deposits by pump dredger and transport to spoil area

(V) Alternatives Identified by CFE

1) Alternative L : Replace existing outlet in arch dam with larger sized low level outlet (with option of installing a new generating unit to utilize discharges)

2) Alternative M : Construct new low level outlet directly below the arch dam abutment foundation with new intake between arch dam and existing power intake

3) Alternative N : Construct a new low level outlet through the arch dam below the existing outlet with installing a new generating unit

4) Alternative O : Construct a new dam downstream of the existing arch dam to create a pool between the dams which would be supplied by water from existing Tunnel No. 1 by construction of a new water conveyance facility. Construct a new power intake in the new pool - use the existing reservoir to collect sediment.

(VI) Erosion-Reducing Operation for Turbines

1) Alternative P : Limitation of partial load operation and use of less jet nozzles
2) Alternative Q : Use of Digipid governor

All of the alternatives were reviewed and a screening was made to select the more favorable alternatives. The screening was based on technical considerations, constructability, effectiveness, and judgement regarding excessively high construction cost in relation to all of the alternative plan elements being considered in this study.

The basic concept for the rehabilitation plan is to prevent sediment load entering into the reservoir by building a large check dam on the main Apluco River, to sluice the reservoir deposits through a new low level outlet to be converted from the existing intake and to install a new power intake leading to the existing power tunnel just downstream the new low level outlet. [Figure 11]

In addition to the above structural measures, erosion reducing operation to hydraulic turbines and dredging are also recommended.

As the result, the following alternatives are recommended with priority.

(1) Alternative C + F : (construction of new power intake and conversion of existing power intake into low level outlet) [Figure 12, 13, 14, 15 and 16]
(2) Alternative I : (construction of check dams) [Figure 17, 18, 19 and 20]
(3) Alternative K : (pump dredging)
(4) Alternative P + Q : (erosion-reducing operation)

It is recommended to resume the dredging operation for the following reasons.

- to remove the increasing sediment deposits before and during the construction of check dam and low level outlet.
- to remove the deposits in the vicinity of the arch dam which could not be sluiced through the low level outlet and spillway.
- to remove the deposits near the power intake in couple with the operation of the low level outlet.

Under the above rehabilitation plan, the sediment inflow into Soledad Reservoir is expected to decrease from 2.0 x 10^6 m^3 to 0.83 x 10^6 m^3 by the effect of the check dam. Out of the inflow, 0.29 x 10^6 will be discharged through the power intake and the remaining of 0.54 x 10^6 m^3 is planned to be sluiced mainly from the low level outlet and partly from the spillway or by dredging. [Figure 11]

13. Cost Estimate :

The cost estimate of the proposed rehabilitation plan was made based on the preliminary design of a packaged structural measures. The result of the estimate, including direct construction cost, contingency and engineering and administration costs is given as follows.

Alternative C + F	:	N. Peso 35.2 x 10^6	
Alternative I	:	N. Peso 47.0 x 10^6	
Sub total		N. Peso 82.2 x 10^6	(US$ 27.4 x 10^6 equivalent)
Alternative K (in case new dredger is procured.)	:	N. Peso 30.0 x 10^6	(US$ 10.0 x 10^6 equivalent)
Alternative P + Q	:	N. Peso 1.2 x 10^6	(US$ 0.4 x 10^6 equivalent)
Total (incld. Alt. K)		N. Peso 113.4 x 10^6	(US$ 37.8 x 10^6 equivalent)
Total (excld. Alt. K)		N. Peso 83.4 x 10^6	(US$ 27.8 x 10^6 equivalent)

The cost for dredging is presented for reference, assuming that a new large-scale dredger is introduced instead of the existing dredging system. Further, the field investigation cost required for topographc, geological, and construction material surveys and the cost for stability analysis of the existing arch dam against the increasing sedimentation level are estimated as follows

Field investigation	:	N.Peso 795,000 (US$ 0.265 x 10^6)
Re-analysis	:	N.Peso 600,000 (US$ 0.20 x 10^6)

14. Implementation Program:

Immediately after the financial arrangement is decided, the re-analysis of the arch dam should be made by a qualified professional consultant. The re-analysis will include

assessment of deformation and stress in the arch dam and foundation in due consideration of seismic load and thermal load at present and in future against the predicted sedimentation level.

Concurrently with this re-analysis, the field investigation program including topography, geology and construction materials should be executed by the CFE's own force or by contract. After the design (or tender design) is refined and consolidated based on the information and data thus obtained, the construction work will start, selecting a qualified constructor(s) by competitive bidding. [Figure 21, 22 and 23]

The construction of the new power intake and low level outlet will be performed concurrently to curtail the construction time, while they can be also built in stage. The check dam will be built with multiple stage river diversion system. It is recommended to build this dam by RCC (roller compacted concrete) from the technical and economical viewpoints The overall construction period is expected to last for 2 years. [Figure 23]

15. Economic Evaluation :

For evaluating the economic viability of the rehabilitation plan, the alternative cost for a coal-fired thermal plant is considered as a benefit. The economic internal rate of return (EIRR) is computed at 18.3 % under an assumption that the rehabilitation plan only contributes to fuel saving in coal-fired plant and 177 % in case that the rehabilitation plan is equivalent to installation of a new coal-fired plant which intends to recover the power and energy to be lost in the Mazatepec Power Station without rehabilitation plan. (Tables 2 and 3).

The above evaluation does not include the cost for dredging. If a new dredger is introduced instead of the existing one, the EIRR is 10.9% in terms of fuel saving and 137% in terms of replacement cost. If the existing dredger can be successfully repaired for normal operation with a quarter (25%) of the cost required for procuring a new dredger, the EIRR is 16.2% and 165% respectively. These economic indicators proves that the proposed rehabilitation plan is fully viable economically. The result of the economic evaluation are summarized below.

Items	Without dredging	With repair of existing dredger *1	With procurement of new dredger
1. Additional investment	-	US$ 2.5 x 10^6	US$ 10.0 x 10^6
2. Additional annual O & M cost	-	US$ 0.5 x 10^6	US$ 2.0 x 10^6
3. Total initial investment cost	US$ 28.25 x 10^6	US$ 30.75 x 10^6	US$ 38.25 x 10^6
4. EIRR by fuel saving	18.3%	16.2%	10.9%
5. EIRR by replacement cost	177%	165%	137%

Note: *1 Assuming 25% of the purchase cost of a new dredger for the cost required for repairing the existing dredger.

16. Financial Evaluation:

The financial feasibility of the rehabilitation plan was evaluated for its financial internal rate of return (FIRR) and repayability of loan, though no condition and term have been decided on the financing and executing system of construction.

Here, it is assumed that the rehabilitation plan includes the dredging operation by repairing the existing dredger. The revenue was estimated by multiplying the current power tariff to the salable energy which is derived by deducting the energies for station use and sediment sluicing and loss in the transmission/distribution system from generated energy. Thus, the annual revenue from the Mazatepec Power Station is computed at US$ 25.15 x 10^6 as follows.

$$621 \times 10^6 \text{ kWh} \times (1 - 0.1) \times (1 - 0.1) \times \text{US\$ } 0.050/\text{kWh} = \text{US\$ } 25.15 \times 10^6$$

where,

Average annual energy production	:	621 x 10^6 kWh
Average tariff	:	N. P 0.150/kWh (US$ 0.050/kWh)
Energy for station use and other losses	:	10%
Energy loss by sediment sluicing	:	10%

The above total revenue should be duly allocated to recover the cost accruing not only from generating side but also from transmission/distribution side. However, it is difficult to know a proper share of the generating side. Then, it is assumed that a half of the

revenue be allocated to the generating side. Under this assumption, the FIRR is computed at 14.05% as shown in Table 4, which is deemed fully acceptable.

The financial aspect was also examined in terms of repayment capability of loan for the initial investment cost. The loan conditions are provisionally assumed as follows.

- Interest rate : 5% per anum
- Repayment period : 15 years including 5-year grace period

It is also assumed that the principal be repaid uniformly over the 10 years after the grace period and the interest be paid after the investment starts. As shown in the cash flow in Table 5, the rehabilitation plan is financially sound since the accumulated balance would become positive in 7 years after the investment starts.

17. Environmental Aspects of Rehabilitation Plan :

The region downstream from the dam and powerhouse is a major rainfed agricultural area, and only limited use of the water resources of the river were noted. Fishing activities are restricted to the 20-km estuarine zone and adjacent waters of the Gulf of Mexico.

The predominant resource utilization in and adjacent to the river system downstream from the Project is the extraction of sand and gravel. On the basis of the aerial and ground level observations of the lower basin conducted in the study it is concluded that proposed rehabilitation plan would not significantly affect conditions or resource utilization of the river course downstream of the Mazatepec Project.

However, construction of the proposed check dam will influence a local gravel road along the Apulco River, though no inundation to residential area would occur. Relocation of this road is necessary when the check dam is built.

18. Recommendation to Watershed Management :

If future watershed management activities are contemplated in the Apulco basin upstream of Soledad Reservoir, such activities should be implemented cooperatively with the appropriate agencies of the State of Puebla for maintenance and improvements in the environmental conditions in the basin. Likewise, such activities should include a strong program of community and individual involvement by the inhabitants of the basin. This should be included in order to identify and implement cost effective means of watershed

management that would benefit both the local inhabitants and the Project. Local involvement would be critical for the long term viability of any watershed management programs that might be implemented.

19. Conclusions and Recommendations:

Conclusions

The Mazatepec Hydroelectric Power Station should continue power and energy production as having done for the past 30 years since it was commissioned in 1962. However, it is feared that the station could not operate properly due to the increasing reservoir sedimentation. The total annual sediment inflow is approximately 2.0 x 10^6 m^3, of which about 1.3 x 10^6 m^3 has been deposited and the rest has been transported mainly through the turbines. Sand abrasion effect to the hydro-mechanical equipment will become more serious than in the past because of encroachment of coarser particles of the sediment load to the intake. A simulation analysis indicates that the reservoir would be filled up to a level of El. 792 m by sediment in and around the year 2000.

For the above situation, alternative studies were made including field investigations for seeking for an appropriate countermeasure against the reservoir sedimentation. Out of the alternatives identified, the following package of countermeasures are selected from technical and economical viewpoints for limiting further rise of the sedimentation level.

- Construction of new power intake and conversion of existing intake into low level outlet
- Construction of large check dam on the main Apulco River
- Repair of the present dredging system (or introduction of a new dredger)
- Introduction of erosion-reducing method for turbines

The proposed structural measures are justified technically and economically.

From the environmental viewpoint, the discharge of sediment from the reservoir through the low level outlet or by dredging would not have significant adverse effect to the riparian conditions in the downstream reaches. Regarding the sediment storage facility proposed on the main stem of the Rio Apulco in the vicinity of Huahuaxtla, land in the proposed reservoir area includes second growth forest and some subsistence agriculture for corn and beans, but it is not anticipated that the reservoir would inundate any residential area or structures. However, a gravel surface road along the Apulco River through the dam and reservoir area will be submerged, which is the only access to and

from the town of Atzalan, and thus a new access to this community would have to be provided as part of the rehabilitation project.

Recommendations

The following recommendations are made to maintain the present function and role of the Mazatepec Power Station and to prolong the useful life of the Project.

(1) Reservoir sedimentation survey should be continued with care periodically. It is essential to fix the range lines for all surveys to make comparison of the results. It is essential to set the survey posts at each end of the range lines and to measure the distance between the posts in advance.

(2) It is noted that the present method employed for measuring suspended solids at the three gagging stations does not offer a proper value of total sediment yield into the reservoir. Use of a depth-integrated sampler is recommended instead of the present sampling method.

(3) CFE is recommended to make clarification of the design conditions and criteria employed in the original design, especially for the allowable earth pressure acting on the dam. It the data is not available, it is advised to consult with the engineering consultant who participated in the original design. Further, reanalysis of stability of the dam should be made by specialist at the earliest time.

(4) CFE is recommended to consult with the manufacturer of the turbines for possible introduction of Digipit governors aiming at erosion-reducing operation.

(5) CFE is recommended to take necessary actions immediately for the implementation of the proposed rehabilitation works, including the repair of the existing dredging system. The financing plan and method and the executing system (conventional design and construction by contracts or turn-key, etc.), should be decided at the earliest time.

(6) Sluicing of the reservoir deposits should be made during the high flow months when the sediment concentration rate is rather high. It is also advised to lower the reservoir level when the sluicing is made, though this operation leads to a loss of energy.

(7) For controlling the trubidity of water in sluicing and dredging the sediment load from the reservoir, an appropriate monitoring and communication system should be established between the Project and the downstream points in collaboration with the CFE's Hydrology Division.

(8) Operation and maintenance of the project facilities are well performed in accordance with the existing guidelines and manuals. These efforts should be continued in future. The following are some recommendations for operation and maintenance.

- Provision of safety fence along the outlet canal of Tunnel No. 1.
- Measurement of thickness of steel penstock when water is drained.
- Provision of bund walls at tank for transformer oil.

TABLES

TABLE 1 ESTIMATE OF SEDIMENT LOAD

Method	Annual mean sediment load (cu.m/yr)	Catchment area (km^2)	Sediment yield rate (mm/yr)	Erosion rate (mm/yr)
(1) Survey of reservoir deposits (30 yrs from 1962 to 1992)	1,345,000	1,460	0.921	1.417 1)
(2) Survey of reservoir deposits (15 yrs from 1962 to 1977)	1,995,000	1,460	1.366	2.102 1)
(3) Survey of reservoir deposits (13 yrs from 1977 to 1990)	589,000	1,460	0.403	0.621 1)
(4) Survey of reservoir deposits (2 yrs from 1990 to 1992)	1,386,500	1,460	0.950	1.461 1)
(5) Survey of deposits at 25 check dams	70 ~ 35,500 (Total 184,000)	0.09 ~ 168.8 (Total 450.6)	0.08 ~ 8.33 (aver. 0.98)	0.41 ~ 10.2 (aver. 1.52) 2)
(6) Measured suspended solid at Buenos Aires (1965-90)	450,000	1,405	0.320	–
(7) Measured suspended solid at Sontalaco (1965-90)	3,130	25	0.125	–
(8) Measured suspended solid at Canal No. 1 (1977-90)	31,600	370	0.085	–

Remarks:
1) Erosion rate assuming the trap efficiency be 0.65.
2) Erosion rate assuming the trap efficiency be 0.35 to 0.82 depending on capacity-inflow ratio at each site.

