APPENDIX F

SEDIMENT CONTROL PLAN

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CHAPTER I EXISTING PROBLEMS OF SEDIMENT IN RIVERS

1.1 General

Major problems of sediment that may cause vital flood disasters were identified through the field reconnaissance and aerophoto interpretation over the entire river reaches. These problems were reconfirmed by the experiences and river damages of Typhoon Gloring in July 1996. They are classified into three (3) kinds, namely, problems of sediment in the alluvial fan, bank erosion in the flood plain and local sediment deposits in the small rivers. These problems are discussed below.

1.2 Problems of Sediment in Alluvial Fan

The alluvial fan complex in the upstream of the Laoag River is mainly formed by the six (6) major tributaries: Cura, Labugaon, Solsona, Madongan, Papa and Bongo rivers. All these tributaries are exposed to the following vital problems. For the morphology of the above rivers, see Appendix E.

(1) Channel Shift around the Alluvial Fan Apex

Excessive sediments are transported downwards through the mountain torrents to the alluvial fan during medium to big scaled floods. A considerable portion of the transported sediments are deposited on the fan apex. This is made possible because the river channel suddenly becomes wide with gentle slope at this point resulting in reduction of the shear force of flood water. In the deposits, big sediments such as boulders with a diameter of more than 300 mm abound.

This excessive sediment deposits at the fan apex causes the rising of flood water level and triggers the breach of existing riverbanks. As a result, the flood flow forms a new river channel by cutting the lands.

Channel shifting not only causes loss of farmlands and damage of irrigation facilities in and along the new channel but also devastates a wide area of farmland by deposition of sediments.

Frequent channel shifts in the past have created a number of distributaries branching from around the fan apex. However, this channel shifting does not occur in all river sections in the alluvial fan. According to the interpretation of aerophotos, the potential channel shifting zone is considered to be limited to the river sections between the fan apex and 2 to 2.5 km downstream. The potential channel shifting zones in the alluvial fan are mostly located in the river stretches with a slope of more than 1.3%.

Reduction of the sediment runoff to the alluvial fan during large floods is considered essential to prevent the above sediment problems. Especially, prevention of boulder deposit is important.

(2) Channel Aggradation in the Alluvial Fan

The six (6) major tributaries in the alluvial fan form their respective indigenous braided channel networks consisting of several wide and shallow branch streams within the river courses. Further, the riverbeds are formed of the sand bars of various types.

The velocity of flood water entraining sediment of various sizes decreases in these river sections with wide and shallow braided channel net works, resulting in much sedimentation on the riverbeds. This sedimentation decreases the flood carrying capacity of the rivers. Therefore, these river stretches in the alluvial fan are always exposed to overbanking floods.

These river conditions are created by excessive sediment runoff during flood time. Hence, reducing the sediment runoff (inflow) from the upstream and increasing the sediment transport capacity of the above river sections are considered necessary for sediment problem mitigation.

(3) Bank Erosion in the Alluvial Fans

Bank erosion is generally caused by stream convergence created by sand bars. Large scale sand bars generate large bank erosion, while small scale sand bars do not have much effect on the riverbanks.

The beds of the six (6) major rivers in the alluvial fan are covered by small scale like sand bars during normal floods. However, large alternating sand bar formations were observed on the beds of many river sections after the flood of 1996 Typhoon Gloring. The length of one alternating bar is estimated at 500 to 700 m.

These alternating sand bars move downward during flood, causing the movement of stream convergence points. Bank erosion may then extend downwards over the river reaches.

The above large scale sand bars are produced mainly by excessive sediment runoff to the rivers. Therefore, sediment control as well as bank protection in the upstream is necessary.

1.3 Problems of Sediment in the Lower Reaches

The lower reaches of the Laoag River cover the Lower Bongo (confluence with Papa River to the confluence with Cura River) and the Laoag Main (confluence with Cura River to the river mouth). These rivers run through the alluvial flood plain. Their geomorphologic and hydraulic mechanisms are quite different from those of the rivers in the alluvial fan.

The major problem of sediment in the lower reaches is bank erosion. Serious sedimentation that may bring about significant flood damage was not identified. This was confirmed through the 1996 flood event.

The river course is no longer braided and flood flow concentrates in one channel. Single or dual mode alternating bars are formed on the riverbeds. Downward movement of these sand bars is unlikely during floods because the natural river bends and confluence of the Solsona, Cura and Guisit rivers will hinder its progress so that stream convergence appears alternately on the right and left riverbanks and the locations are almost fixed. Therefore, bank protection works are only necessary for some river sections.

1.4 Problems of Local Sediment

Some problems of sediment were locally identified in the upstream of three (3) rivers; Boot, Madongon and Lading. The location of these rivers is shown in Fig. F.1.1. Their local sediment problems are summarized below.

(1) Boot River

The Boot River, a tributary of the Guisit River, covers a catchment area of 21.8 km^2. Its flood plain with a slope of about 1.2% extends downward from the mouth of the mountain valley. Land along the river course ranging in width from 100 to 200 m has been devastated by sediment from the river.

The farmlands in the flood plain are not well developed due to lack of irrigation water. Therefore, the necessity of sediment control is limited only to some small areas.

(2) Madongon River

The Madongon River is a tributary of the Cuyep-cuyep River which is one of the major tributaries of the Solsona River. The catchment area is estimated at 10.7 km^2. The river forms an alluvial fan with a very steep slope, varying from 5.0% to 1.7% in about 3 km distance from the mouth of the mountain valley to the confluence with the Cuyep-cuyep River. Land along the river course ranging in width from 200 - 400 m has been devastated by sediment from the river.

Debris deposits around the fan apex were identified in the field survey and confirmed by the residents. The debris flow seems to have occurred in the flood of 1967 Typhoon Gening. The 1996 Typhoon Gloring did not bring new sediment deposits in the river and the alluvial fan.

The above facts imply that sediment runoff and transport in the Madongon River may be caused mainly by debris flow of more than 10 years in probability. Sediment runoff and transport by normal floods are considered small.

Problem of sediment in this river basin is considered to be limited to some small areas and frequency is presumed to be low. Sediment control in this basin is not also considered to have much effect on the downstream reaches because only a small drainage basin is involved and severe sediment runoff is not frequent.

(3) Lading River

The Lading River, a tributary of the Bongo River, drains 4.3 km^2. The river also forms an alluvial fan with a steep slope of about 5% over the river distance of about 2 km from the mouth of the mountain valley. Land along the river course ranging in width from 100 to 200 m has been devastated by sediment from the river.

According to information from residents, some paddy fields along the river were washed away by debris flow in the 1984 flood. This was confirmed during the field reconnaissance. The sediment runoff of the Lading River is also considered to be of debris flow type.

The sediment problems of this basin were identified in some small areas but they are not considered frequent. Sediment control in this basin is not considered so effective to the downstream reaches from the same reason as the Madongon.

CHAPTER II SEDIMENT BALANCE ANALYSIS

2.1 Methodologies

2.1.1 Sediment Transport Type

Fluvial sediments in transit are classified as bed material load and wash load according to their origin. Further, bed load material is also classified as bed load and suspended load according to its transport mechanisms. As a result, whole sediments in transit by flood water are categorized into three components, namely bed load, suspended bed material load (hereinafter called "suspended load") and wash load, as shown below.

- Sediment transport
  - bed material load
    - bed load
    - suspended load
  - wash load

The methodologies for estimation of the above three (3) components are described below.

(1) Bed Load

The bed load is transported downwards by rolling or sliding on the surface of riverbed. It is always in contact with the riverbed and is not suspended by all means. The actual mode of movement varies depending on the transport rate determined by the balance of the shear stress of flood flow and critical shear force of grain itself.

So far many bed load equations have been proposed on the basis of dimension analytical examinations and experimental data. Among them, Ashida & Michiue's equation [1] is employed in this study since this equation is applicable for a wide range of riverbed slope from a steep bed of alluvial fan to a gentle bed of flood plain. The equation is given below.

$$q_B/\{(\sigma/\rho-1)gd^3\}^{1/2} = 17\tau_{*e}^{3/2}\,(1-\tau_{*c}/\tau_*)\,(1-U_{*c}/U_*)$$

Where q_B is sediment runoff per unit river width per unit time, σ is sediment particle density, ρ is water density, g is gravitational acceleration, d is sediment particle diameter, τ_{*c} is critical shear stress, U_{*c} is critical shear velocity, τ_* is shear stress, and U_* is shear velocity $[\tau_*=U_*^2/\{(\sigma/\rho-1)gd\}]$.

Furthermore, effective shear stress τ_{*e} is obtained from effective shear velocity U_{*e} by using the following stream resistance equation.

$$U_0/U_{*e} = 6.0+5.75\log[R/\{d\,(1+2\tau_*)\}]$$

Where U_0 is average flow velocity, R is radius depth.

Regarding critical shear velocity, Iwagaki's equation [2] is employed. The equation is given for a uniform bed with a mean diameter (d) of gravel mixture as follows.

$$d \geq 0.303\ \text{cm} : U_{*c}^2 = 80.9\,d$$

$$0.118 \leq d < 0.303\ \text{cm} : U_{*c}^2 = 134.6\,d^{31/22}$$

$$0.0565 \leq d < 0.118\ \text{cm} : U_{*c}^2 = 55.0\,d$$

$0.0065 \leq d < 0.0565$ cm : $U_{*c}^2 = 8.41\, d^{11/32}$

$d < 0.0065$ cm : $U_{*c}^2 = 226\, d$

On the gravel mixture bed, big size particles easily move because they are exposed to water flow on the bed surface, while small particles do not easily move because they are shaded by big particles. Therefore, modified Egiazaroff's equation [3] is used to estimate critical shear stress of individual particles on the gravel mixture bed after estimation of critical shear velocity U_{*cm}^2 for the mean diameter by using Iwagaki's equation. The equation is given below.

$$d_i/d_m \geq 0.4 : \tau_{*ci} = \tau_{*cm} \{\log_{10} 19/\log_{10}(19\times d_i/d_m)\}^2 (d_i/d_m)$$

$$d_i/d_m < 0.4 : \tau_{*ci} = 0.85\, \tau_{*cm}$$

Where d_i is diameter of individual particle of gravel mixture, d_m is mean diameter of gravel mixture, τ_{*ci} is critical shear stress to the particle with a diameter (d_i), τ_{*cm} is critical shear stress to the particle with a mean diameter (d_m) [$\tau_{*cm} = U_{*cm}^2/\{(\sigma/\rho-1)gd\}$]

(2) Suspended Load

The suspended load is transported downwards, floating in the river water. It does not contact with the riverbed all the time. Its settling force is smaller than the upward component of turbulence force of the river water. The size of suspended load is in a wider range than that of wash load. It includes coarse sand.

Ashida & Michiue's equation [4),5)] is adopted from the same reason as mentioned above. The equation is given below.

$$Q_s = C_B [\{1+U_*/(\kappa U_0)\} \Lambda_1 + \Lambda_2 U_*/(\kappa U_0)] Q$$

Here, $\Lambda_1 = \{a/(h-a)\}^Z \int_{a/h}^{1} \{(1/\eta)-1\}^Z d\eta$

$\Lambda_2 = \{a/(h-a)\}^Z \int_{a/h}^{1} \ln \eta\, \{(1/\eta)-1\}^Z d\eta$

$\eta = Z/h$

$Z = w_0/(1.2\, \kappa\, U_*)$

Where Q_s is sediment discharge per time, C_B is sediment concentration at a height of [a] above bed surface, κ is Karman constant, Λ_1 and Λ_2 are parameters of concentration distribution, h is flow depth, and w_0 is terminal settling velocity of sediment particle.

(3) Wash Load

The wash load is finer in size and usually originates from hilly areas. The wash load in the Laoag River is considered to originate from not only hill and mountain slopes but also paddy fields. Sampling and laboratory tests of flood water were carried out in the lower reaches of the Laoag River to estimate the transport volume of wash load.

2.1.2 Procedure of Analysis

Sediment balance analysis is composed of two processes, namely preparation of input data and construction of sediment transport model. The preparation of input data includes modeling of riverbed materials, modeling of river channel cross section, preparation of discharge duration curve, and preparation of wash load rating curve. The construction of sediment transport model includes uniform/non-uniform flow calculation and estimation of bed load and suspended load transport. These procedures are illustrated in Fig. F.2.1.

2.2 Preparation of Input Data

2.2.1 Riverbed Material and Initial Movement

Riverbed material survey including sampling and laboratory tests was carried out for all river reaches from the fan apex of each major tributary to the river mouth in May 1996. Grain size and distribution of each sampled material were computed. The typical grain size distributions of riverbed materials are shown in Fig. F.2.2 in Phi scale classification. This figure indicates that riverbed material, in particular, boulders and cobbles are well sorted in proportion to the riverbed gradient.

The riverbed materials covered by armour layer are not moved by small flood. Once large particles composing armour layer on the riverbed starts moving by shear stress of flood current, the riverbed materials covered by the armour layer also start moving toward downstream. The critical discharge which cause initial movement of riverbed materials is estimated in order to determine the river flow regime for which sediment transport is to be calculated. The initial movement of the representative particle at the fan apex of each major tributary is examined on the assumption that the armour layer forms a uniform riverbed composed of representative particles.

The results of the examination are shown in Fig. F.2.3. Based on this figure, the critical discharge for the initial movement of riverbed is set at 1 $m^3/s/km^2$. Therefore, the sediment balance analysis is conducted for the flood discharges larger than 1 $m^3/s/km^2$.

2.2.2 River Channel Cross Section

Cross section survey was also carried out for whole stretches of the major tributaries and main river at an interval of 500 to 600 m. The entire river stretches are divided into sections at every location where the riverbed slope apparently changes. A representative cross section is established by each river section (called "block"). The longitudinal profiles and slopes of the rivers are presented in Fig. F.2.4.

2.2.3 Preparation of Hydrological Data

(1) Selection of Hydrological Average Year

The hydrological average year needs to be selected to calculate the average annual sediment balance of the Basin. The hydrological average year is determined from the annual rainfall records of the Basin. Fig. F.2.5 shows a series of annual rainfall observed at the Laoag City Station of PAGASA for the years 1961 to 1995. In this series, the year of 1968 recorded both average and median annual rainfall values. Therefore, the year of 1968 is defined as the hydrological average year for which the annual sediment balance is estimated.

(2) Estimation of Flood Duration Curve

Daily rainfall in the hydrological average year of 1968 (PAGASA in Laoag City) is shown in Fig. F.2.6. Flood runoffs in 1968 at the major locations of the Basin were simulated for the above daily rainfall records by using the simulation model discussed in Appendix B, Climate and Hydrology. Actual simulation was performed for the daily rainfall series which may cause larger flood discharges than the critical discharge of initial sediment movement estimated before (1 $m^3/s/km^2$). A consecutive 2-day rainfall of more than 50 mm generates a flood discharge almost equivalent to the critical discharge. These simulated hydrological series in 1968 are used for the annual sediment transport analysis.

However, a more detailed hydrological series is necessary for the estimation of wash load since even a small flood flow entrains wash load. The flood duration curve at Gilbert Bridge of Laoag City in 1968 was estimated by combining computed flood discharges and observed daily discharges more than 70 m^3/s (equivalent to the threshold discharge of wash load entrainment) for estimation of the annual wash load of the Basin. The flood duration curve at Gilbert Bridge is shown also in Fig. F.2.6.

Sediment balance at the design flood time is analyzed for the upper tributaries. The design flood hydrographs with a 25-year frequency at the major locations of the Basin are referred to Appendix B, Climate and Hydrology.

2.2.4 Wash Load Sampling and Testing

(1) Activities Performed

First of all, the sampling and observation site was set at the Gilbert Bridge taking into account that a flow sensor has been installed there and access is easy. After that, daily ocular inspections of color of river flow was done in order to catch the occurrence of suspended material loading. The river changed its water color from green to brown on June 26, 1996 for the first time in the rainy season after occasional showers in the mountains. From then on, sampling activities started.

During the passage of Typhoon Gloring, frequent sampling was made referring to the flood water level and velocity recorded by the flow sensor. Then, laboratory test was done to examine sediment concentration by using the gravimetric method with the cooperation of the research laboratory of Mariano Marcos State University in Batac.

Through these activities, the following facts have been clarified:

The sampled suspended particles consist of only clay and silt. The sampling at this time is considered to have caught only wash loads originating from the land surface of the Basin.

The threshold discharge to generate wash load is estimated to be 70 m^3/s, judging from the fact that the color of river water first changed from green to brown when the river discharge reached 70 m^3/s.

Density of the wash loads is estimated at 2.0 g/cm^3.

(2) Establishment of Wash Load Rating Curve

The water discharge is computed, based on the water level and flow velocity observed by the flow sensor. Then, the sediment rating curve, which shows the relationship between water discharge and sediment concentration, is obtained by regression analysis as shown in Fig. F.2.7. The equation is given below.

$$Cs = 2.547\ Q^{0.697} \quad \text{(correlation coefficient = 0.936)}$$

Where Cs is sediment concentration in mg/l, and Q is water discharge in m^3/s. In addition, this equation is converted to the following equation by assuming particle density as 2.0 g/cm^3.

$$Qs = 1.274\times10^{-6}Q^{1.697}$$

Where Qs is wash load in m^3/s. This equation is similar to the wash load observation in Japan, $Qs = (4\times10^{-8}-6\times10^{-6})Q^2$.

2.3 Annual Sediment Runoff

The average annual sediment transport including bed load and suspended load is computed for the major locations in the basin by using the simulated flood discharge data in 1968, as shown in Fig. F.2.8. In addition, annual wash load volume is also computed by using the flood duration curve and sediment rating curve at Gilbert Bridge. The estimates are summarized below.

(1) Annual Sediment Runoff to the Sea

Annual sediment runoff to the sea is estimated at 370,000 m^3 (570,000 m^3 on account of porosity of 35%) with the following breakdown.

- Wash Load : 462,900 m^3 or 81.2% of total (including porosity)
- Bed Load and Suspended Load : 107,1 00 m^3 or 18.8% of total (including porosity)

(2) Annual Sediment Deposit

Annual sediment runoff from the mountains to the six (6) major tributaries in the alluvial fan is estimated as follows on account of porosity.

River	Catchment Area (km^2)	Annual Sediment Runoff (m^3)	Specific Sediment Runoff (m^3/km^2)
Cura	69.5	54,600	790
Labugaon	100.5	154,700	1,540
Solsona	79.0	114,500	1,450
Madongan	153.8	223,100	1,450
Papa	51.4	99,600	1,940
Bongo	57.0	78,300	1,370
Total	511.2	724,800	1,420

The annual sediment balance between inflow of 733,000 m^3 including inflow of 8,200 m^3 from the Guisit River and outflow of 107,100 m^3 may be deposited in the Laoag River every year. This volume of 625,900 m^3 is equivalent to an average riverbed rising of 1.8 cm per year over the whole river stretches, as explained below in detail.

(3) Typical Deposit Area

The following river stretches are considered as typical sediment deposit areas from Fig. F2.8.

(1)	Around the alluvial fan apexes	:	192,400 m^3	(31%)
(2)	Middle reaches in alluvial fan	:	288,800 m^3	(46%)
(3)	Around the alluvial fan ends	:	50,700 m^3	(8%)
(4)	In the Lower Bongo River	:	16,100 m^3	(3%)
(5)	In the Laoag River	:	77,900 m^3	(12%)
	Total		625,900 m^3	

The annual sediment deposit in each river stretch is estimated as shown below.

River Stretch	Annual Deposit (1000 m^3/yr)	Channel Length (km)	Average Channel Width (m)	Annual Riverbed Aggradation (cm/yr)
Cura/Labugaon	144.2	15.0	320	3.0
Solsona/Madongan	270.1	19.5	270	5.1
Papa	72.7	7.2	210	4.8
Upper Bongo	44.9	11.8	240	1.6
Lower Bongo	16.1	10.8	390	0.4
Laoag	77.9	31.5	540	0.5
Whole Stretch	625.9	95.8	370	1.8

The Solsona/Madongan and Papa rivers may be affected by the heaviest sediment accumulation. This computation may not be accurate because there are some uncertainties in setting the model parameters such as flood discharge, riverbed materials and others. However, the tendency of riverbed deformation in each river course can be grasped from the computations.

2.4 Sediment Balance during Design Flood

Sediment runoff discharge from the mountains to the alluvial fan during a big flood is considered very large, but the sediment transport capacity of river channels is limited. Therefore, the riverbed of tributaries in the alluvial fan, especially around the fan apex, may be much aggradated temporarily at the time of a large flood.

The sediment balance at the fan apex during the design flood of a 25-year probability is calculated for the six (6) major tributaries, as summarized below.

River	Sediment Transport Volume (1,000 m^3)		
	Inflow to Alluvial Fan	Transport Capacity at Fan Apex	Balance
Cura	71.3	42.6	28.7
Labugaon	185.2	112.8	72.4
Solsona	166.9	108.9	58.0
Madongan	454.5	302.8	151.7
Papa	147.3	93.0	54.3
Bongo	97.5	63.4	34.1
Total	1,122.7	723.5	399.2

From the above table, the following facts are apparent:

(1) The design flood will bring a large amount of sediment (1,122,700 m^3) to the alluvial fan for a very short time. This is equivalent to 1.5 times of the average annual sediment runoff (724,800 m^3).

(2) The fan apexes will be affected by a large amount of sediment deposition only by one time flood. The total sediment deposit at the apexes of the six (6) major tributaries is estimated at 399,200 m^3.

(3) Control of the sediment runoff at the time of big floods is required.

CHAPTER III POSSIBLE STRUCTURAL MEASURES

3.1 Comparison of Possible Structural Measures

As discussed in the previous Chapter, the Laoag River Basin is affected by two (2) kinds of problems on sediment, as follows:

(1) Excessive Annual Sediment Runoff from the Mountains

The Laoag River receives sediment that exceeds its transport capacity every year, resulting in riverbed aggradation to some extent. The average annual excessive sediment is roughly estimated at 600,000 m^3/year. However, the rate of riverbed aggradation is not high except for some critical river sections. The annual riverbed aggradation of the basin is in the range of 0.4 cm and 5.1 cm, averaging 1.8 cm. The adverse effects of sediment deposit gradually accumulates although the impact is not serious during a short period of flood occurrence. Countermeasures should be viewed from a long-term perspective but implementation be undertaken in phases.

(2) Large Amount of Sediment Runoff to the Alluvial Fan at Large Floods

The sediment runoff much exceeds the sediment transport capacity of the river channel, causing a large sediment deposition at the fan apexes of the basin. This problem does not frequently occur. However, once it happens, it will breach the riverbanks and bring about significant damages on the alluvial fan area. To prevent such catastrophic disasters, highly reliable structural measures should be adopted.

To cope with the above two (2) kinds of sediment problems, the following four (4) measures are considered possible:

(1) Reforestation in the mountains
(2) Construction of sabo dam
(3) Construction of sand pocket
(4) Channel dredging

These measures are compared in terms of appropriate construction site, expected function, structural component, physical advantage and disadvantage, and adaptability to the basin, as shown in Table F.3.1.

As evident from Table F.3.1, the following measures are effective:

(1) Reforestation and construction of sabo dam are considered effective for mitigation of the annual excessive sediment runoff. Channel dredging may also be an effective measure when continuous aggregate production is executed in Laoag River, especially the upper tributaries. However, aggregate production in the upper tributaries in the future is expected to be 100,000 m^3/year at most (see Appendix I, Multipurpose Development of the Project).

(2) Only the construction of sabo dam is considered practicable to prevent a catastrophic disaster.

3.2 Selection of Suitable Sabo Dam Site

As discussed in Chapter I and II, serious sediment problems occur in the upper major tributaries, namely, Cura, Labugaon, Solsona, Madongan, Papa and Bongo. The sediment problems in the Boot, Madongon and Lading rivers are limited to small local areas and sediment control in such rivers will produce no significant effect on the downstream reaches.

The following functions expected for a sabo dam were considered in addition to sediment runoff control in identification of sabo dam sites:

(1) To consolidate the sediment deposits that accumulated around the mouth of the mountain valley so as to prevent secondary erosion; and

(2) To protect the irrigation diversion dams from serious frictional wear caused by boulder collision.

The selected sabo dam sites are shown in Fig. F.3.1 as discussed below.

(1) Cura, Labugaon, Madongan and Papa River

An enormous volume of sediment deposit have accumulated on the valley extending over some distance upstream of the intake or the diversion dams. These accumulated sediments should be consolidated by sabo dam. Four (4) sabo dam sites are selected:

(a) Just upstream of the NIS intake on the Cura River, and

(b) Just upstream of the irrigation diversion dams on the Labugaon, Madongan and Papa rivers.

Furthermore, another upstream damsite is selected in each river basin for alternative study.

(2) Solsona River

Two sabo dam sites are proposed; one approximately 2 km upstream of the irrigation diversion dam and the other at approx. 3 km upstream. These sites are selected mainly from topographic and geological aspects. The consolidation of accumulated sediment in the valley is not necessary.

(3) Bongo River

The most suitable site upstream of the diversion dam has already been selected for the Nueva Era Dam in INIP-Phase II. However, the sabo dam in this present Study is proposed at the same site because the implementation of INIP-Phase II is not clear. If Nueva Era Dam is constructed as proposed, a sediment control structure will not be necessary in the Bongo River, because the Nueva Era Dam will produce more effects in sediment control than sabo dams. If the dam is not realized, a sabo dam is proposed to be constructed at the site.

Furthermore, another damsite is selected 1.7 km upstream of the above-mentioned site for alternative study.

CHAPTER IV SEDIMENT CONTROL PLAN

4.1 Sediment Control Effects of Sabo Dam

A sabo dam has three kinds of sediment control effects, namely, (1) control of excessive sediment runoff at fan apex during floods, (2) reduction of annual sediment deposit on the riverbed and (3) reduction of large-sized sediment runoff to the downstream reaches. These sediment control mechanism and effects of sabo dam are discussed below.

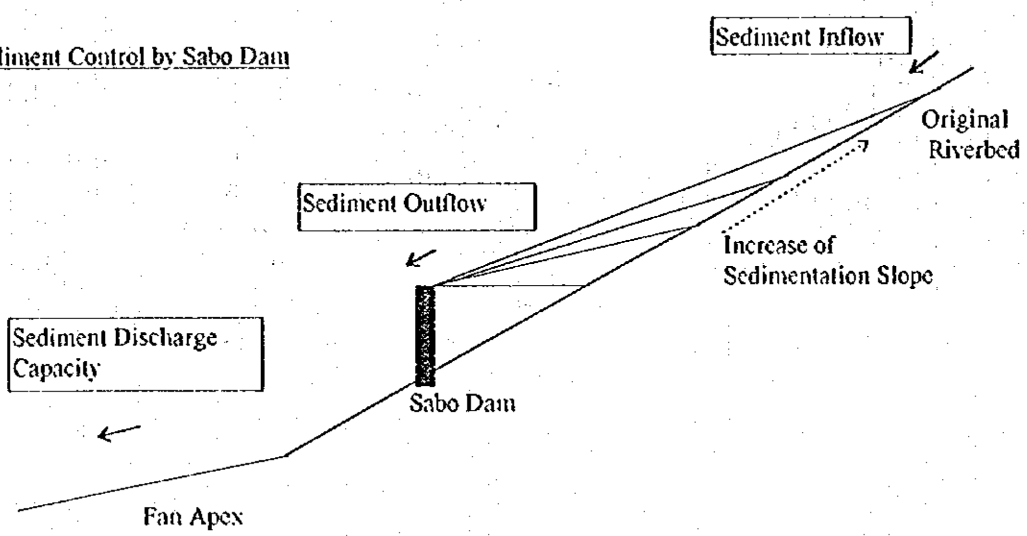
(1) Control of Excessive Sediment Runoff at Fan Apex during Floods

Immediately after construction of a sabo dam, all sediment runoff from the mountains to the sabo dam (sediment inflow) are trapped by the empty sedimentation basin and no sediment is discharged to the downstream. Once the sabo dam is filled, it begins to discharge sediment. Furthermore, the sedimentation gradient of the sabo dam becomes steeper with the lapse of time; hence, sediment outflow increases according to the increase of sedimentation gradient.

