Paper No. 659

SEDIMENTATION OF TARBELA & MANGLA RESERVOIRS

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ABSTRACT

Pakistan has two major storage reservoirs at Tarbela and Mangla Dams. The loss of storage capacity due to sedimentation is unavoidable and will continue to affect the long-term operation of the reservoirs. The sediment deposition in the reservoir gradually reduces storage capacity and water and power benefits of the Project. The pattern of sedimentation in Mangla reservoir threatens to block free flow between the main stem and the storages in the side arms. Yearly sedimentation surveys of Tarbela and Mangla reservoirs are carried out. Last sedimentation surveys indicates that gross storage capacity of these reservoirs has lost upto 28.23% and 20.54% respectively. Studies for flushing sediment from Tarbela reservoir with mathematical models have been carried out. Geotechnical exploration of the delta were also conducted. The possible measures to reduce the deposited sedimentation by dredging and flushing are under consideration as a long term strategy to maintain available storage volume. Studies for sediment flushing with existing outlets of Tarbela are under active consideration. World wide experience of these practices is very limited on large reservoirs. Different options for extending the life of reservoir have been discussed.

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TARBELA RESERVOIR SEDIMENTATION

General

Tarbela is one of the world's greatest water resources development project built on the river Indus. The Project is the capstone of the Indus Basin Plan, to ensure a continued and improved supply of water to millions of acres of irrigated land in Pakistan, besides generating hydro electricity and controlling floods. It is located about 100 km North West of Islamabad. The construction work on Tarbela Dam was started in 1968 and all the civil works were completed in 1974. Salient features of the Project are given in Table-1. Lay out plan of the Project is given in Fig-1.

Emerging from the land of the glaciers on the northern slopes of Kailash ranges, some 5,182 meters above sea level, the river Indus has its source from the Lake Mansrowar in the Himalayan catchment area. It flows over 2900 Km before it outfalls into the Arabian Sea, draining an area of about 963,480 Sq. km. The catchment area of Indus at Tarbela is 169,600 Sq. km, which is unique in the sense that it contains seven of the world's ten highest peaks and seven of the world largest glaciers. The mean annual flow at Tarbela is 79 Billion Cubic Meters (BCM) of which at present only 13 percent can be impounded at Tarbela.

Indus Hydrology

The upper Indus river basin above Tarbela is about 1126 km long. Most of the upper Indus drainages area comprises snow covered high mountains with a small monsoon area of 18130 Sq. km just above Tarbela.. The snow and glacier melt constitute 90% of the flows. The summer monsoon flood from lower area alongwith the base flow generates peak discharges. The post Tarbela data reveals that floods ranging from 8495 CMS to over 14727 CMS have been observed since 1974. Considering recorded data, annual inflow to Tarbela less than 74 BCM is termed as dry year, between 74 & 79 BCM is called an average year and above 79 BCM is known as wet year. Inflows greater than 79 BCM are given in Table-2.

Sedimentation Process

The drainage area of Indus at Tarbela Dam is 169,600 Sq.Km out of which 10,400 Sq.Km lies immediately above Tarbela Dam, falls in the active monsoon zone with annual precipitation range of 800-1500 mm. Additional 7700 Sq.Km located further northward is also exposed to the receding effects of monsoon rains annually averaging 600 to 1200 mm. The bulk of Indus drainage area, 94 percent of total catchment area, lies outside the monsoon belt. The northern areas generally receive scanty winter rains and precipitation largely in the form of snow. The moving glaciers crush rocks on their way and leave behind a lot of sediments when they melt which is carried by the river due to steep gradient.

The velocity of the inflows containing the sediment decreases upon entering Tarbela reservoir, which reduces the sediment carrying capacity of the river water.

The coarse sediment tends to deposit in the upper reaches of the reservoir, while the finer particles travel downstream towards the dam and settle in the reservoir. Comparatively young geological formations of erodable nature in the Indus catchment are also responsible for higher sediment yield.

A network of 73 Range Lines has been established for Tarbela reservoir as shown in Fig-2. Bathymetric survey of the reservoir with the help of depth-soundings & position determination is carried out annually during high reservoir.

