Directorate General of Water Resources
Ministry of Public Works
The Republic of Indonesia

THE STUDY ON COUNTERMEASURES FOR SEDIMENTATION IN THE WONOGIRI MULTIPURPOSE DAM RESERVOIR IN THE REPUBLIC OF INDONESIA

FINAL REPORT

VOLUME-IV SUPPORTING REPORT II

JULY 2007

JAPAN INTERNATIONAL COOPERATION AGENCY

NIPPON KOEI CO.,LTD
YACHIYO ENGINEERING CO.,LTD

FINAL REPORT

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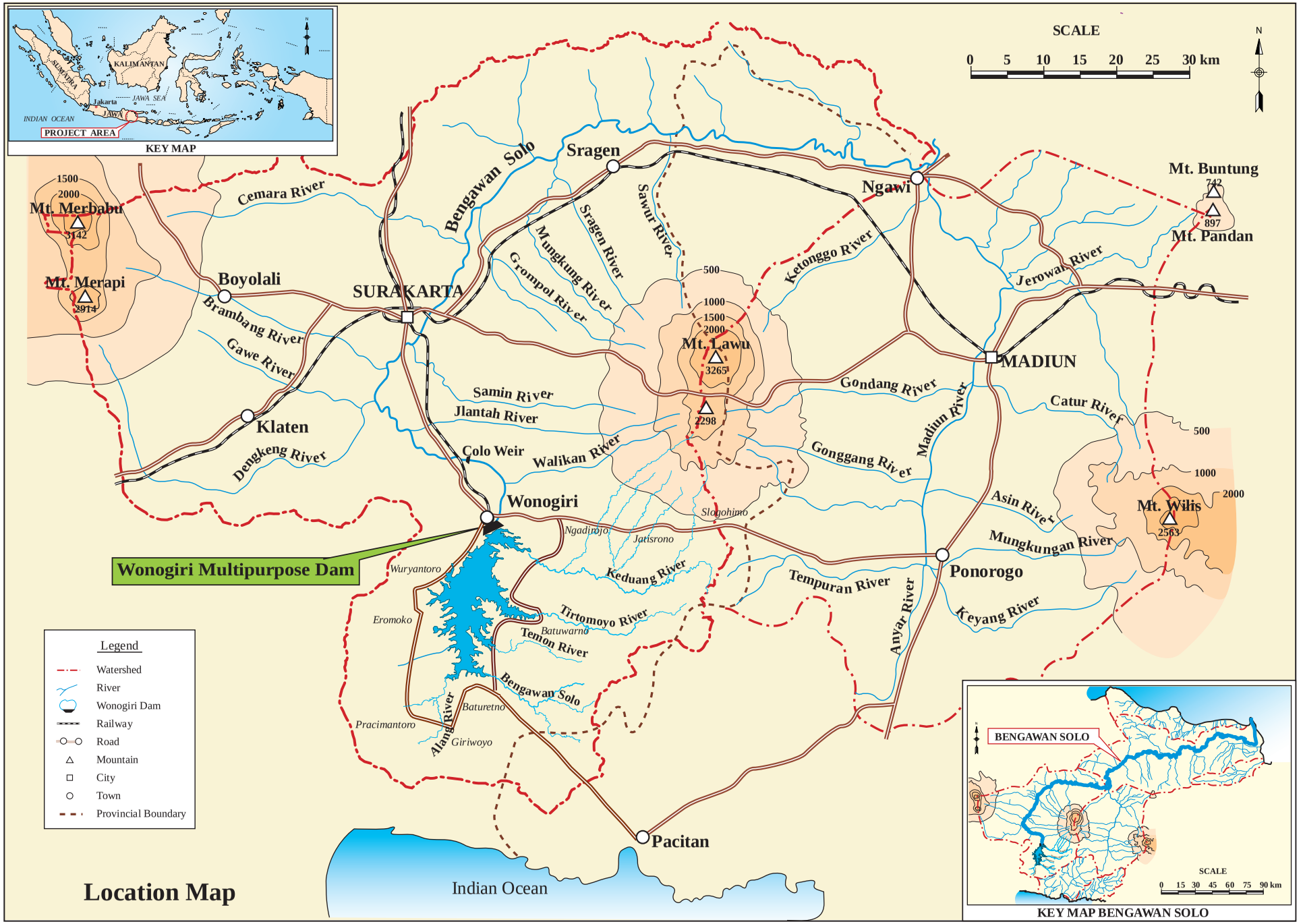
EXCHANGE RATE

The exchange rate used in this Study is:	
Master Plan Study	US Dollar (US$) 1.00 = Indonesia Rupiah (Rp.) 10,035 = Japanese Yen (Y) 119.63 as of December 2005
Feasibility Study	US Dollar (US$) 1.00 = Indonesia Rupiah (Rp.) 9,050 = Japanese Yen (Y) 118.92 as of December 2006


KEY MAP
KALIMANTAN
SUMATERA
JAWA SEA
Jakarta
JAWA
INDIAN OCEAN
PROJECT AREA
SCALE
0 5 10 15 20 25 30 km
N
Mt. Merbabu
3142
Mt. Merapi
2914
Mt. Buntung
742
Mt. Pandan
897
Mt. Lawu
3265
2298
Mt. Wilis
2563
1500
2000
500
1000
Boyolali
SURAKARTA
Klaten
Wonogiri
Ngawi
MADIUN
Ponorogo
Pacitan
Sragen
Bengawan Solo
Cemara River
Brambang River
Gawe River
Dengkeng River
Grompol River
Mungkung River
Sragen River
Sawur River
Ketonggo River
Jerowar River
Samin River
Jlantah River
Colo Weir
Walikan River
Gondang River
Madiun River
Catur River
Gonggang River
Asin River
Mungkungan River
Tempuran River
Keyang River
Anyar River
Keduang River
Tirtomoyo River
Temon River
Bengawan Solo
Alang River
Wonogiri Multipurpose Dam
Wuryantoro
Eromoko
Pracimantoro
Giriwoyo
Baturetno
Batuwarno
Ngadirojo
Jatisrono
Slogohimo
Indian Ocean
Legend
Watershed
River
Wonogiri Dam
Railway
Road
Mountain
City
Town
Provincial Boundary
Location Map
BENGAWAN SOLO
SCALE
0 15 30 45 60 75 90 km
KEY MAP BENGAWAN SOLO

Abbreviation (1/3)

Abbreviation	Indonesian	English
ADB	Bank Pembangunan Asia	Asian Development Bank
AMDAL	Analisis Mengenai Dampak Lingkungan	Environmental Impact Analysis
APBD	Anggaran Pendapatan dan Belanja Daerah	Provincial Government Development Budget (Provincial Budget)
APBN	Anggaran Pendapatan dan Belanja Negara	Central Government Development Budget (National Budget)
BAKOSURTANAL	Badan Koordinasi Survey dan Pemetaan Nasional	National Coordination Agency for Surveys and Mapping
Balai PSDA	Balai Pengelolaan Sumber Daya Air	Regional Office of Water Resources Management
Balai PDAS	Balai Pengelolaan Daerah Aliran Sungai	Regional Office of Watershed Management
BAPEDAL	Badan Pengendalian Dampak Lingkungan	Environmental Impact Management Agency
BAPEDALDA	Badan Pengendalian Dampak Lingkungan Daerah Propinsi	Provincial Office of Environmental Impact Management Agency
BAPEEDA	Badan Perencanaan Pembangunan DaerahTingkat I	Regional Development Planning Agency of Province
BAPPENAS	Badan Perencanaan Pembangunan Nasional	National Development Planning Agency
BB	BB	Brachiaria Brizantha
BBI	Balai Benih Induk	Seed Production enter
BBLH	Biro Bina Lingkungan Hidup	Bureau of Environmental Guidance
B-C	-	Net Present Value
BD	-	Brachiaria Decumbens
BIMAS	Bimbingan Masal	Mass Guideline for Agricultural Divelopment
BKPH	Bagian Kesatuan Pemangkuan Hutan	Forest Administration Sub-unit
BMG	Badan Meteorologi dan Geofisika	Meteorological and Geophysical Agency
BOD	-	Biochemical Oxygen Demand
BP2TPDAS	Balai Penelitian dan Pengembangan Teknologi Pengolohan Daerah Aliran Sungai	Watershed Management Technology Centera, Ministry of Forestry
BPDAS Solo	Balai Pengeloloan Daerah Aliran Sungai Solo	Solo River Management Office of Ministry of Forestry
BPKH	Balai Pemantapan Kawasan Hutan	Forest Area Consolidation Bureau
BPPHH	Balai Pengendalian Peredaran Hasil Hutan	Forestation Result of Agricultural Extension Office
BPS	Biro Pusat Statistik	Central Bureau of Statistics
BPTP Terpadu	Balai Pengkajian Teknologi Pertanion	Integrated Agricultural Technology Assessment Center
BPTPH	Balai Proteksi Tanaman Pangan dan Hortikultura	Provincial Plant Protection Center
Cd		Cadmium
CDMP	-	Comprehensive Developmant and Management Plan Study for Bengawan Solo River Basin under Lower Solo River Improvement Project
COD	Kebutuhan Oksigen untuk proses kimia	Chemical Oxygen Demand
Cr	Khrom	Chromium
Cu	-	Copper
CWL	Tinggi Muka Air Kendali	Control Water Level
DAS	Daerah Aliran Sungai	Watershed, Catchment
DEM	-	Digital Elevation Method
DEPDAGRI	Departemen Dalam Negeri	Ministry of Home Affairs
DEPHUT	Departemen Kehutanan	Ministry of Forestry
DEPKES	Departemen Kesehatan	Ministry of Health
DEPTAN	Departemen Pertanian	Ministry of Agriculture
DFWL	Tingi Muka Air Banjir Rencana	Design Flood Water Level
DG	Direktorat Jendral	Directorate General
DGLWM	Direktorat Jendral Pengelolaan Lahan dan Air	Directorate General for Land and Water Management
DGWR	Direktorat Jenderal Sumber Daya Air	Directorate General of Water Resources
DHF	_	Dengue Hemorrhagic Fever
Dinas LHKP	Dinas Lingkungan Hidup, Kehutanan dan Pertambangan	Environment, Forestry and Mining Services of kabupaten Wonogiri
DIP	Daftar Isian Proyek	Approved Project Budget
DIPERTA	Dinas Pertanian Tanaman Pangan Daerah Propinsi Jawa	Provincial Agricultural Service of Central Java
DO	Oksigen Terlarut	Dissolved Oxygen
DPRD	Dewan Perwakilan Rakyat Daerah	Regional House of Representatives
DPU	Departemen Pekerjaan Umum	Ministry of Public Works
EFWL	Tinggi Muka Air Banjir Ekstra	Extra Flood Water Level
EIA	Analisis Dampak Lingkungan	Environmental Impact Assessment
EIRR	-	Economic Internal Rate of Return
EU	Uni Eropa	European Union
FAO	Badan Pangan Dunia	United Nations Development Programme /Food and Agriculture Organization
FORDA	Litbang Departemen Kehutanan	Forestry Research & Development Agency
GDP	-	Gross Domestic Product
GIS	Sistem Informasi Geografis	Geological Information System
GMU	Universitas Gadjah Mada	Gadjah Mada University