TABLE 2 — CASH FLOW FOR ECONOMIC ANALYSIS BY FUEL COST SAVING IN COAL-FIRED THERMAL PLANT

(Unit : million US$)

	Year	Cost: Capital Cost	Cost: O&M Cost	Cost: Total Cost	Benefit: Capital Cost	Benefit: O&M Cost	Benefit: Fuel Cost	Benefit: Total Cost	Net Benefit (B-C)
1	1995	9.42		9.42					-9.42
2	1996	9.42		9.42					-9.42
3	1997	9.42	2.40	11.82					-11.82
4	1998		2.55	2.55					-2.55
5	1999		2.55	2.55					-2.55
6	2000		2.55	2.55		1.13	12.98	14.11	11.56
7	2001		2.55	2.55		1.13	12.98	14.11	11.56
8	2002		2.55	2.55		1.13	12.98	14.11	11.56
9	2003		2.55	2.55		1.13	12.98	14.11	11.56
10	2004		2.55	2.55		1.13	12.98	14.11	11.56
11	2005		2.55	2.55		1.13	12.98	14.11	11.56
12	2006		2.55	2.55		1.13	12.98	14.11	11.56
13	2007		2.55	2.55		1.13	12.98	14.11	11.56
14	2008		2.55	2.55		1.13	12.98	14.11	11.56
15	2009		2.55	2.55		1.13	12.98	14.11	11.56
16	2010		2.55	2.55		1.13	12.98	14.11	11.56
17	2011		2.55	2.55		1.13	12.98	14.11	11.56
18	2012		2.55	2.55		1.13	12.98	14.11	11.56

EIRR = 18.27%

Notes :
(1) Total construction cost is US$ 28.25 x 10^6.
(2) During the construction, power stop is inevitable due to plug concrete in the power tunnel. Loss of energy is valued at US$ 2.40 x 10^6.
(3) O&M cost for hydropower is assumed at 2% of capital cost plus existing cost of US$ 2.0 x 10^6.
(4) O&M cost for coal-fired thermal plant is assumed at US$ 0.00176 / kWh x 1.15.
(5) Fuel cost is assumed at US$ 0.0202 / kWh x 1.15.
(6) Energy output is assumed at 90% of the past average output of 621GWh due to use of water for sluicing sediment load.

TABLE 3 — CASH FLOW FOR ECONOMIC ANALYSIS BY INSTALLATION AND OPERATION OF NEW COAL-FIRED THERMAL PLANT

(Unit : million US$)

	Year	Cost: Capital Cost	Cost: O&M Cost	Cost: Total Cost	Benefit: Capital Cost	Benefit: O&M Cost	Benefit: Fuel Cost	Benefit: Total Cost	Net Benefit (B-C)
1	1995	9.42		9.42					-9.42
2	1996	9.42		9.42					-9.42
3	1997	9.42	2.40	11.82	74.33			74.33	62.51
4	1998		2.55	2.55	74.33			74.33	71.78
5	1999		2.55	2.55	74.33			74.33	71.78
6	2000		2.55	2.55		1.13	12.98	14.11	11.56
7	2001		2.55	2.55		1.13	12.98	14.11	11.56
8	2002		2.55	2.55		1.13	12.98	14.11	11.56
9	2003		2.55	2.55		1.13	12.98	14.11	11.56
10	2004		2.55	2.55		1.13	12.98	14.11	11.56
11	2005		2.55	2.55		1.13	12.98	14.11	11.56
12	2006		2.55	2.55		1.13	12.98	14.11	11.56
13	2007		2.55	2.55		1.13	12.98	14.11	11.56
14	2008		2.55	2.55		1.13	12.98	14.11	11.56
15	2009		2.55	2.55		1.13	12.98	14.11	11.56
16	2010		2.55	2.55		1.13	12.98	14.11	11.56
17	2011		2.55	2.55		1.13	12.98	14.11	11.56
18	2012		2.55	2.55		1.13	12.98	14.11	11.56

EIRR = 177.33%

Notes :
(1) Peak capacity for 5 hours with 90% dependable flow :
220,000 x [7.57 x (24 / 5) / 55.2] = 144,800 kW
220,000 kW : installed capacity
7.57 m3/s : 90% dependable flow
55.2 m3/s : max. plant discharge
(2) Unit construction cost of coal-fired thermal plant is US$ 1,339 / kW in 1991.
(3) Capital cost of new thermal plant is:
144,800 kW x US$ 1,339 / kW x 1.15 = US$ 222,970

TABLE 4 CASH FLOW FOR FINANCIAL RATE OF RETURN

(Unit : million US$)

	Year	Cost: Capital Cost	Cost: O&M Cost	Cost: Total Cost	Revenue	Balance
1	1995	10.25		10.25		-10.25
2	1996	10.25		10.25		-10.25
3	1997	10.25	2.40	12.65		-12.65
4	1998		3.05	3.05		-3.05
5	1999		3.05	3.05		-3.05
6	2000		3.05	3.05	12.58	9.53
7	2001		3.05	3.05	12.58	9.53
8	2002		3.05	3.05	12.58	9.53
9	2003		3.05	3.05	12.58	9.53
10	2004		3.05	3.05	12.58	9.53
11	2005		3.05	3.05	12.58	9.53
12	2006		3.05	3.05	12.58	9.53
13	2007		3.05	3.05	12.58	9.53
14	2008		3.05	3.05	12.58	9.53
15	2009		3.05	3.05	12.58	9.53
16	2010		3.05	3.05	12.58	9.53
17	2011		3.05	3.05	12.58	9.53
18	2012		3.05	3.05	12.58	9.53

IRR = 14.05%

Notes : (1) Assuming that the existing dredger be repaired at US$ 2.5 million.
(2) Revenue is assumed as follows.

Total energy generated	:	621 x 10^6 kWh
Loss by flushing	:	10 %
Loss by station use and by transmission	:	10 %
Revenue attributable to generating side	:	50 %

621 x 10^6 kWh x 0.9 x 0.9 x US$ 0.05/kWh x 0.5 = 12.575 x 10^6 kWh

TABLE 5 CASH FLOW FOW FOR LOAN REPAYABILITY

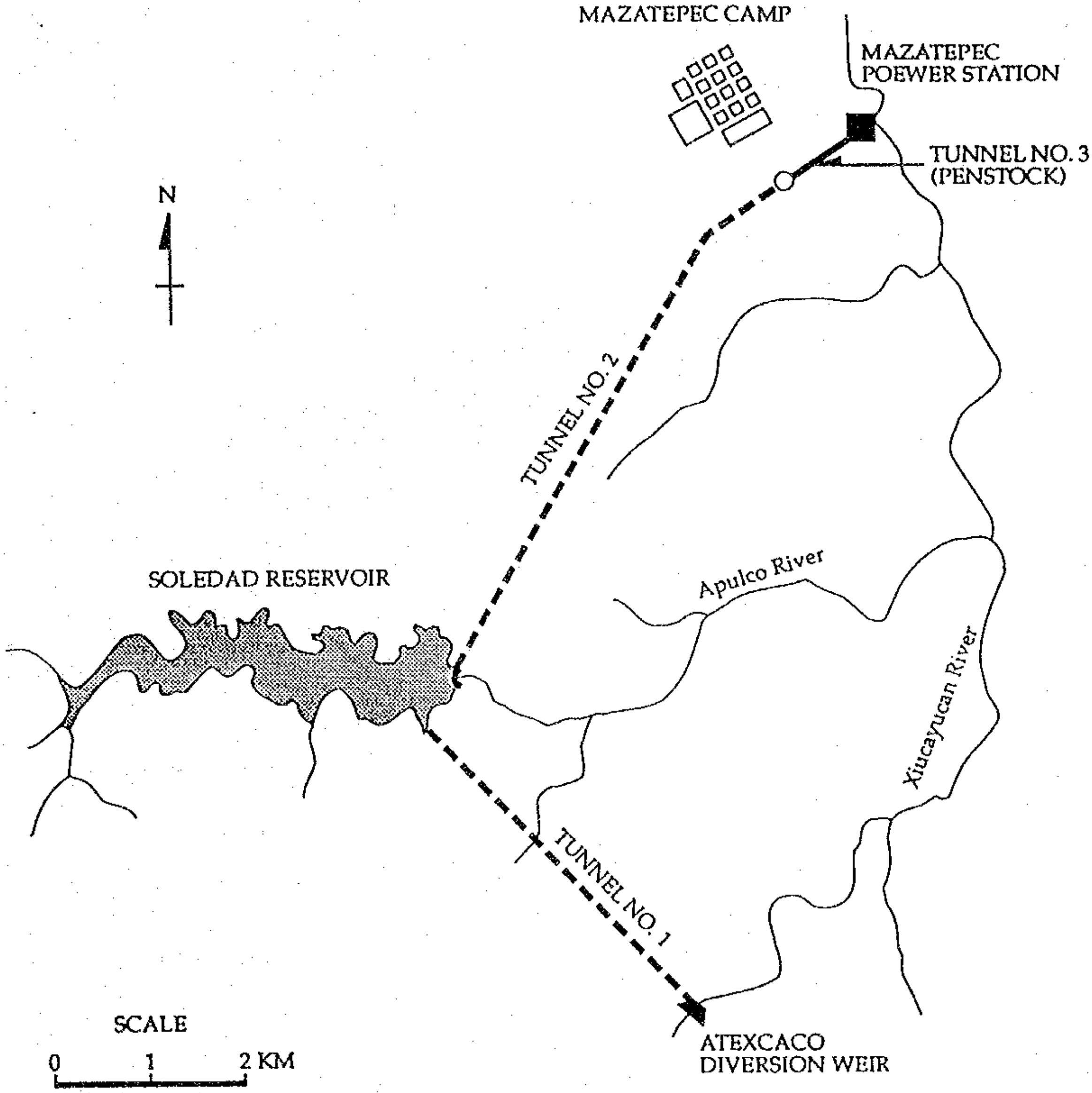
(Unit : million US$)

	Year	Cost: Capital Cost	Cost: O&M Cost	Cost: Interest	Cost: Repayment of principal	Revenue	Balance	Accumulated balance
1	1995	10.25		0.256			-0.256	-0.256
2	1996	10.25		0.769			-0.769	-1.025
3	1997	10.25	2.40	1.281			-3.681	-4.706
4	1998		3.05	1.538			-4.588	-9.294
5	1999		3.05	1.538			-4.588	-13.881
6	2000		3.05	1.384	3.075	12.58	5.071	-8.810
7	2001		3.05	1.230	3.075	12.58	5.225	-3.585
8	2002		3.05	1.076	3.075	12.58	5.379	1.794
9	2003		3.05	0.923	3.075	12.58	5.533	7.326
10	2004		3.05	0.769	3.075	12.58	5.686	13.013
11	2005		3.05	0.615	3.075	12.58	5.840	18.853
12	2006		3.05	0.461	3.075	12.58	5.994	24.846
13	2007		3.05	0.308	3.075	12.58	6.148	30.994
14	2008		3.05	0.154	3.075	12.58	6.301	37.295
15	2009		3.05	0	3.075	12.58	6.455	43.750
16	2010		3.05			12.58	9.530	53.280
17	2011		3.05			12.58	9.530	62.810
18	2012		3.05			12.58	9.530	72.340
Total		30.75	48.15	12.300	30.750	163.54	72.340	

Notes : (1) Loan with an interest rate of 5% for a repayment period of 15 years including 5 year grace period.
(2) Principal is repaid uniformly over 10 years.