Finally, the sedimentation slope of the sabo dam gets near the original slope of the riverbed. As a result, sediment outflow of the sabo dam almost equal to its inflow, resulting in less sediment control effects. However, if the sabo dam is provided with sufficient sedimentation capacity, it will be able to effectively control sediments for years.

The sediment control effect of sabo dam is schematized as follows.

Sediment Control by Sabo Dam



- The sediment outflow is always smaller than the sediment inflow until the sedimentation slope returns to the original one.
- Sediment control benefits are great until the sediment outflow becomes bigger than the sediment discharge capacity at the fan apex.

The sediment outflow of the six (6) sabo dams for a design flood with a 25-year frequency is calculated for the various sedimentation slopes of sabo dam as shown in Fig. F.4.1. The sediment discharge capacity at the respective fan apexes are also shown for comparison. These are also tabulated below.

River	Outflow of Sabo Dam (10^3m^3)				Discharge Capacity at Fan Apex (10^3m^3)
	Original Bed	1/2 of Original Bed Slope	2/3 of Original Bed Slope	3/4 of Original Bed Slope	
Cura	71.3	20.2	35.4	43.5	42.6
Labugaon	185.2	61.1	97.8	118.5	112.8
Solsona	166.9	46.5	79.5	99.2	108.9
Madongan	454.5	120.8	213.0	266.5	302.8
Papa	147.3	41.0	70.8	88.0	93.0
Bongo	97.5	32.2	51.7	62.1	63.4

It is apparent from the above values that:

(a) The sediment outflow of the sabo dams is reduced to 27-46% of the sediment inflow (equal to the sediment outflow under the original riverbed slope) when the sedimentation gradient of the sabo dams is 1/2 of the original riverbed slope.

(b) The sediment outflow is reduced to about 60% of the sediment inflow even when the sedimentation gradient is 3/4 of original riverbed slope.

(c) In all the rivers, the sediment discharge capacities at the fan apexes are almost equivalent to the sediment outflows of the sabo dams with the sedimentation slope equal to 3/4 of original slope.

Thus, the sediment control function of sabo dam for protecting the alluvial fan areas is fully expected until the sedimentation slope rises up to 3/4 of the original slope. If proper sedimentation capacity is provided in the proposed sabo dams, this efficiency will last for a long time.

(2) Reduction of Annual Sediment Deposit on the Riverbed

The major tributaries on the alluvial fan complex are affected by the following rate of riverbed aggradation as described in Chapter II 2.3;

Cura/Labugaon Rivers	:	3.0 cm/year
Solsona/Madongan Rivers	:	5.1 cm/year
Papa River	:	4.8 cm/year
Upper Bongo River	:	1.6 cm/year

These riverbed aggradations can be mitigated by sabo dam. The mitigation effect varies depending on the sedimentation capacity of sabo dam.

(3) Reduction of Large-sized Sediment Runoff to the Downstream Reaches

As flood water flows in the sedimentation basin, its shear force decreases due to reduction of the hydraulic gradient. Then, the sediment transported, particularly, large-sized sediment are trapped in the sedimentation basin. This process enables the average sediment size of outflow to smaller than that of the inflow. This is the sieving effect of sabo dam.

The grain composition of sediment outflow for the design flood is calculated for three cases of sedimentation slopes: 1/2 of original slope, 2/3 of original slope, and the original slope, as shown also in Fig. F.4.1.

The sieving effect of the sabo dams is confirmed as follows:

(a) In proportion to the reduction of sedimentation slope of sabo dam, the ratio of sand component increases, while the ratio of pebbles, cobbles and boulders decreases.

(b) The composition ratio of cobbles and boulders decreases from 5 to 10% on the original bed to 0-6% on the bed with 1/2 of the original slope. The main cause of channel shifting around the fan apex is the excessive deposit of large-sized particles such as cobbles and boulders. The sieving effect of sediments by sabo dam will contribute much to the prevention of channel shifting around the fan apex.

4.2 Alternatives

4.2.1 Alternative Sabo Dams

The required sediment control in each river can be attained by a single dam or a series of dams. Generally, a single dam costs lower than a series of dams. However, construction of the former is difficult to perform.. This scheme require some advance investment.

The following are the basic concepts to set up the alternatives:

(1) The lower site is selected as a single dam alternative, so as to protect the existing irrigation diversion dam as well as to store sediment; and

(2) Both of the lower and upper sites are selected as a series of dams.

In the Cura, Madongan, Papa, and Bongo rivers, there is sufficient storage capacity for a single dam site. On the contrary, in the Labugaon and Solsona rivers, sufficient capacity for a single dam is not possible due to topographic constraints. Therefore, at least two dams are necessary to attain the target sediment control.

Salient features of the respective sabo dam sites are shown below.

River	Sabo Dam Site	Catchment Area (km^2)	Dam Site Width (m)	Riverbed Slope (%)
Cura	No. 1	68.2	170	1.08
	No. 2	63.1	70	1.08
Labugaon	No. 1	100.5	100	1.15
	No. 2	90.9	160	1.15
Solsona	No. 1	72.2	30	2.58
	No. 2	68.2	90	2.58
Madongan	No. 1	153.8	120	1.52
	No. 2	101.9	300	1.52
Papa	No. 1	51.4	210	2.08
	No. 2	35.3	210	2.08
Bongo	No. 1	56.0	170	1.17
	No. 2	52.8	100	1.17

4.2.2 Design Dam Height and Sedimentation Volume

The lifetime of a sabo dam is generally limited. However, the lifetime can be extended by providing a sufficient sedimentation capacity to the sabo dam. Parallel with prolonging its lifetime, the sediment storage effect is more apparent in the downstream reaches of the sabo dam where it restraints channel aggradation. In this Study, the required effective sedimentation capacity of the proposed sabo dam is determined to satisfy the following criteria:

(1) The sediment outflow of the sabo dam in design flood has to be equal to or lower than the sediment discharge capacity of the river channel at the fan apex. As mentioned in 4.1, the capacity at the fan apex is approximately equivalent to the sediment outflow from the sabo dam with 3/4 of the original slope. Thus, the design sedimentation slope is determined at 3/4 of the original slope.

(2) The sedimentation slope should be planned not exceeding the design slope for the design life of sabo dam. In this study, the design life of sabo dam is set at 20 years. Consequently, the required height and sedimentation volume can be estimated.

(3) Sediment control can also curb the average annual riverbed aggradation in the lower reaches within an allowable level for the period of 20 years. In this study, the allowable riverbed aggradation of 2.5 cm/year is determined taking into consideration some effects by reforestation projects and sieving of sabo dam.

(4) Finally, compared with two required sedimentation volumes, the design height and sedimentation volume is determined by selection of larger one.

(5) In the case of a series of dams, the lower dam (No. 1) will be constructed first. The upper dam (No. 2) will be constructed when the lower dam is filled. The design life of the lower dam is set at 10 years.

The locations and longitudinal profiles of alternative sabo dams are shown in Fig. F.4.2. The design dam height and sedimentation volume are summarized below.

River	Single Dam Alternative			Series Dams Alternative		
	Dam Site	Design Height (m)	Design Volume (1000 m^3)	Dam Site	Design Height (m)	Design Volume (1000 m^3)
Cura	No. 1	9.0	750	No. 1	6.5	391
	-	-	-	No. 2	4.5	150
Labugaon	-	-	-	No. 1	10.0	1,043
	-	-	-	No. 2	7.0	511
Solsona	-	-	-	No. 1	10.0	233
	-	-	-	No. 2	10.0	233
Madongan	No. 1	7.0	2,192	No. 1	5.5	1,353
	-	-	-	No. 2	8.0	1,011
Papa	No. 1	7.0	707	No. 1	5.5	436
	-	-	-	No. 2	4.0	262
Bongo	No. 1	9.0	692	No. 1	6.5	361
	-	-	-	No. 2	4.0	137

4.3 Preliminary Structural Design

4.3.1 General

Sixteen (16) sabo dams are selected as alternatives in the preceding section. They have effective heights ranging from 4.0 m to 10.0 m. These dams are designed as gravity concrete dams in consideration of foundation conditions (river deposits of gravel/boulders) as discussed below. Details of the preliminary structural design are based on the Japanese technical guideline entitled "River and Sabo Works Technical Standard", since there are no suitable guidelines established by the DPWH. Further, costs of sabo dams are also estimated as below.

4.3.2 Design of Sabo Dams

(1) Geological Conditions

At the time of this Master Plan Study, geological conditions of proposed sabo dam sites can be known only from site observation and the Report of the Detailed Design on Ilocos Norte Irrigation Project (Phase I), July 1981. This Project performed core boring investigations at the proposed five (5) diversion dams (Labugaon, Solsona, Madongan, Papa and Nueva Era).

Geological investigation of INIP revealed that these diversion dam sites have two geological layers consisting of river deposits and bed rock. River deposits are mainly composed of sand, gravel and boulder. They are slightly loose, but no soft deposits such as clay and silt are observed. Gravel of the river deposits mainly consists of diorite and andesite, and the matrices are composed of medium to coarse sand. Boulders having a maximum diameter of 1.5 m almost consists of diorite. The maximum thickness of river deposits ranges from 3 m to 20 m, i.e., 9 m at Labugaon Diversion Dam Site, 3 m at Solsona, 16 m at Madongan, 6 m at Papa, and 20 m at Nueva Era (Bongo). The bearing stress of these river deposits is sufficient for the construction of sabo dams; however, piping and scouring should be taken into consideration.

(2) Dam Type and Components

Judging from the purpose of sabo dam (sediment control) and the availability of economical construction materials on site (sand and stones), a gravity type (trapezoidal shape) concrete structure is considered most suitable. On the design of foundation of sabo dam, bedrock is desirable from the technical viewpoint. However, in case that deep river deposits exist on the objective bedrock, it is not economical to construct a dam on the bedrock. Vast soil excavation is necessary and concrete volume of dam increases. Accordingly, most of the proposed sabo dams are designed on river deposits (so-called "floating type") except Solsona No. 1 and No. 2 sabo dams which will be constructed on the rock base because river deposits are assumed to be thin.

A typical sabo dam consists of the following components and functions (refer to Fig. F.4.4; structural layouts of sabo dam):

(a) Main dam (to control sediment)

(b) Apron (to protect scouring of riverbed from falling water)

(c) Sub-dam (to reinforce the apron and to make water pool on apron)

(d) Side walls (to protect river sides from erosion by flowing water)

(3) Design of Major Dimensions

Basic design of sabo dams is to determine the sizes of overflow sections and slopes of gravity structure based on the stability analysis.

(a) Determination of Overflow Section

Overflow sections of sabo dams should have a sufficient opening for releasing large flood with a 100-year probability. Design flood ranges from 820 m^3/s to 2,390 m^3/s (refer to Fig. F.4.3). Overflow width is based on the present river channel width at respective dam site. Furthermore, it is assumed that 10% additional sediment is contained into the design flood discharge.

(b) Structural Stability Analysis of Dam

Major structural dimensions of sabo dams should be determined from the results of stability analysis on sliding, overturning and bearing stress. In case that height of sabo dam is below 15 m, only the flood water pressure is considered in the analysis.

(c) Major Structural Dimensions

Top width of dams is designed to be 2.5 m. Downstream slope of main dams should be protected from discharge sediment; gradient of 0.2 vertical to 1 horizontal is usually used. Upstream slope of main dams should be determined from the calculation of stability analysis. Major dimensions of alternative sabo dams are shown in Table F.4.1.

4.3.3 Cost Estimate

Construction cost of alternative sabo dam is estimated on the following conditions:

(1) Construction works are to be executed by contract.

(2) Price level is as of August, 1996.

(3) Exchange rates used to convert foreign currency into local currency are US$1.0 = 26.0 Pesos = 105 Yen (1.0 Peso = 4.0 Yen).

(4) Main construction cost consists of costs for preparatory works, main civil works and miscellaneous works. Preparatory works cover the establishment of contractor's site offices; water, power supply and communication systems; topographic survey and soil investigation; transportation of construction equipment; installation of concrete production plant; etc. This cost for preparatory works is estimated as about 10% of cost of main civil works and miscellaneous works.

(5) Cost of main civil works consisting of excavation and concrete works is estimated by multiplying work quantities by the respective unit costs.

(6) Miscellaneous works covers construction and maintenance of temporary roads, cofferdams and scaffold, and minor civil work items including waterstops, drainage pipes of dams, etc. Cost of miscellaneous works is estimated as 15% of cost of main civil works.

(7) Unit cost of work comprises direct costs of materials, labor and equipment, and indirect costs of contractor's expenses, overhead, profit, insurance, field supervision, tax, etc.

(8) Government administration cost is assumed at 5% of main construction cost.

(9) Cost of engineering services covering detailed design and construction supervision of the project is estimated as 10% of main construction cost.

(10) Physical contingency is assumed as 10% of main construction cost, administration cost and engineering services cost.

(11) Major works, in principle, will be executed as follows:

(a) First, cofferdams using riverbed material and sand bags are temporarily constructed to divert the river course by to a half width of the river. Then, excavation and concrete works are executed.

(b) Excavation work will be done using backhoes (0.6 m^3 class) and excavated materials (gravel/boulder) are hauled upstream of sites by dump trucks (11-ton).

(c) Concrete will be produced at plants (0.4 to 1.0 m^3 capacity) to be installed nearby using riverbed materials as concrete aggregates. Ready mix concrete is transported by truck mixers to dam sites and poured by using truck cranes (15-16 ton class).

Construction costs of alternatives are estimated as shown in Tables F.4.2 and F.4.3.

4.4 Optimum Sediment Control Plan

4.4.1 Optimum Plan

(1) Comparison of Construction Cost

The alternatives have almost the same sediment control effects. To determine the optimum combination of the sabo dams, the construction costs of alternatives are compared in terms of present value.

The present value is calculated under the following conditions:

(a) Discount rate is 15%; and

(b) A series of sabo dams are constructed stage-wise. The upper dam is constructed 10 years after the construction of the lower dam.

The calculated construction costs are shown in Table F.4.2. The gross construction costs of alternatives and their present value are summarized below.

(Unit: million pesos)

River	Single Dam Alternative		Series of Dams Alternative	
	Gross Cost	Present Value	Gross Cost	Present Value
Cura	82.0	82.0	79.7	61.0
Labugaon	140.0	91.6	140.0	91.6
Solsona	88.9	51.6	88.9	51.6
Madongan	65.7	65.7	169.4	81.5
Papa	65.9	65.9	84.9	59.4
Bongo	67.3	67.3	70.5	53.2

(2) Optimum Development

As evident from the above table, a single dam is more appropriate for the Madongan River while a series of dams is more applicable for the Cura and Bongo rivers.

For the Papa River, a series of dams is more economical than a single dam in terms of the present value. However, the economical advantage is negligible. Hence, a single dam is recommended for Papa River.

The optimum sabo dam development is summarized below.

River	Dam Site	Dam Height (m)	Design Volume (10^3 m^3)
Cura	No. 1	6.5	391
	No. 2	4.5	150
Labugaon	No. 1	10.0	1,043
	No. 2	7.0	511
Solsona	No. 1	10.0	233
	No. 2	10.0	233
Madongan	No. 1	7.0	2,192
Papa	No. 1	7.0	707
Bongo	No. 1	6.5	361
	No. 2	4.0	137
Total			5,958

Structural layouts of ten (10) optimum sabo dams selected are shown in Fig. F.4.4.

Construction costs of the ten (10) optimum sabo dams are summarized as follows.

(Unit: million pesos)

Sabo Dam	Main Constructio n Cost	Adm. Cost	Engineering Cost	Physical Contingenc y	Total
Cura No. 1	43.4	2.2	4.3	5.0	54.9
Cura No. 2	19.6	1.0	2.0	2.2	24.8
Labugaon No. 1	59.8	3.0	6.0	6.9	75.7
Labugaon No. 2	50.9	2.5	5.1	5.8	64.3
Solsona No. 1	31.1	1.6	3.1	3.6	39.4
Solsona No. 2	39.1	2.0	3.9	4.5	49.5
Madongan	51.9	2.6	5.2	6.0	65.7
Papa	52.1	2.6	5.2	6.0	65.9
Bongo No. 1	37.5	1.9	3.8	4.3	47.5
Bongo No. 1	18.2	0.9	1.8	2.1	23.0
Total	403.6	20.3	40.4	46.4	510.7

4.4.2 Verification of Sediment Control Effect

(1) Variation of Sediment Control Efficiency

The sediment control efficiency of sabo dam can reasonably be defined as the ratio of the sediment discharge capacity at the fan apex to the sediment outflow from the sabo dam. The control efficiency is larger than the design one (100%) until the sedimentation of sabo dam reaches the design sedimentation volume. Even after the design sedimentation volume is reached, a considerable extent of control efficiency will be maintained.

The variation in the sabo dam control efficiency in the respective rivers are calculated by defining the control efficiency as follows:

Control Efficiency = $(Q_{in} - Q_{out}) / (Q_{in} - Q_{apex})$

Where, Q_{in} : Sediment inflow to sabo dam

Q_{out} : Sediment outflow from sabo dam

Q_{apex} : Sediment discharge capacity at fan apex

Change of the control efficiency and sedimentation slope in each river is illustrated in Fig. F.4.5. As evident from the above figure, the control effect of the sabo dams will be maintained for a long time. Efficiency in all target rivers will be maintained more than 75% even after 30 years.

(2) Control of River Bed Aggradation

The height or sedimentation volume of the sabo dams are designed to control the annual aggradation rate of the riverbed in the alluvial fan rivers to less than 2.5 cm/year throughout the 20 years of project life. The estimated average annual aggradation rates for 20 years in case with and without the project are compared as follows.

River	Average Annual Aggradation (cm/year)	
	Without Sabo Dam	With Sabo Dam
Cura/Labugaon	3.0	0.7
Solsona/Madongan	5.1	2.5
Papa	4.8	2.3
Upper Bongo	1.6	0.6

The above riverbed aggradations will be further decreased by the ongoing reforestation projects and the sediment sieving effects of the sabo dams.

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TABLES

Table F.3.1 Comparison of Possible Structural Measures

Structural Measures	Appropriate Location	Expected Functions	Principal Components of Structure	Advantage	Disadvantage	Adaptability to This Basin
Reforestation	Hill and mountain slopes	- Prevention of soil erosion	None	- Various additional effects to environment and local community are expected.	- Long period is needed to complete works. - Effectiveness is not clear against mass earth movement like landslide.	High but no special plan is proposed. DENR has already prepared the master plan.
Construction of Sabo Dam	Upper stretch of the fan apex	- Control of sediment runoff to alluvial fan	- Dam - Consolidation structures in downstream of dam	- Sediment control with a high reliability is expected. - No maintenance work is necessary. - It can prevent structural damage of irrigation diversion dam by constructing just upstream of irrigation dam.	- Excessive degradation of the river channel around fan apex is apprehended.	High There are many possible sabo dam sites.
Construction of Sand Pocket	Just downstream of the fan apex	- Control of sediment runoff to alluvial fan	- Lateral dike - Transverse dike with spillway - Consolidation structures inside the pocket	- It can enclose potential channel shifting zone at fan apex, resulting in reduction of risk of channel shifting.	- Continuous dredging of sand pocket is necessary to maintain necessary storage volume. - Wide area is needed to obtain necessary capacity. - Insufficient maintenance of the sand pocket increases risk of over-bank flooding of sand pocket.	Low There is no possible site with a large capacity.
Channel Dredging	Whole river stretches on the alluvial fan	- Security of flood carrying capacity of channel	None but heavy equipment is necessary	- Effects easily appears on site.	- Continuous dredging is necessary.	High when multipurpose dredging is expected.

Table F.4.1 Major Dimensions of Alternative Sabo Dams

Alternative	Name of Dam		Main Dam						Apron		Counter-dam	Total	Hydraulic Conditions		
			Effective Height He (m)	Total Height Ht (m)	Crown Width Wc (m)	Slope (down-stream)	Slope, N (up-stream)	Top Length Lt (m)	Length La (m)	Thickness Ta (m)	Effective Height Hs (m)	Concrete Volume (m3)	Design Discharge (m3/s)	Overflow Depth Df (m)	Overflow Width Wf (m)
Single Sabo Dam	Cura	No.1	9.0	11.5	2.5	0.20	0.60	170	24	1.3	2.0	20,100	1,080	2.8	150
	Madongan	No.1	7.0	9.5	2.5	0.20	0.70	120	26	2.1	2.5	16,000	2,390	6	100
	Papa	No.1	7.0	9.5	2.5	0.20	0.50	210	17	0.9	1.5	16,100	820	1.9	200
	Bongo	No.1	9.0	11.5	2.5	0.20	0.60	170	25	1.5	2.2	16,500	890	3.4	90
A Sries of Sabo Dams	Cura	No.1	6.5	9.0	2.5	0.20	0.55	170	18	1.1	1.7	13,400	1,080	2.8	150
		No.2	4.5	7.0	2.5	0.20	0.60	70	20	1.8	1.9	5,900	1,000	5.3	50
	Labugaon	No.1	10.0	12.5	2.5	0.20	0.80	100	30	2.0	2.8	18,500	1,580	4.9	90
		No.2	7.0	9.5	2.5	0.20	0.60	160	21	1.4	2.0	15,400	1,430	3.6	130
	Solsona	No.1	10.0	12.5	2.5	0.20	0.80	30	40	2.0	4.8	9,600	1,140	9.7	20
		No.2	10.0	12.5	2.5	0.20	0.75	90	40	2.0	4.5	11,900	1,080	9.4	20
	Madongan	No.1	5.5	8.0	2.5	0.20	0.65	120	23	2.0	2.2	12,800	2,390	6	100
		No.2	8.0	10.5	2.5	0.20	0.55	300	21	1.1	1.8	28,100	1,600	2.4	270
	Papa	No.1	5.5	8.0	2.5	0.20	0.45	210	15	0.8	1.3	12,400	820	1.9	200
		No.2	4.0	6.5	2.5	0.20	0.35	210	11	0.6	1.0	8,100	570	1.6	180
	Bongo	No.1	6.5	9.0	2.5	0.20	0.60	170	20	1.3	1.8	11,600	890	3.4	90
		No.2	4.0	6.5	2.5	0.20	0.50	100	15	1.2	1.4	5,500	840	3.5	80

Table F.4.2 Construction Cost of Alternative Sabo Dams (Summary)

(1) Single Sabo Dam

Unit : million pesos

Sabo Dam		Civil Works	Administration	Engineering	Physical Cont.	Total	Grand Total
Cura	No.1	64.9	3.2	6.5	7.4	82.0	82.0
Madongan	No.1	51.9	2.6	5.2	6.0	65.7	65.7
Papa	No.1	52.1	2.6	5.2	6.0	65.9	65.9
Bongo	No.1	53.2	2.7	5.3	6.1	67.3	67.3

(2) A Series of Sabo Dams

Unit : million pesos

Sabo Dam		Civil Works	Administration	Engineering	Physical Cont.	Total	Grand Total
Cura	No.1	43.4	2.2	4.3	5.0	54.9	
	No.2	19.6	1.0	2.0	2.2	24.8	79.7
Labugaon	No.1	59.8	3.0	6.0	6.9	75.7	
	No.2	50.9	2.5	5.1	5.8	64.3	140.0
Solsona	No.1	31.1	1.6	3.1	3.6	39.4	
	No.2	39.1	2.0	3.9	4.5	49.5	88.9
Madongan	No.1	41.6	2.1	4.1	4.9	52.7	
	No.2	92.2	4.6	9.2	10.7	116.7	169.4
Papa	No.1	40.3	2.0	4.0	4.6	50.9	
	No.2	26.8	1.3	2.7	3.2	34.0	84.9
Bongo	No.1	37.5	1.9	3.8	4.3	47.5	
	No.2	18.2	0.9	1.8	2.1	23.0	70.5

Table F.4.3(1) Construction Cost of Alternative Sabo Dams (Breakdown)

Single Dam: (1) Cura Sabo Dam No.1 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				64,900,825
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			5,900,075
1.2 Main Works				51,305,000
(1) Structure Excavation(Gravel/Boulder)	m3	11,800	75	885,000
(2) Structure Excavation(Rock)	m3	500	340	170,000
(3) Concreting Works	m3	20,100	2,500	50,250,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			7,695,750
2. ADMINISTRATION COST (5% OF 1.)	l.s			3,245,041
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			6,490,083
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			7,463,595
TOTAL				82,099,544

Single Dam: (2) Madongan Sabo Dam No.1 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				51,853,615
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			4,713,965
1.2 Main Works				40,991,000
(1) Structure Excavation(Gravel/Boulder)	m3	11,400	75	855,000
(2) Structure Excavation(Rock)	m3	400	340	136,000
(3) Concreting Works	m3	16,000	2,500	40,000,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			6,148,650
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,592,681
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			5,185,362
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			5,963,166
TOTAL				65,594,823

Table F.4.3 (2) Construction Cost of Alternative Sabo Dams (Breakdown)

Single Dam: (3) Papa Sabo Dam No.1 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				52,065,503
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			4,733,228
1.2 Main Works				41,158,500
(1) Structure Excavation(Gravel/Boulder)	m3	10,300	75	772,500
(2) Structure Excavation(Rock)	m3	400	340	136,000
(3) Concreting Works	m3	16,100	2,500	40,250,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			6,173,775
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,603,275
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			5,206,550
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			5,987,533
TOTAL				65,862,861

Single Dam: (4) Bongo Sabo Dam No.1 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				53,231,200
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			4,839,200
1.2 Main Works				42,080,000
(1) Structure Excavation(Gravel/Boulder)	m3	8,800	75	660,000
(2) Structure Excavation(Rock)	m3	500	340	170,000
(3) Concreting Works	m3	16,500	2,500	41,250,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			6,312,000
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,661,560
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			5,323,120
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			6,121,588
TOTAL				67,337,468

Table F.4.3 (3) Construction Cost of Alternative Sabo Dams (Breakdown)

Series Dams: (1) Cura Sabo Dam No.1 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				43,350,918
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			3,940,993
1.2 Main Works				34,269,500
(1) Structure Excavation(Gravel/Boulder)	m3	8,900	75	667,500
(2) Structure Excavation(Rock)	m3	300	340	102,000
(3) Concreting Works	m3	13,400	2,500	33,500,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			5,140,425
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,167,546
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			4,335,092
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			4,985,356
TOTAL				54,838,911