Trap Efficiency

The heavy sediment particles drop upon entry into the reservoir. In the upper reaches sediment form top set slopes while the suspended small size Particles move downstream due to outlets operation. A part of these sediments settle in the downstream reaches forming bottom set slopes, while a part of these suspended particles is flushed out from outlets during the reservoir operation. The trap efficiency is reducing day by day as the delta pivot point is advancing towards outlets. The trap efficiency of previous years of Tarbela reservoir is given in Table-3.

Sediment Behavior in the Reservoir

The high sediment load of the Indus River is associated with the snowmelt runoff that usually begins to enter Tarbela reservoir in late May to early June. When the reservoir is at minimum elevation. Since during the initial period of high runoff, a large downstream demand exists for irrigation water, only inflow in excess of irrigation demand can be stored in the reservoir.

Operation of the project for irrigation purposes results in the reservoir not starting to fill until mid-June to mid-July, well after the start of high inflows. During this period of high inflow and low reservoir level, the river passes over the delta deposits shifting the sediment from the upper end of the delta to the downstream face, Pivot point of the delta. During this period the pivot point advances downstream. The delta does not advance downstream if it remains covered under water. As the flows increase, the delta is drowned and the sediments drop on Upstream end of the reservoir.

The reservoir fills quickly, usually in less than a month, as downstream irrigation demand decrease due to rains and high inflows continue. The Tarbela reservoir has been filled to its maximum El.472 m. in almost all the years. Ideally the reservoir should reach its max level by 20^{th} August and remain full till mid-September. It is the period when reservoir is well above the level of the delta and a deposit of new sediments is formed in the upper reservoir on top of the existing delta surface.

The reservoir is lowered as irrigation releases are made. The draw down of the reservoir continues until minimum water level is reached usually in April or early May of the next year when the inflows are low. The process then repeats itself with the start of snowmelt runoff & high flows in late May to early June.

The profile of the delta is influenced by the way the reservoir is operated. The pivot point (the intersection of the top set and fore set slopes) advances towards the dam faster in the year when the minimum operating level at the start of the high flow season is low and kept so for longer period. It rises along with the top set slope in the years when minimum operating level is higher. High temperature during the months of May and June accelerate the snowmelt, causing the river channel to widen the banks in the upper reaches of reservoir resulting in considerable increase of sediment in the water flowing downstream. The sediments so eroded and the new sediments brought by the inflows are deposited in the main reservoir causing the delta to rise and advance downstream towards the main dam.

Current Status

With the yearly cycle of reservoir operation, the delta formation is continuously reworked and moved downstream closer and closer to the dam. The Pivot Point of delta has been advancing at about one Km per year and is presently located at about 10.6 Km upstream of the dam at an elevation of 413.3 m Fig-3. The yearly hydrographic surveys reveal that about 61 m deep sediment deposits have accumulated at 16 Km upstream of the dam. The capacity of reservoir is decreasing due to this heavy sediment load. The remaining storage capacity calculated from hydrographic survey 2005 is as under:-

Reservoir Capacity	Initial (1974) BCM	Year 2005 BCM	Reduction %
Gross Storage	14.344	10.295	28.23
Live Storage (El. 417 m)	11.948	8.695	27.22
Dead Storage (El. 417 m)	2.395	1.598	33.30

The average sedimentation rate in Tarbela reservoir is 0.132 BCM per year.

The Problems due to Reservoir Sedimentation

Various problems, which arise as a result of heavy sedimentation of the reservoir, are as follows:-

a) A loss of live storage, which is causing gradual reduction in the regulated yield of reservoir. This in turn would result in reduction in water availability for the agriculture for Rabi and early Kharif seasons and also reduction in the firm energy available from the Project.

b) The physical effect of sediment, which includes the risk of clogging of low level tunnel outlet particularly in a seismic activity, the erosive action of sediment-laden water on outlet concrete structures and Power turbines will result in exorbitant maintenance costs.

Available Options and their analysis.

For maximizing the benefits of Tarbela reservoir the following four options can be considered:

(i) Manage the distribution of sediments within the reservoir.

(ii) Minimize the flow of sediments into the reservoir.

(iii) Maximize evacuation of sediments from the reservoir.

(iv) Increase the live storage volume of reservoir.