Abbreviation (2/3)

Abbreviation	Indonesian	English
GNKPA	Gerakan Nasional Kemitraan Penyelamatan Air	National Movement of the Partnership for Water Preservation
GNP	Pendapatan Nasional	Gross National Product
GOI	Pemerintah Indonesia	Government of Indonesia
GOJ	Pemerintah Jepang	Government of Japan
GPS	Sistem Posisi Global	Global Position System
GRDP	Produk Domestik Regional Bruto	Gross Regional Domestic Product
GERHAN	Gerakan Nasional Rehabilitasi Hutan dan Lahan	National Movement for Forest & Land Rehabilitation
H-A	-	Relation between reservoir water level and reservoir surface area
H-V	-	Relation between reservoir water level and reservoir capacity volume
HKTI	Himpunan Kerukunan Tani Indonesia	Farmer's Association
HPI	Indek Kemiskinan	Human Poverty Index
IBRD (WB)	Bank Dunia	International Bank of Reconstruction and Development (Work Bank)
IEE	Pengkajian Pendahuluan Lingkungan	Initial Environmental Examination
IPAIR	Iuran Pelayanan Irigasi	Irrigation Service Fee
IPEDA	Iuran Pen Bangunan Daerah	Village Land Tax, Provincial Development Tax
ISPA	Infeksi Saluran Pernafasan Atas	Upper Respiratory Nasopharynx
JAMALI	Sistem Interkoneksi Jawa-Madura-Bali	Java-Madura-Bali power generation system
JBIC	-	Japan Bank of International Cooperation
JICA	-	Japan International Cooperation Agency
JIS	Standar Industri Jepang	Japanese Industrial Standards
JPY, Yen	Yen	Japanese Yen
K2TA	Kelompok Konservasi Tanah dan Air	Soil and Water Conservation Farmer Group
KBD	Kebun Bibit Desa	Seeding Garden Village
KCI	-	Polassium Chloride
KESBANLINMAS	Badan Kesatuan Bangsa dan Perlingdungan Masyarakat	National Unity and Society Protection Board
KIMPRASWIL	Departemen Pemukiman dan Prasarana Wilayah	Ministry of Housing and Regional Infrastructure
KPH	Kesatuan Pemangkuan Hutan	Forest Administration Unit
KT	Kelompok Tani	Farmers' Group at Village Level
KUD	Koperasi Unit Desa	Village Cooperative Unit
LHKP Wonogiri	Lingkungan Hidup, Kehutanan dan Pertambangan	Forestry Sub-services of Wonogiri Human Environment, Forestry and Mining Services Office
LKMD	Lembaga Ketahanan Masyarakat Desa	Village Social Activities Group, Village Welfare Institution
LPTP	NGO (Lembaga Pengembangan Teknologi Perdesaan)	-
LSM	Lembaga Swadaya Masarahkat	Nongovernmental Organization (NGO)
LWL	Tinggi Muka Air Rendah	Low Water Level
M&E	Pemantauan dan Evaluasi	Monitoring and Evaluation
MOU	Nota Kesepahaman	Memorandum of Understanding
MT I	Musim Tanam I	Cropping Season I
MT II	Musim Tanam II	Cropping Season II
MT III	Musim Tanam III	Cropping Season III
NGO	Lembaga Swadaya Masyarakat	Non Governmental Organization
NHWL	Tinggi Muka Air Normal	Normal High Water Level
NO2	Nitrit	Nitrogen Dioxide
NO3	Nitrat	Nitrogen Trioxide
NTU	-	Nephelometric Turbidity Unit
O&M, O/M	Operasi dan Pemeliharaan	Operation and Maintenance
Otonomi daerah	Otonomi Daerah	-
OECF	-	Overseas Economic Cooperation Fund
OTCA	Lembaga Kerjasama Teknis Luar Negei	Overseas Technical Cooperation Agency
P4K	Pembinaan Peningkatan Pendapatan Petani-Nelayan Kecil	Farmer Groups of Small-Scale Farmers
Pb	-	Lead
PBS	Proyek Bengawan Solo	Bengawan Solo River Basin Development Project
P2AT	Proyek Pengembangan Air Tanah	Groundwater Development Project
P3A, HIPPA	Perkumpulan Petani Pemakai Air, Himpunan Petani	Water User's Association (WUA)
PABBS	Proyek Penyediaan Air Baku Bengawan Solo	Bengawan Solo River Water Supply Project
PBS	Proyek Bengawan Solo	Bengawan Solo River Basin Development Office
PCM	Pertemuan Konsultasi Masyarakat	Public Consaltaiton Meeting
PDAM	Perusahaan Daerah Air Minum	Regional Drinking Water Supply Company
PDAS	Pengelolaan Daerah Aliran sungai	Watershed Management
PDRB	Produk Domestik Regional Bruto	Product Domestic Regional Brutto
Perum	Perusahaan Umum	Public Corporation

Abbreviation (3/3)