Series Dams: (2) Cura Sabo Dam No.2 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				19,554,416
1.1 Preparatory Works (12% of 1.2 + 1.3)	l.s			2,095,116
1.2 Main Works				15,182,000
(1) Structure Excavation(Gravel/Boulder)	m3	4,400	75	330,000
(2) Structure Excavation(Rock)	m3	300	340	102,000
(3) Concreting Works	m3	5,900	2,500	14,750,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			2,277,300
2. ADMINISTRATION COST (5% OF 1.)	l.s			977,721
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			1,955,442
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			2,248,758
TOTAL				24,736,336

Table F.4.3 (4) Construction Cost of Alternative Sabo Dams (Breakdown)

Series Dams: (3) Labugaon Sabo Dam No.1 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				59,826,910
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			5,438,810
1.2 Main Works				47,294,000
(1) Structure Excavation(Gravel/Boulder)	m3	11,200	75	840,000
(2) Structure Excavation(Rock)	m3	600	340	204,000
(3) Concreting Works	m3	18,500	2,500	46,250,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			7,094,100
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,991,346
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			5,982,691
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3)	l.s			6,880,095
TOTAL				75,681,041

Series Dams: (4) Labugaon Sabo Dam No.2 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				50,864,408
1.1 Preparatory Works (12% of 1.2 + 1.3)	l.s			5,449,758
1.2 Main Works				39,491,000
(1) Structure Excavation(Gravel/Boulder)	m3	11,400	75	855,000
(2) Structure Excavation(Rock)	m3	400	340	136,000
(3) Concreting Works	m3	15,400	2,500	38,500,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			5,923,650
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,543,220
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			5,086,441
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3)	l.s			5,849,407
TOTAL				64,343,476

Table F.4.3 (5) Construction Cost of Alternative Sabo Dams (Breakdown)

Series Dams: (5) Solsona Sabo Dam No.1 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				31,135,445
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			2,830,495
1.2 Main Works				24,613,000
(1) Structure Excavation(Gravel/Boulder)	m3	5,000	75	375,000
(2) Structure Excavation(Rock)	m3	700	340	238,000
(3) Concreting Works	m3	9,600	2,500	24,000,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			3,691,950
2. ADMINISTRATION COST (5% OF 1.)	l.s			1,556,772
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			3,113,545
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			3,580,576
TOTAL				39,386,338

Series Dams: (6) Solsona Sabo Dam No.2 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				39,142,320
1.1 Preparatory Works (12% of 1.2 + 1.3)	l.s			4,193,820
1.2 Main Works				30,390,000
(1) Structure Excavation(Gravel/Boulder)	m3	4,000	75	300,000
(2) Structure Excavation(Rock)	m3	1,000	340	340,000
(3) Concreting Works	m3	11,900	2,500	29,750,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			4,558,500
2. ADMINISTRATION COST (5% OF 1.)	l.s			1,957,116
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			3,914,232
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			4,501,367
TOTAL				49,515,035

Table F.4.3 (6) Construction Cost of Alternative Sabo Dams (Breakdown)

Series Dams: (7) Madongan Sabo Dam No.1 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				41,624,825
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			3,784,075
1.2 Main Works				32,905,000
(1) Structure Excavation(Gravel/Boulder)	m3	9,800	75	735,000
(2) Structure Excavation(Rock)	m3	500	340	170,000
(3) Concreting Works	m3	12,800	2,500	32,000,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			4,935,750
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,081,241
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			4,162,483
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			4,786,855
TOTAL				52,655,404

Series Dams: (8) Madongan Sabo Dam No.2 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				92,255,576
1.1 Preparatory Works (12% of 1.2 + 1.3)	l.s			9,884,526
1.2 Main Works				71,627,000
(1) Structure Excavation(Gravel/Boulder)	m3	17,000	75	1,275,000
(2) Structure Excavation(Rock)	m3	300	340	102,000
(3) Concreting Works	m3	28,100	2,500	70,250,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			10,744,050
2. ADMINISTRATION COST (5% OF 1.)	l.s			4,612,779
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			9,225,558
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			10,609,391
TOTAL				116,703,304

Table F.4.3 (7) Construction Cost of Alternative Sabo Dams (Breakdown)

Series Dams: (9) Papa Sabo Dam No.1 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				40,302,268
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			3,663,843
1.2 Main Works				31,859,500
(1) Structure Excavation(Gravel/Boulder)	m3	10,100	75	757,500
(2) Structure Excavation(Rock)	m3	300	340	102,000
(3) Concreting Works	m3	12,400	2,500	31,000,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			4,778,925
2. ADMINISTRATION COST (5% OF 1.)	l.s			2,015,113
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			4,030,227
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			4,634,761
TOTAL				50,982,368

Series Dams: (10) Papa Sabo Dam No.2 Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				26,778,164
1.1 Preparatory Works (12% of 1.2 + 1.3)	l.s			2,869,089
1.2 Main Works				20,790,500
(1) Structure Excavation(Gravel/Boulder)	m3	6,300	75	472,500
(2) Structure Excavation(Rock)	m3	200	340	68,000
(3) Concreting Works	m3	8,100	2,500	20,250,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			3,118,575
2. ADMINISTRATION COST (5% OF 1.)	l.s			1,338,908
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			2,677,816
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			3,079,489
TOTAL				33,874,377

Table F.4.3 (8) Construction Cost of Alternative Sabo Dams (Breakdown)

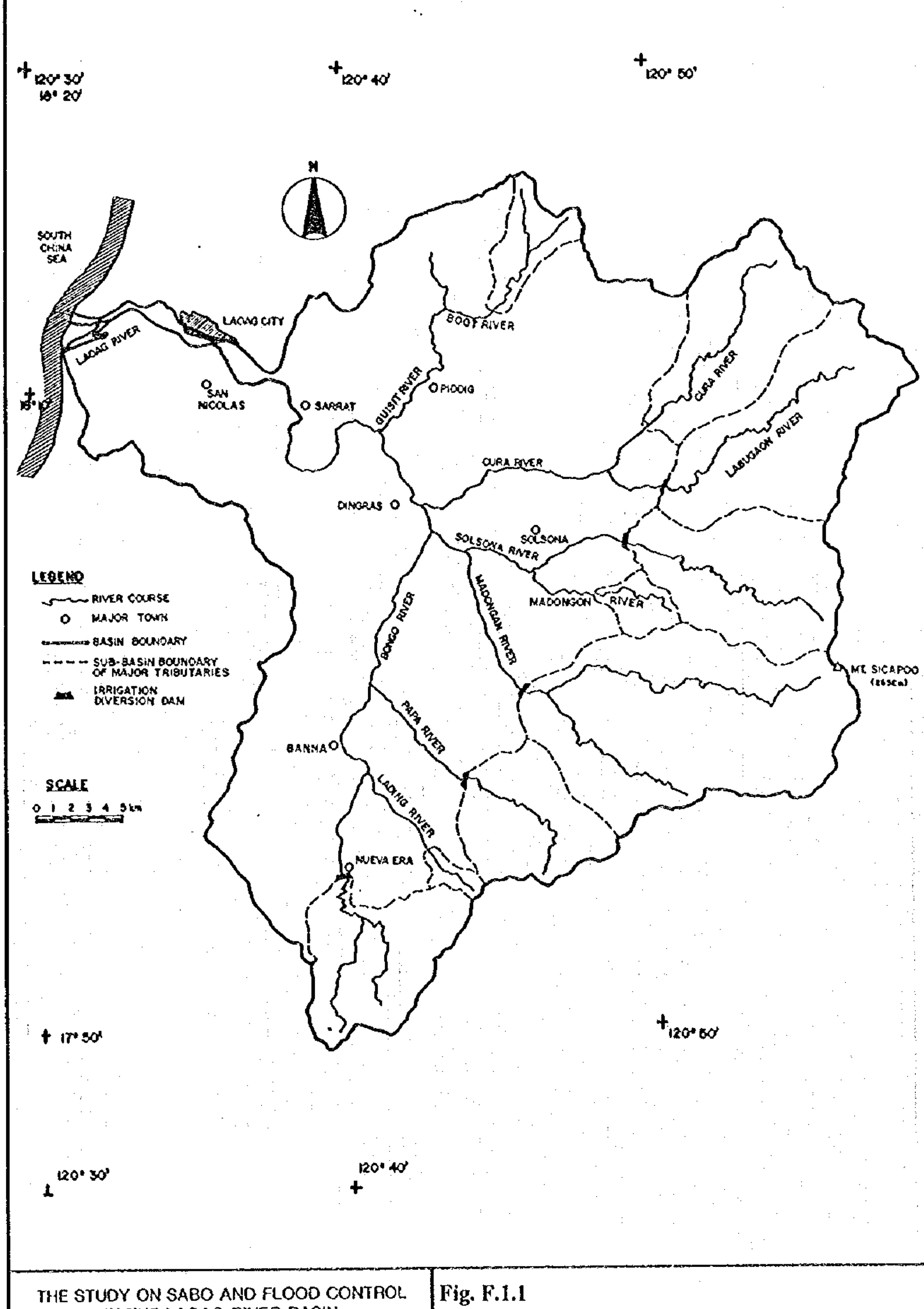
Series Dams: (11) Bongo Sabo Dam No.1 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				37,540,140
1.1 Preparatory Works (10% of 1.2 + 1.3)	l.s			3,412,740
1.2 Main Works				29,676,000
(1) Structure Excavation(Gravel/Boulder)	m3	7,200	75	540,000
(2) Structure Excavation(Rock)	m3	400	340	136,000
(3) Concreting Works	m3	11,600	2,500	29,000,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			4,451,400
2. ADMINISTRATION COST (5% OF 1.)	l.s			1,877,007
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			3,754,014
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			4,317,116
TOTAL				47,488,277

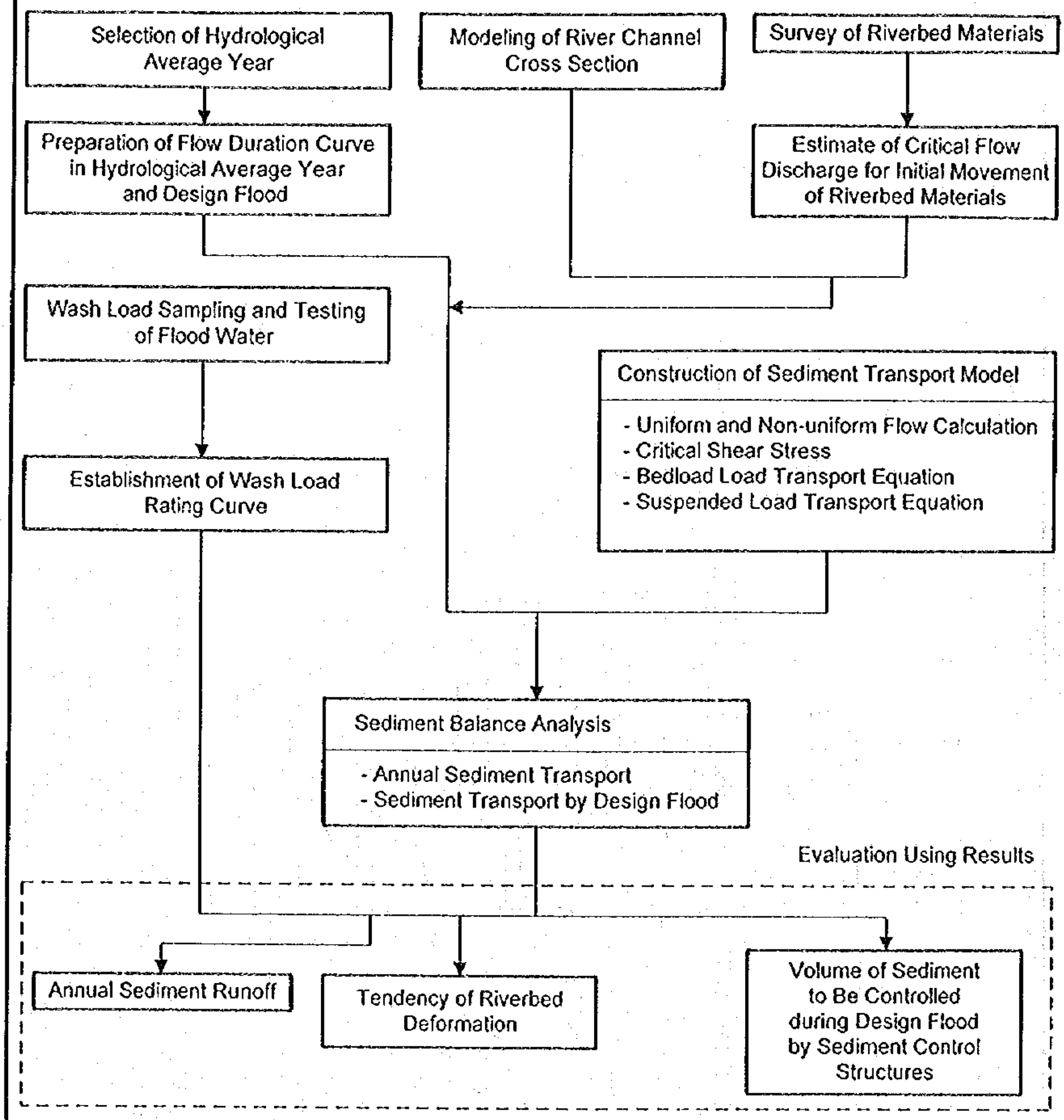
Series Dams: (12) Bongo Sabo Dam No.2 — Unit:pesos

Work Item	Unit	Quantity	Unit Cost	Amount
1. MAIN CONSTRUCTION COST				18,203,304
1.1 Preparatory Works (12% of 1.2 + 1.3)	l.s			1,950,354
1.2 Main Works				14,133,000
(1) Structure Excavation(Gravel/Boulder)	m3	4,200	75	315,000
(2) Structure Excavation(Rock)	m3	200	340	68,000
(3) Concreting Works	m3	5,500	2,500	13,750,000
1.3 Miscellaneous Works (15% of 1.2)	l.s			2,119,950
2. ADMINISTRATION COST (5% OF 1.)	l.s			910,165
3. ENGINEERING SERVICES COST (10% OF 1.)	l.s			1,820,330
4. PHYSICAL CONTINGENCY COST (10% OF 1., 2. & 3.)	l.s			2,093,380
TOTAL				23,027,180

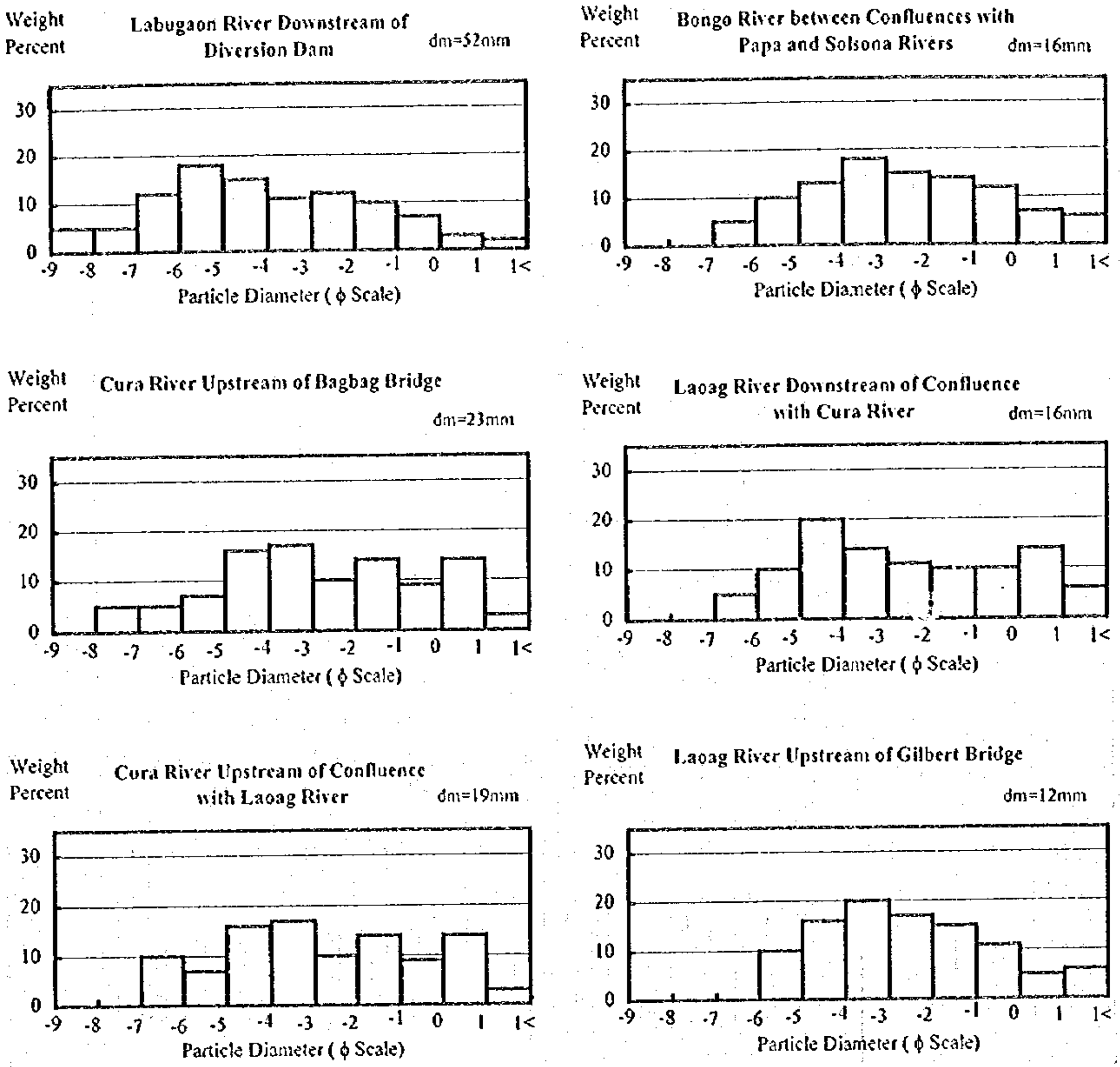
FIGURES



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. F.1.1
JAPAN INTERNATIONAL COOPERATION AGENCY	Location of Tributaries



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	**Fig. F.2.1**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Procedure of Sediment Balance Analysis**



Sediment Classification

Sediment Size Class	Phi Scale	Sieve Size (mm)
Small Boulders	-9 to -8	256-512
Large Cobbles	-8 to -7	128-256
Small Cobbles	-7 to -6	64-128
Very Coarse Pebbles	-6 to -5	32-64
Coarse Pebbles	-5 to -4	16-32
Medium Pebbles	-4 to -3	8-16
Fine Pebbles	-3 to -2	4-8
Very Fine Pebbles	-2 to -1	2-4
Very Coarse Sand	-1 to 0	1-2
Coarse Sand	0 to 1	1-0.5
Medium/Fine Sand and Silt	1 <	< 0.5

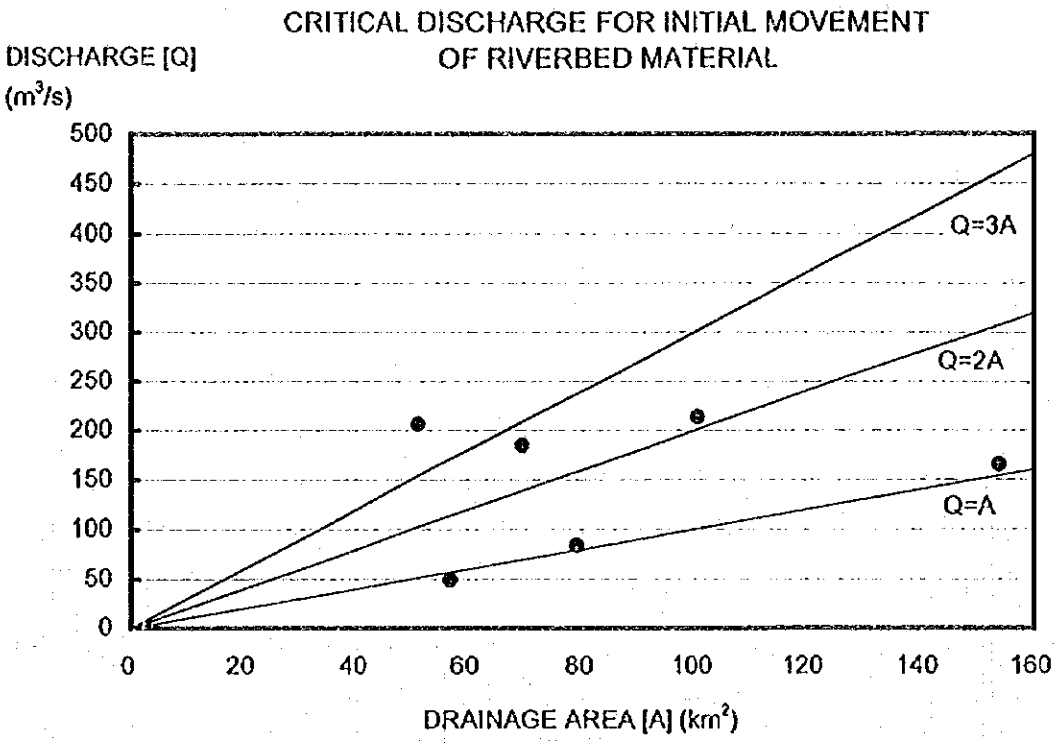
Phi= $-\log_2 d$

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. F.2.2

Typical Grain Distribution of Riverbed Material

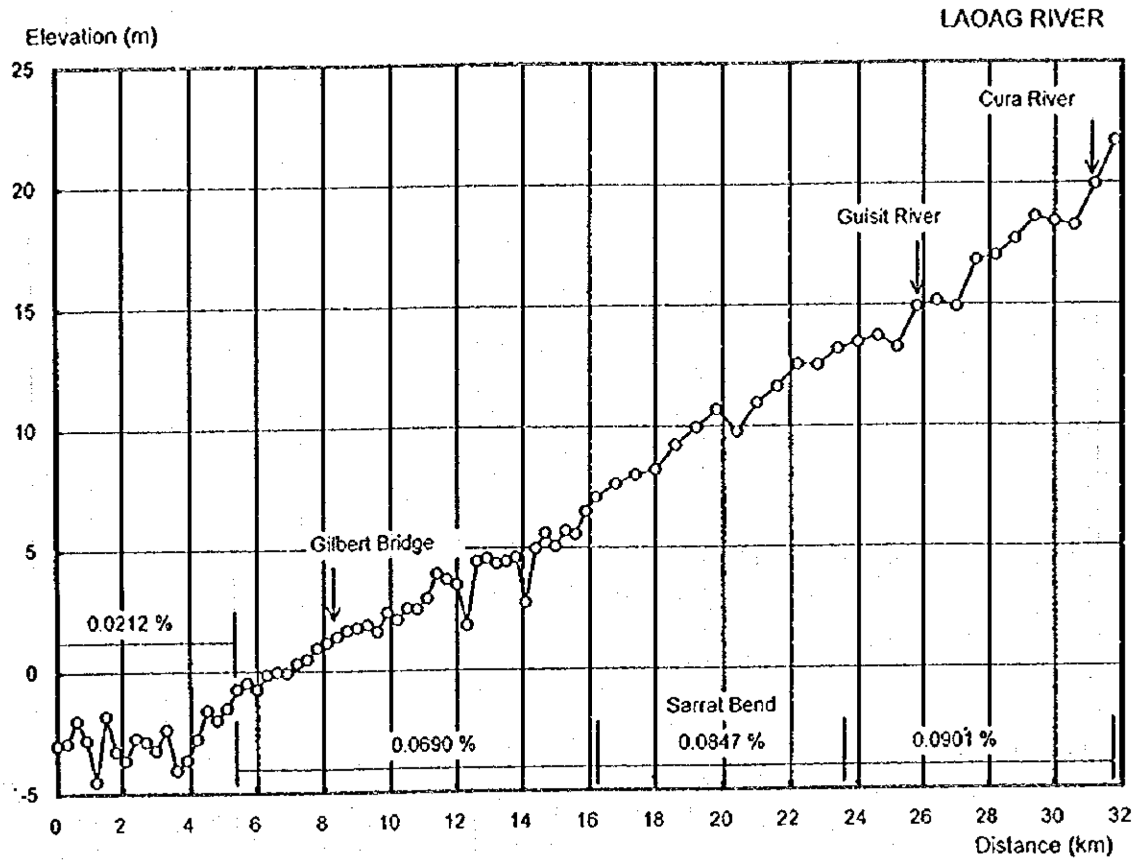


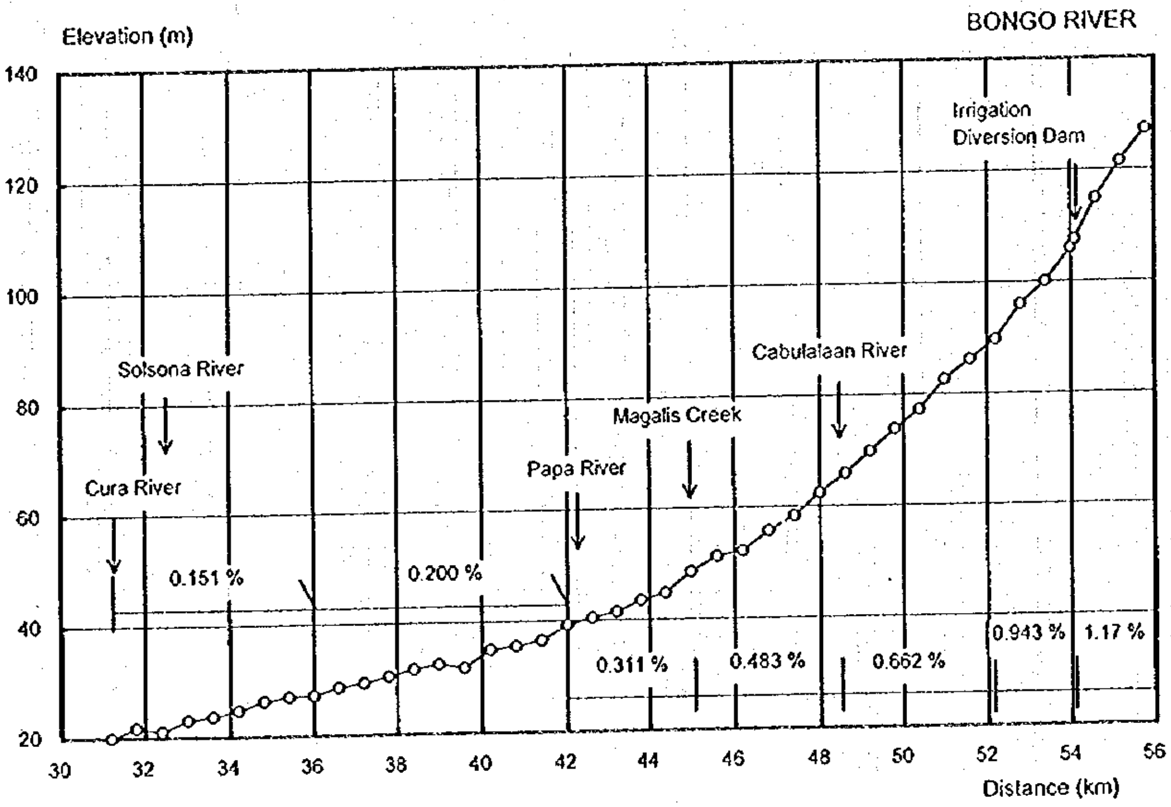
FLOW DISCHARGE GENERATING CRITICAL SHEAR VELOCITY

River	Drainage Area (km2)	Diameter of Material in Armour Layer (cm)	Critical Shear Velocity (cm/s)	Equivalen Flow Discharge (m3/s)	Specific Discharge (m3/s/km2)
Cura	69.5	15	34.8	185.0	2.66
Labugaon	100.5	20	40.2	213.6	2.13
Solsona	79.0	25	45.0	84.2	1.07
Madonga	153.8	20	40.2	165.5	1.08
Papa	51.4	30	49.2	206.4	4.02
Bongo	57.0	15	34.8	49.6	0.87