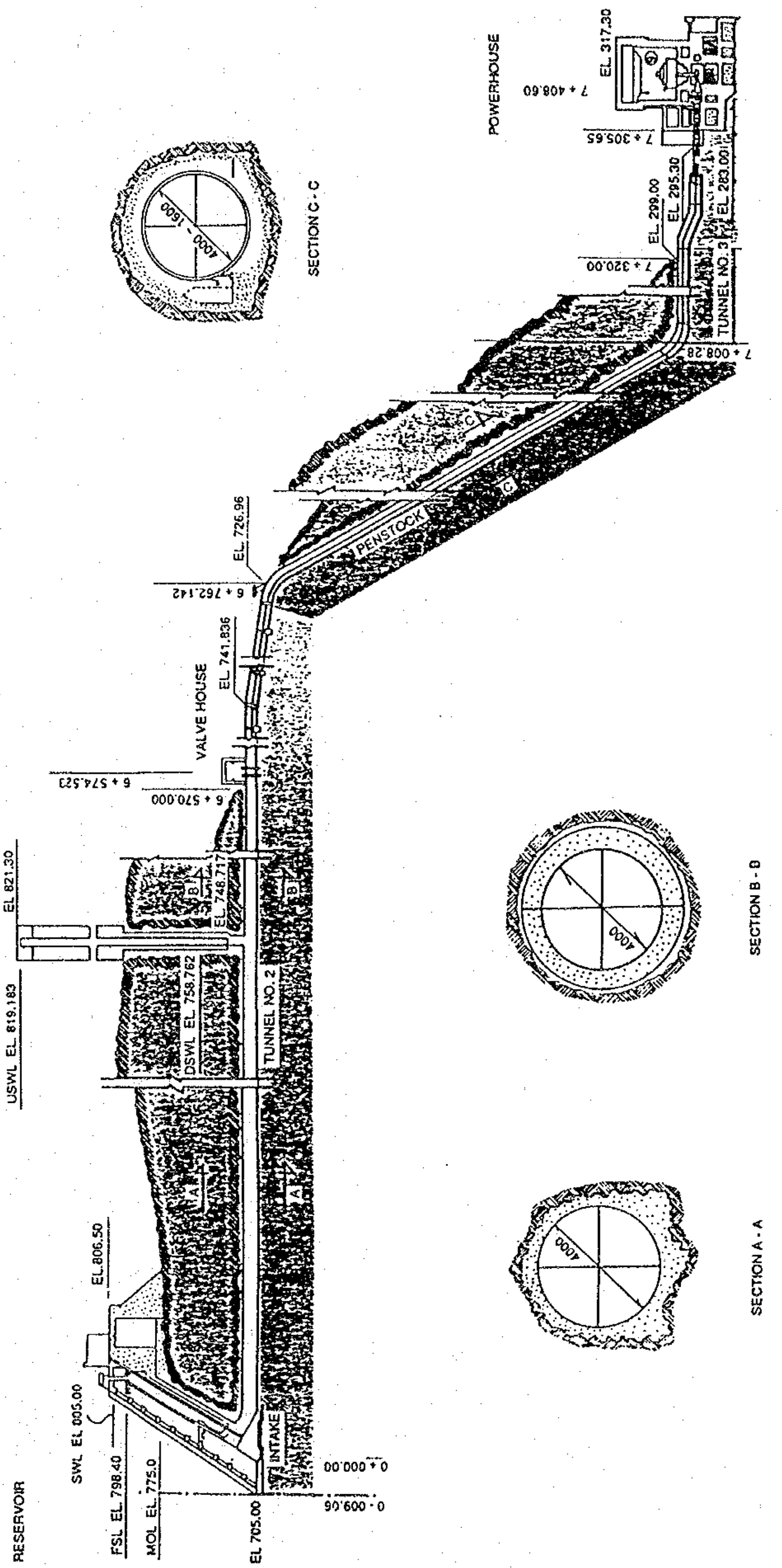
FIGURES

FIGURE 1



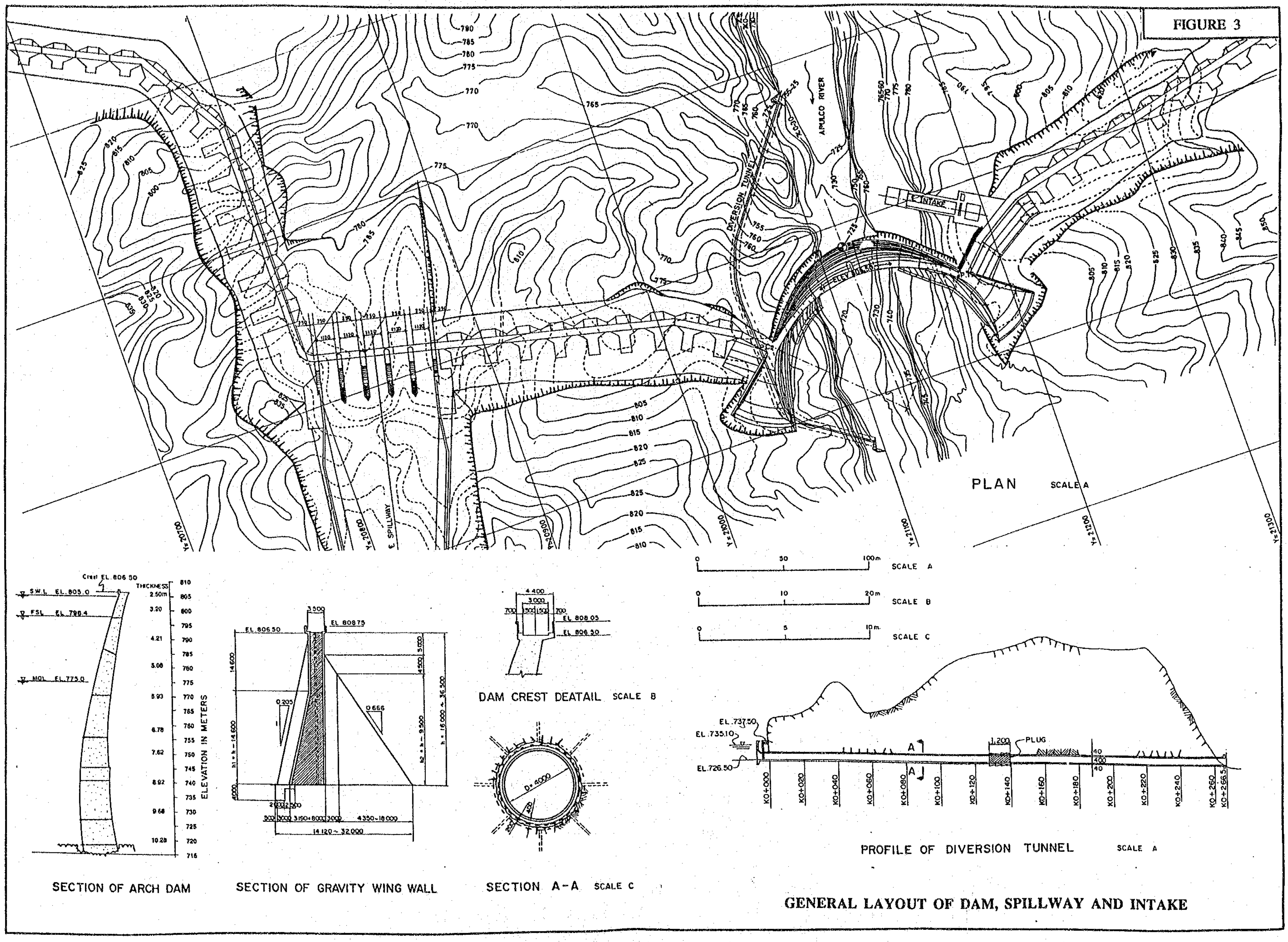
GENERAL LAYOUT OF PROJECT

FIGURE 2

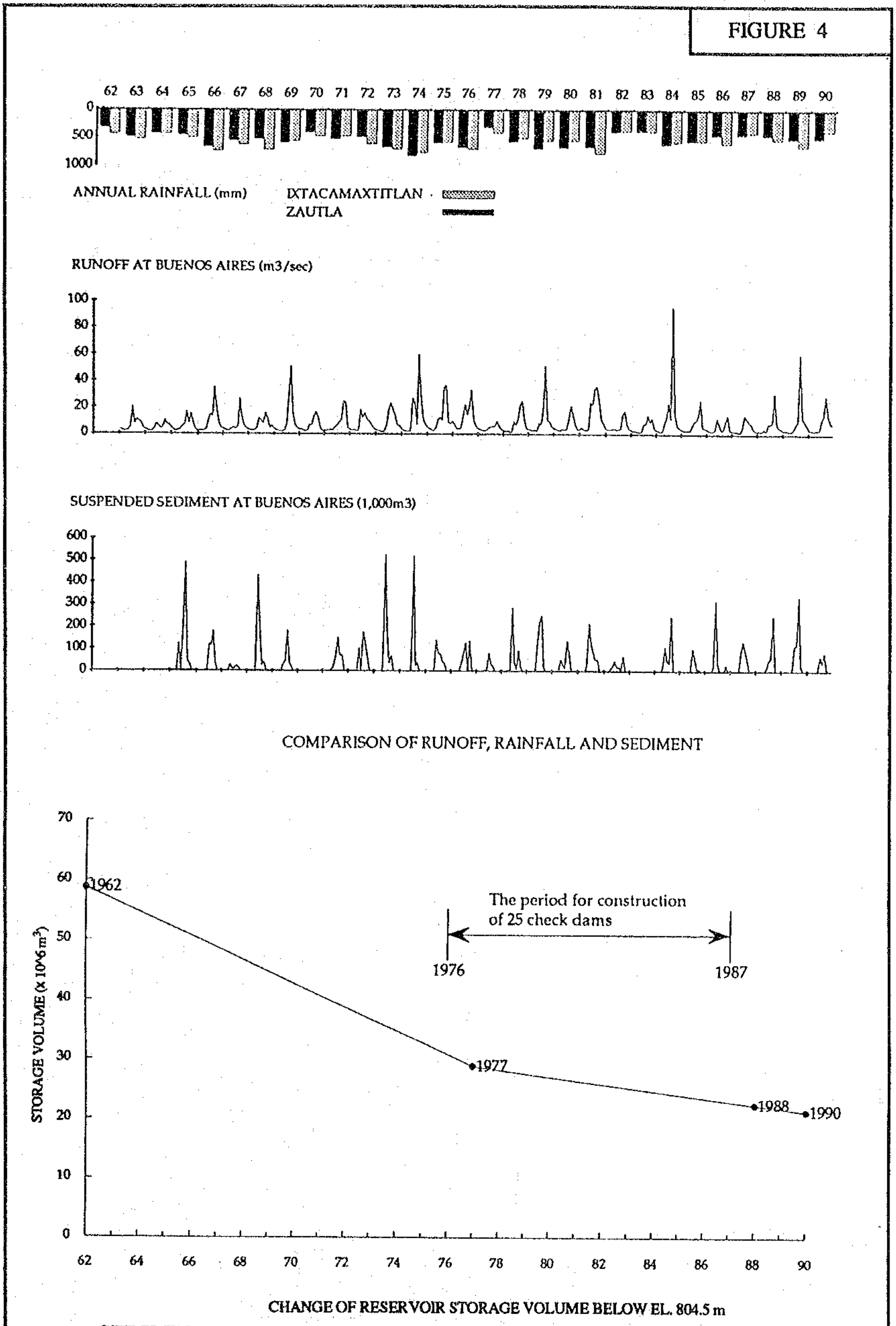


PROFILE OF WATERWAY

FIGURE 3

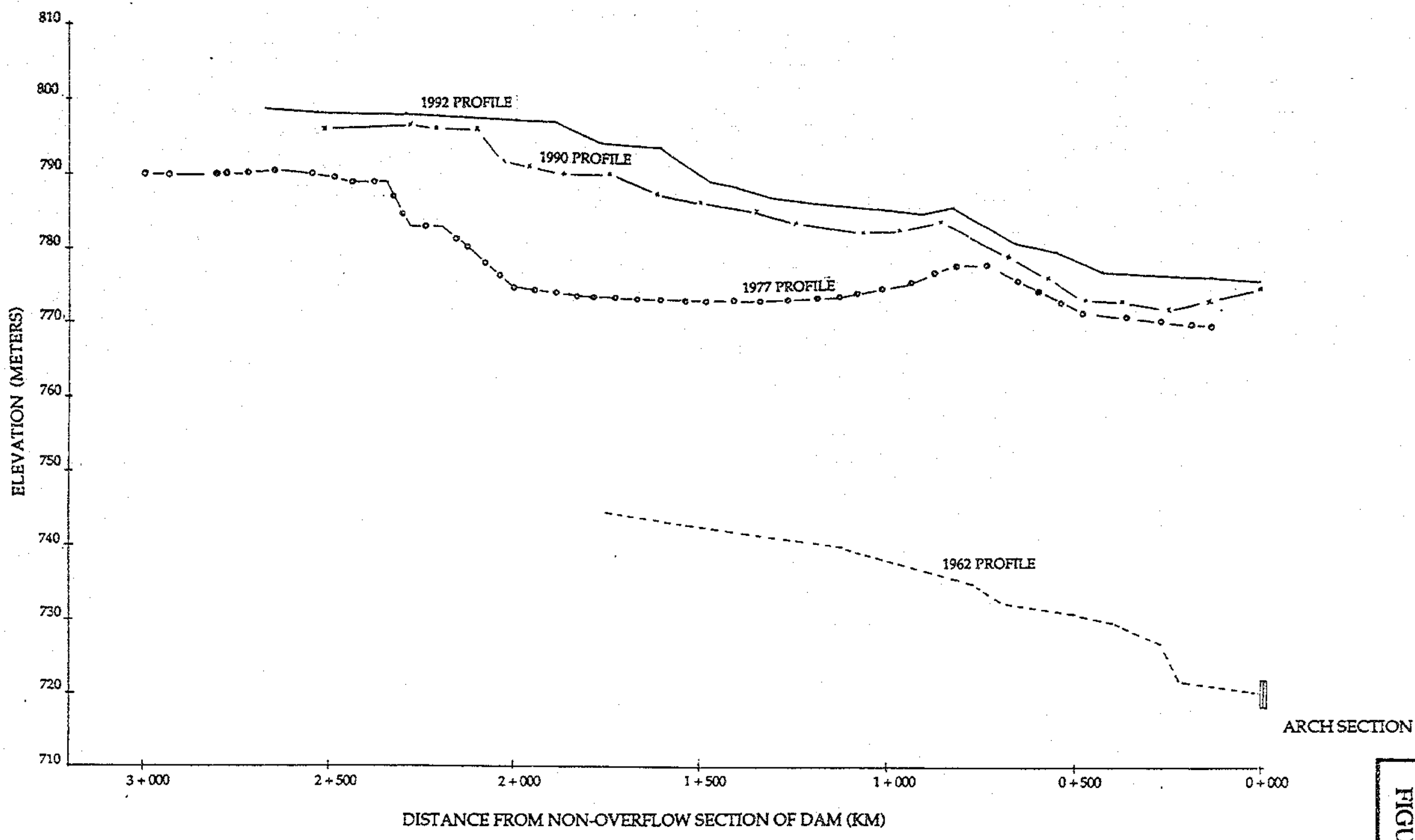


GENERAL LAYOUT OF DAM, SPILLWAY AND INTAKE



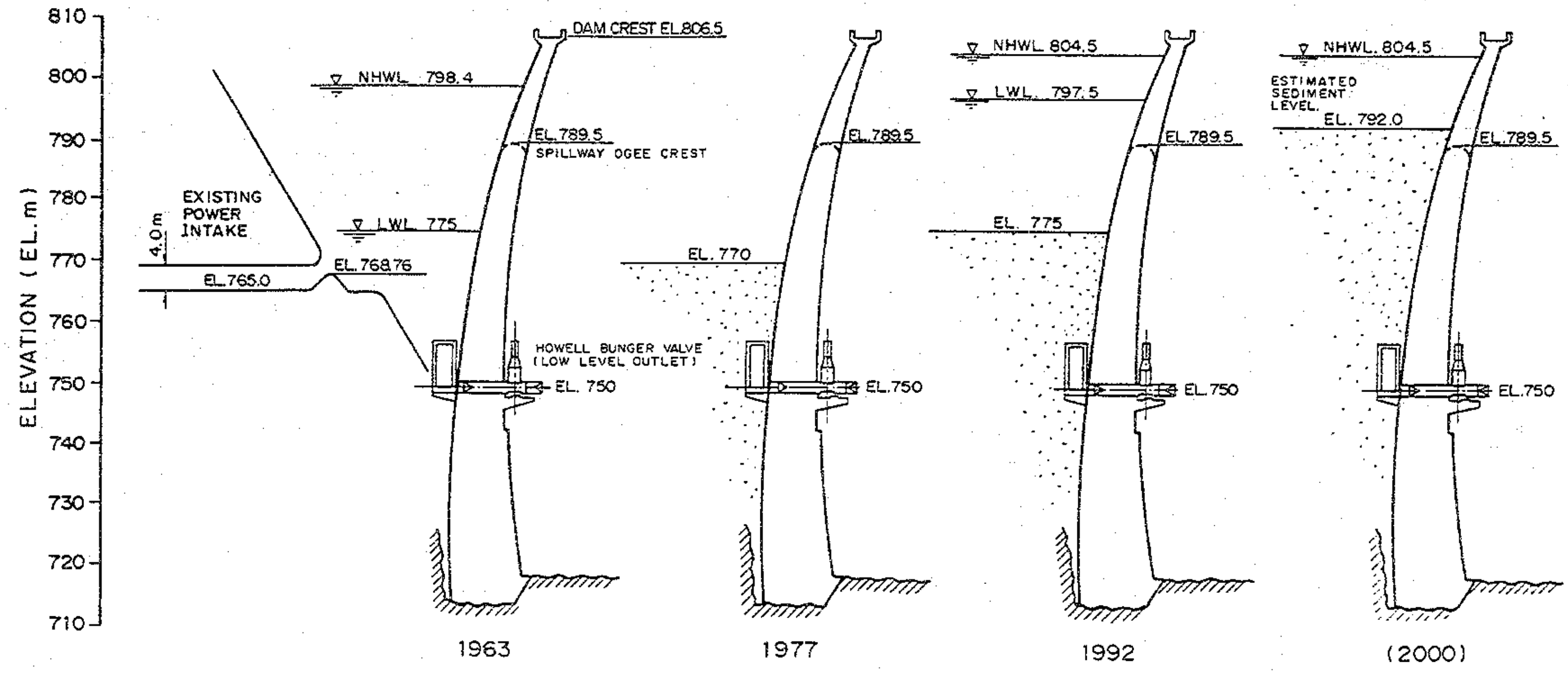
SEDIMENTATION PROCESS AND HYDROLOGICAL CONDITIONS

FIGURE 5