Abbreviation	Indonesian	English
PERSEPSI	NGO (Perhimpunan untuk Studi dan Pengembangan Ekonomi dan Sosial)	-
pH	Nilai Keasaman	pH value
PHBM	Pengololaan Hutan Bersama Masyarakat	Community Participated Forest Management
PJP	Pembangunan Jangka Panjang	Twenty-Five Year Long Term Development Plan
PIPWS Bengawan	Proyek Induk Pengembangan Wilayah Sungai Bengawan	Bengawan Solo River Basin Development Office
PJT	Perum Jasa Tirta	Public Water Service Corporation
PKL	Penyuluh Kuhutanan Lapangan	Field Forestry Extension Worker
PKSDABS	Proyek Pengembangan Konservasi Sumber Daya Air Bengawan Solo	Bengawan Solo River Water Resources Conservation Development Project
PLTA Wonogiri	Pusat Listrik Tenaga Air Wonogiri	Wonogiri Power Station
PMF	Banjir Maksimum yang mungkin terjadi	Probable Maximum Flood
PO4	-	Phosphoric Tetroxide
PPL	Penyuluh Pertanian Lapangan	Field Extension Workers
ppm	Seper juta	parts per million
PPTPA	Penitia Pelaksana Tata Pengaturan Air	River Basin Water Resources Management Committee
PRA	Analisa Partisipatori Pedesaan	Participatory Rural Appraisal
PROPENAS	Program Pembangunan National	Five-Year National Development Program
PSAPBBS	Proyek Pengelolaan Sumber Air dan Pengendalian Banjir Bengawan Solo	Bengawan Solo River Water Resources Management and Flood Control Project
PSDA	Pekerjaan Umum Sumber Daya Air	Water Resource Management
PT CMA	PT Citra Mandala Agritrans	-
PTPA	Panitia Tata Pengaturan Air	-
PU	Pekerjaan Umum	Ministry of Public Works
REI	-	Rain Erosivity Index
RENSTRA	Rencana Strategis	Strategic Plan
REPEDA	Rancangan Peraturan Daerah	Annual Plan
Rp.	Rupiah	Indonesian Rupiah
RPH	Resort Pemangkuan Hutan	Field Unit of KPH
RTL	Rencana Tindak Lanjut	Field Technical Planning in Upper Solo Watershed Protection Project in Wonogiri Watershed
RTT	Rencana Teknis Tahunan	Yearly Technical Planning in Upper Solo Watershed Protection Project in Wonogiri Watershed
RUTRK-RDTRK	Rencana Umum/Detail tata Ruang Kota	General City Site Plan, Detailed City Site Plan
RWL	Muka Air Waduk	Reservoir Water Level
SBRLKT	Sub Balai Rehabilitasi Lahan dan Konservasi Tanah	Sub Unit for Land Rehabilitation and Soil Conservation
SCF	Faktor Konversi Standar	Standard Conversion Factor
SDR	Nisbah Pengantaran Sedimen	Sediment Delivery Ratio
SEA	Penilaian Lingkungan Strategis	Strategic Environmental Assessment
SFC	Perum Perhutani	State Forest Corporation
SHFD	Debit banjir tertinggi standar	Standard Highest Flood Discharge
SI	-	Stress Index
SS	Padatan Tersuspensi	Suspended Solid
SWOT	Kekuatan, Kelemahan, Kesempatan, Ancaman	Strength, Weakness, Opportunity, Threat
TDS	Total Padatan Terlarut	Total Dissolved Solid
TIU	Unit Pelaksana Teknis	Technical Implementation Unit
TOR	Kerangka Acuan Kerja	Terms of Reference
TSS	Total Padatan Tersuspensi	Total Suspended Solid
UKL	Upaya Kelola Lingkungan	Environmental Management Efforts
UNDP/FAO	Badan Pangan Dunia	United Nations Development Programme /Food and Agriculture Organization
UPL	Upaya Pemantau Lingkungan	Environmental Monitoring Efforts
UPR	Unit Pembenihan Rakyat	Community Nursery Unit
UPTD	Unit Pelaksana Teknis Daerah	Local Technical Implementation Unit
US$, USD	Dollar Amerika	US dollar
USAID	-	US Agency for International Development
USLE	Persamaan Kehilangan Tanah Umum	Universal Soil Loss Equation
VAP	Rencana Kerja Desa	Village Action Plan
WC3	Komite Koordinasi Konservasi DAS	Watershed Conservation Coordinating Committee
WKPP	Wilayah Kerja Penyuluhan Pertanian	Working Area of Agricultural Extension
WM	Pengelolaan Daerah Aliran sungai (DAS)	Watershed Management
WRM	Pengelolaan Sumber Daya Air (SDA)	Water Resource Management
Zn	Seng	Zinc

Annex No.7 Preliminary Design and Technical Evaluation on Structural Sediment Management Alternatives

THE STUDY ON
COUNTERMEASURES FOR SEDIMENTATION
IN
THE WONOGIRI MULTIPURPOSE DAM RESERVOIR
IN
THE REPUBLIC OF INDONESIA

FINAL REPORT

SUPPROTING REPORT

Annex No.7: Preliminary Design and Technical Evaluation on Structural Sediment Management Alternatives

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CHAPTER 1 BASIC CONDITION FOR CONSIDERING COUNTERMEASURES

1.1 Basic Conditions for Preliminary Design

In accordance with dam design and reservoir operation rule, restricting conditions for countermeasures of sedimentation in view of flood control and water utilization shall be considered in this section.

(1) Principal Feature of the Wonogiri Dam

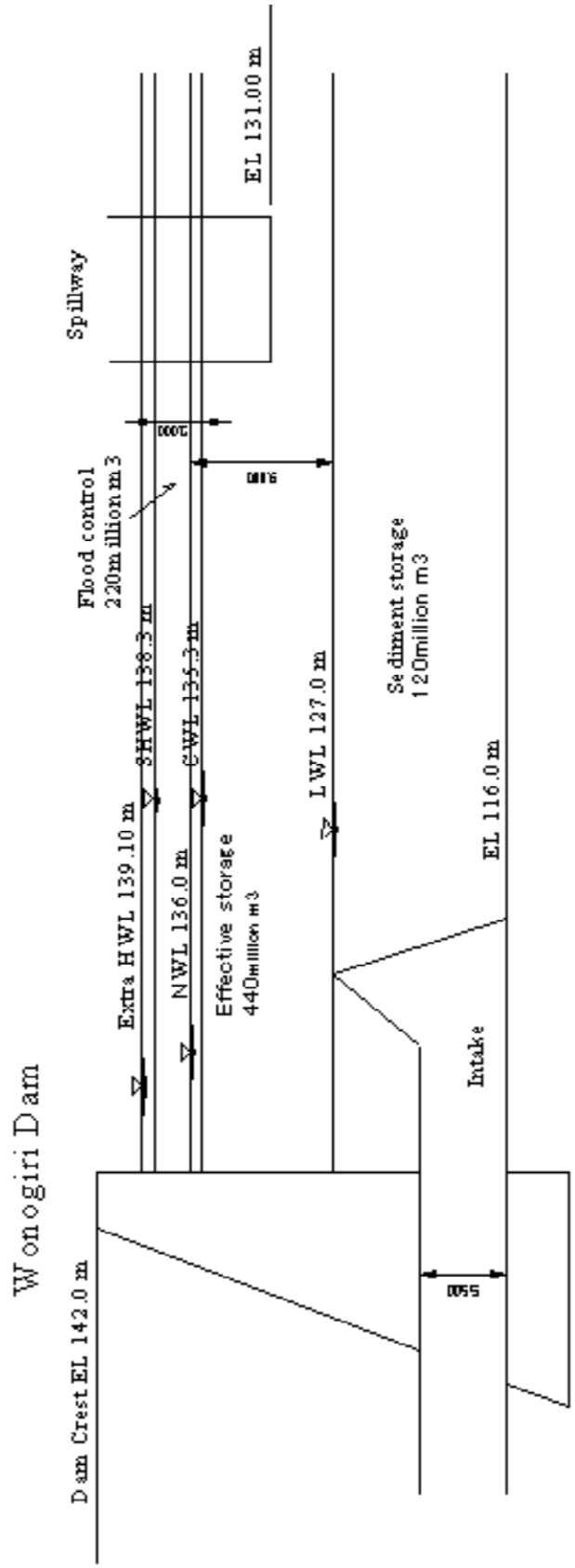
The principal features of the Wonogiri dam and reservoir are shown in Table 1.1.1 and the allocation of the storage capacity of the dam and designated water levels are shown in Figure 1.1.1

Figure 1.1.2 shows the general layout of the Wonogiri dam, and Figure 1.1.3 shows the profile and typical cross section of dam.