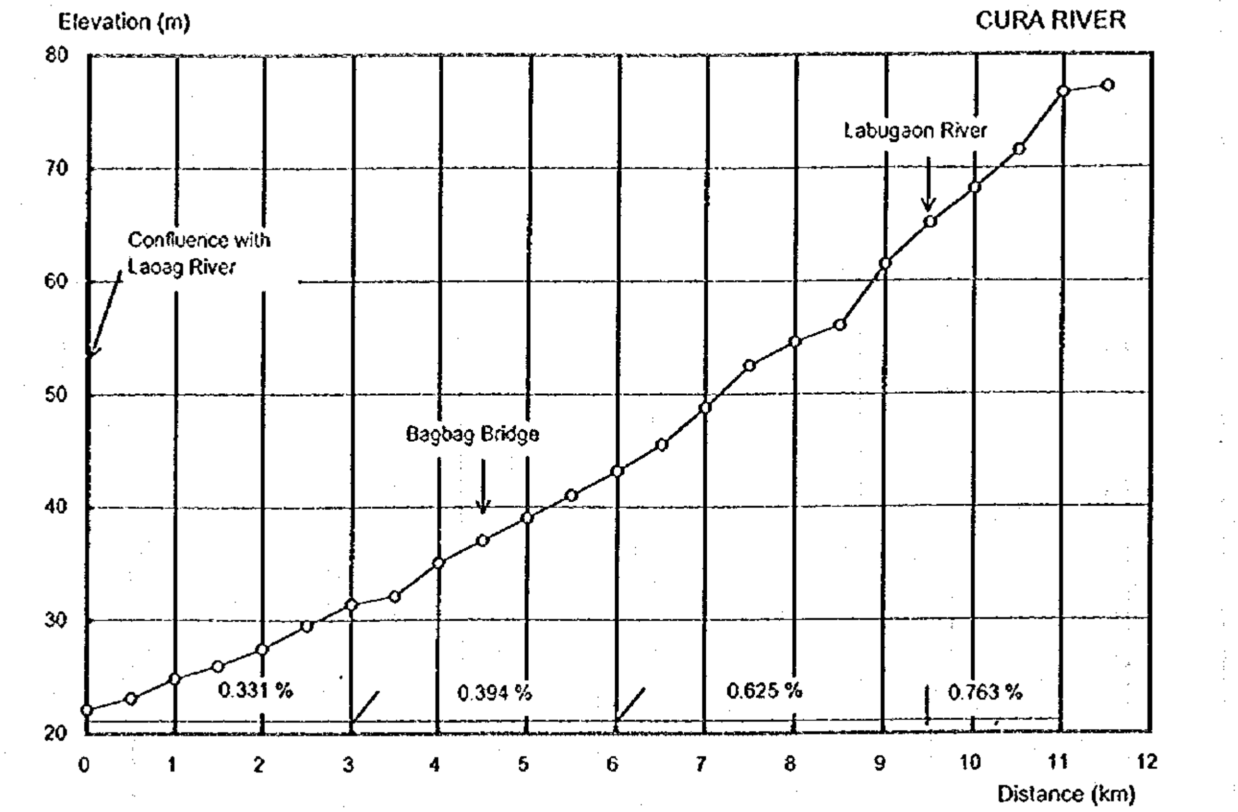
Fig. F.2.3

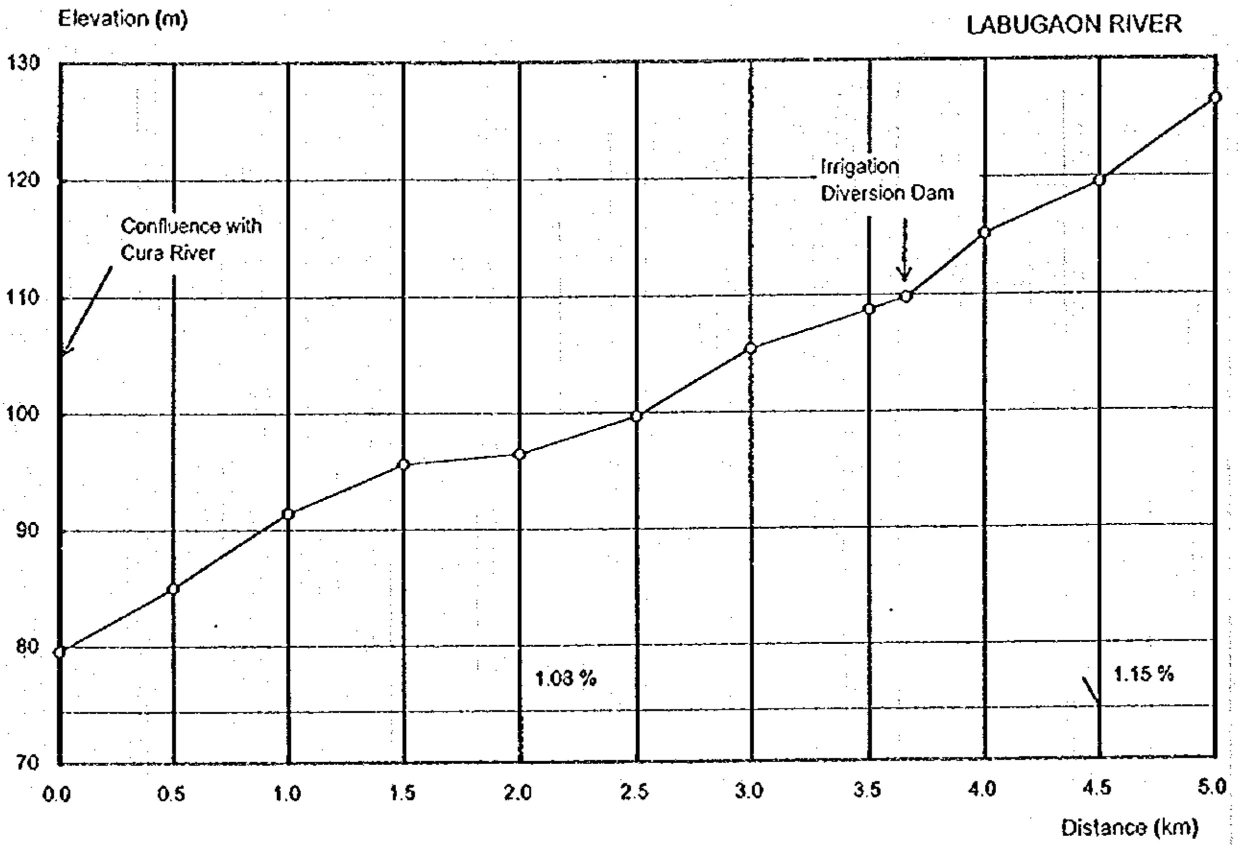
Initial Movement of Armour Layer in Each Tributary



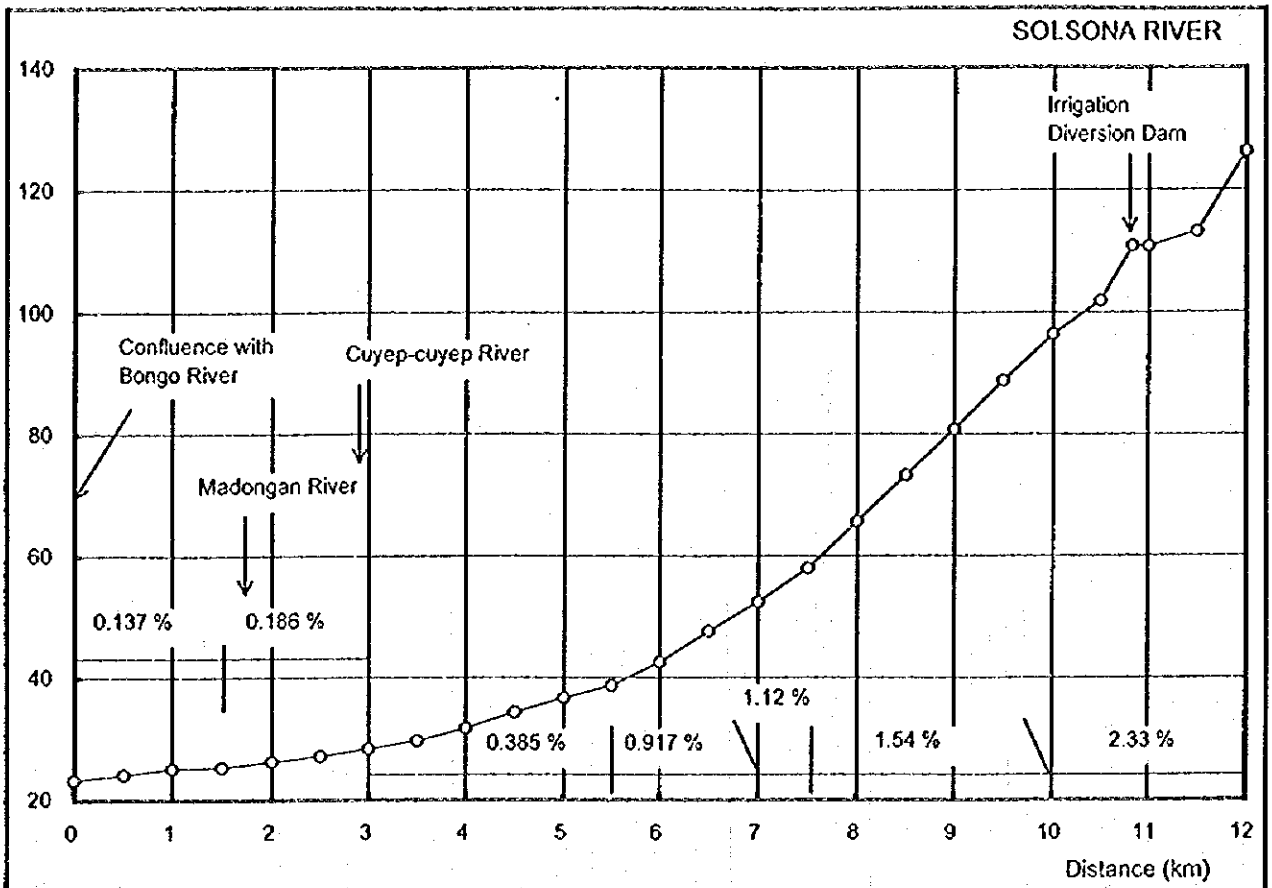


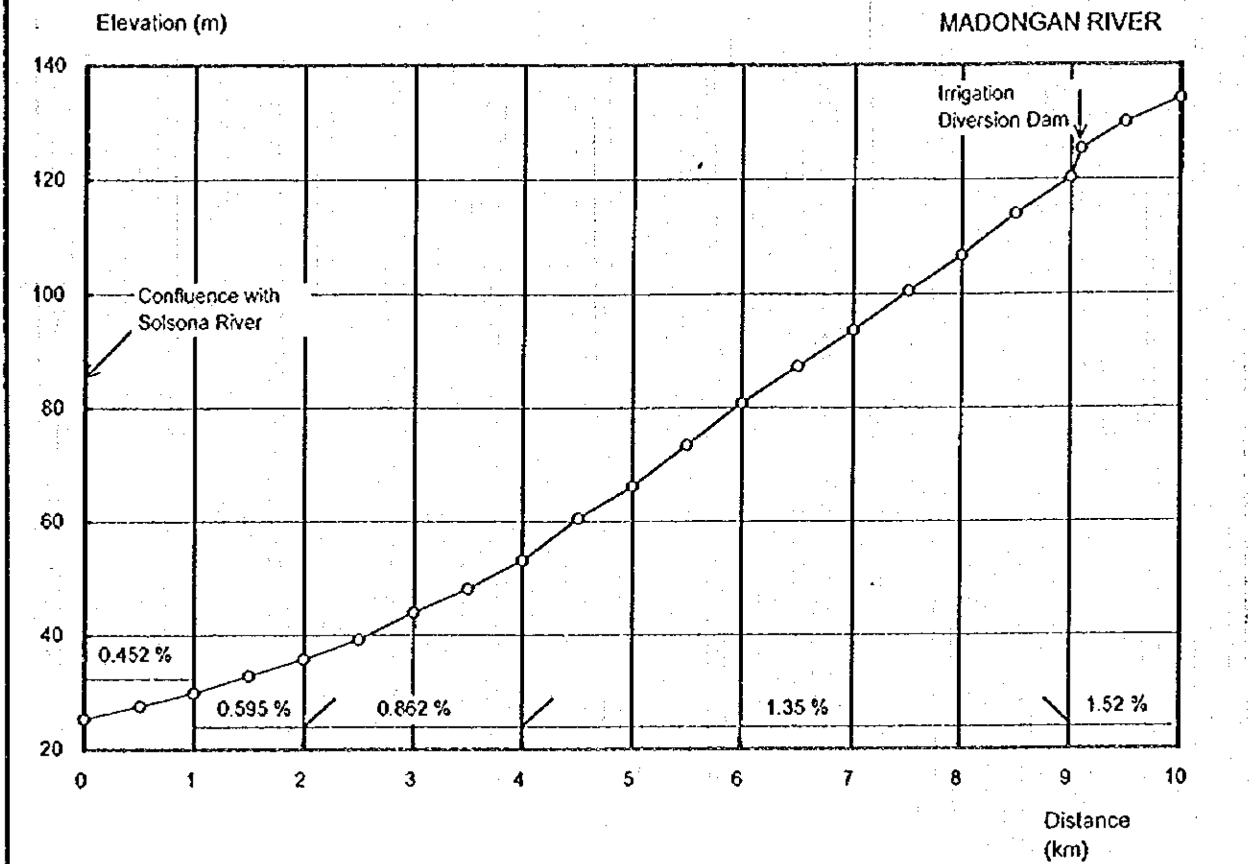
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. F.2.4(1)** **Longitudinal Profile and Riverbed Slope (Laoag and Bongo Rivers)**



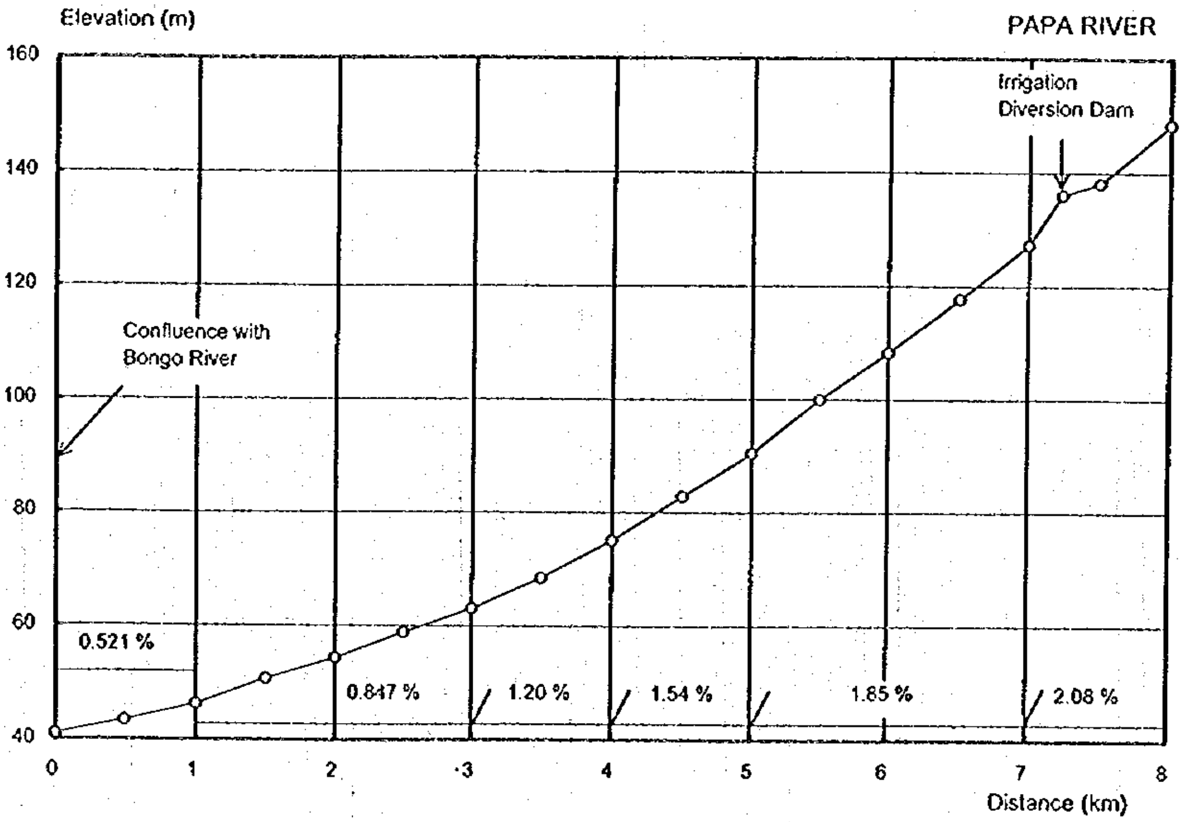


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. F.2.4(2)** **Longitudinal Profile and Riverbed Slope (Cura and Labugaon Rivers)**

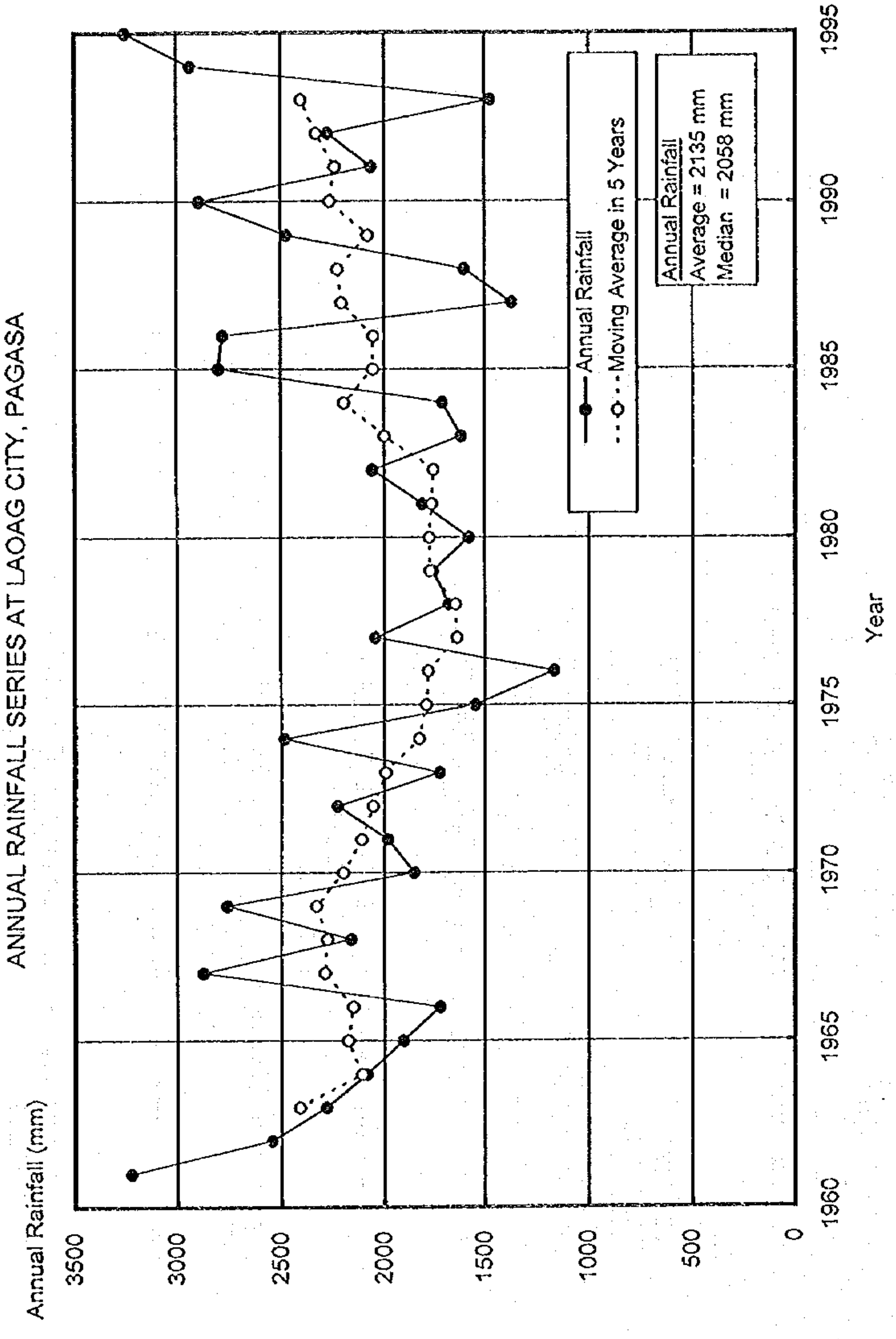




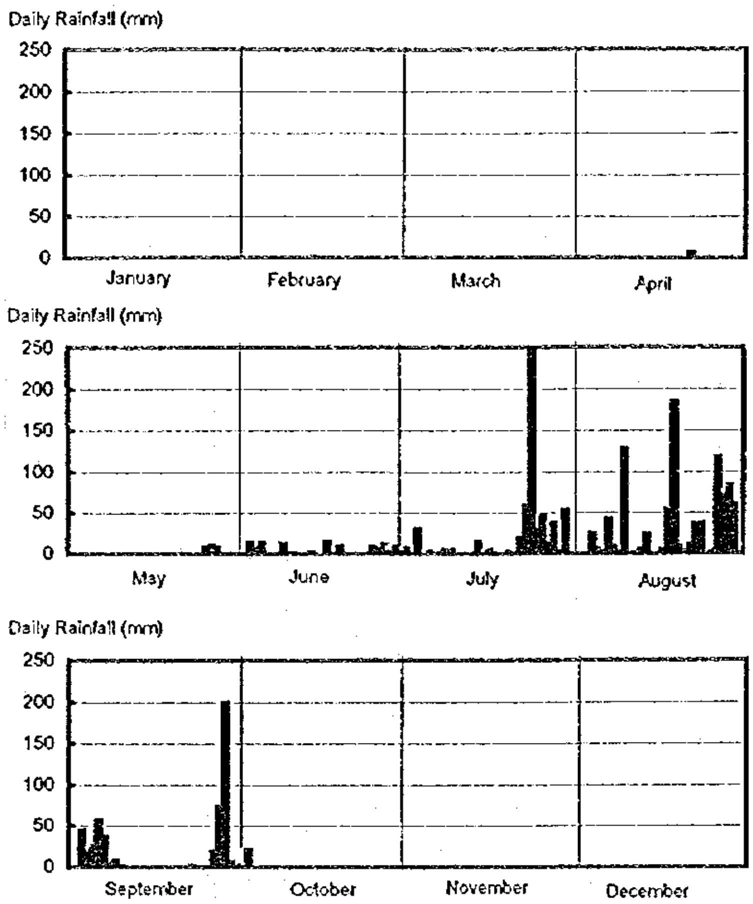
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	**Fig. F.2.4(3)**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Longitudinal Profile and Riverbed Slope (Solsona and Madongan Rivers)**



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	**Fig. F.2.4(4)**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Longitudinal Profile and Riverbed Slope (Papa River)**

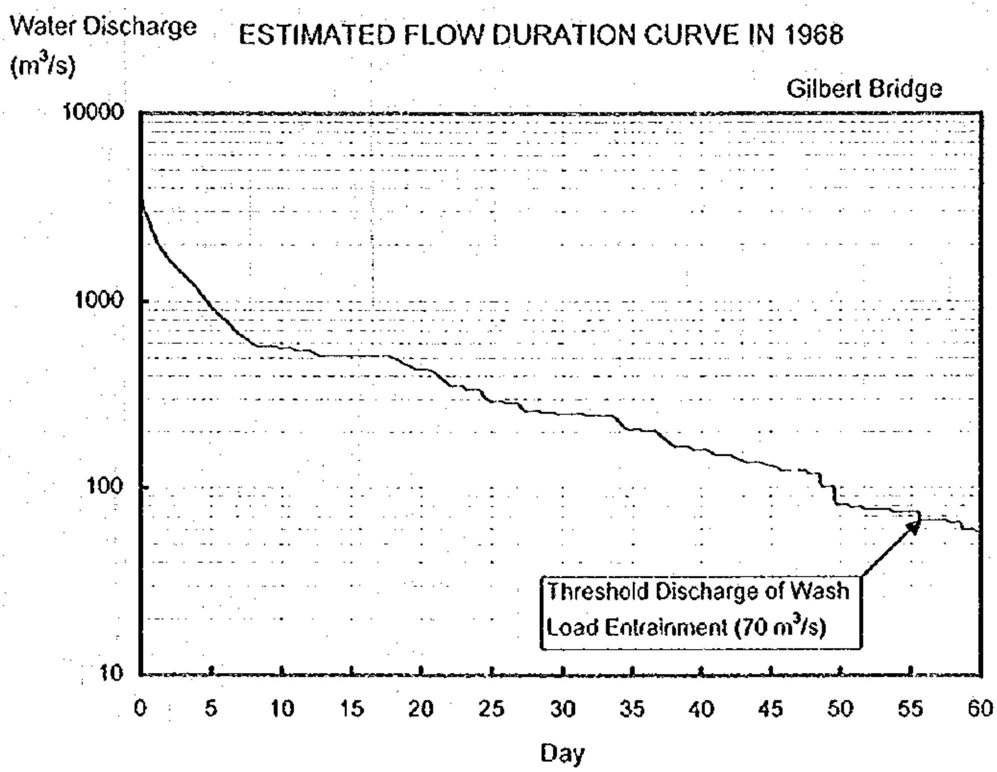


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. F.2.5
JAPAN INTERNATIONAL COOPERATION AGENCY	Annual Rainfall at Laoag City