Each of the above options has been analyzed below in the light of its practicality, safety and sustainability:

(i) The sedimentation pattern within the reservoir can be managed by means of reservoir operational policy and by protecting low level tunnel intakes from sediment clogging. Raising the minimum reservoir level every year by 1.2 m would result in deposition of sediments in the upper reaches of reservoir only and thus would delay the advancement of sediment delta. Though this option entails no capital cost but would progressively result in increased loss of live storage. Minimum reservoir level of 417 m fixed in 1998 is being maintained in order to use optimally the available storage.

(ii) Protection of tunnel intakes against sediment clogging by construction of an underwater dyke in front of the intakes as proposed by the Consultants has been studied. This option not only involves tremendous stability and construction problems but also its benefits in the absence of sediment flushing from the reservoir seems minimal.

Reduction of sediment influx either by watershed management or by construction of check dams in the upper catchment is impractical as about 90% of total runoff is dominated by snow / glacier melt. Nothing can be done at this attitude on the steep mountains. Most of the catchment area is out of the monsoon zone. Water shed Management is being implemented by the NWFP Forest Department upto Besham and it has very little effect. Diamer Basha Dam shall have some positive impact as it would enhance its life.

(iii) Evacuation of 200 million tons of yearly sediments by flushing through four low level high capacity outlets from the left bank has been proposed by the consultants.

(a) This option would comprise four 12 m diameter tunnels driven through the left abutment, possibly underneath the auxiliary spillway and discharging into its plunge pool. The abutment is weak. There have been a lot of problems and it has stabilised after a lot of remedial works.

This proposal carries a large number of grey areas which need to be prudently addressed before taking it to a feasibility stage.

WAPDA considers the under water dyke and the four tunnels an unprecedented option, the example of which does not exist else where in the World. Moreover, this option would in no time adversely affect the downstream hydropower Project of Ghazi Barotha and Chashma and kill them much earlier.

(b) Measures in terms of dredging of sediments from this mega reservoir are almost impossible. The dredging of sediment is generally carried out at seashores where mobilization from open seas is possible. The dredging option in case of Tarbela reservoir is not only prohibitive in cost but also is without any precedence and impractical. Any dredging proposal to be effective must provide for removal and disposal of 550,000 tons of sediments every day. Realistically, the target is unattainable even if hundred of dredgers and ancillary equipment are deployed over the reservoir stretch of 50 Sq. Km. to work round the clock.

(iv) Measure to increase the live storage capacity of reservoir would entail raising of crest of all embankment dams. Considering the existing foundation conditions at the site and other geotechnical problems of the embankment dams, this option poses serious stability threats to the Project. Therefore, this option is also discounted as being nonfeasible and impractical.

As the delta comes closer, the trap efficiency reduces and the sediments starts passing through the existing outlets. Studies are underway to flush the sediments through the existing outlets. If an other reservoir is available to store the water downstream, we can operate Tarbela reservoir at low level and flush a part of the yearly sediments.

For flushing the delta should be close to the dam. The reservoir has to be depleted to its lowest level. Power house has to be closed. Discharges of the order of 0.0056 million cumecs passed over the exposed delta, So that they can create shear velocity and entrain the deposited sediments. Large low level outlet capacity is required to pass the discharge. The outlets need to be steel lined to withstand the abrasion otherwise after flushing they would erode and it may not be possible to close the gates to refill the reservoir as happened in volta dam. It may not be possible to refill the reservoir in a drought year. The reservoir is operated on irrigation demand and cannot be operated in flushing mode without the assurity of its refilling.

MANGLA RESERVOIR SEDIMENTATION

General

The catchment area of Mangla Reservoir consists of steep hilly terrain with generally thin vegetational cover. It generates high sediment yield in the river particularly during the high flood season of July to September when monsoon rainfall occurs in the catchment.

There are three main rivers i.e. Jhelum, Poonch and Kanshi, which contribute sediment to Mangla Reservoir. Surface Water Hydrology Project (SWHP) of WAPDA has established gauges on these rivers to measure the water discharge and sediment load. The sediment samples are collected and sediment load is calculated from the sediment rating and flow duration curves.

The gross reservoir storage was 7.259 BCM. About 20% of the gross storage capacity of Mangla reservoir has been lost because of sedimentation since its impounding in 1967 as measured by the hydrographic surveys.