Table 1.1.1 Principal Features of Wonogiri Multipurpose Dam and Reservoir

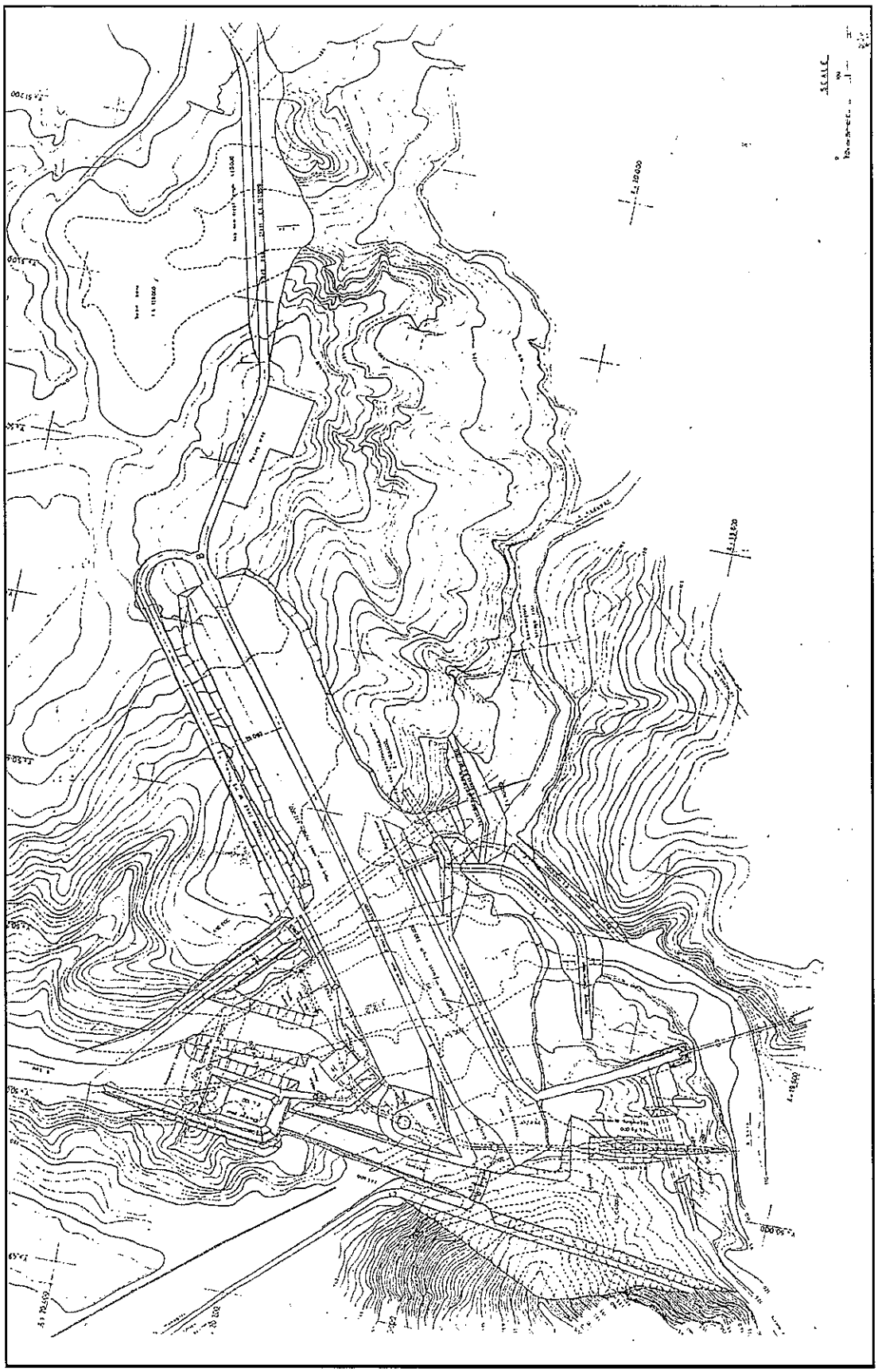
Dam type	Rockfilll	Normal Water Level	EL. 136.0 m
Dam height	40 m	Design Flood Level	EL. 138.3 m
Crest length	830 m	Extra Flood Water Level	EL. 139.1 m
Embankment volume	1,223,300 m^3	Spillway (Radial gate)	7.5 m x 7.8 m x 4 nos.
Catchment area	1,350 km^2	Overflow Crest Height	EL. 131.0 m
Reservoir area	90 km^2	Flood inflow discharge	4,000 m^3/s
Gross storage capacity	735 x 106 m^3	Design discharge at flooding	400 m^3/s
Active storage capacity	615 x 106 m^3	Design flood discharge	5,100 m^3/s
Flood control storage capacity	220 x 106 m^3	PMF(Provable maximum flood)	9,600 m^3/s
Irrigation & hydro power storage capacity	440 x 106 m^3	Power plant installed capacity	12.4 MW
Sediment storage capacity	120 x 106 m^3	Design head	20.4 m
Sediment deposit level	EL. 127.0 m	Max. discharge	75 m^3/s

Source: PBS



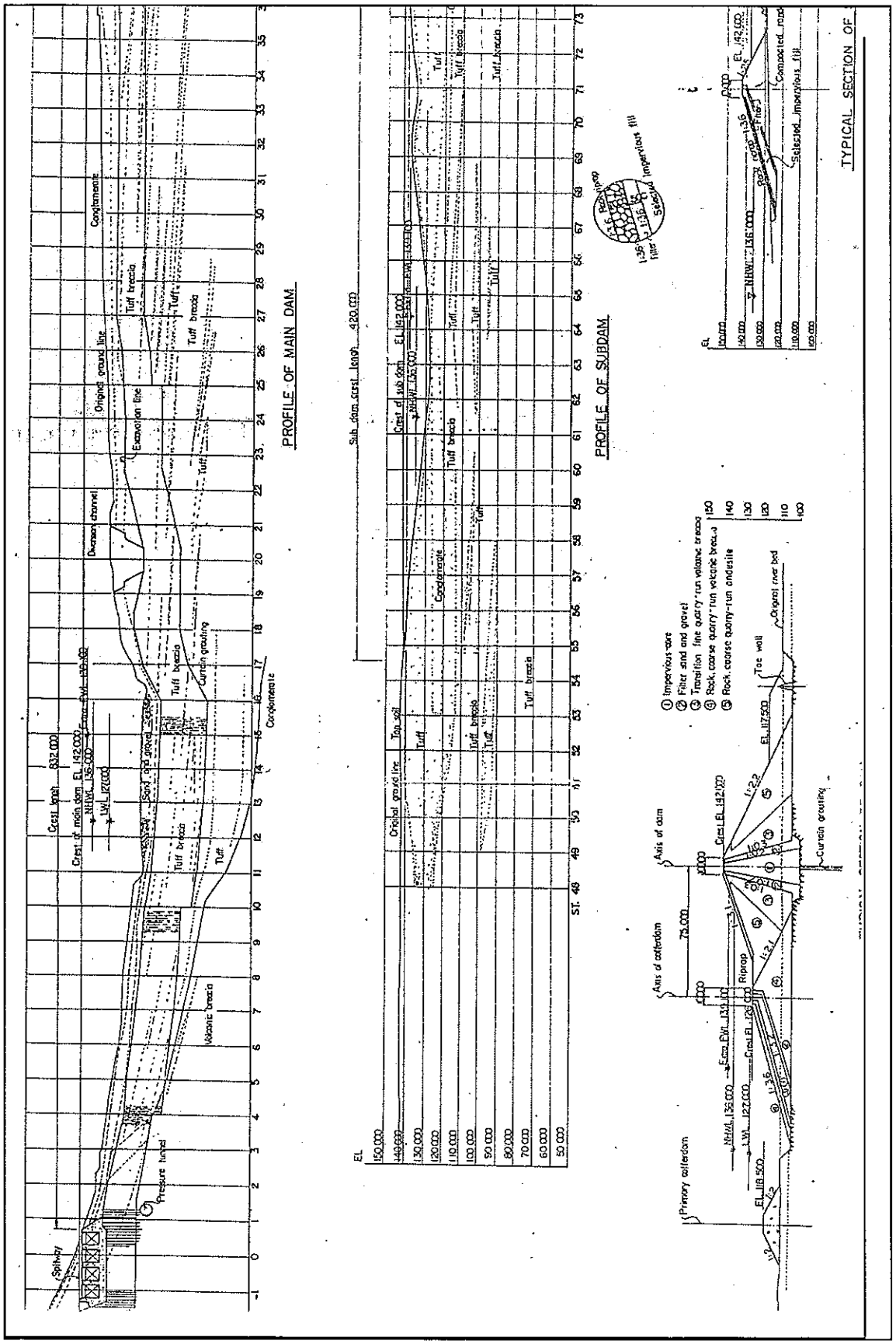
Source: PBS

Figure 1.1.1 Allocation of Storage Capacity and Water Levels of Wonogiri Dam



Source: WONOGIRI MULTIPURPOSE DAM PROJECT, COMPLETION DRAWINGS

Figure 1.1.2 General Layout of Wonogiri Dam



Source: WONOGIRI MULTIPURPOSE DAM PROJECT, COMPLETION DRAWINGS

Figure 1.1.3 Profile and Typical Section of Wonogiri Dam

(2) Design Concept

1) Reservoir

Wonogiri reservoir was designed to have total storage of 735 million m^3 at maximum flood water level of EL.138.3 m (lake surface area : 87 km^2). Normal high water level and low water level were set at EL.136.0 m and EL.127.0 m respectively, between which 440 million m^3 was secured as an active storage for the use of irrigation water supply, power generation and etc. As flood control capacity, about 220 million m^3 was provided above the elevation of 135.3 m which would have to be maintained during flood season. Below low water level, storage capacity of 120 million m^3 was prepared for sedimentation which is estimated as total volume of it for 100-years.

Operation rule of reservoir was established so that it should be recovered full storage by every May and successively release water to meet irrigation demand. Water released is to be utilized first for power generation and then for irrigation at the Colo weir 13 km downstream from dam.

At the end of every rainy season, water level should be recovered to normal water level not to obstacle the water utilization for irrigation.

If any surplus water exists, mostly wet season, it will be used for power generation being added to required irrigation released.

Average discharge during dry season (Jun to September: maximum irrigation period) is 27. 5m^3/sec, whereas during rainy season 20.7 m^3/sec on average is discharged including surplus water for power generation.

2) Dam

Dam to be constructed at the site immediately downstream of confluence of east tributary of the Kuduang River was designed of a central core type rockfill dam. Due to topographic condition of the dam site, a low sub dam had to be provided with on the right bank ridge.