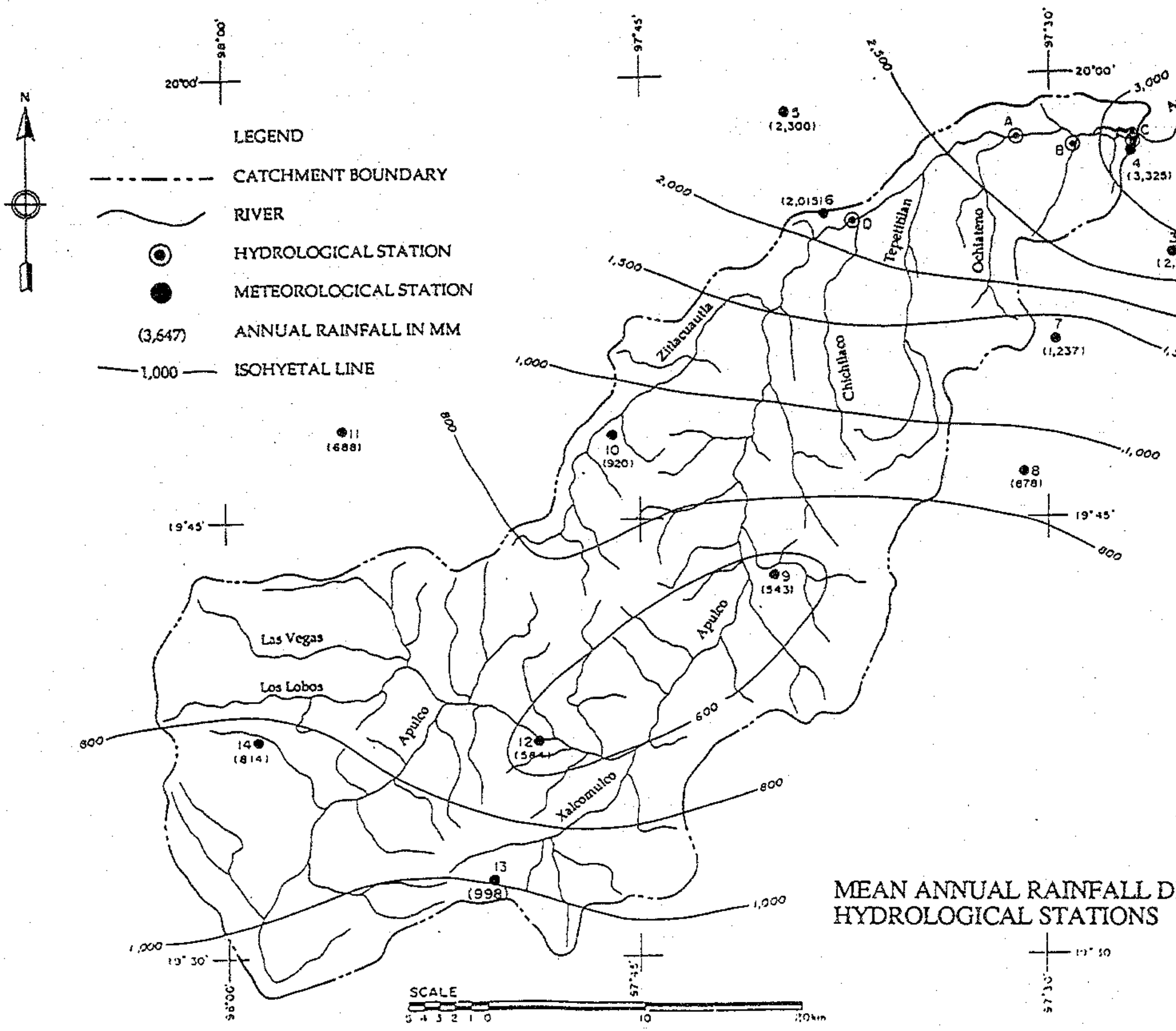
RESERVOIR BED PROFILES

FIGURE 6



PROGRESS AND PREDICTION OF RESERVOIR SEDIMENTATION

FIGURE 7



METEOROLOGICAL STATION

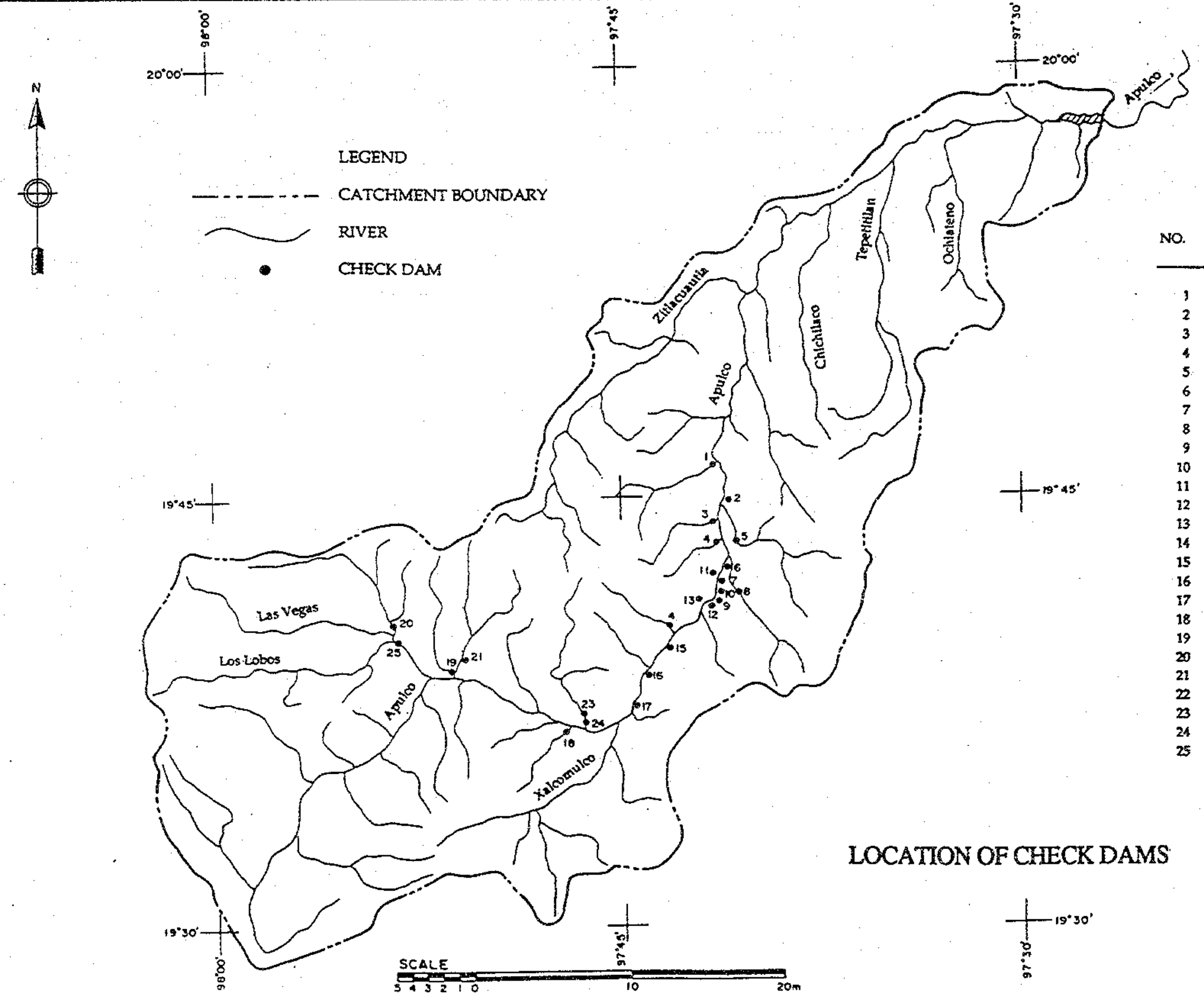
1. SAN JUAN ACATENO
2. ATEXCACO
3. LA PAGODA
4. LA SOLEDAD
5. TEPECAPAN
6. HUAHUAXTLA
7. TLATLAUQUI
8. GOMEZ PONIENTE
9. ZAUTLA
10. CAPULUAQUE
11. AQUIXTLA
12. IXTACAMAXTITLAN
13. SAN ANTONIO
14. LA GLORIA