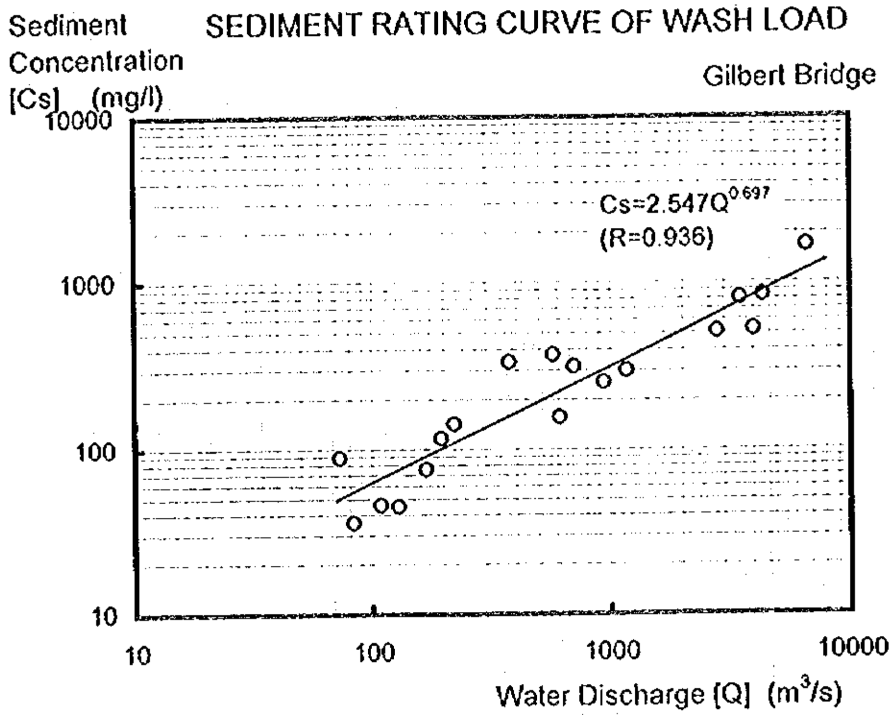


DAILY RAINFALL OBSERVED AT PAGASA LAOAG CITY STATION IN 1968

ESTIMATED FLOW DURATION CURVE IN 1968



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. F.2.6
JAPAN INTERNATIONAL COOPERATION AGENCY	Daily Rainfall and Flood Duration Curve in 1968



Observed Sedimet Concentration (Wash Load)

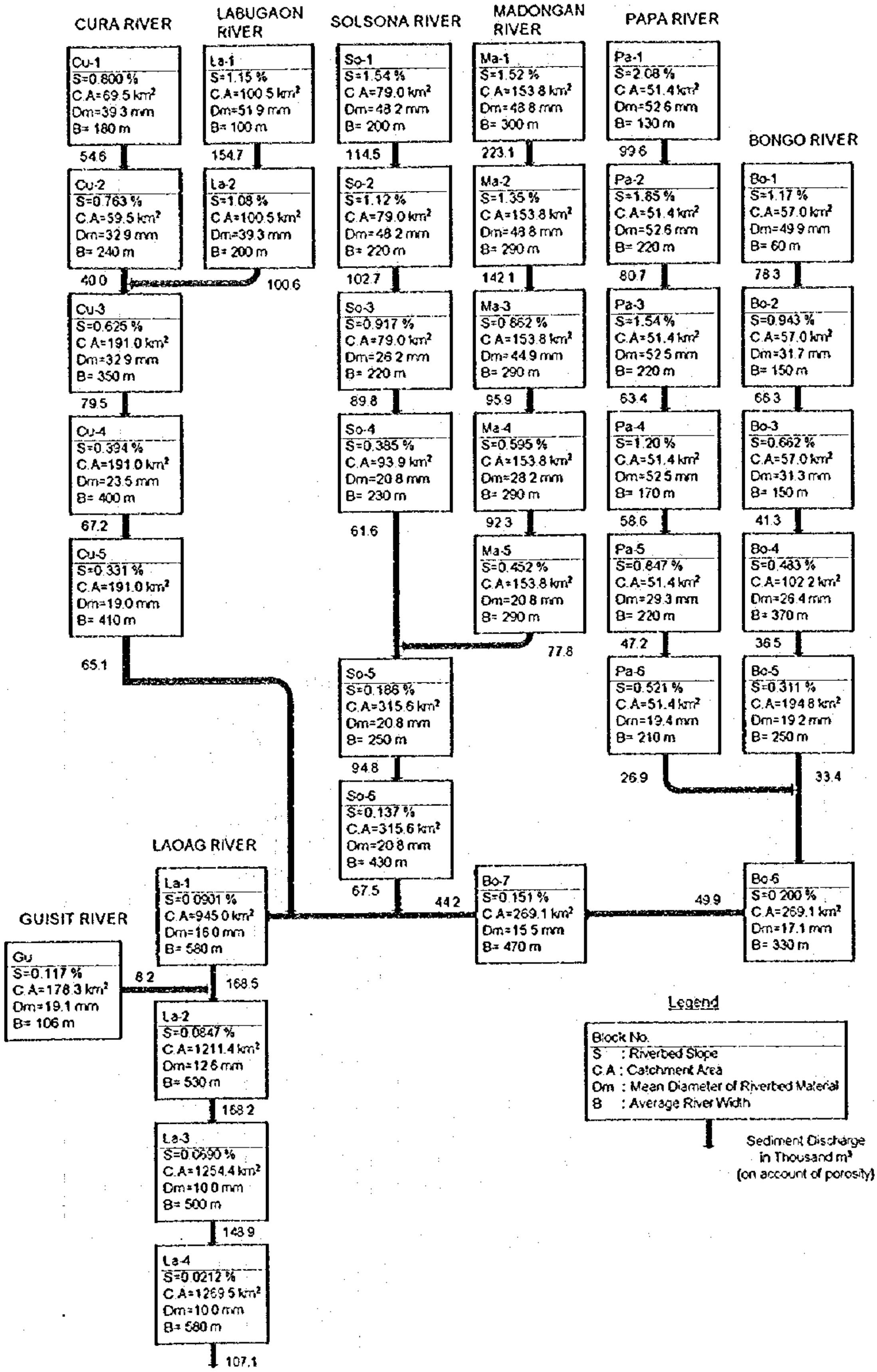
No.	Month	Date	Time	Water Level (m)	Velocity (m/s)	Area (m2)	Discharge (m3/s)	Sediment Concentration (mg/L)
1	June	26	2:03 PM	2.11	0.63	164.7	73	89
2	June	26	5:25 PM	2.14	0.69	172.2	83	36
3	June	28	9:00 AM	2.74	0.84	333.4	196	117
4	July	17	9:10 AM	2.47	0.61	255.2	109	46
5	July	24	11:30 AM	2.46	0.73	252.7	129	45
6	July	24	2:06 PM	2.56	0.86	280.4	169	76
7	July	24	3:56 PM	2.79	0.91	348.1	222	143
8	July	24	5:35 PM	3.12	1.20	446.2	375	337
9	July	24	7:25 PM	3.47	1.49	552.1	576	374
10	July	24	9:15 PM	3.73	1.60	632.6	709	317
11	July	25	5:45 AM	3.71	1.40	626.4	614	157
12	July	25	9:40 AM	4.14	1.77	760.9	943	256
13	July	25	11:00 AM	4.48	1.93	868.7	1174	301
14	July	25	1:20 PM	5.65	2.52	1590.6	2806	511
15	July	25	3:00 PM	6.49	2.84	2016.7	4009	526
16	July	25	5:45 PM	8.07	3.34	2854.7	6674	1673
17	July	26	9:00 AM	6.94	2.79	2253.7	4402	842
18	July	26	2:25 PM	6.37	2.58	1953.4	3528	805

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. F.2.7

Wash Load Rating Curve

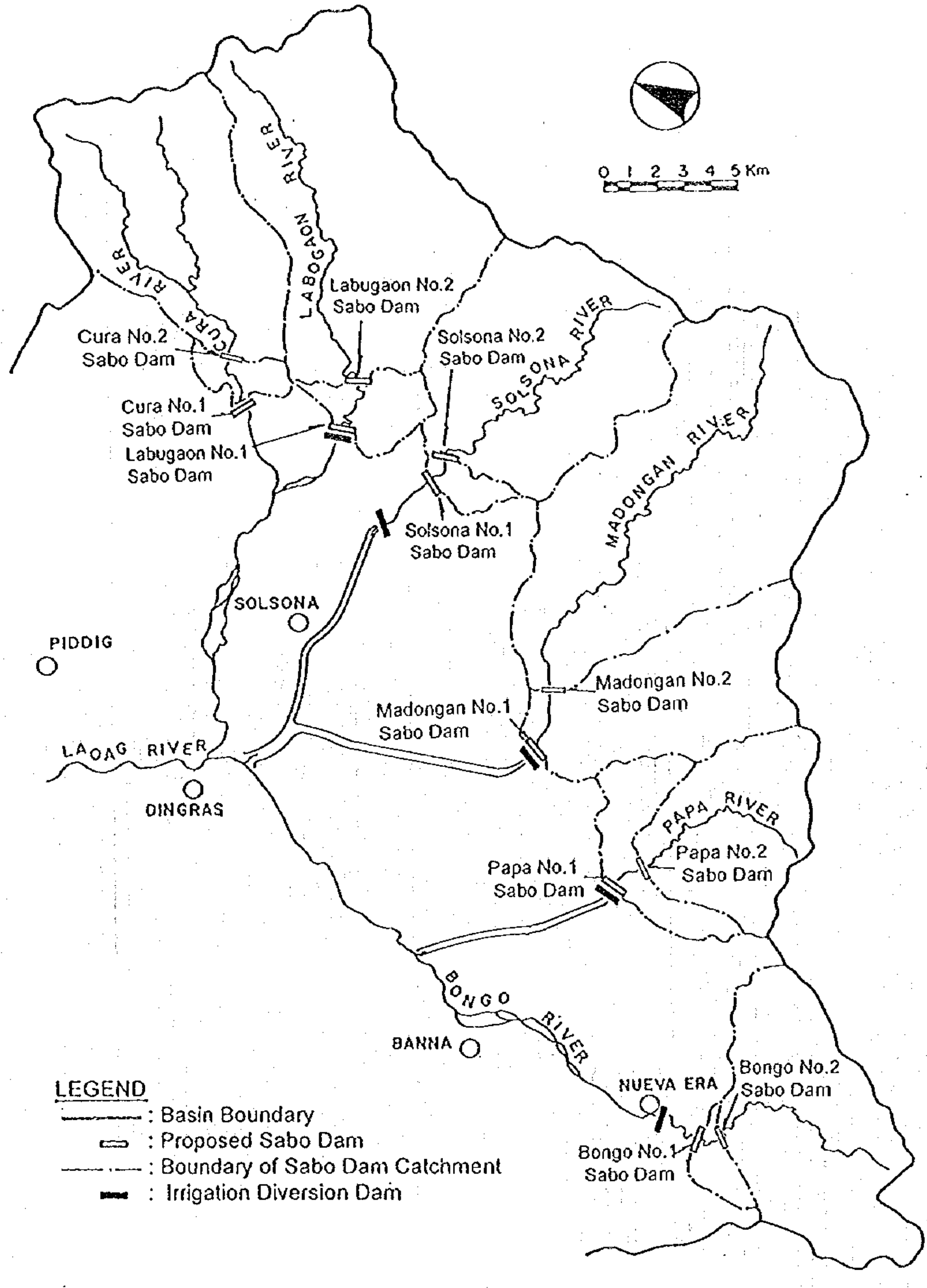


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

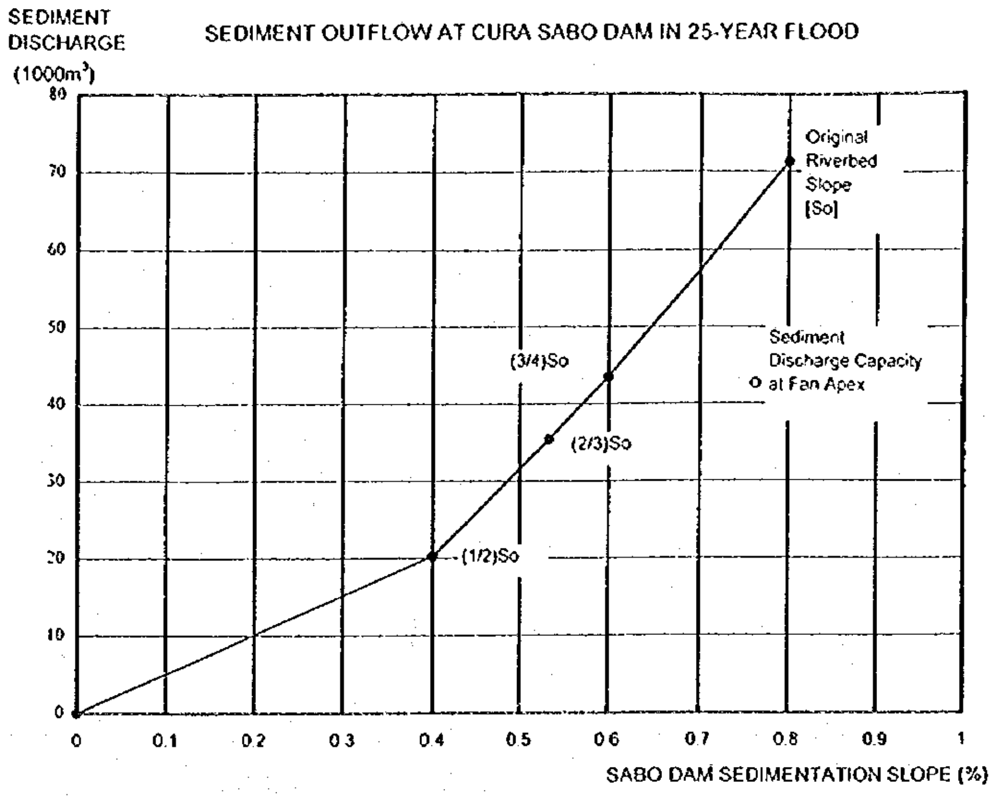
JAPAN INTERNATIONAL COOPERATION AGENCY

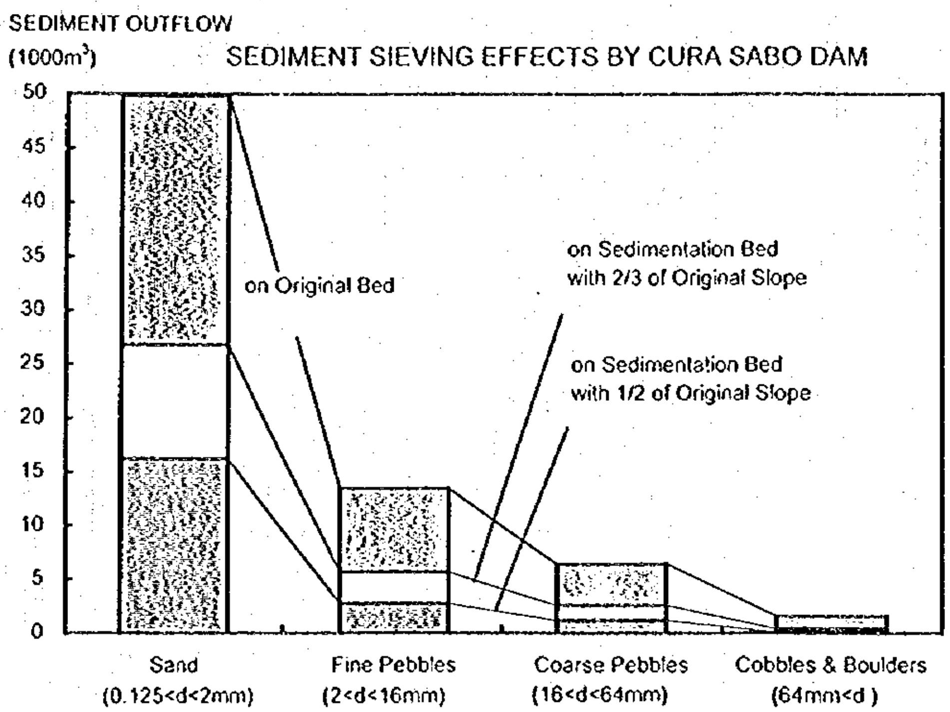
Fig. F.2.8

Annual Sediment Balance of Bedload and Suspended Load

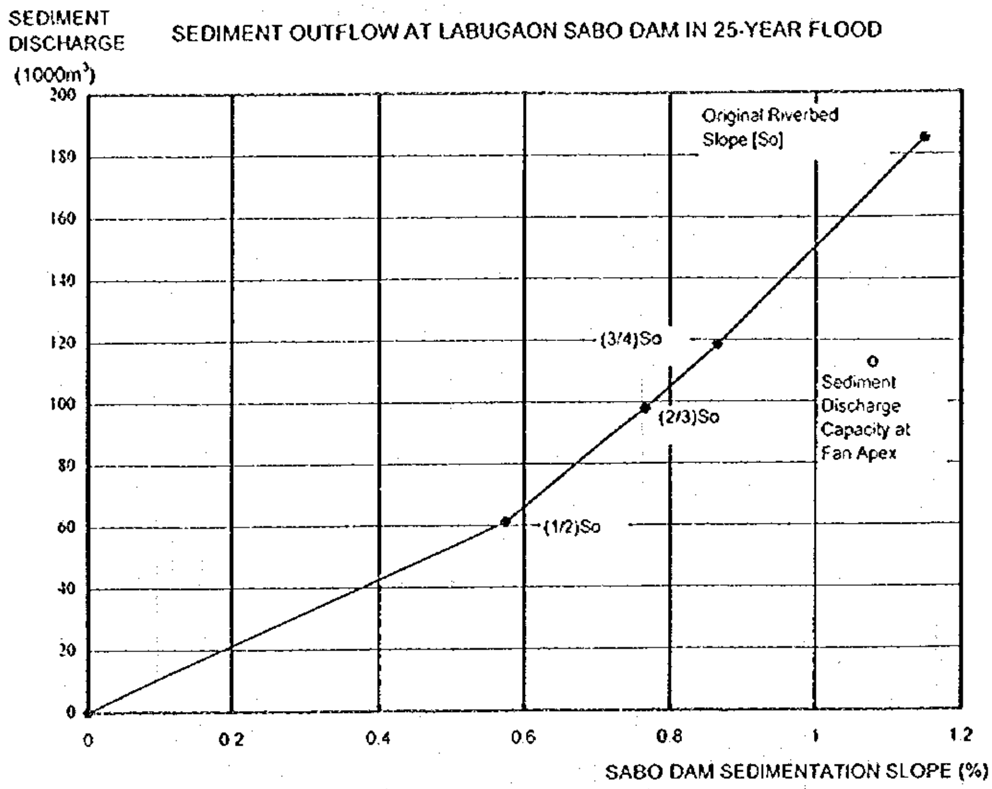


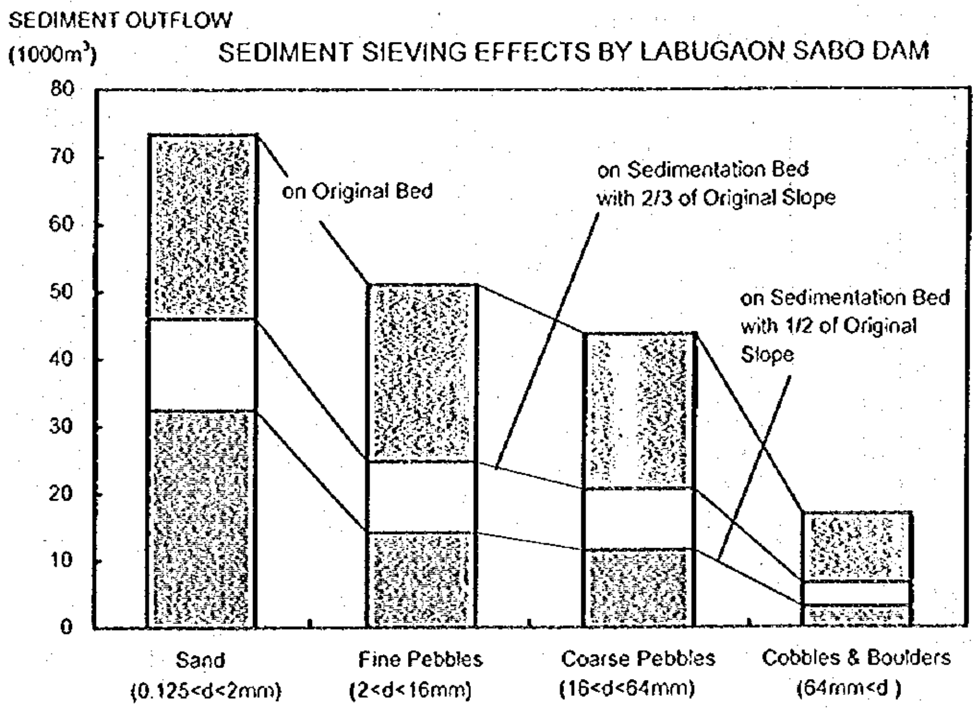
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. F.3.1
JAPAN INTERNATIONAL COOPERATION AGENCY	Location of Potential Sabo Damsites





THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	**Fig. F.4.1 (1)**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Sediment Outflow and Sieving Effects of Sabo Dam during Design Flood (Cura R.)**



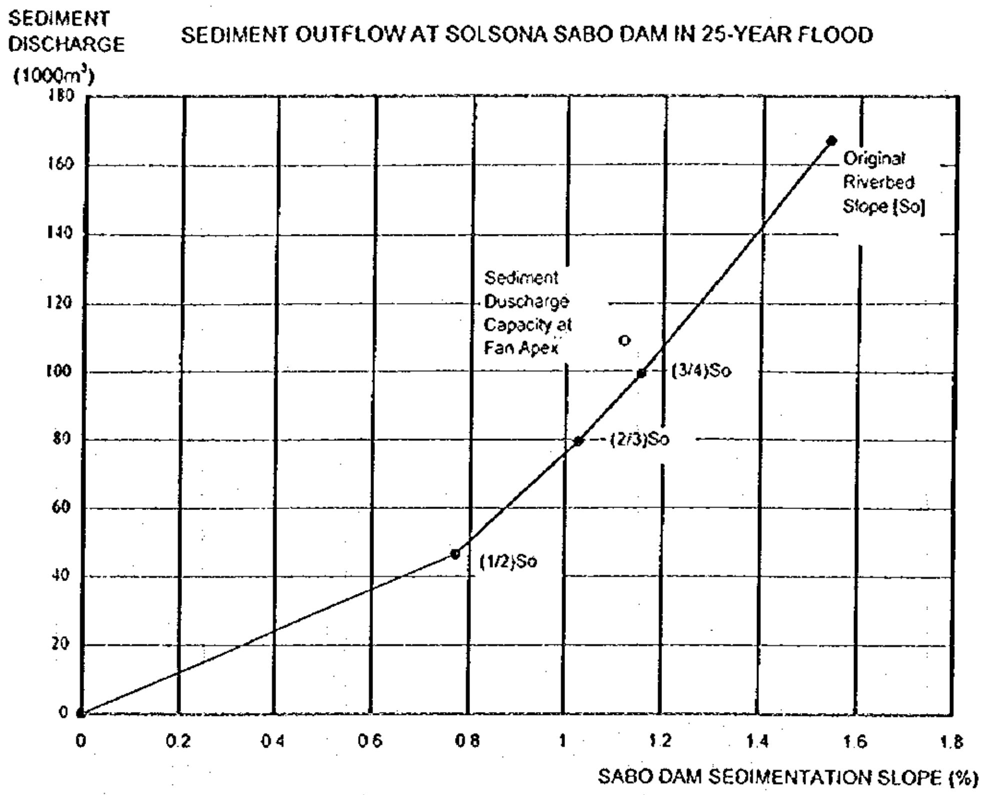


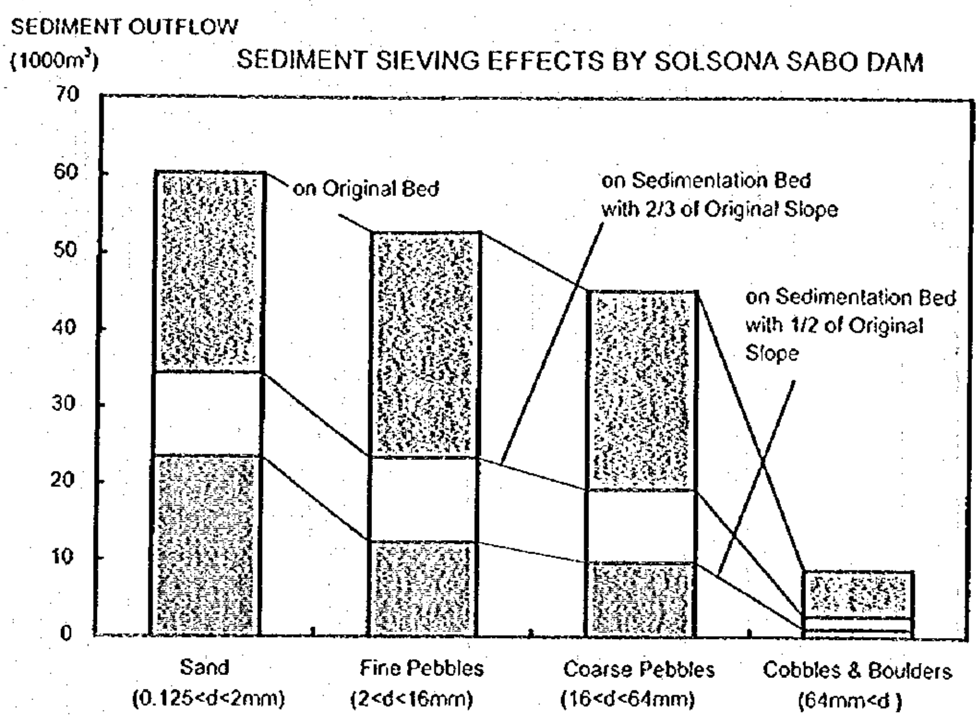
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

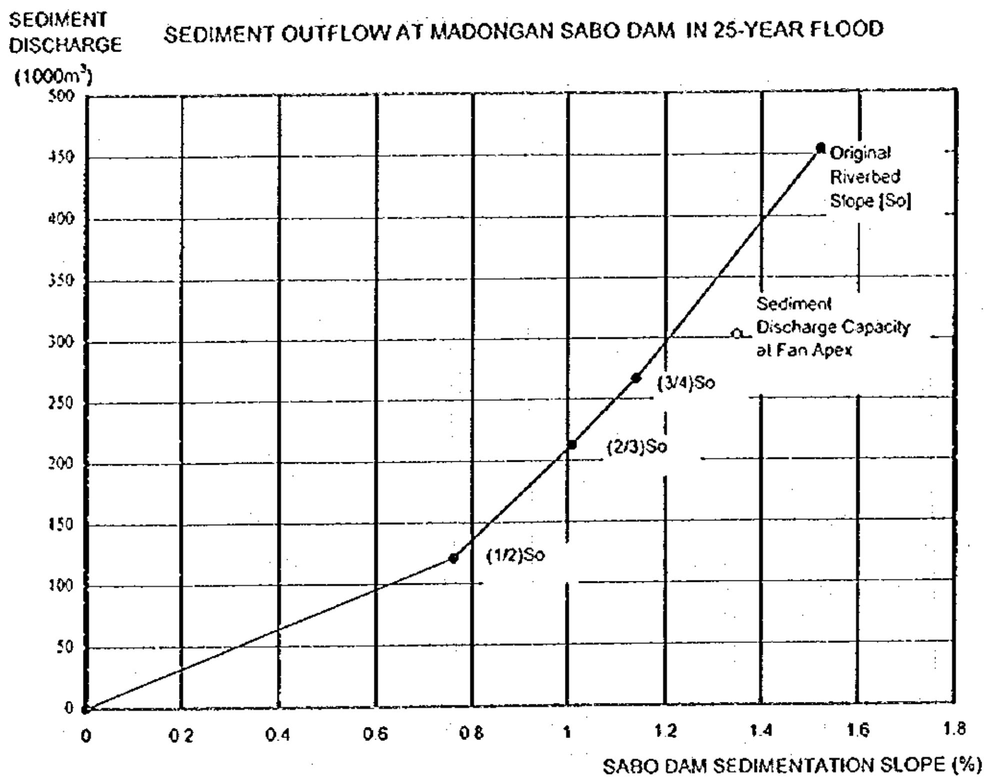
Fig. F.4.1 (2)

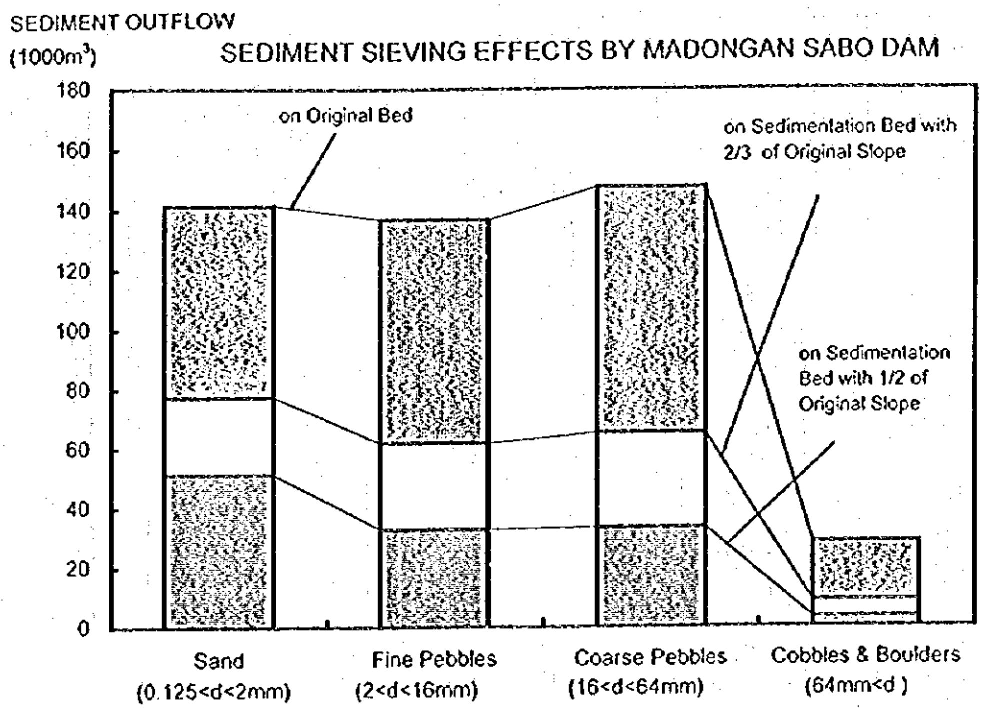
Sediment Outflow and Sieving Effects of Sabo Dam during Design Flood (Labugaon R.)





THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. F.4.1 (3)** **Sediment Outflow and Sieving Effects of Sabo Dam during Design Flood (Solsona R.)**



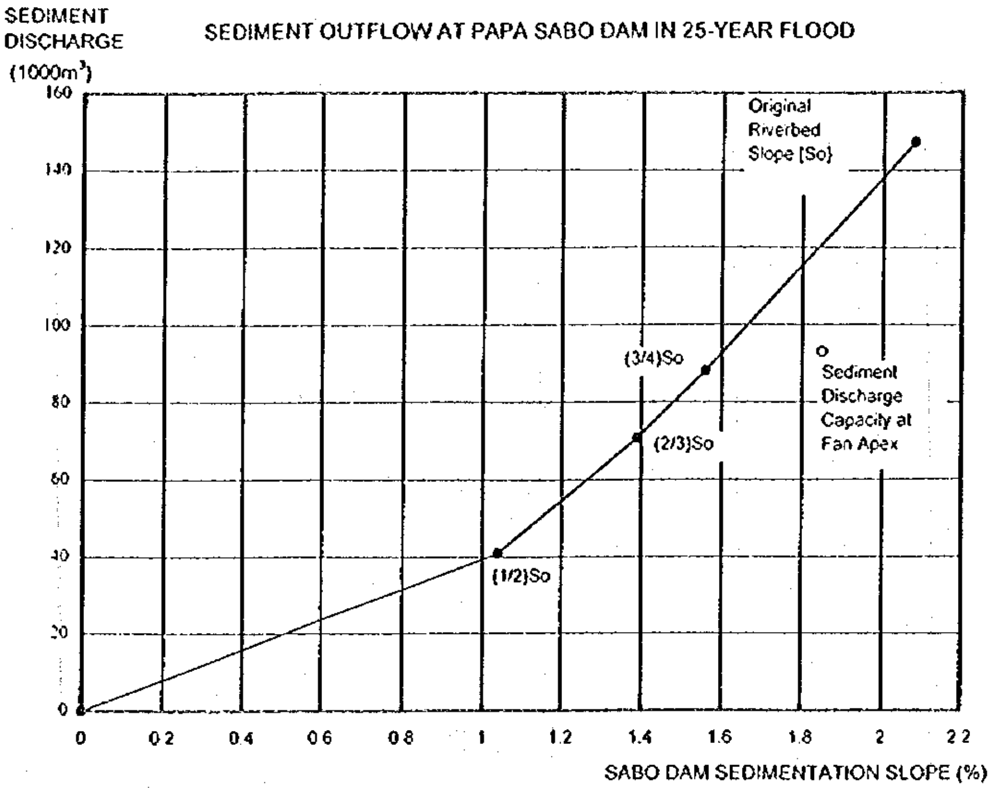


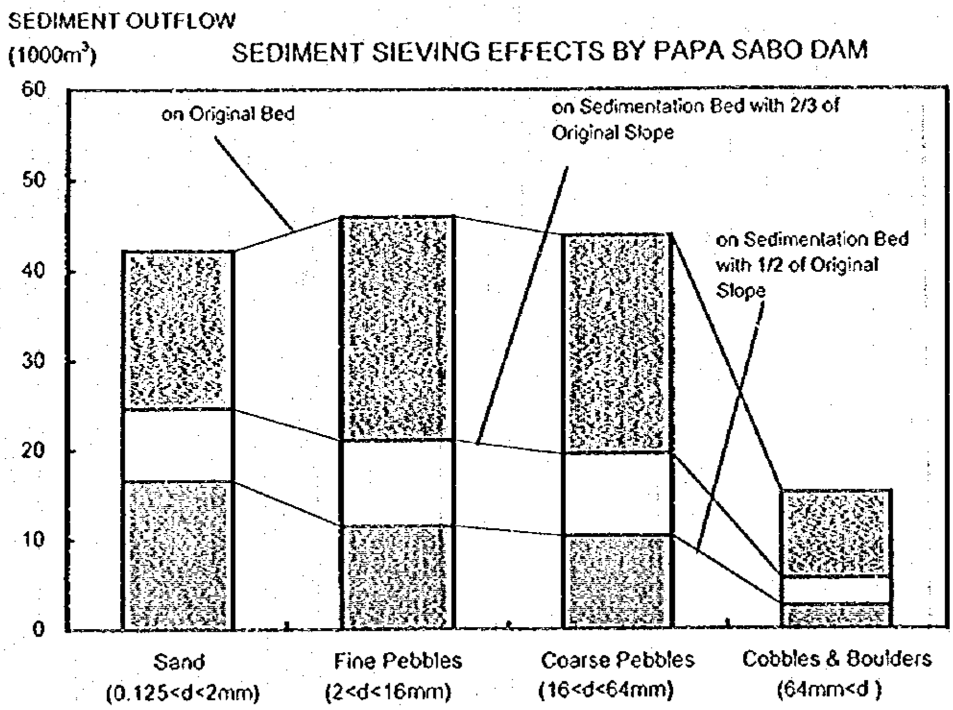
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

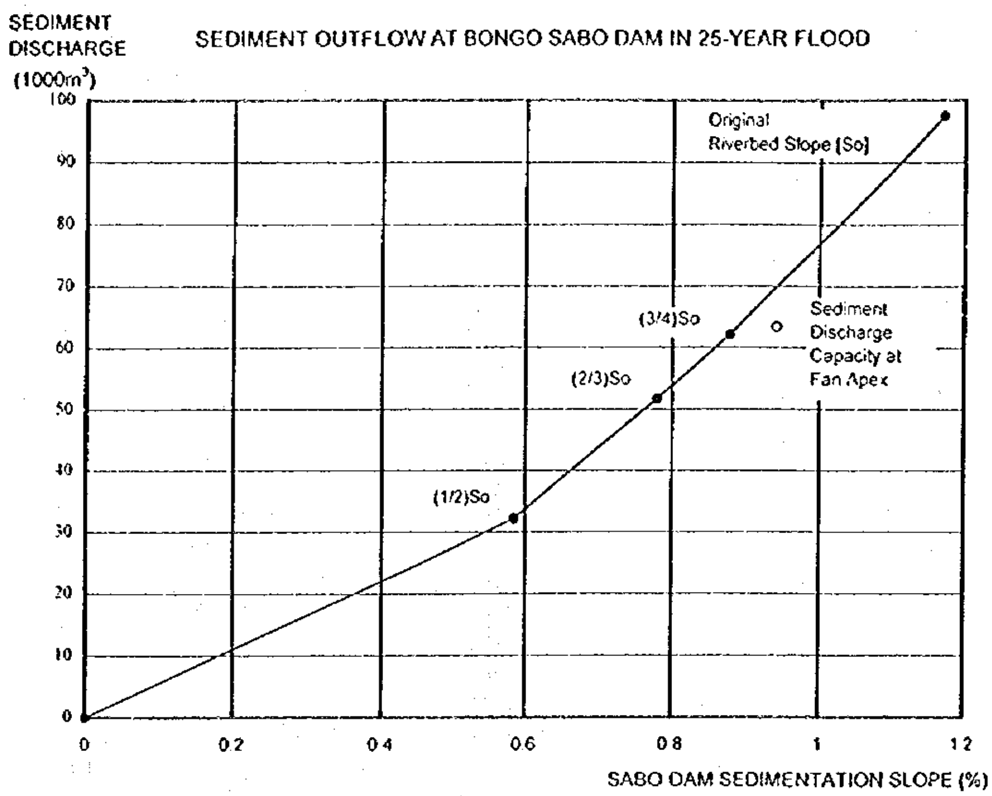
Fig. F.4.1 (4)

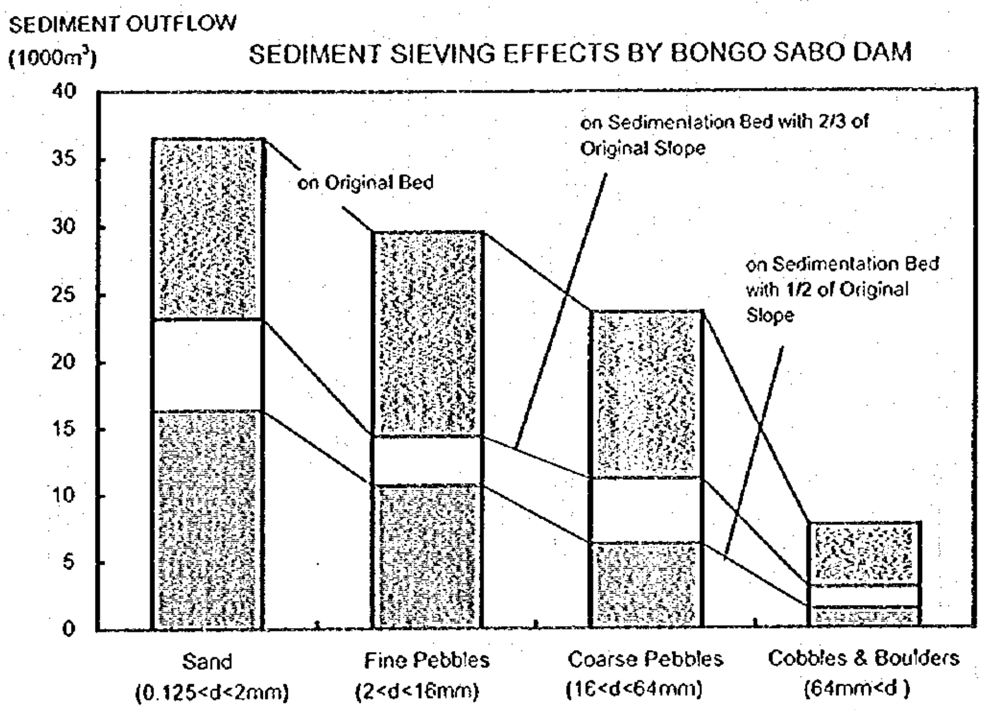
Sediment Outflow and Sieving Effects of Sabo Dam during Design Flood (Madongan R.)



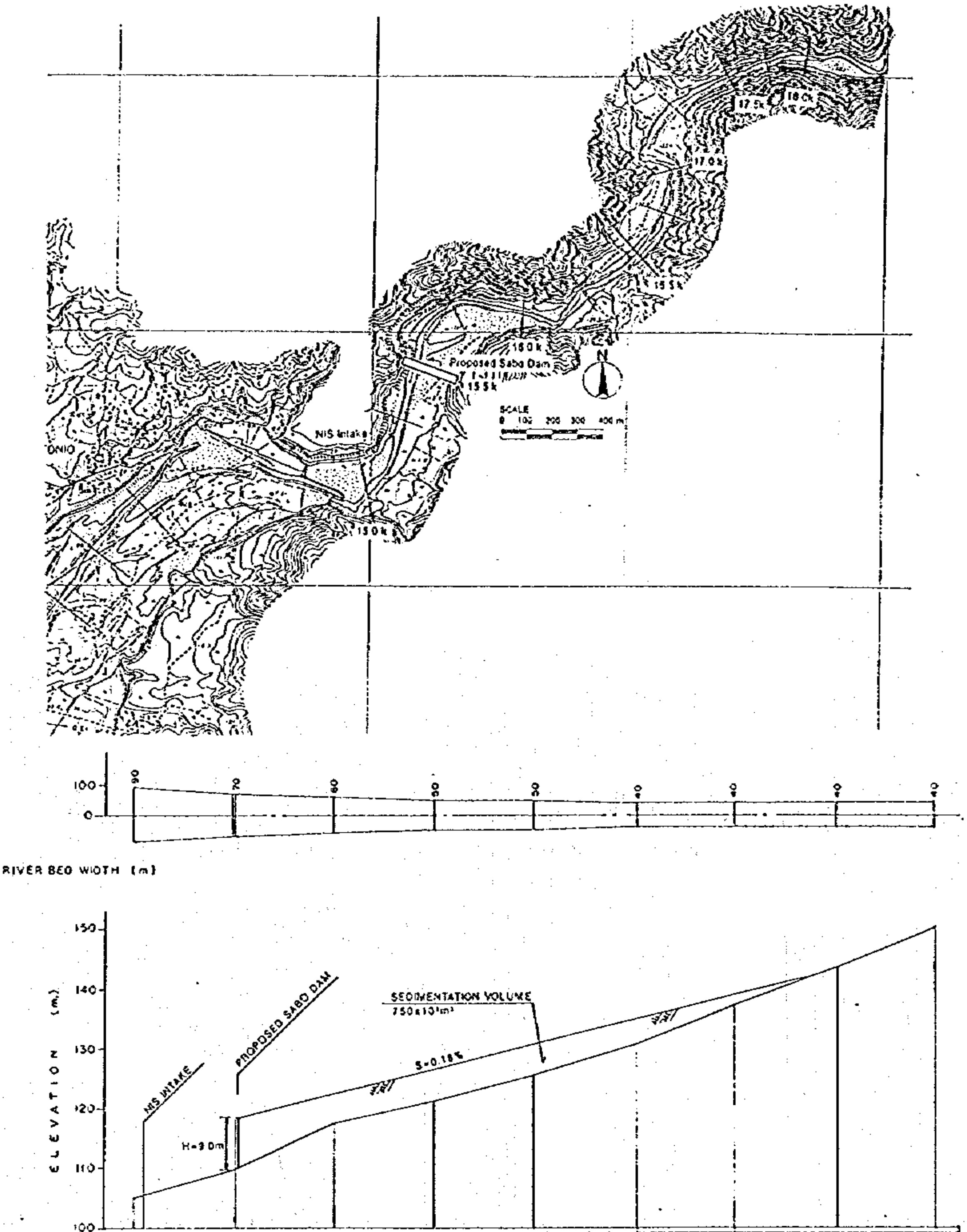


THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	**Fig. F.4.1 (5)**
JAPAN INTERNATIONAL COOPERATION AGENCY	**Sediment Outflow and Sieving Effects of Sabo Dam during Design Flood (Papa R.)**





THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. F.4.1 (6)
JAPAN INTERNATIONAL COOPERATION AGENCY	Sediment Outflow and Sieving Effects of Sabo Dam during Design Flood (Bongo R.)

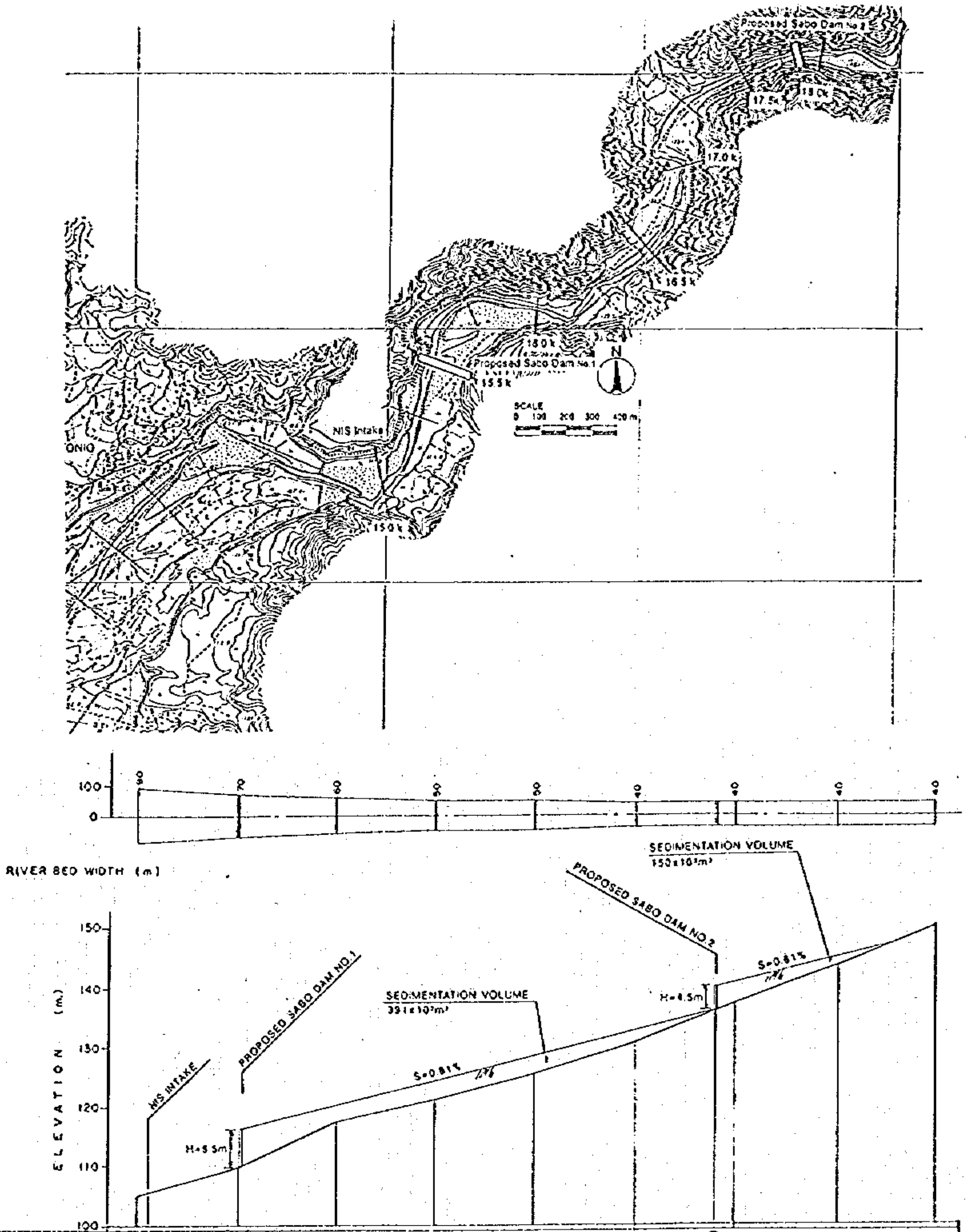


RIVER BED ELEVATION (m)	105.02	109.79	117.44	121.10	125.26	130.97	137.32	143.72	150.12
CUMMULATIVE DISTANCE (m)	15,000 (15,050)	15,500	16,000	16,500	17,000	17,500	18,000	18,500	19,000
DISTANCE (m)	0.00 (50.00)	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
SLOPE (%)	1.08								

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (1)
Plan and Longitudinal Profile of Potential Sabo Dam (Cura : Single Dam Alternative)

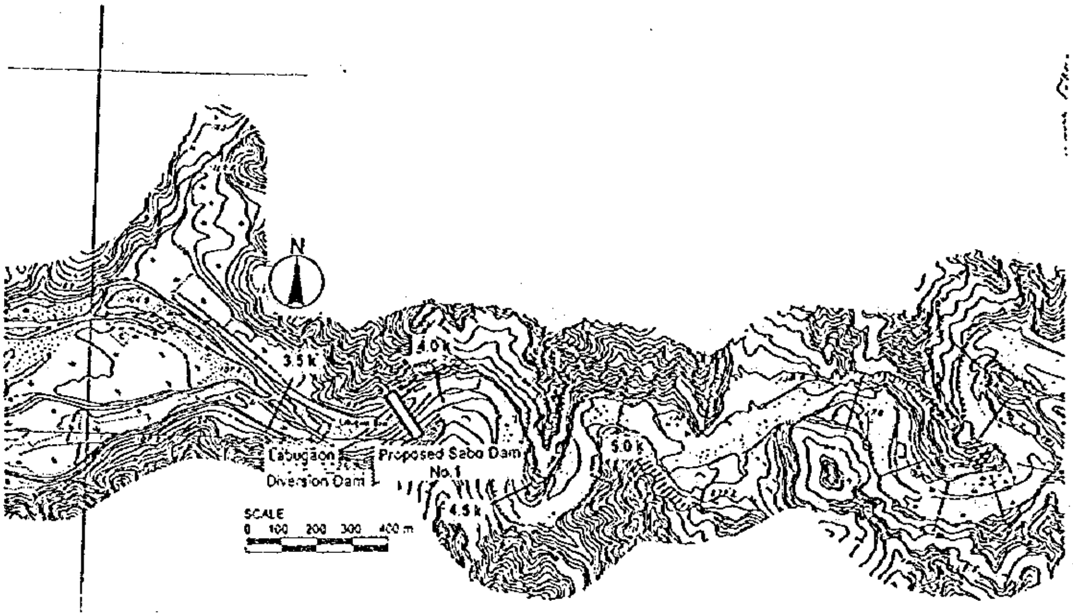


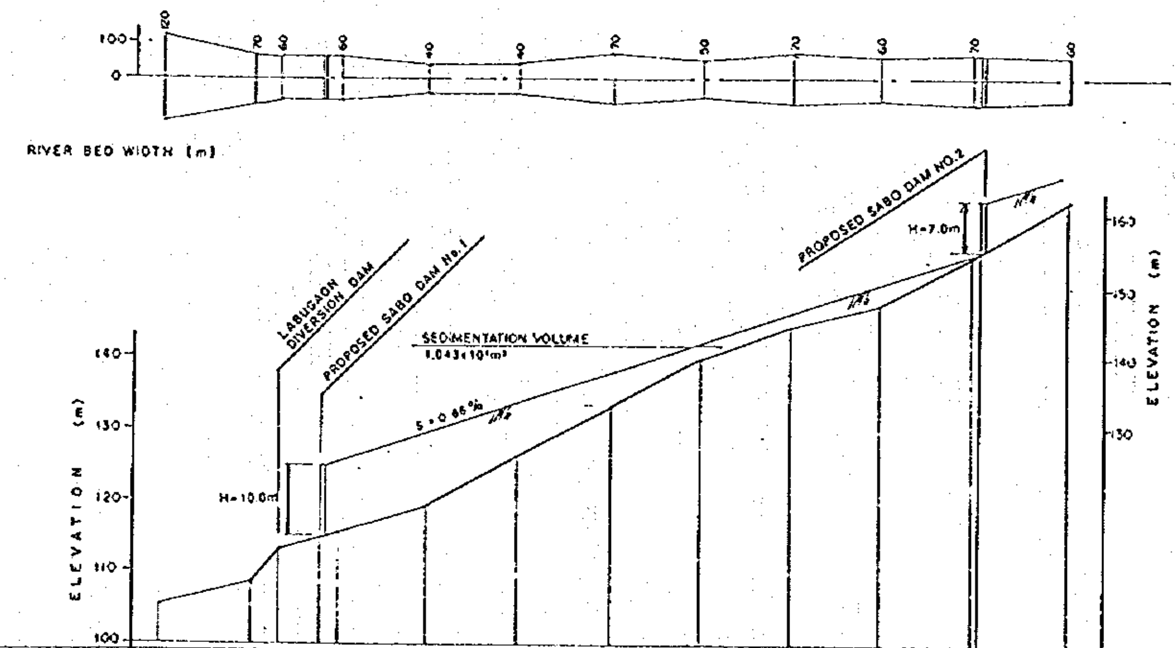
RIVER BED ELEVATION (m)	105.02	109.79	117.44	121.10	125.26	130.92	(136.04)	137.32	143.72	150.12
CUMMULATIVE DISTANCE (m)	15,000	15,500	16,000	16,500	17,000	17,500	(17,900)	18,000	18,500	19,000
DISTANCE (m)	0.00	500.00	500.00	500.00	500.00	500.00	(400.00)	500.00	500.00	500.00
SLOPE (%)	1.08									

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (2)
Plan and Longitudinal Profile of Potential Sabo Dam (Cura : Series Dams Alternative)