Height of the dam rises 40. 0m above the base rock and top of crest was set at EL.142.0 m at which the dam had a free board of 2.9 m even above the extra ordinary flood water level and of 6.0 m above the normal high water level. Total crest length is 834 m. Total embankment volume was estimated at 1.8 million m^3.

3) Spillway

Spillway was designed of overflow weir with radial gates and chuteway with flip bucket end and with plunge pool on the left bank adjacent to the main dam.

It has effective width of overflow weir of 30 m (4@7.5 m), rectangular reinforced concrete chuteway width of 30m to 20m and total chuteway length of 360 m, and 51 m long plunge pool at the downstream end.

Four number of roller gates, 7.5 m wide and 7.8 m high were provided with overflow crest.

This spillway was designed to accommodate extra ordinary flood and to evacuate the discharge 1,360 m^3/s at the maximum water level of EL.139.1 m.

Spillway was also designed to regulate the floods under such rule as whenever the

reservoir water level was lower than EL.138.2 m, the discharge from spillway should be maintained a constant outflow of 400 m^3/sec, while the water level rises above EL.138.2 m, free overflow should be allowed by fully opening of crest gates until the reservoir surface went down to EL.135.3 m, i.e. the control water level during flood season.

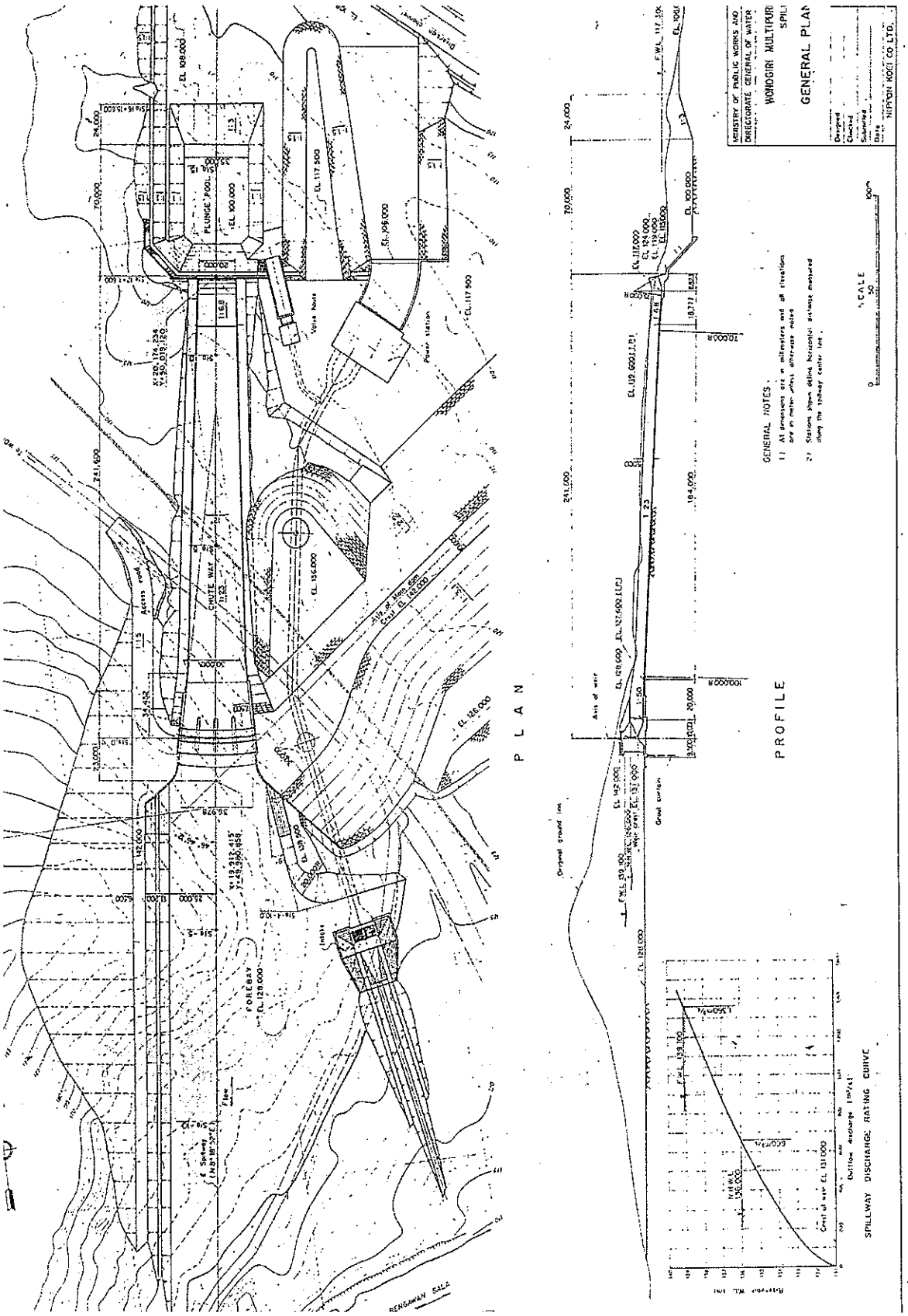
Table 1.1.2 shows the design flood, design discharge and water level coincided with flood

Design flood hydrograph is shown in figure 1.1.4.

Table 1.1.2 Design Flood and Discharge from Spillway

Flood discharge	Maximum inflow (m^3/sec)	Maximum outflow (m^3/sec)	Water level (EL. m)
Basic highest flood discharge (S.H.F.D)	4,500	400	138.3
Design flood discharge for spillway	5,200	1,170	
Extra ordinary flood	9,600	1,360	139.1

Source: PBS



Source: WONOGIRI MULTIPURPOSE DAM PROJECT, COMPLETION DRAWINGS

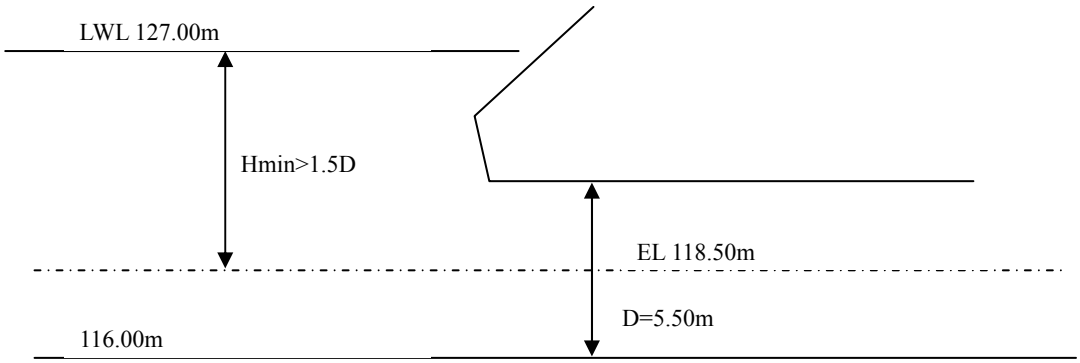
Figure 1.1.4 Plan and Profile of Spillway

4) Intake and Waterway

Horizontal Inlet of bell-mouth type with Intake gate is finally selected as intake structure. The bottom elevation of inlet is set at EL.116.00 m. Inlet structure has two square parts of 5.5 m wide each and inclined steal trash-rack at the entrance. A semicircular intake tunnel has an inside diameter of 5.5 m and connects the inlet structure to the gate operating shaft for accommodating the maximum discharge of 75 m^3/s.

In order to prevent the air suction into the waterway, the minimum water depth at entrance should be deeper than 1.5 times the diameter of tunnel.

As illustrated below this design standard is followed in the current design.