HYDROLOGICAL STATION

A. BUENOS AIRES
B. SONTALACO
C. CANAL TUNNEL I
D. RANCHO APULCO

MEAN ANNUAL RAINFALL DISTRIBUTION AND METEO-HYDROLOGICAL STATIONS

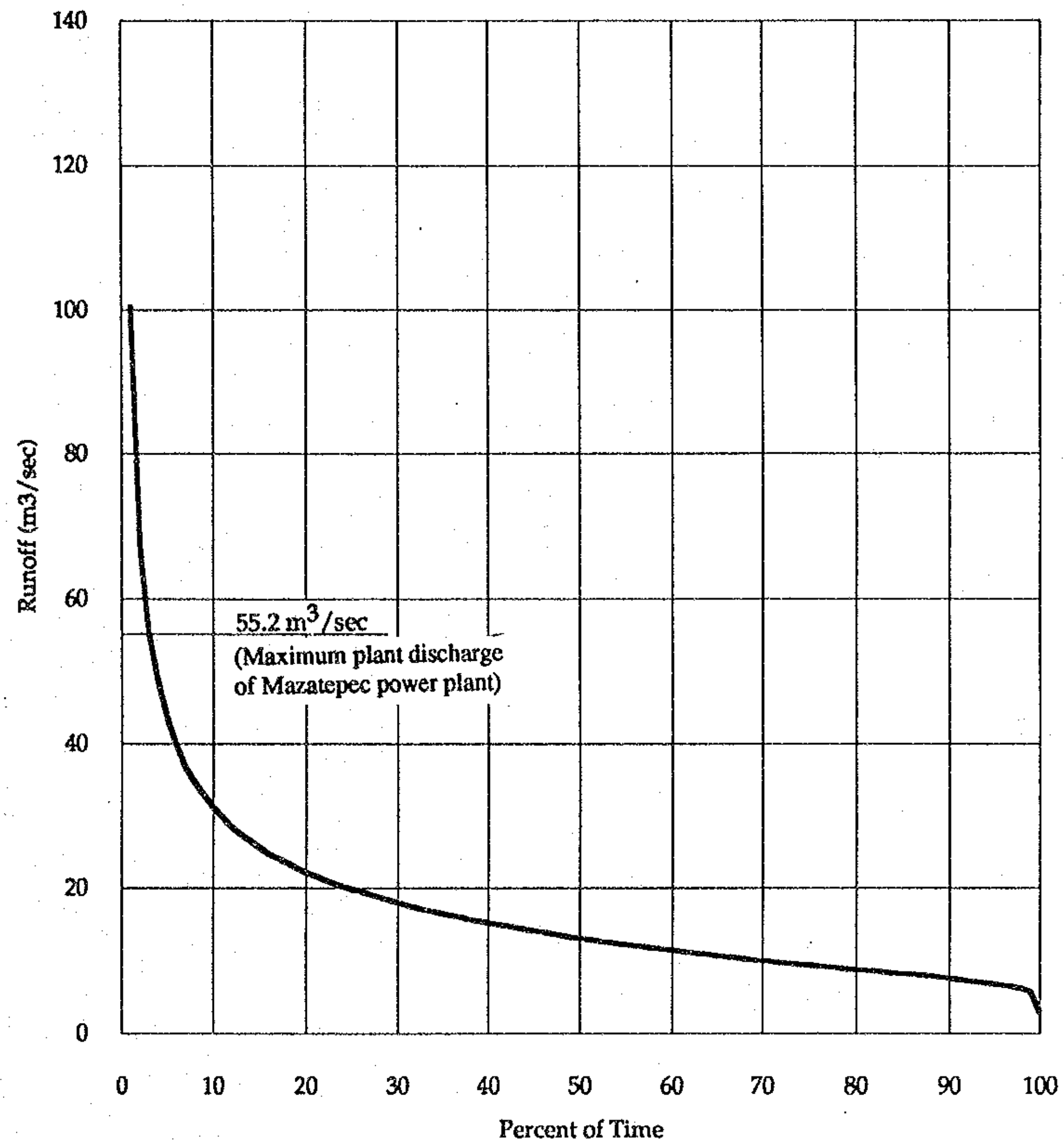
FIGURE 8



NO.	NAME OF DAM
1	Sta. Ines Morelos
2	El Durazo
3	Tenanpulco No.3
4	Coacal NO.1
5	Sta. Cruz
6	Pantijacan
7	Amaxac No.10
8	Amaxac No.7
9	Xalahuit No.1
10	Xalahuit No.2
11	Sn. Luis No.1
12	Apopoza
13	Quiquimititan
14	Sn. AnoresYahuitlalpan
15	La Paz
16	Pedacillos
17	Zocavon
18	Nopala
19	St. Maria Soltoltepec
20	Los Plumajes
21	El Pipian
22	Atemoloni
23	Acatla
24	Tatempango
25	Cuchac NO.1