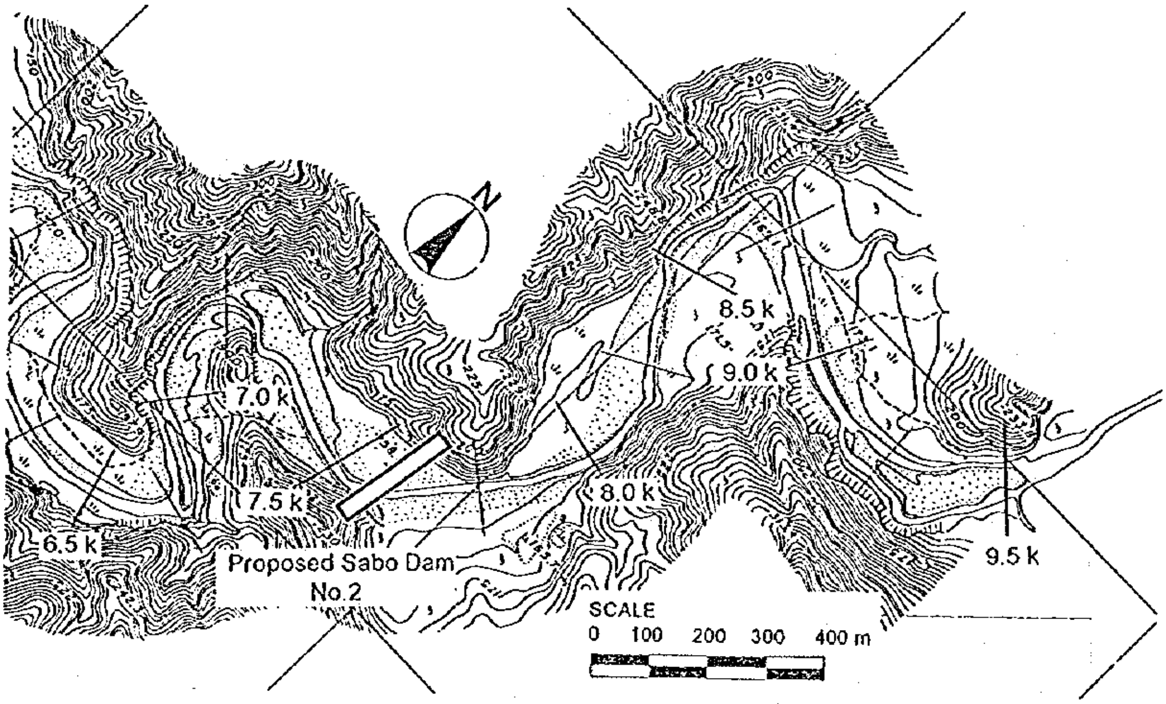


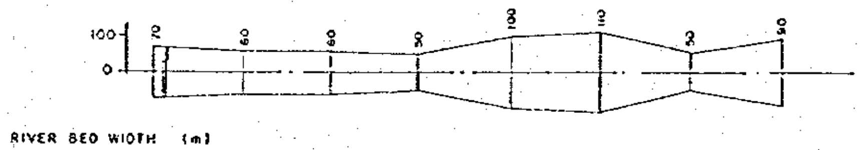
RIVER BED ELEVATION (m)	105.44	108.76	(112.81)	(114.40) 115.20	119.49	126.49	133.25	130.88	144.46	147.84	154.50 (153.21)	161.59
CUMMULATIVE DISTANCE (m)	3,000	3,500	(3,658)	(3,890) 4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500 (7,550)	8,000
DISTANCE (m)	0.00	500.00	(158.00)	(232.00) 500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00 (50.00)	500.00
SLOPE (%)	0.93				1.15							

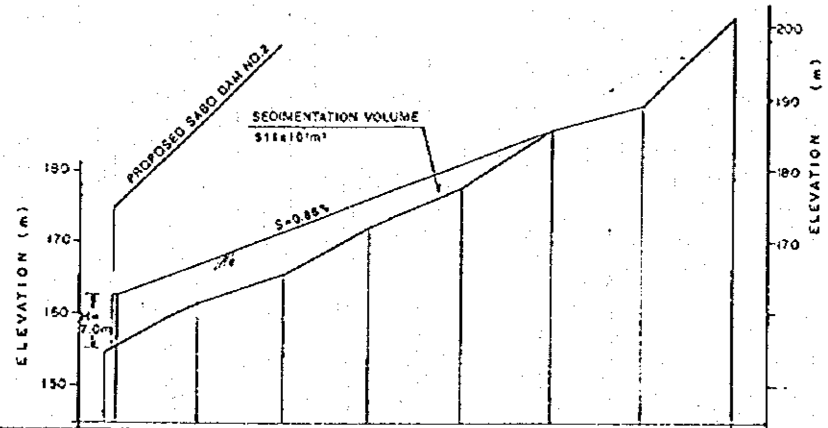
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (3)
Plan and Longitudinal Profile of Potential Sabo Dam (Labugaon : No.1 Sabo Dam)





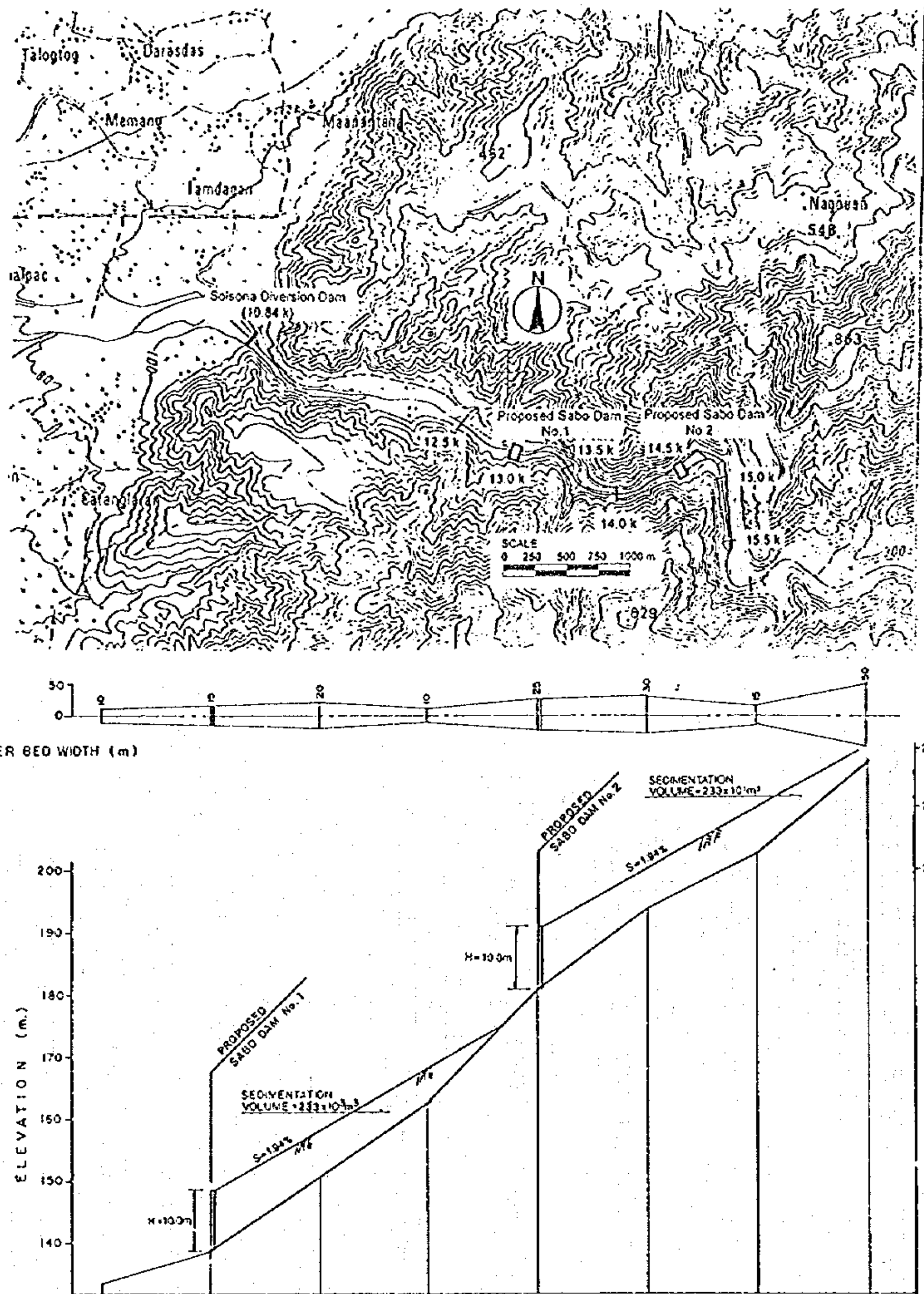


RIVER BED ELEVATION (m)	154.50 (155.21)	161.50	165.11	172.08	177.50	185.70	189.05	201.12
CUMMULATIVE DISTANCE (m)	7,500 (7,550)	8,000	8,500	9,000	9,500	10,000	10,500	11,000
DISTANCE (m)	0.00 (50.00)	500.00	500.00	500.00	500.00	500.00	500.00	500.00
SLOPE (%)	1.15							

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (4)
Plan and Longitudinal Profile of Potential Sabo Dam (Labugaon : No.2 Sabo Dam)

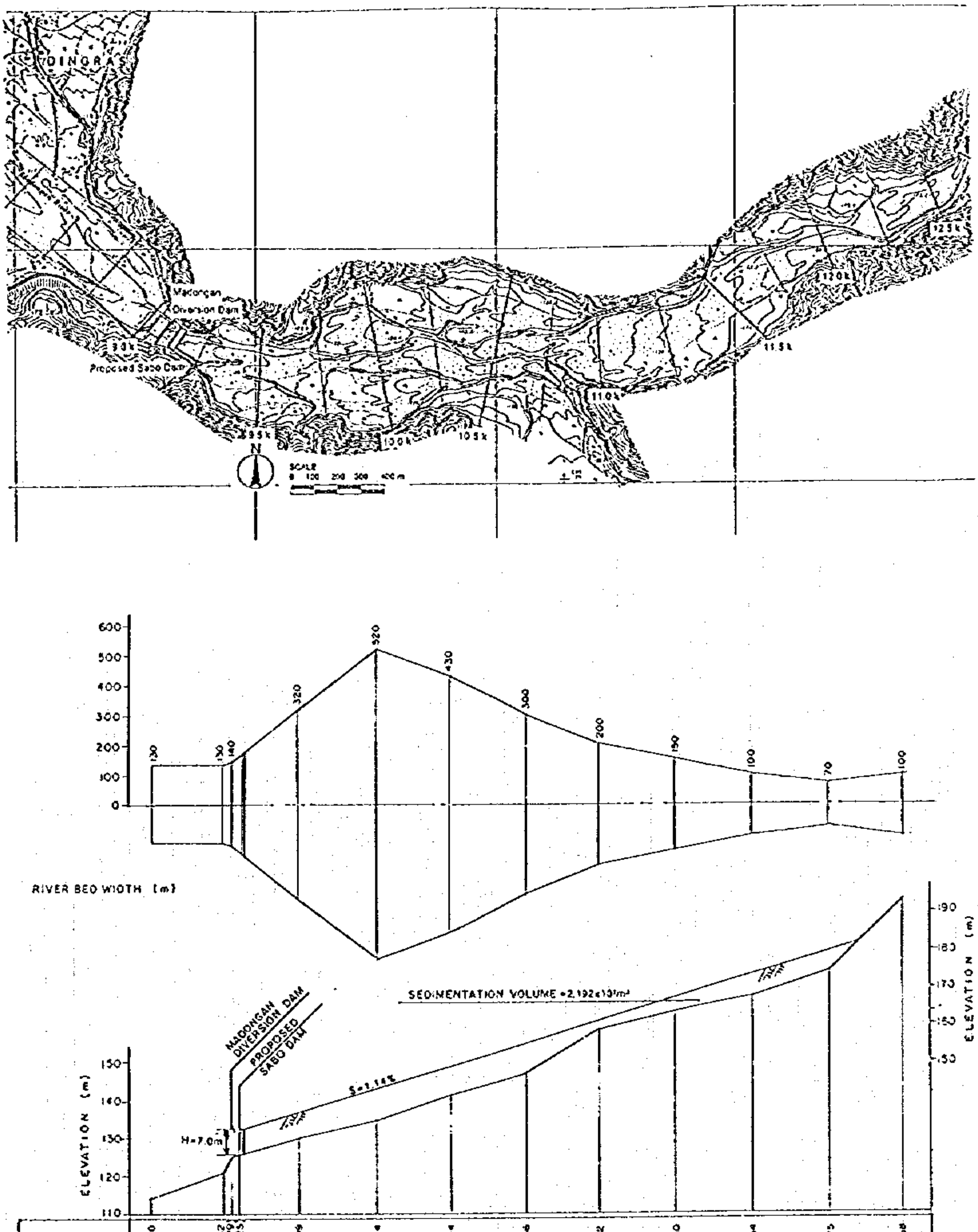


RIVER BED ELEVATION (m)	133.34	138.62	150.82	162.88	181.15	194.01	203.07	217.99
CUMMULATIVE DISTANCE (m)	12,500	13,000	13,500	14,000	14,500	15,000	15,500	16,000
DISTANCE (m)	0.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
SLOPE (%)	258							

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (5)
Plan and Longitudinal Profile of Potential Sabo Dam (Solsona : No.1 & No.2 Sabo Dams)

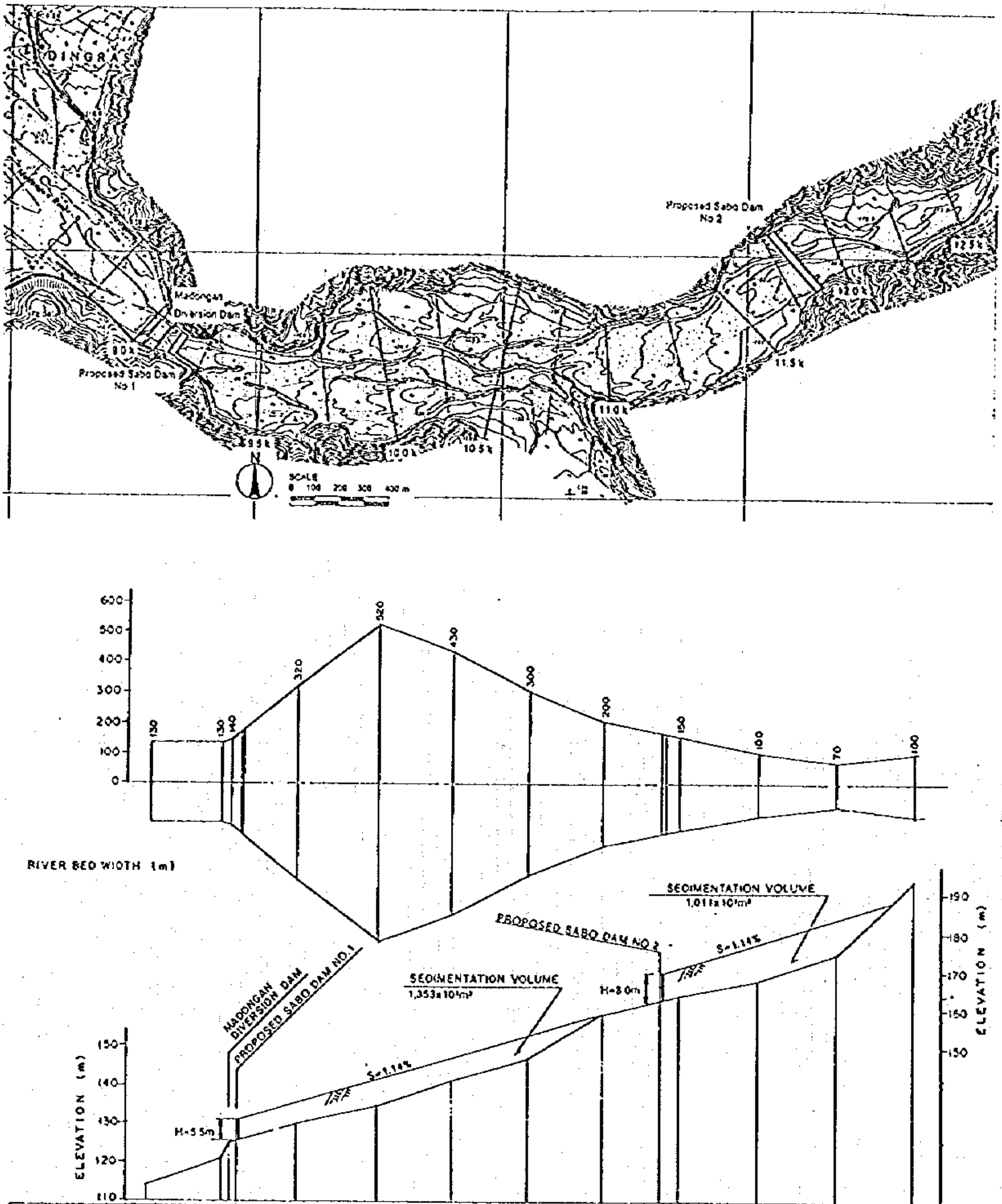


RIVER BED ELEVATION (m)	114.00	120.32 (121.29) (122.25)	129.99	134.14	140.94	147.36	158.52	163.30	167.54	174.75	193.58
CUMMULATIVE DISTANCE (m)	8,500	9,000 (9,050) (9,100)	9,500	10,000	10,500	11,000	11,500	12,000	12,500	13,000	13,500
DISTANCE (m)	0.00	500.00 (50.00) (50.00)	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
SLOPE (%)	1.35	1.52									

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

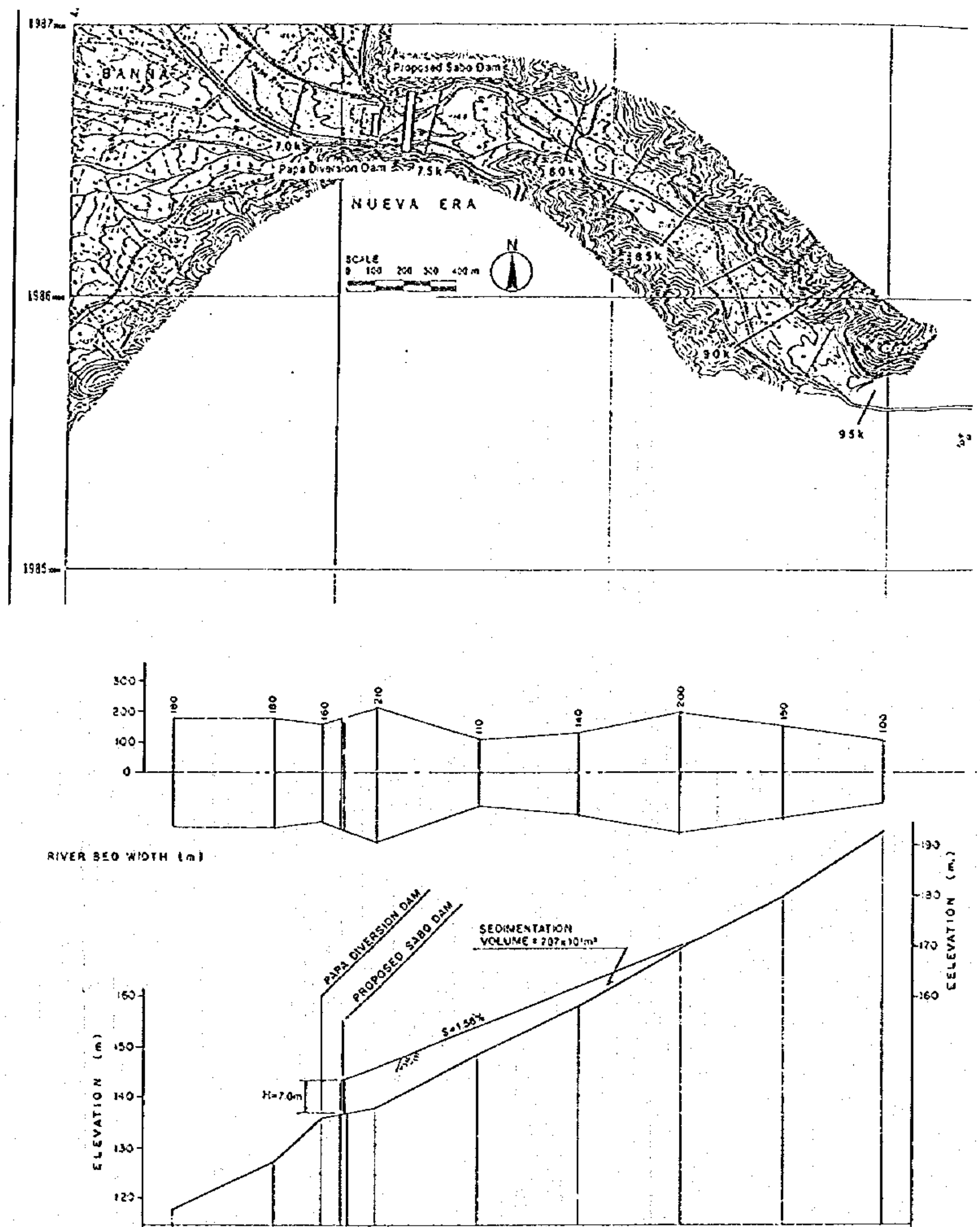
Fig. 4.2 (6)
Plan and Longitudinal Profile of Potential Sabo Dam (Madongan : Single Dam Alternative)



RIVER BED ELEVATION (m)	CUMMULATIVE DISTANCE (m)	DISTANCE (m)
114.00	8,500	0.00
120.32 (121.29) (122.25)	9,000 (9,050) (9,100)	500.00 (50.00) (50.00)
129.96	9,500	500.00
134.14	10,000	500.00
140.94	10,500	500.00
147.36	11,000	500.00
156.92	11,500	500.00
162.15	11,880	(380)
163.30	12,000	500.00
167.54	12,500	500.00
174.75	13,000	500.00
193.56	13,500	500.00

SLOPE (%): 1.35 (8,500–9,000); 1.52 (9,000–13,500)

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. 4.2 (7)
JAPAN INTERNATIONAL COOPERATION AGENCY	Plan and Longitudinal Profile of Potential Sabo Dam (Madongan : Series Dams Alternative)

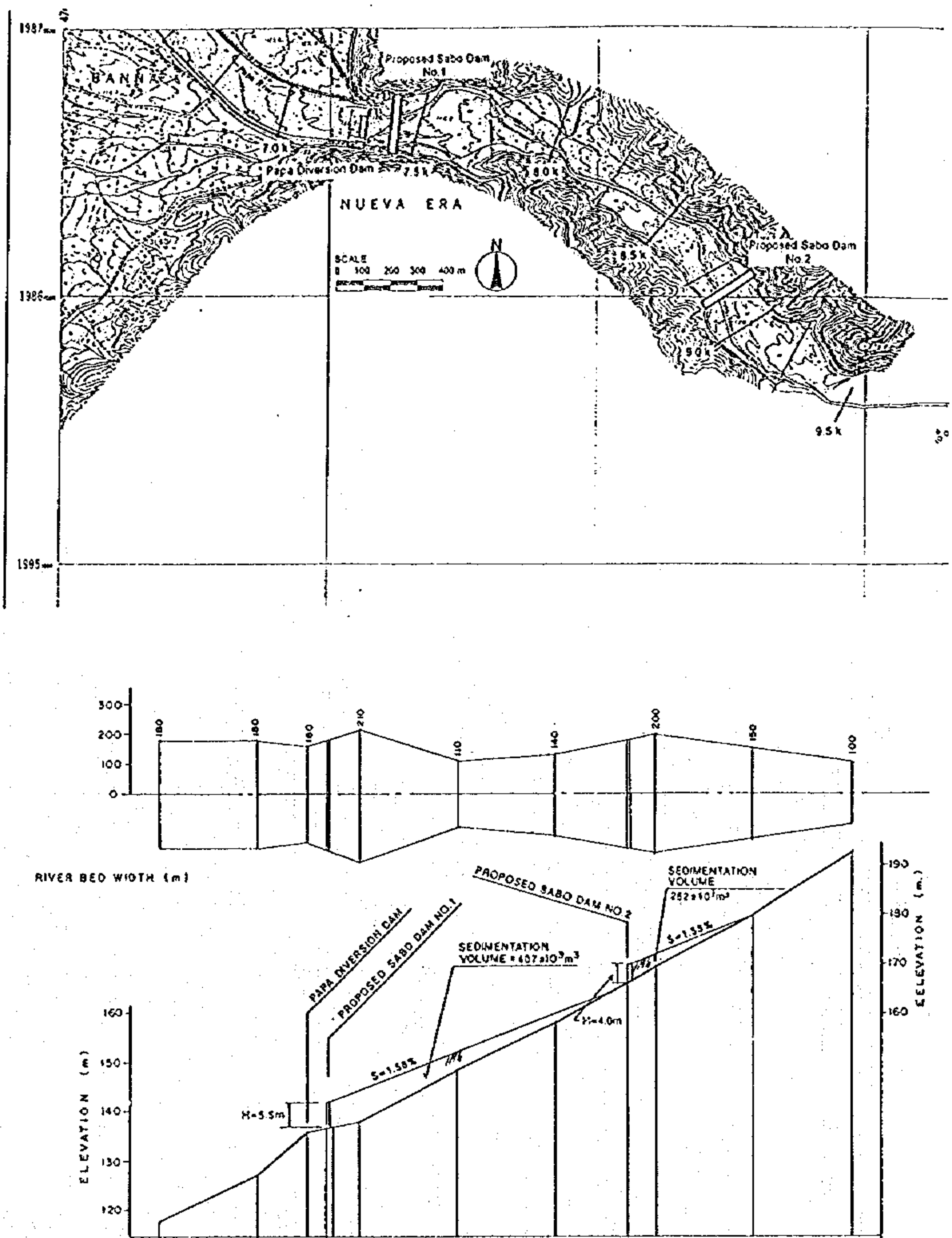


RIVER BED ELEVATION (m)	117.70	127.30	(130.00)	(136.83)	138.1[illegible]	148.43	158.12	169.[illegible]	180.15	192.63
CUMMULATIVE DISTANCE (m)	6,500	7,000	(7,240)	(7,340)	7,500	8,000	8,500	9,000	9,500	10,000
DISTANCE (m)	0.00	500.00	(240.00)	(100.00)	500.00	500.00	500.00	500.00	500.00	500.00
SLOPE %	1.85					2.08				

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (8)
Plan and Longitudinal Profile of Potential Sabo Dam (Papa : Single Dam Alternative)

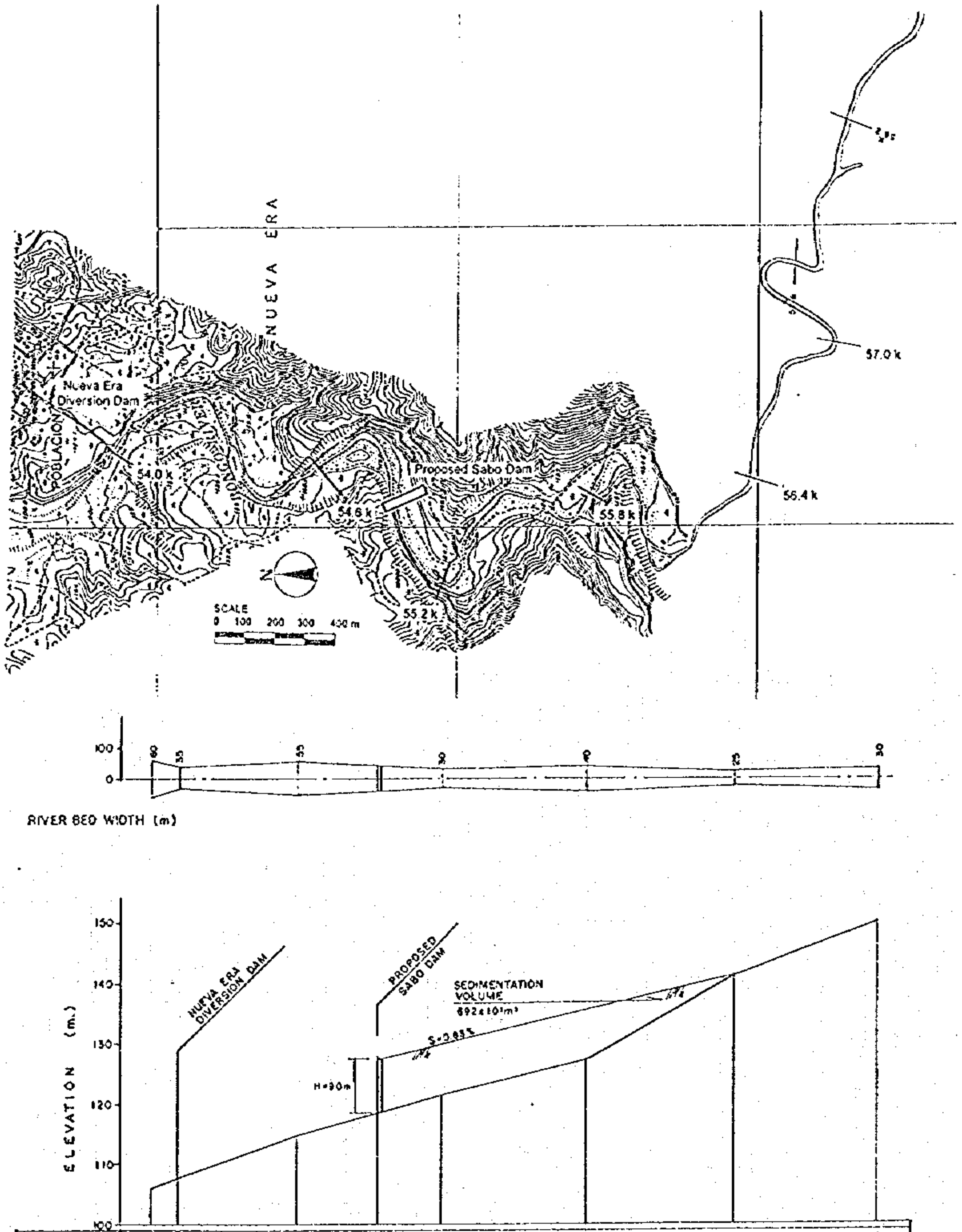


RIVER BED ELEVATION (m)	117.78	127.30	(136.00)	(136.83)	138.1[illegible]	148.43	158.12	(166.67)	169.99	180.15	192.63
CUMMULATIVE DISTANCE (m)	6,500	7,000	(7,240)	(7,340)	7,500	8,000	8,500	(8,860)	9,000	9,500	10,000
DISTANCE (m)	000	500.00	(240.00)	(100.00)	500.00	500.00	500.00	(360.00)	500.00	500.00	500.00
SLOPE %	1.85					2.03					