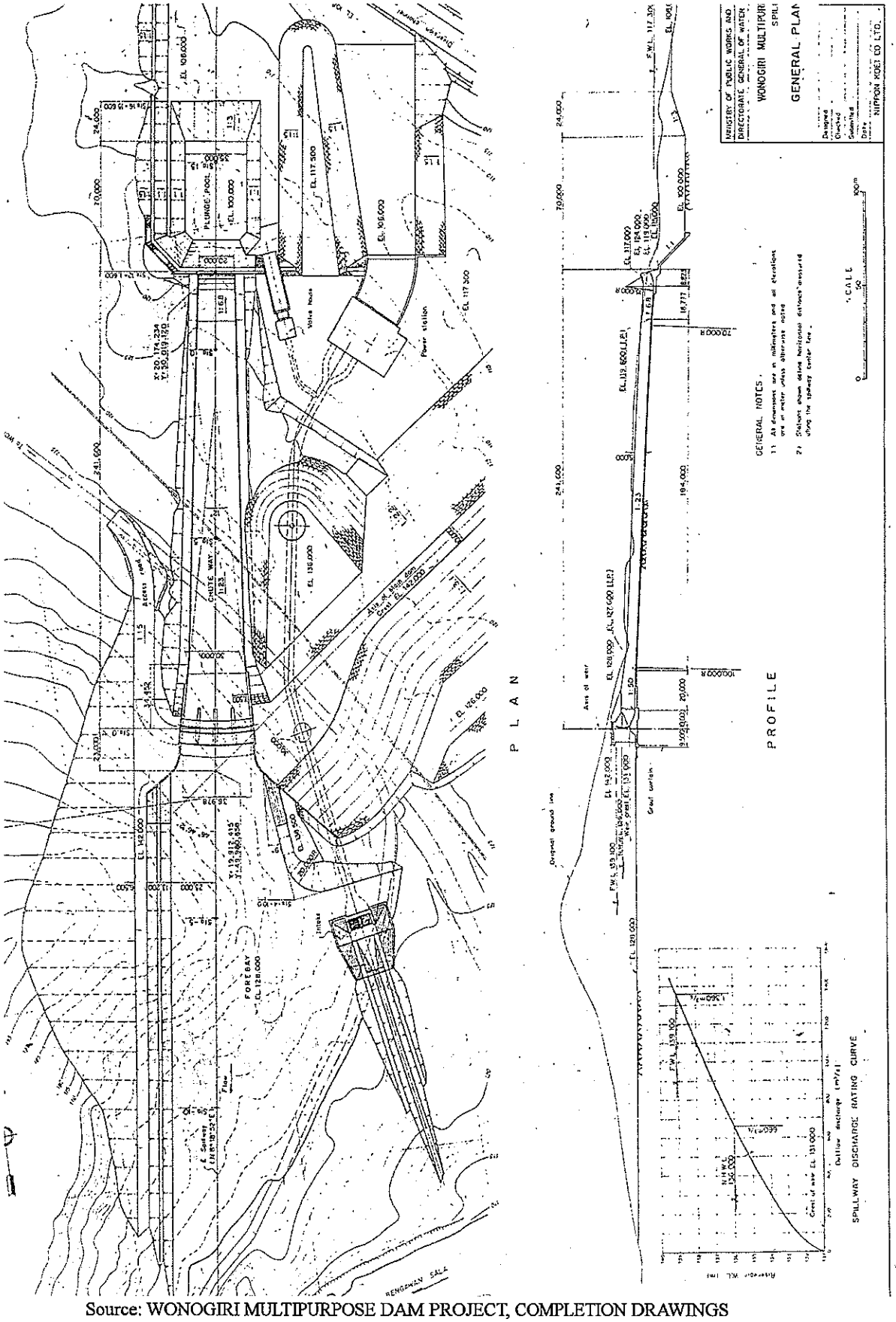
Hmin=8.5m
1.5D=1.5×5.5=8.25m
∴ Hmin > 1.5D

Wave height at Intake when the reservoir water level sticks to the low water level(WL.127.00m) can be estimated from the following SMB formula.

$Ht = 0.00086\ V^{1.1} F^{0.45}$

Where the fetch is taken to 1,700 m, then the wave height is 66 centimeters.

Intake facilities to take the surface water of reservoir are not provided in the Wonogiri dam, since these facilities are suited to regions with chilly weather such as in the northern part of Japan.



Source: WONOGIRI MULTIPURPOSE DAM PROJECT, COMPLETION DRAWINGS

Figure 1.1.5 Plan and Profile of Intake

(3) Flood Control Plan

1) Master Plan

Flood control plan is composed of flood control at Wonogiri dam and Improvement plan of downstream of the Solo River.

In case peak inflow at Dam site is below design flood inflow of 4,000 m^3/s, most of the inflow is controlled in the reservoir and 400 m^3/s outflow is discharged from dam.

Due to these flood control, flood flow at downstream is decreased to approximately 2,000 m^3/s at Surakarta.

Capacity of flow at downstream of the Solo River was only 500 m^3/s, and river improvement works were implemented to increase the capacity of flow from 500 m^3/s to 2,000 m^3/s.

Design flood adopted in the flood control plan was (SHFD) standard hydrograph of flood discharge, whose occurrence probability is 60-years at Wonogiri dam site and 40-years at Surakarta.

Design flood discharge is shown in following table at respective control points.

Table 1.1.3 Design Flood Discharge（m^3/s)

Condition of river	Dam site	Surakarta	Ngawi
Current discharge	4,000	2,160	1,890
Before flood control at dam	4,000	5,300	4,900
After flood control at dam	400	2,000	2,830

Source: PBS

2) Flood Control at Reservoir

The reservoir water level is controlled not to exceed the control water level (EL135.3 m) during the flood season from December 1st to April 15th for eliminating the possibility of overtopping of a Probable Maximum Flood (PMF) on the dam crest. The reservoir provides 220 million m^3 of flood control capacity to regulate the standard highest flood discharge (SHFD) with peak discharge of 4,000 m^3/s to the constant outflow of 400 m^3/s. The peak outflow discharge is 1,170 m^3/s for the design discharge of 5,100 m^3/s for spillway, which is equivalent to 1.2 times a 100-year probable flood, and 1,360 m^3/s for PMF of 9,600 m^3/s. Since the completion of the Wonogiri dam in 1982, no flooding has so far occurred in Surakarta, largest city in the Bengawan Solo River basin. The Wonogiri dam has much contributed to social welfare in the basin and has greatly benefited the people in the downstream area.

Flood discharge adopted in the design stage are as shown below.

For estimate of abnormal flood discharge for dam design, the probable maximum flood analysis was introduced.

Table 1.1.4 Peak Discharge

Flood	Discharge (m^3/sec)	Remarks
Dry season diversion	350	20-year flood
Diversion	3,100	20-year flood
Standard highest flood (SHFD)	4,000	60-year flood
Spillway Design	5,100	1.2 times 100-year flood
Extra ordinary	9,600	Probable maximum flood

Source: PBS

3) Run-off Records

Monthly mean run-off data for the period from 1953/54 to 1972/75 were used for the Dam design report prepared by JICA F/S team on October 1975.

Observed run-off data at Wonogiri for the period from 1975/76 to 2003/4 are supplemented in the above data.

Average annual run-off at the Wonogiri dam site is newly estimated at about 31.73/sec in yearly mean. 12.7 m^3/sec in driest year and 56.4 m^3/sec in the wettest year in the dam design stage.

(4) Wonogiri Irrigation System

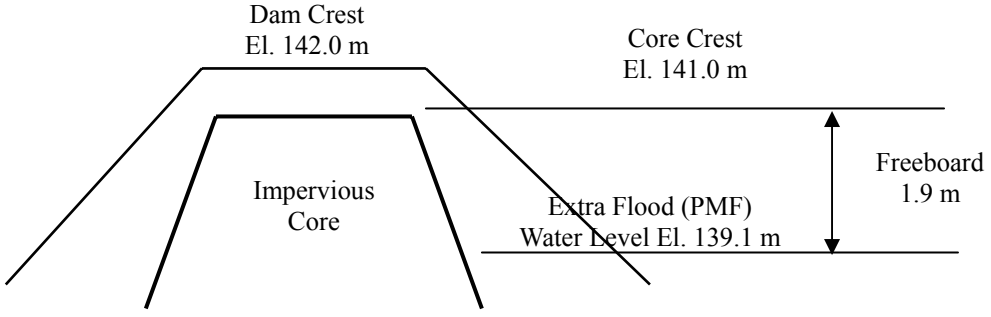
Immediately after completion of the Wonogiri Irrigation Project in 1983, the water supply to the Wonogiri irrigation system was commenced. Irrigation water is taken from the Colo intake weir located about 13 km downstream of the Wonogiri dam. The Wonogiri irrigation system comprises 94 km long main canal and 105 km long secondary canal. At present, the irrigation area has been extended from 24,000 ha in the original plan to 30,000 ha where triple cropping farming is being practiced.

(5) Power Generation at the Wonogiri Hydropower Station

The powerhouse is located just downstream of the Wonogiri dam. It accommodates the generating equipment with an installed capacity of 12.4 MW to produce annual energy output of 55,000 MWh. The maximum discharge for power generation is 75 m^3/s.

(6) Freeboard by the 1978 Detailed Design

According to the Completion Report of Wonogiri Multipurpose Dam Project, the crest elevation of the impervious core zone of Wonogiri dam is El. 141.0 m as illustrated below.



The freeboard of 1.9 m as shown above, given by the difference between the crest of impervious core (El. 141.0 m) and the Extra Flood Water Level (El. 139.1 m), was originally allocated for additional allowance against water wave by the concurrent wind

at the occurrence of PMF.

As mentioned in Section 3.1, the freeboard of 1.9 m was provided to prevent rising of the reservoir water surface from overtopping the impervious core zone of the embankment due to wave action that might coincide with the occurrence of PMF.