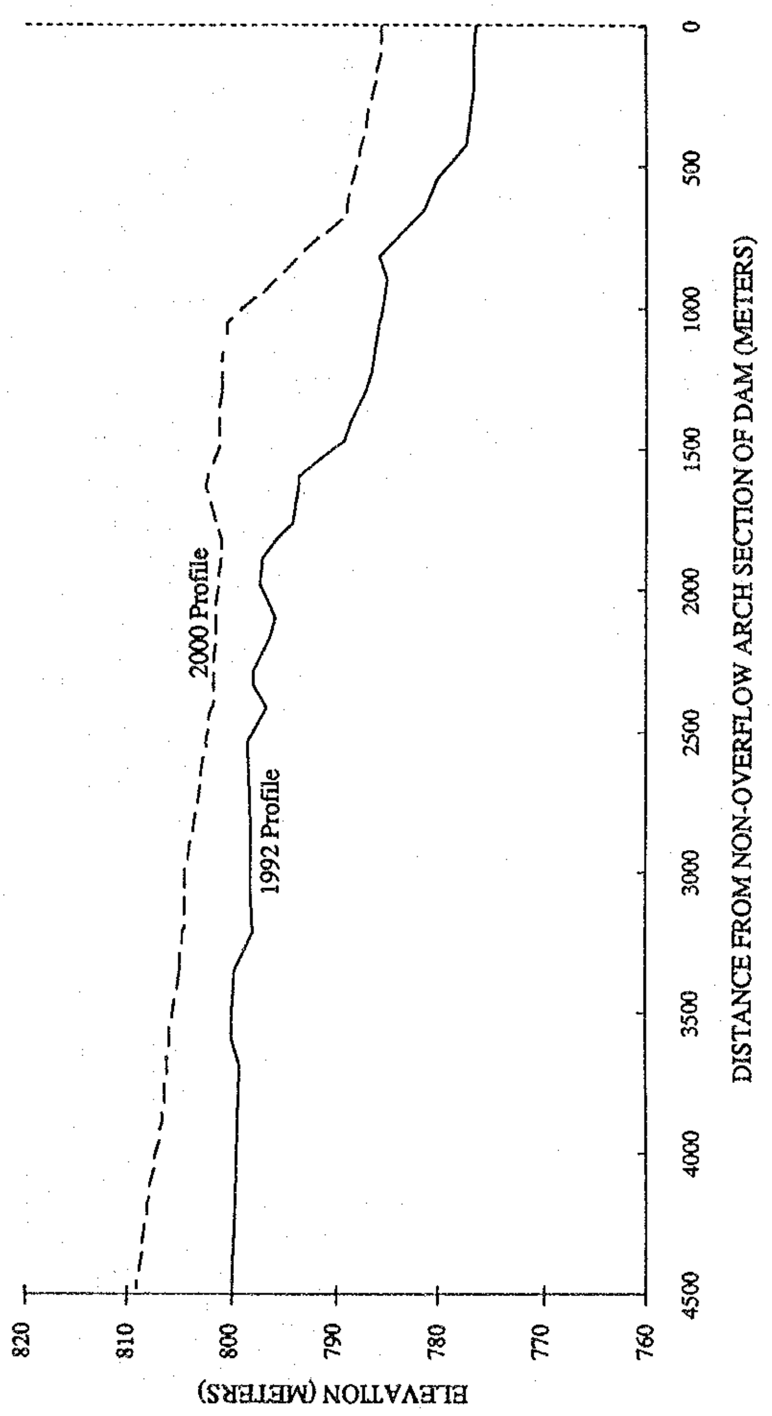
LOCATION OF CHECK DAMS

FIGURE 9



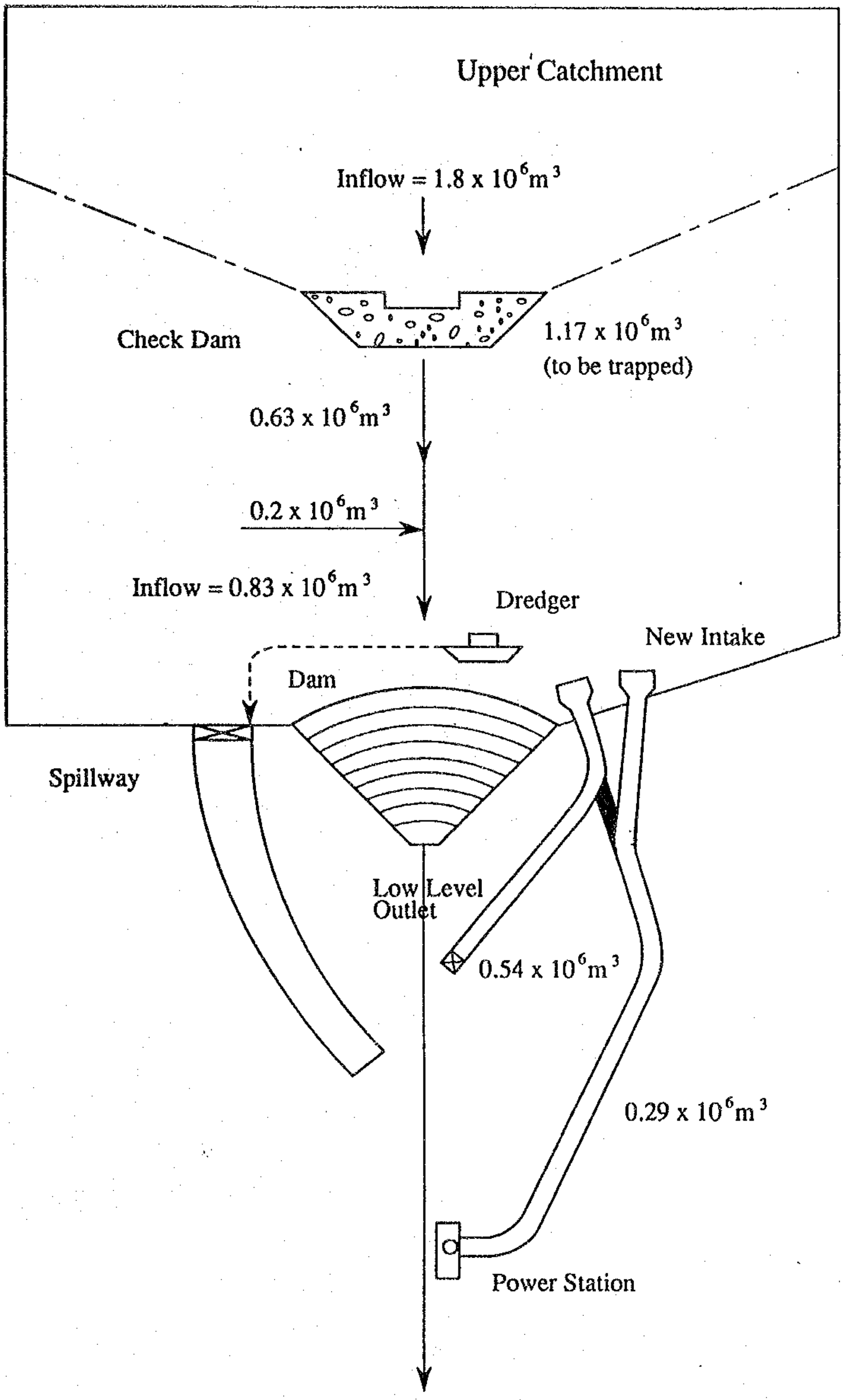
FLOW DURATION CURVE OF RESERVOIR INFLOW

FIGURE 10



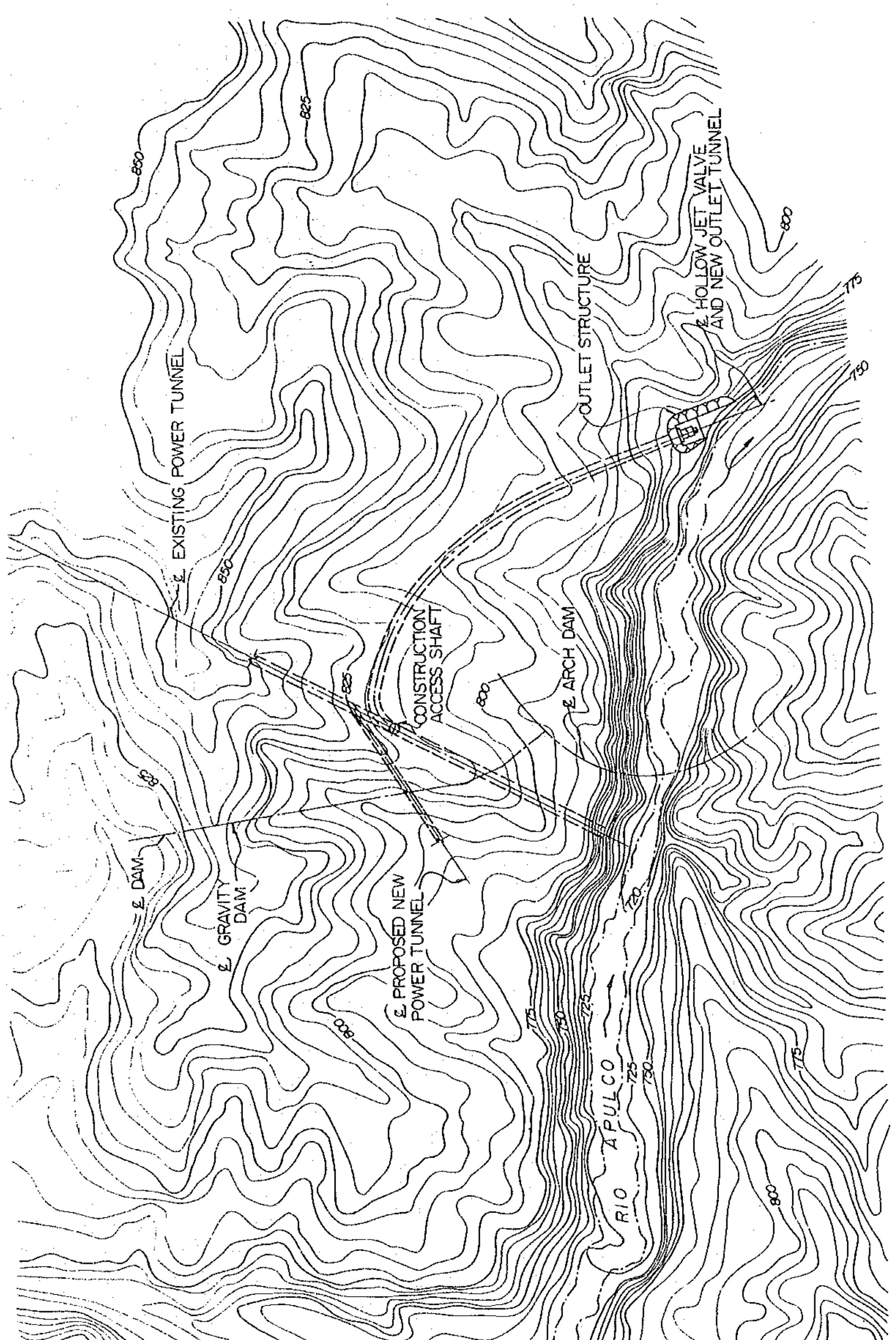
RESERVOIR BED PROFILES BY HEC-6 MODEL

FIGURE 11

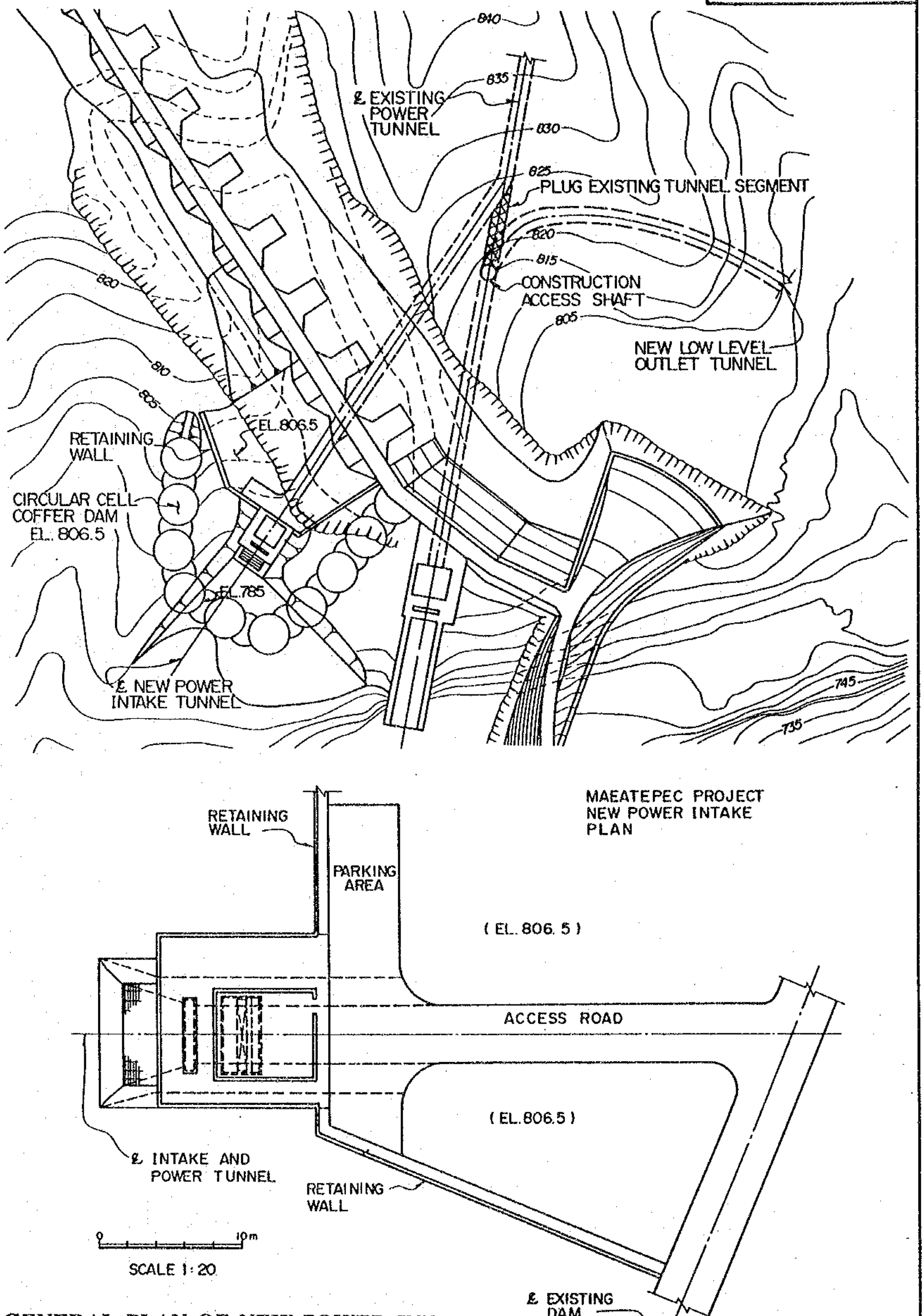


SEDIMENT BALANCE FOR REHABILITATION PLAN

FIGURE 12

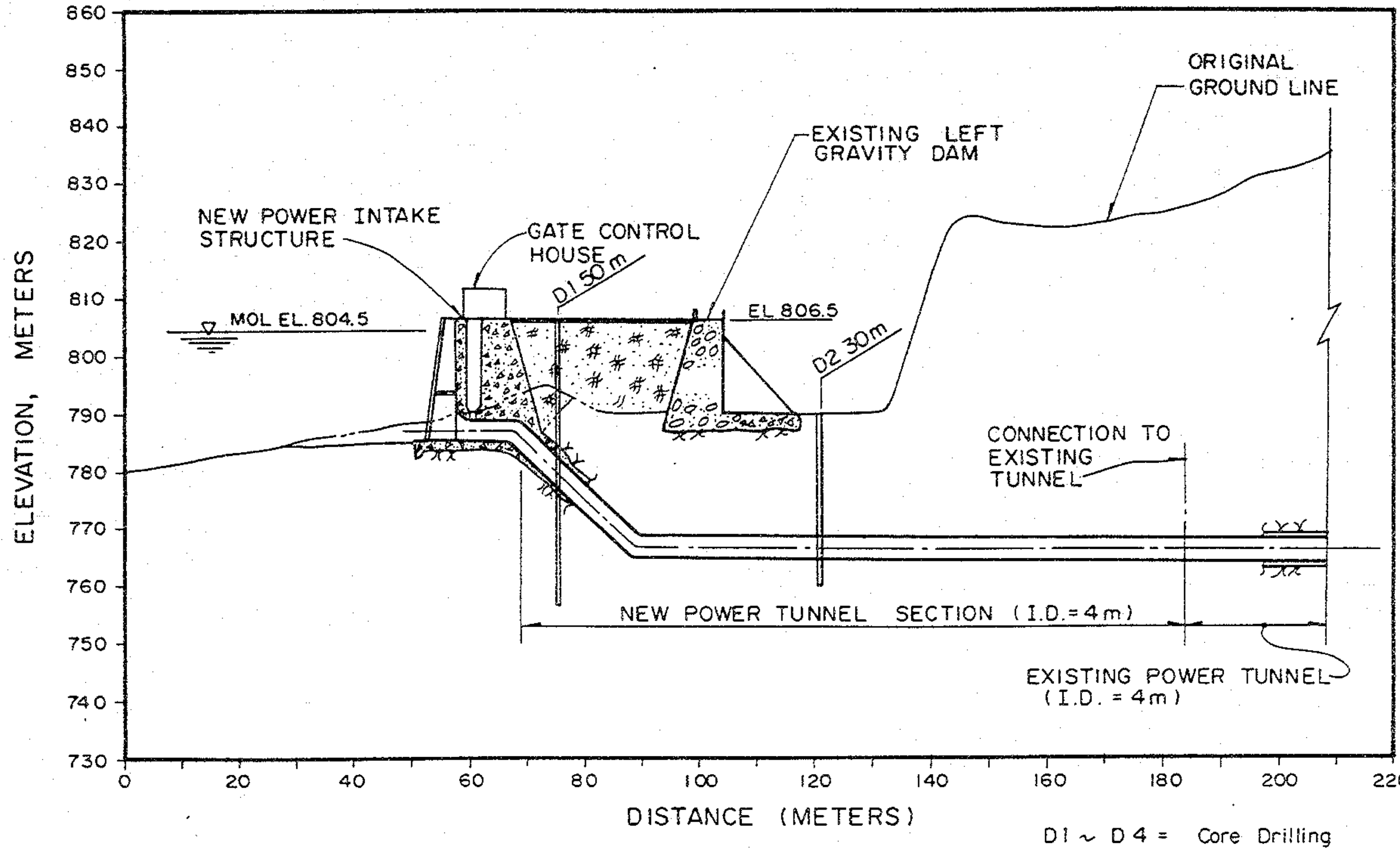


GENERAL PLAN OF NEW LOW LEVEL OUTLET



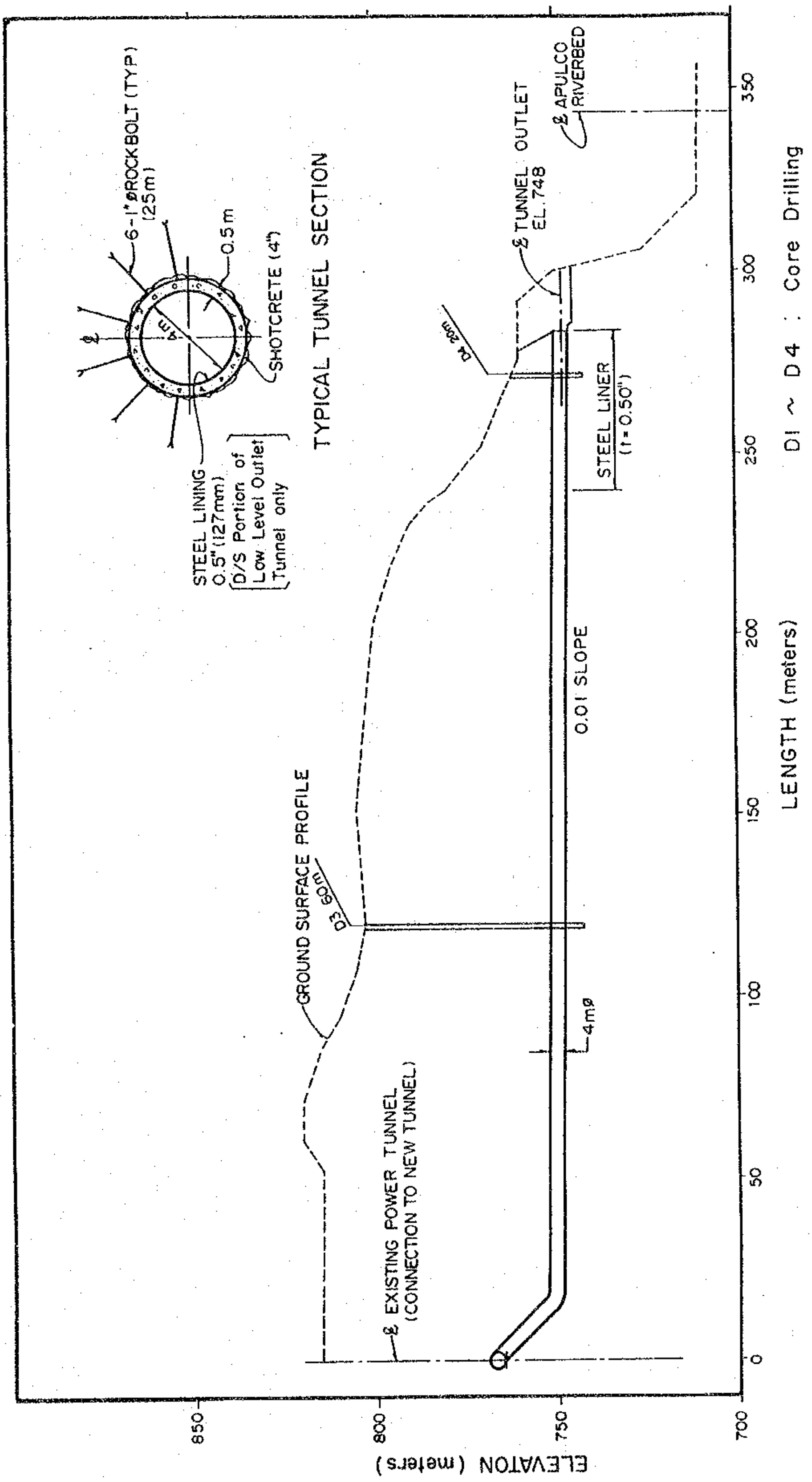
GENERAL PLAN OF NEW POWER INTAKE AND DEWATERING PLAN DURING CONSTRUCTION

FIGURE 14



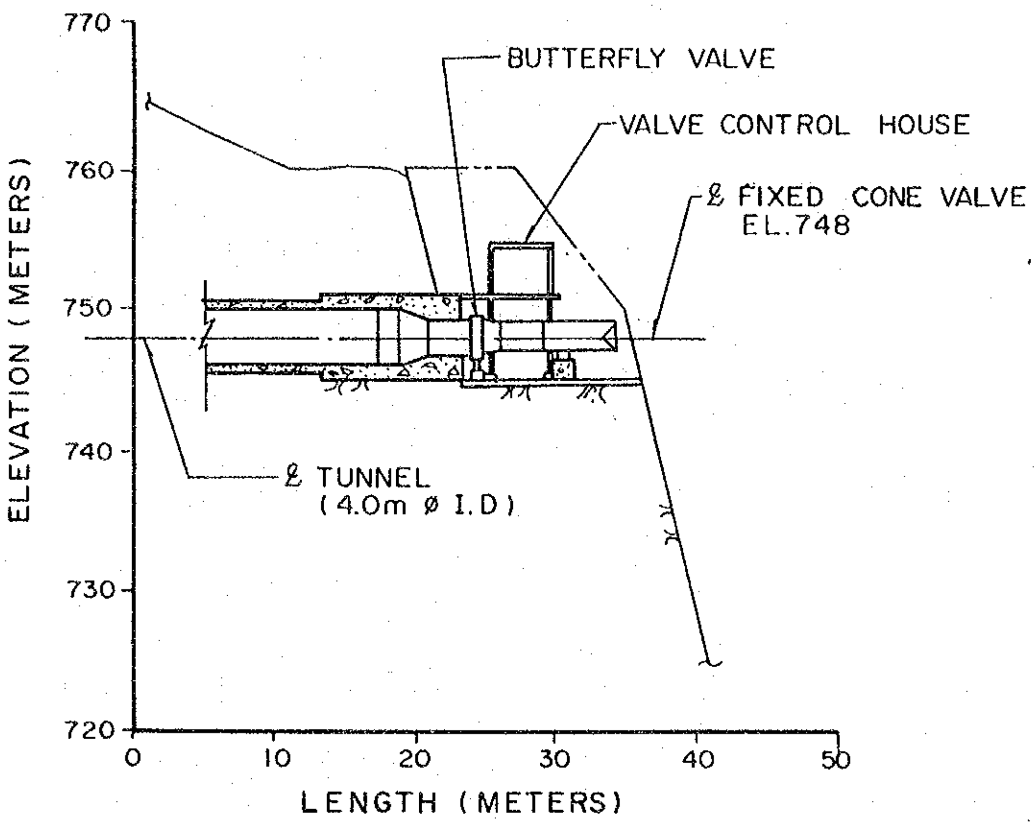
PROFILE OF NEW POWER INTAKE

FIGURE 15