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (9)
Plan and Longitudinal Profile of Potential Sabo Dam (Papa : Series Dams Alternative)

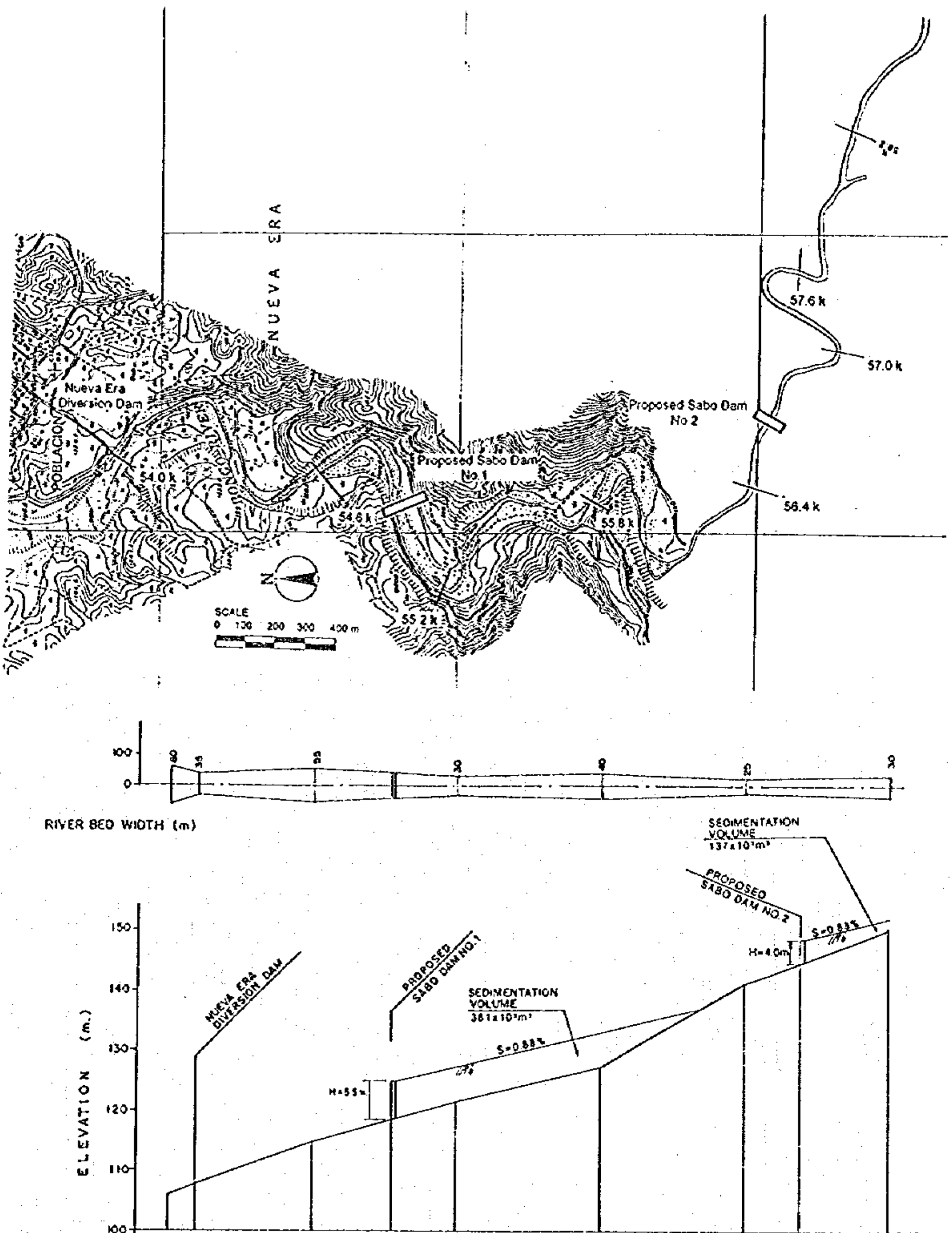


RIVER BED ELEVATION (m)	106.03	(107.86)	114.67	(118.70)	121.50	127.25	141.22	150.35
CUMMULATIVE DISTANCE (m)	54,000	(54,105)	54,600	(54,950)	55,200	55,800	56,400	57,000
DISTANCE (m)	0.00	(105.00)	600.00	(350)	600.00	600.00	600.00	600.00
SLOPE (%)	1.17							

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (10)
Plan and Longitudinal Profile of Potential Sabo Dam (Bongo : Single Dam Alternative)

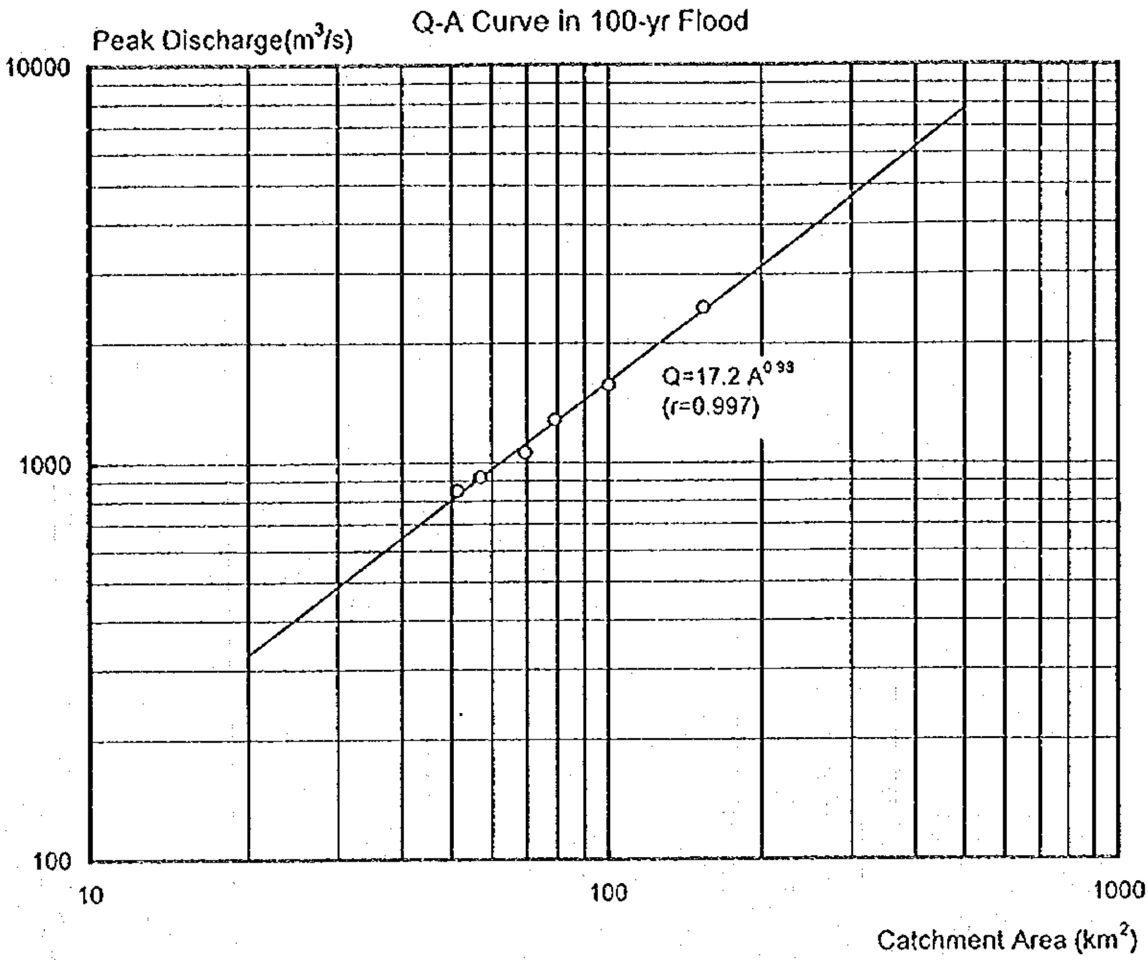


RIVER BED ELEVATON (m)	106.03	(107.86)	114.67	(118.70)	121.50	127.25	141.22	(144.57)	150.35
CUMMULATIVE DISTANCE (m)	54,000	(54,105)	54,600	(54,950)	55,200	55,800	56,400	(56,620)	57,000
DISTANCE (m)	0.00	(105.00)	600.00	(350)	600.00	600.00	600.00	(220.00)	600.00
SLOPE (%)	1.17								

THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 4.2 (11)
Plan and Longitudinal Profile of Potential Sabo Dam (Bongo : Series Dams Alternative)



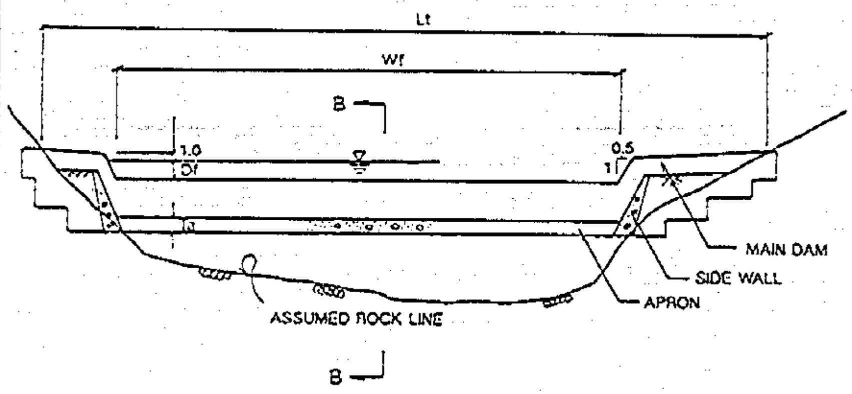
Design Discharge for Spillway of Alternative Sabo Dams

River	Dam Site	Catchment Area (km^2)	Peak Discharge in 100-yr Flood (m^3/s)
Cura	No.1	68.2	1,080
	No.2	63.1	1,000
Labugaon	No.1	100.5	1,580
	No.2	90.9	1,430
Solsona	No.1	72.2	1,140
	No.2	68.2	1,080
Madongan	No.1	153.8	2,390
	No.2	101.9	1,600
Papa	No.1	51.4	820
	No.2	35.3	570
Bongo	No.1	56.0	890
	No.2	52.8	840

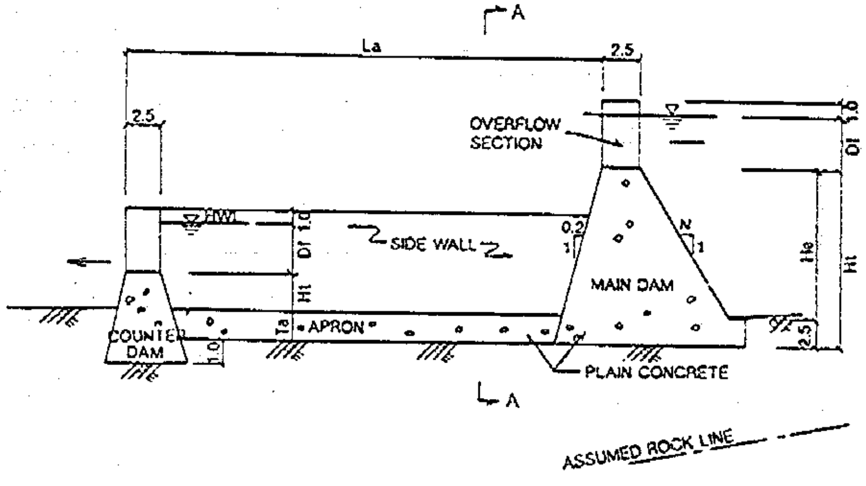
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. F.4.3
Design Discharge of Sabo Dam



ELEVATION A-A



LONGITUDINAL SECTION B-B

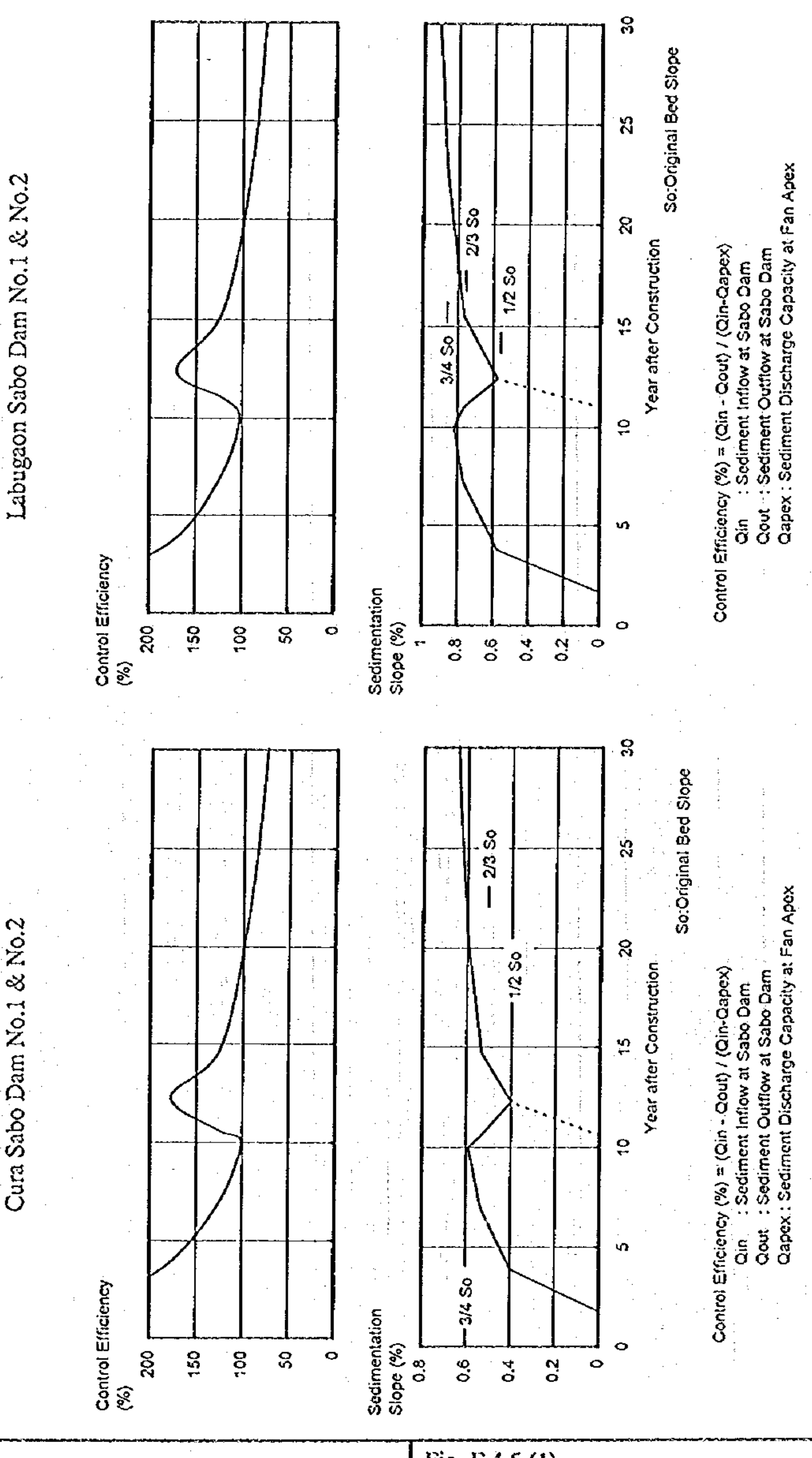
MAJOR DIMENSIONS OF OPTIMUM SABO DAMS

Name of Dam		Main Dam: Effective Height He (m)	Total Height Ht (m)	Crown Width Wc (m)	Slope (down-stream)	Slope, N (up-stream)	Top Length Lt (m)	Apron: Length La (m)	Thickness Ta (m)	Counter-dam: Effective Height Hs (m)	Total Concrete Volume (m3)	Hydraulic Conditions: Design Discharge (m3/s)	Overflow Depth Df (m)	Overflow Width Wf (m)
Cura	No.1	6.5	9.0	2.5	0.20	0.55	170	18	1.1	1.7	13,400	1,080	2.8	150
	No.2	4.5	7.0	2.5	0.20	0.60	70	20	1.8	1.9	5,900	1,000	5.3	50
Labugaon	No.1	10.0	12.5	2.5	0.20	0.80	100	30	2.0	2.8	18,500	1,580	4.9	90
	No.2	7.0	9.5	2.5	0.20	0.60	160	21	1.4	2.0	15,400	1,430	3.6	130
Solsona	No.1	10.0	12.5	2.5	0.20	0.80	30	40	2.0	4.8	9,600	1,140	9.7	20
	No.2	10.0	12.5	2.5	0.20	0.75	90	40	2.0	4.5	11,900	1,080	9.4	20
Madongan	No.1	7.0	9.5	2.5	0.20	0.70	120	26	2.1	2.5	16,000	2,390	6	100
Papa	No.1	7.0	9.5	2.5	0.20	0.50	210	17	0.9	1.5	16,100	820	1.9	200
Bongo	No.1	6.5	9.0	2.5	0.20	0.60	170	20	1.3	1.8	11,600	890	3.4	90
	No.2	4.0	6.5	2.5	0.20	0.50	100	15	1.2	1.4	5,500	840	3.5	80

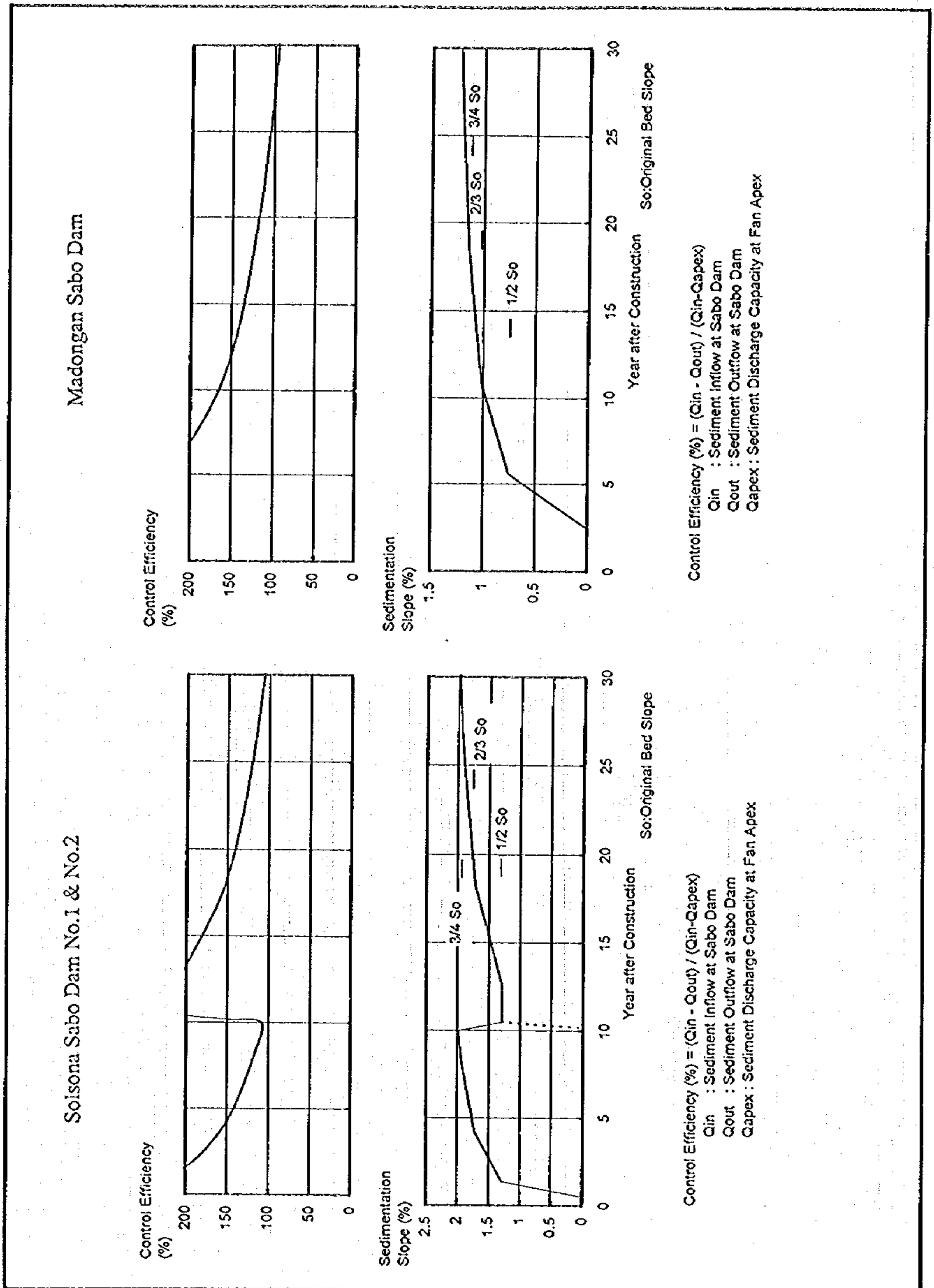
THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN

JAPAN INTERNATIONAL COOPERATION AGENCY

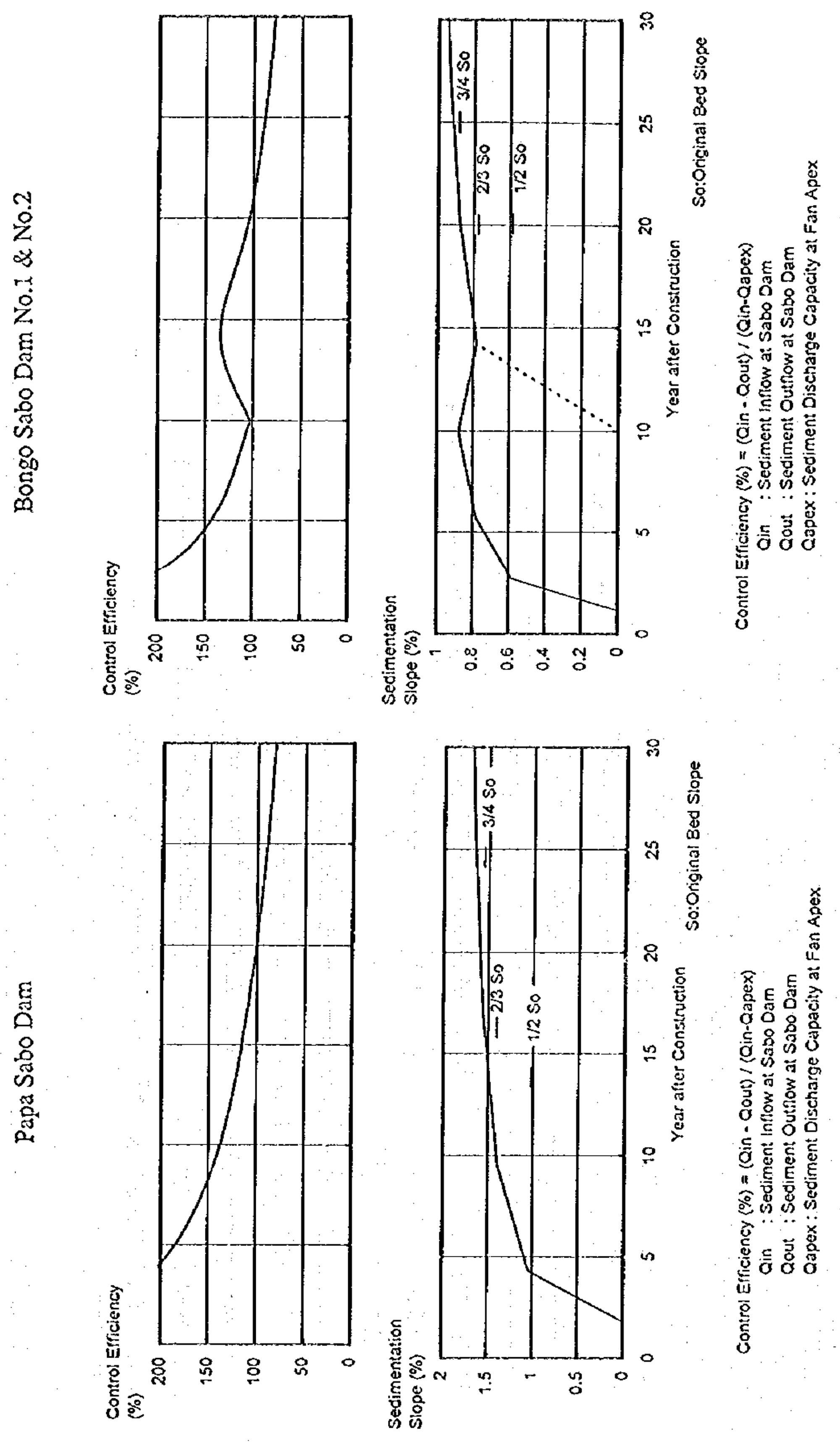
Fig. F.4.4
Structural Layouts of Optimum Sabo Dams



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN	Fig. F.4.5 (1)
JAPAN INTERNATIONAL COOPERATION AGENCY	Control Efficiency of Proposed Sabo Dam (Cura and Labugaon)



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. F.4.5 (2) Control Efficiency of Proposed Sabo Dam (Solsona and Madongan)



THE STUDY ON SABO AND FLOOD CONTROL IN THE LAOAG RIVER BASIN JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. F.4.5.(3) Control Efficiency of Proposed Sabo Dam (Papa and Bongo)