The wave height (*Ht*) due to wave action is usually estimated by the following equation (S.M.B. method):

$Ht = 0.00086 \times V^{1.1} \times F^{0.45}$

where, *Ht:* Wave height (m)
V: Mean wind velocity (m/sec)
F: Fetch distance (m)

According to the design report in 1978, the wave height (Ht) was estimated to be 1.76 m applying that the mean wind velocity (*V*) and fetch distance (*F*) were assumed 20 m/sec and 15,000 m. This means that the crest of the impervious core zone should be higher than El. 140.86 m (= El. 139.10 m + 1.76 m). As a result the crest elevation of the impervious core zone was decided El. 141.0 m.

(7) Geological Data

Although it was confirmed that the dominat geological formation covering the wonogiri damsite was alternation of tuff and tuff breccia, volcanic breccia was detected as the base mass under the left abutment, volcanic breccia presumably forms the base formation in the whole area of damsite.

There exists unconformity in geological epoch ; volcanic breccia belongs to Pliocene while tuff and tuff breccia to Miocene.

Andesite mass was found in the volcanic breccia at the center of the left ridge, of which thickness is about 20 m. Since the reliability as foundation of structure seems better than volcanic breccia, spillway weir shall be located on the andesite mass. The existence of andesite and consolidated volcanic breccia suggests that the rock to be excavated from forebay is able to be used as material of dam embankment and other uses.

(Dm site)

Relatively low elevation ridge is extend on the right bank of the dam. hence width of dam become comparatively long as 1,440 m. Earth covering of the surface soil is thick, and foundation rock exist in depth approximately 15 m from surface of the ground. At the portion of left side of the dam, abutment rises about 100 m high from riverbed with hard rock. Earth covering on foundation rock is approximately 5-10 m.

1.2 Restricting Conditions of Flood Control

(1) Safety Discharge from Dam

Flood control plan of Wonogiri dam is that most of flood flow under 4,000 m^3/s at dam site is controlled to be 400 m^3/s discharge from dam. As gate type is adopted for flood control, 400 m^3/s of flood flow as the fixed release-rate operation shall be discharged at flooding by operating the flood control gates. Hence in case of releasing reservoir water for countermeasure of sedimentation as a water flow utilization method, maximum discharge shall be regulated under 400 m^3/s of safety discharge.

(2) Available Water Flow for Sediment Removal (Flushing/Sluicing)

In case of lowering water level under normal water level for utilization of water use capacity, it deemed difficult to utilize the water flow for sediment removal. Figure 1.2.1 shows the actual reservoir operation of Wonogiri dam. According to the figure, about during eight (8) years from dam completion of 1983 to 1991, normal water level had been kept under EL.136.0 m water level, which is normal reservoir operation rule. While, from 1991 up to now, water level have been pulled up to EL.137.0 m except draught years, which had been breached thedam operation rule. In rainy season at the beginning of November to December, spill out flow from existing spillway had conducted to flood control at the water level being low. As the flow out for sediment removal, it is consider using this out flow. Annual average volume of spill out flow is estimated about 200 million m^3, which is available to use for sediment flushing.

(3) Restricting Conditions from Water Utilization

1) Probable Draw Down of Reservoir Water Level

In Wonogiri dam, 440 million m^3 of water- use capacity at dry season is planned to store to utilize for irrigation and power. To meet such requirement, water level of EL.136.0 m should be kept at the end of rainy season. Therefore it is unable to lower water level at dry season. On the other hand, limited water level of EL.135.3 m during flood season had been designated for flooding. Figure 1.2.1 shows the actual reservoir operation. According to the figure, the month being lowest water level is obviously identified at November - December, which is the end of dry-season and the beginning of wet season. Therefore, from the beginning of rainy season, it is deemed effective to use inflow water for sediment flushing. However on actual dam reservoir operation, as reservoir storage turn-over rate is few as 2-4 times, water level was set more than limit water level EL.135.3 m.

2) Probable Flow Water Utilization

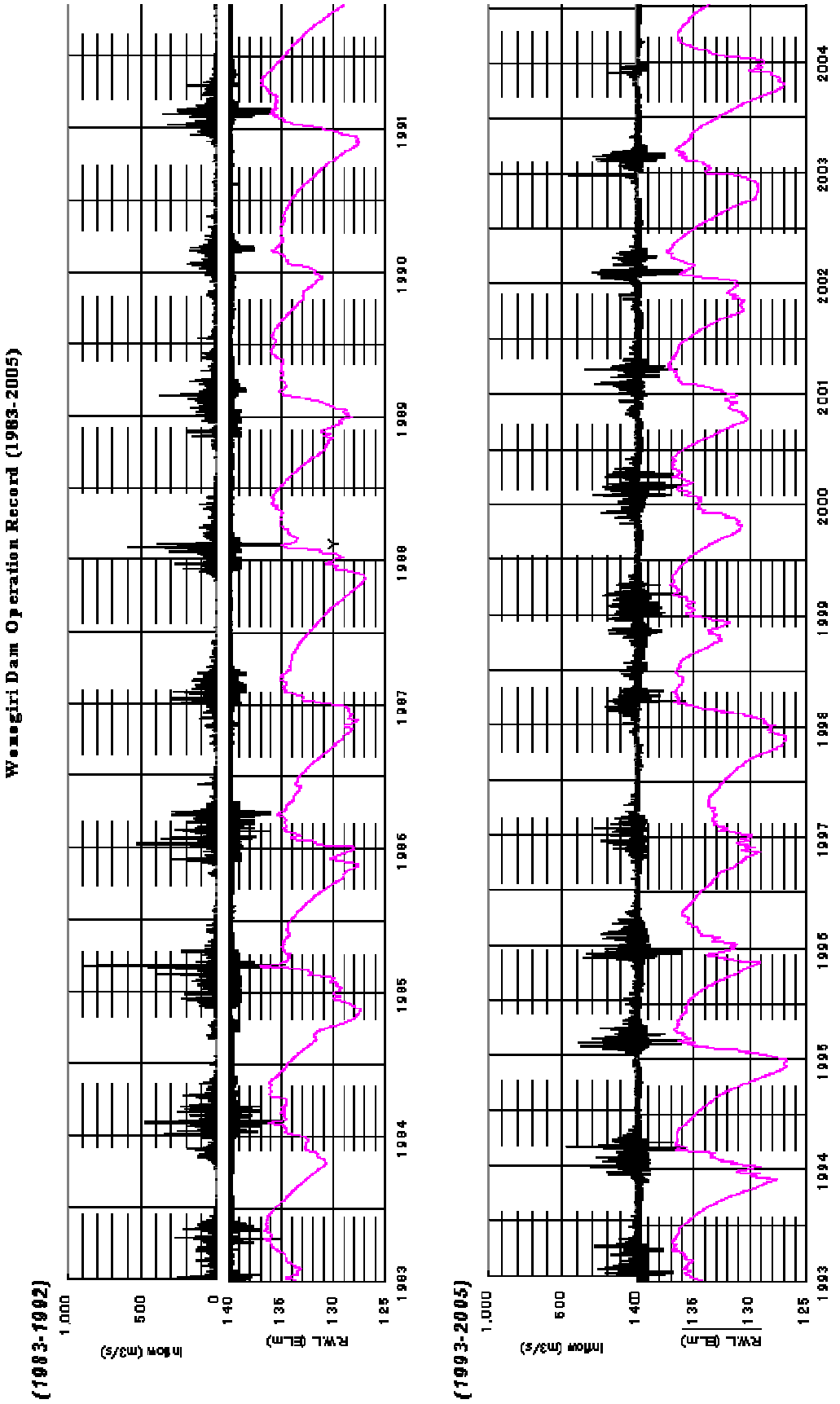
In case of drawing down the water level of water-use capacity under than Normal water level, it is deemed difficult to use inflow for sediment flushing/removal.

1.3 Features of Sedimentation

Features of sedimentation in the Wonogiri reservoir considered from the result of field surveys are as follows:

(1) Topographical Condition

Most of the sediment in the reservoir deposited near the dam had been caused by discharge from the Keduang River. The Wonogiri reservoir is primary separated the Keduang River portion and the Solo River portion including other rivers, and the Keduang River occupies one-third (1/3) of Wonogiri dam Uppermost basin, whereas capacity of the reservoir of the Keduang River portion is presumed to occupy only no more than one-thirtieth (1/30) of reservoir, and that outlet of the Keduang River is very near to the dam compared with the main upstream tributaries. From these condition, portion of the Keduang River had been filled with sediment rapidly.



Source: PBS

Figure 1.2.1 Wonogiri Dam Operation Record

(2) Facility Planning

1) Location of Outlet Facilities

Outlet facilities are gathered at left side of the dam, which is the portion of the Solo River. Therefore discharge of the Keduang River had run to the right side of dam at first, and then turned it direction to left side after hitting the dam body, running in front of dam to outlet facilities. On the way to the outlet facilities, massive sediment included in the discharge of the Keduang River had subsided and accumulated at the front of the dam. And sedimentation was presumed to proceed to the portion of the Solo River in front of outlet facilities by discharge from the Keduang River.