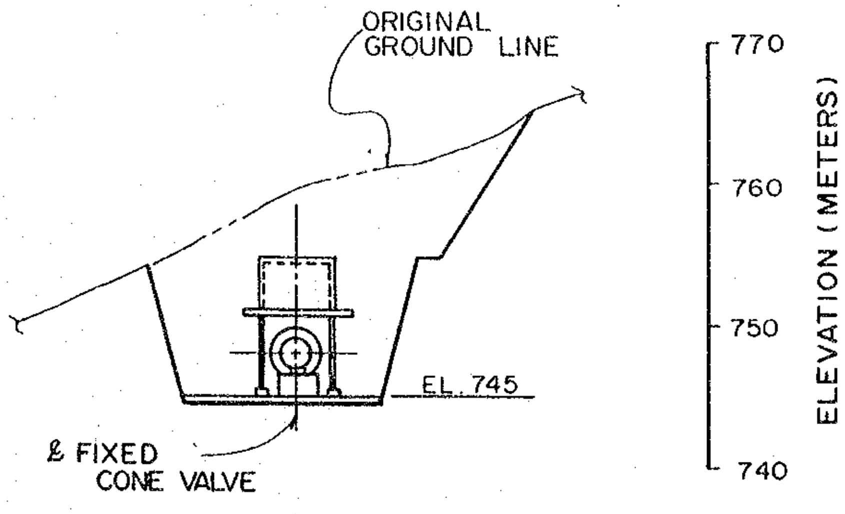


NEW LOW LEVEL OUTLET TUNNEL PROFILE

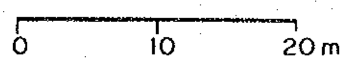
FIGURE 16



PROFILE



SECTION



LOW LEVEL OUTLET

FIGURE 17

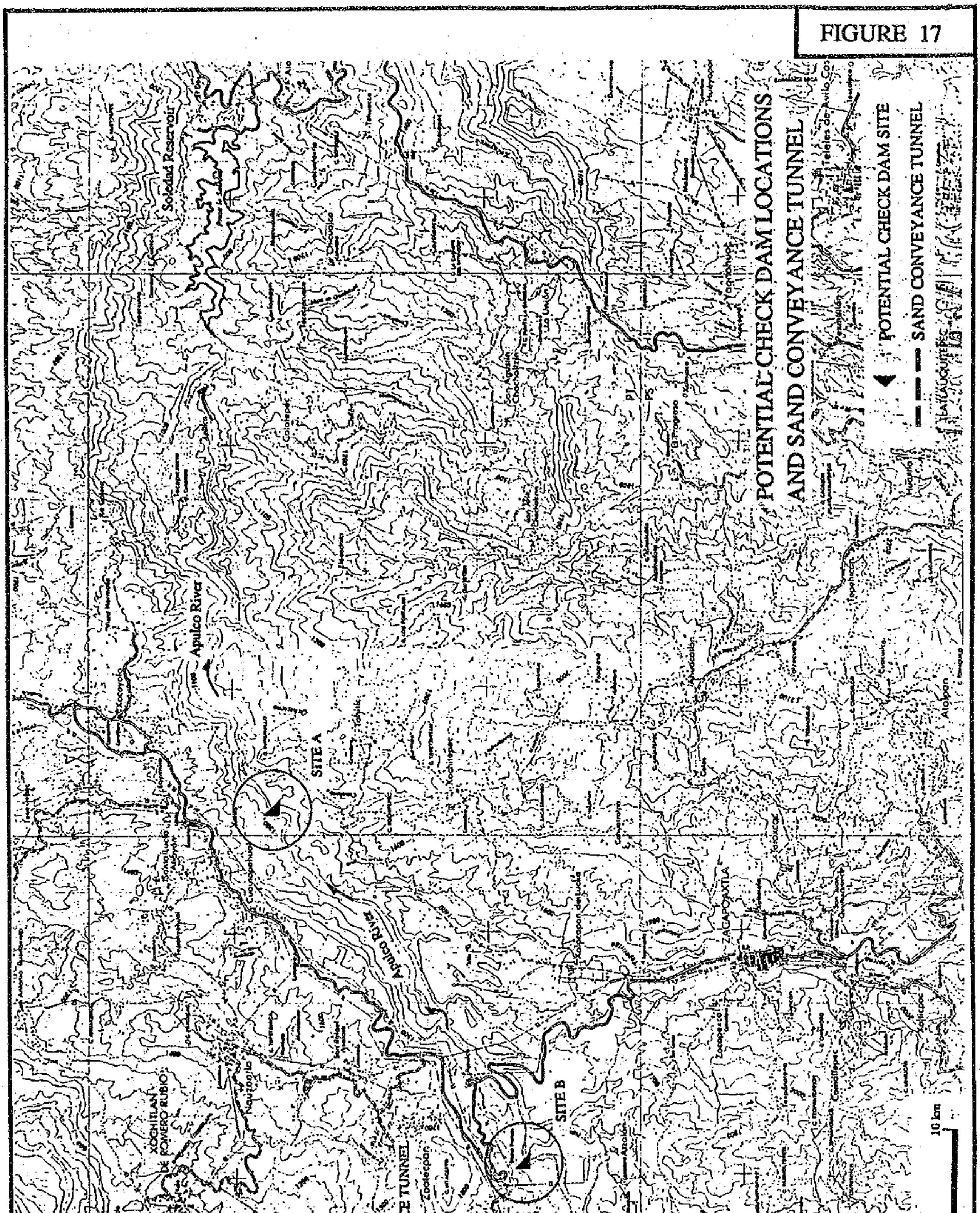
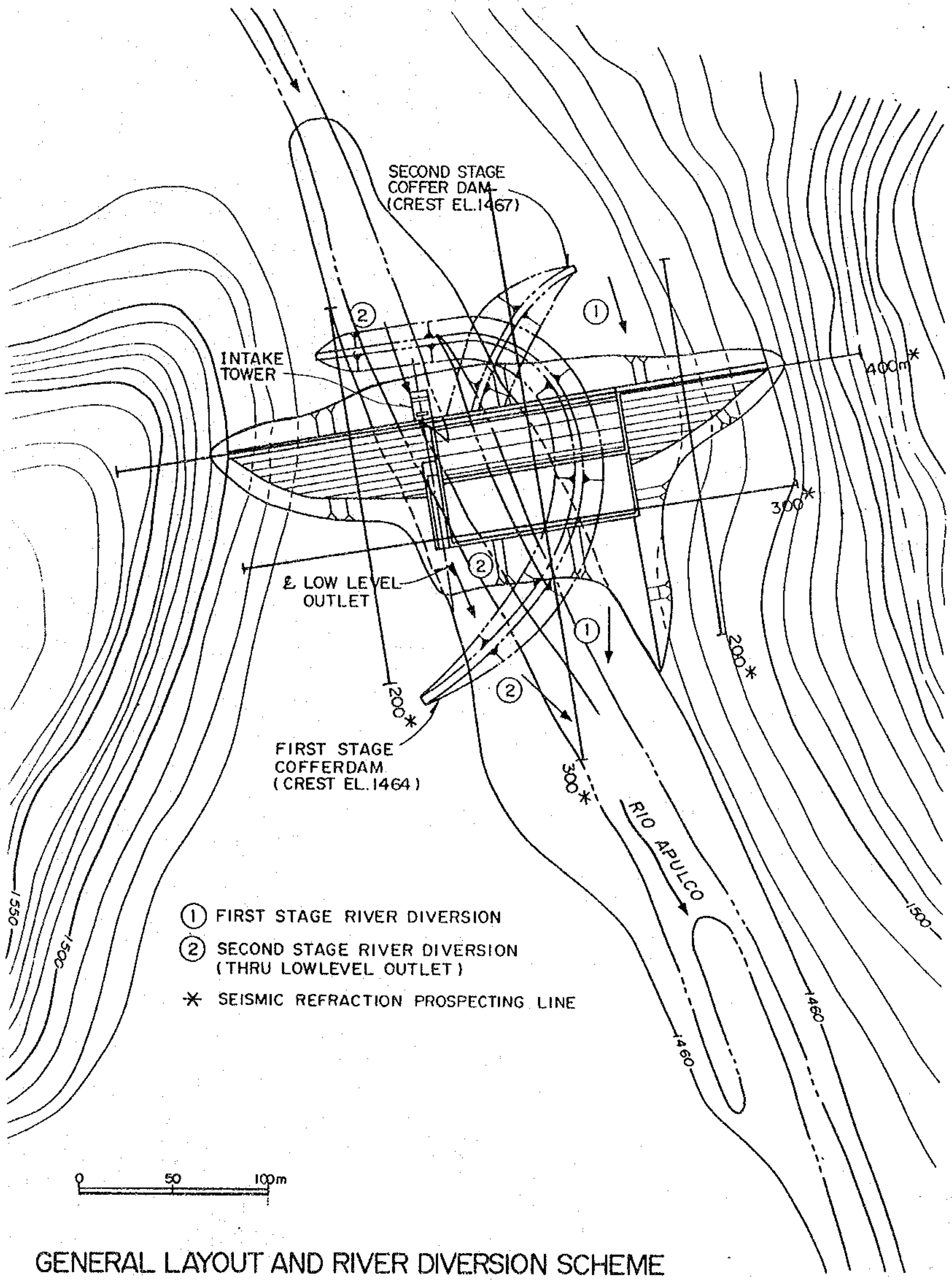
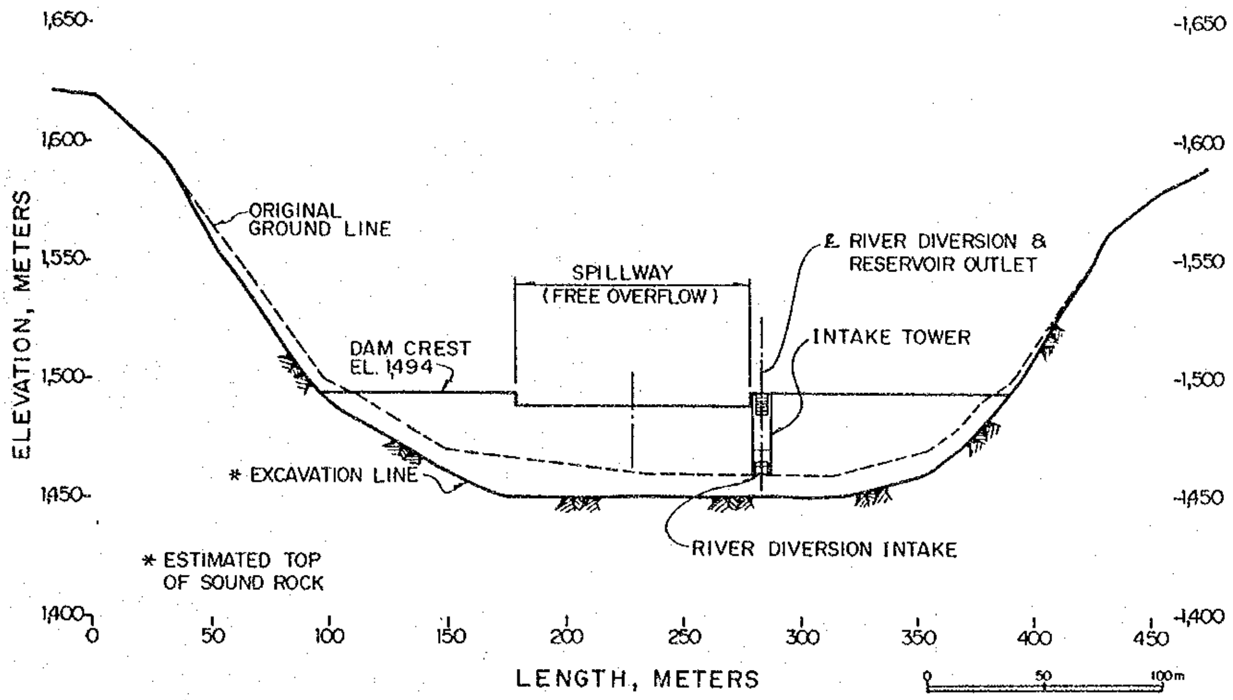

POTENTIAL CHECK DAM LOCATIONS
AND SAND CONVEYANCE TUNNEL
POTENTIAL CHECK DAM SITE
SAND CONVEYANCE TUNNEL
SITE A
SITE B
SITE C
Soledad Reservoir
Apulco River
SAND CONVEYANCE TUNNEL
HUAHUAXTLA
ZACAPOAXTLA
XOCHITLAN DE ROMERO RUBIO
SCALE
0
5
10 km

FIGURE 18

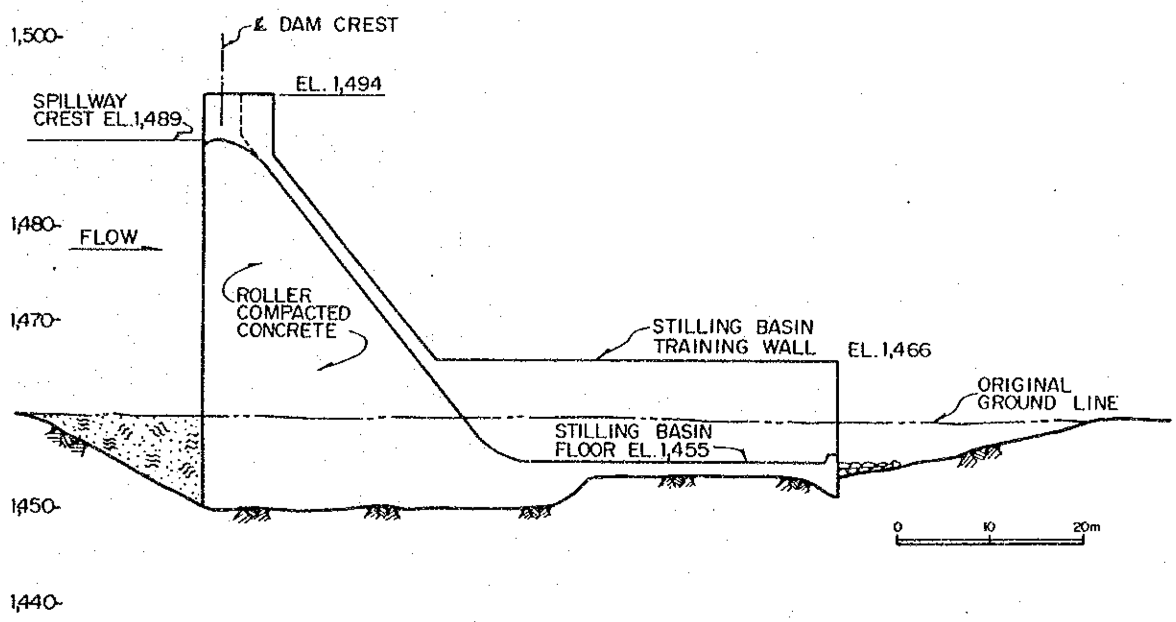


GENERAL LAYOUT AND RIVER DIVERSION SCHEME OF CHECK DAM (15 YEAR LIFE).