2) State of Intake

Intake facilities for irrigation and power generation is laid on with it foundation height EL.116.0 m, which is 11.0 m below planned sediment deposit elevation on dam plan. This is the only facility that sediment might be able to flow out to down stream at below EL.131.0 m of spillway weir overtopping height. This inlet was constructed by ditching the natural ground whose elevation is approximately EL.126.0 m at the right side and EL.129.0 m at left side on average. This topographical condition formed the reservoir of the Keduang River into looking like a vase, whose rim is EL.126.0 m and the bottom of it was approximately EL.110.0 m, original Keduang riverbed This condition contributed to the sedimentation of the reservoir of the Keduang River portion, consequently at and around of Intake had been surrounded by sediment. Sediment deposited on the original ground table EL.126.0 m of right side and EL.129.0 m of left side, had dropped into the ditch of Intake at EL.116.0 m and accumulated at the front of Intake. When trashrack furnished on the Intake surface was covered with garbage, sedimentation was proceeding on the Intake, consequently it might be clogging from lower portion. However intake has some attractive force to flush sediment, clogging of inlet could be eliminated by removing the trash. According to the interview with power plant office, activity of trash remove has been conducted at least twice a year Jun and December by themselves since 1993.

3) State of Spillway

Overtopping portion of spillway weir is set at EL.131.0 m. Sediment flushing can not be conducted until the sediment rises to more than same elevation.

CHAPTER 2 ALTERNATIVES OF COUNTERMEASURES FOR SEDIMENTATION

2.1 Preliminary Alignment of Conceivable Alternative Structures

Consequently, the sedimentation problems of the Wonogiri reservoir had become quite serious in view of the following points, requiring the urgent countermeasures to solve them:

a) Sediment deposit at and around intake structure
b) Decrease of effective storage volume
c) High sediment yield in watershed of the Wonogiri dam and its inflow into the Wonogiri reservoir

This Study will propose the following three (3) countermeasures to improve the above 3 problems on Sedimentation of the Wonogiri reservoir:

i) Countermeasure to keep proper function of intake structure
ii) Countermeasure to remove/control sediment from the reservoir
iii) Countermeasures to conserve watershed above the Wonogiri dam

(1) Countermeasures to Keep Proper Function of Intake Structure

The following alternative countermeasures are conceivable as those to cope with sediment deposit at and around Intake structure in the Wonogiri reservoir.

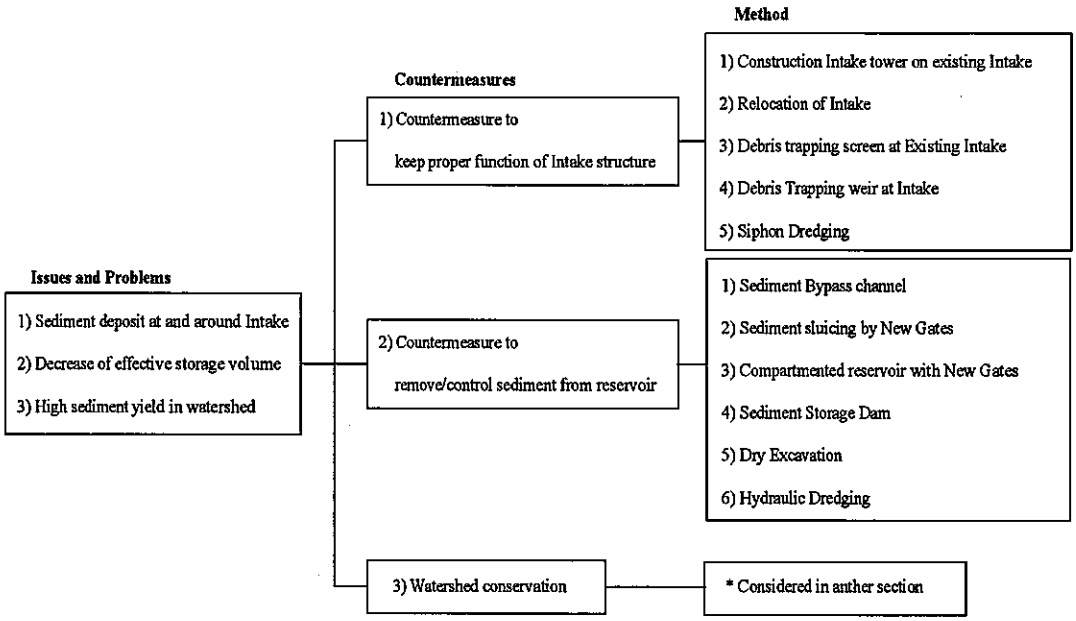
a) Sediment removal from existing intake structure and its surrounding places
   i) Introduction of new sediment removal system utilizing a difference between water levels
   ii) Conventional dredging using dredger
b) New construction of intake structure to enable to keep proper function of intake structure even in case it is completely filled with sediments.
   iii) Construction of Intake tower with higher intake level than that of existing one
   iv) Replacement of intake structure on left bank of the dam
c) Garbage Prevention into the front of Inlet
   v) Double screen

(2) Sediment Removal from the Reservoir

Considering the sediment inflow characteristics of the tributaries in the Wonogiri dam catchment (uppermost Solo River basin) that are obtained from the available information, the countermeasures for the whole reservoir sedimentation will be formulated by dividing the dam catchment into the Keduang River basin and Solo mainstream basin as shown in Figure 2.1.1. To formulate the countermeasure for the entire reservoir sedimentation, the following components will be examined in this Study:

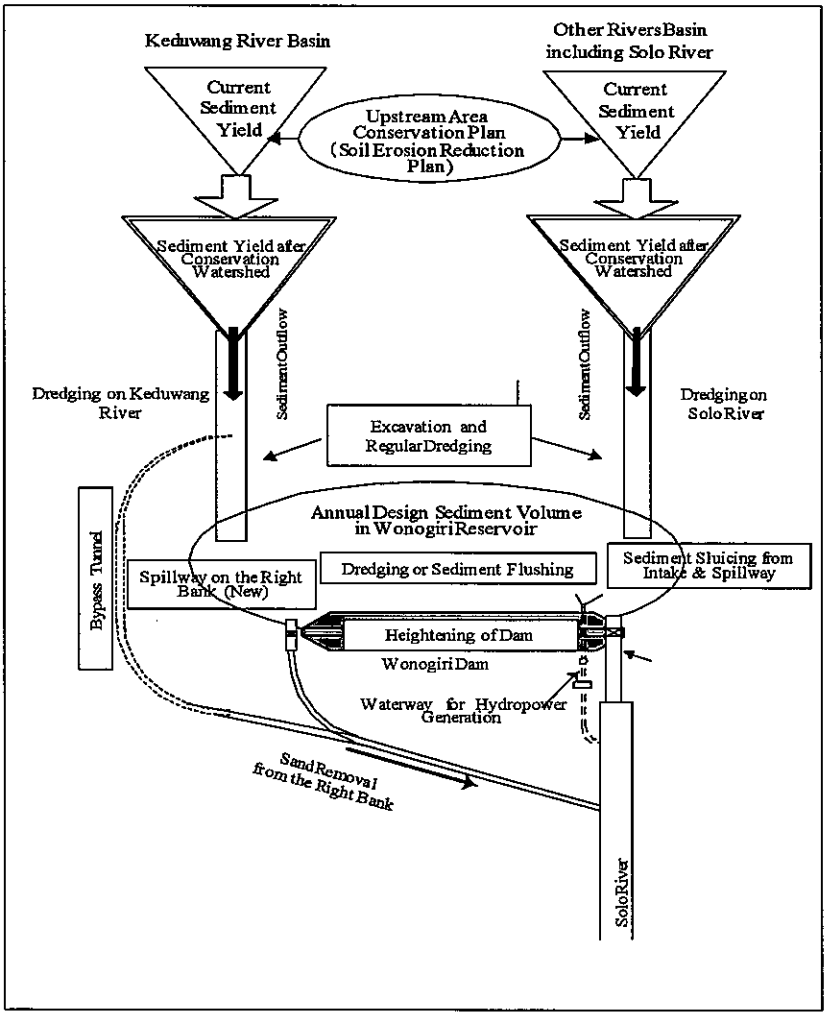
i) Keduang River sediment bypass
ii) Sediment sluicing by new gates
iii) Sediment storage reservoir with new gates in the reservoir
iv) Sediment sluicing by existing outlets
v) Sediment storage dam
vi) Dredging
vii) Check dam on each tributary and dry excavation

This Study will propose the countermeasures for the sedimentation problems of the entire reservoir by combining the above components.



Source: JICA Study Team

Figure 2.1.1 Countermeasures for Sedimentation Issues in Wonogiri Reservoir



Source: JICA Study Team

Figure 2.1.2 Conceivable Countermeasures for the Whole Reservoir Sedimentation