FIGURE 19



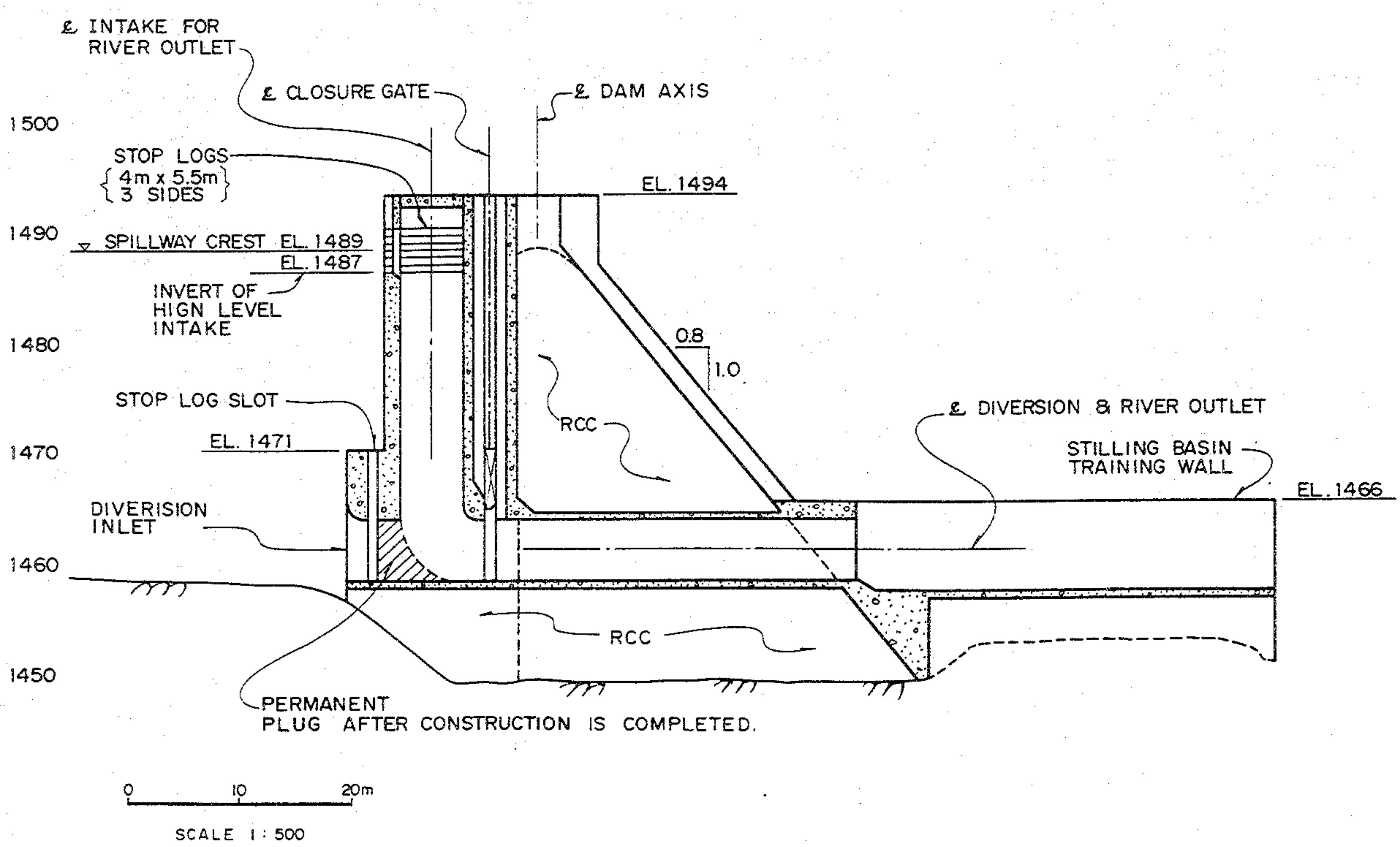
UPSTREAM ELEVATION OF CHECK DAM



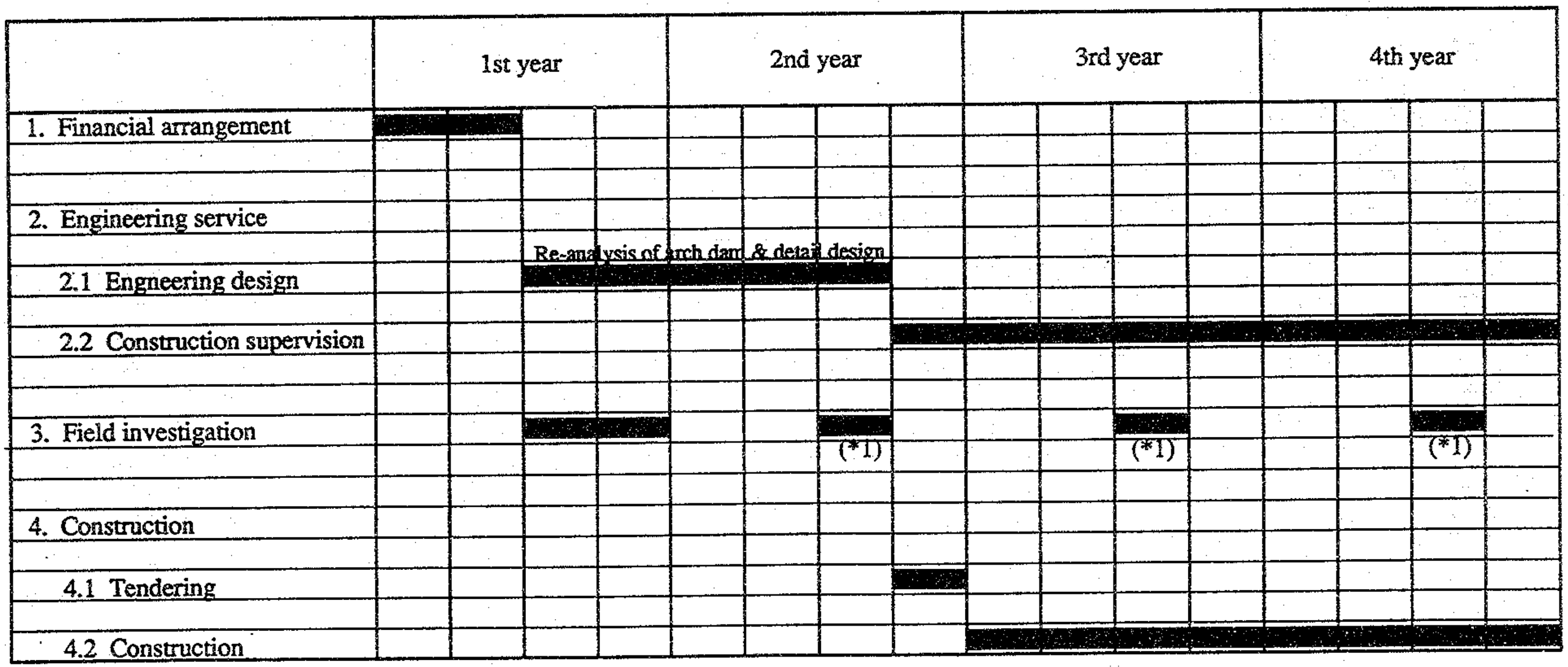
SECTION THRU SPILLWAY CENTERLINE CHECK DAM

SECTIONS OF CHECK DAM

FIGURE 20



DIVERSION AND RIVER OUTLET OF CHECK DAM



Note: (*1) Bathymetric survey in Soledad Reservoir

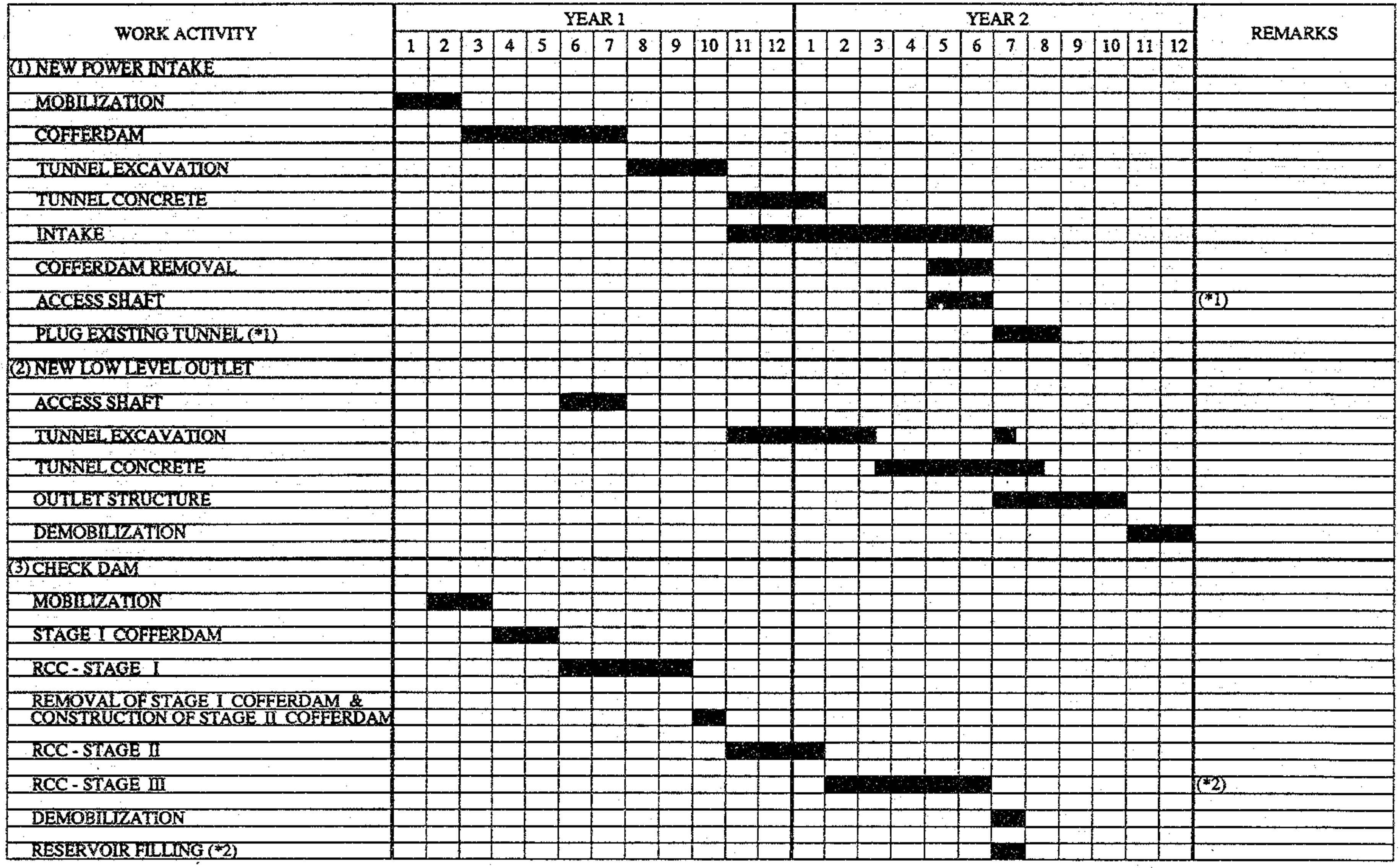
Outline Implementation Schedule of Rehabilitation Plan

FIGURE 21

Work Items	Month 1	2	3	4	5	6	7	Remarks
A. Topographic Survey								
A-1 Preparation/Mobilization								
A-2 Aerophotographic mapping								For the proposed reservoir and road relocation.
(1) Shooting								20 km², 1/2,000
(2) Ground control survey								
(3) Levelling								
(4) Mapping								
A-3 Ground Survey								
(1) Profile/Section survey								For the check dam and intake site
(2) Plane table survey								- do -
B. Geological Survey								
B-1 Preparation/Mobilization								
B-2 Seismic refraction prospecting								For check dam site : 1,400 m for 5 lines
B-3 Core drilling								For check dam : 200 m long for 6 holes
								and intake and tunnel : 160 m long for 4 holes
C. Construction Material Survey								
C-1 Sand & gravel								For concrete aggregate for building concrete dam
C-2 Quarry site								
D. Bathymetric Survey of Soledad Reservoir								By using echo sounder at every 6 month.
D-1 Entire reservoir area								
D-2 Dam and intake area								
E. Measurement of Turbidity of Water								
E-1 Reservoir								By using turbidity water at every 6 month.
E-2 Downstream								

FIELD INVESTIGATION SCHEDULE

FIGURE 23



(*1) The existing power tunnel and Mazatepec Powerplant will be shut down during this period.
(*2) Coincides with the shutdown of the Mazatepec Powerplant after construction of the new power intake is complete.

CONSTRUCTION TIME SCHEDULE

JICA