The raising of Mangla dam shall extend the life of reservoir about 80 years and compensate for the progressive depletion of the storage capacity.

Impact of Sedimentation

There are three major impacts of continued sediment deposition in the reservoir:

(i) Depletion of live storage resulting in reduction of regulation capacity for planned water releases.

(ii) Abrasion of power machinery and concrete structures when sediment delta reaches the intakes and abrasive coarse silt enters the water passages.

The analysis of data, shows that the average rate of sediment deposition is substantially lower than the preliminary estimates (0.039 BCM vs 0.07 BCM). Possible reason can be unrealistically high concentration readings at the sediment measuring stations on the main river and tributaries, which resulted in raising the yield estimates.

Mangla Reservoir Components

Mangla reservoir is composed of six different pockets, their original and remaining storage capacities are presented in Table-4.

Table-4 Deposited Sediment Volume

Pockets	Original BCM	Remaining in 2002 BCM	Sediment Volume BCM
Jhelum Upper	0.753	0.463	0.290

Jhelum Lower	0.444	0.258	0.186
Kanshi	0.346	0.248	0.097
Poonch	1.580	1.271	0.308
Khad & Jari	1.975	1.852	0.123
Main	2.160	1.745	0.420

These reservoir pockets are connected through narrow sections Fig- 4. This shape of the reservoir does not permit a regular pattern of sediment deposition and therefore complicates the sediment management in the reservoir. However, the survey of each pocket are carried out separately at range lines and the results are then compiled for each pocket as well as the whole reservoir.

CURRENT STATUS

In order to monitor the rate of sediment deposition in the reservoir, periodic hydrographic surveys are carried out. Mangla reservoir catchment area consists of steep hilly terrain. High sediment yield is generated during monsoon rainfall. Three rivers i.e. Jhelum, Poonch and Kanshi contribute the sediment in 6 pockets of the reservoir.

The capacity of reservoir is decreasing due to heavy sediment load. As per year 2005 hydrographic survey. The remaining storage capacity of the reservoir is give in Table-5

Table-5 Loss of Storage Capacity due to Sedimentation

Reservoir Capacity	Original (BCM)	Year 2005 (BCM)	Reduction %
Gross Storage	7.259	5.768	20.54
Live Storage	6.593	5.605	14.98
Dead Storage	0.666	0.163	75.56

The average annual sediment rate of deposition (1967-2005) is 0.038 BCM

The major delta is advancing toward the dam and at present its pivot point is at 7.9 Km. upstream of Main Dam. The delta profile is given in Fig-5.

SEDIMENTATION STUDIES

Sedimentation studies were mainly concentrated on analyzing the measured sediment data at gauging stations on Jhelum river and its tributaries (Poonch and Kanshi rivers) and to estimate the historic sediment inflow to Mangla reservoir, tentative estimation of the quantities of sediment deposition under the various options of Mangla dam raising applying Brune's curve, determination of the natural slopes of the existing delta as observed in various hydrographic surveys over the past years and rate of advancement of the front of the sediment delta in the Jhelum branch, and to assess the potential growth and movement of the delta under the future operation of the reservoir.

SEDIMENT SIMULATIONS

The main purpose of sediment simulation studies was to predict future sediment deposition pattern in the Mangla reservoir, rate of movement of sediment delta and changes in storage capacity relationship, to evaluate effect of operational policies; such as raising minimum operation level and the operation of rule curves and to determine, if it is viable, the scope and best strategy for flushing.

Before carrying out the sediment simulation studies for the Mangla Raising Project, a review of the available mathematical models was carried out and finally the model HEC6KC was used to carryout the simulations due to the fact that it has been used and calibrated against a number of Similar large Projects within Pakistan and it has the facilities to simulate the main process within Mangla.

The geometric data defines the physical size and shape of the river and channel network. Jhelum river is the main river and as such is taken as the main stem. The main tributaries; Poonch and Kanshi rivers are taken as principal tributaries and Khad river which is a tributary of Poonch river, is taken as secondary tributary. A total of 79 cross sections were used to represent the geometry of the Jhelum river and its tributaries with 49 cross sections for Jhelum river main stem, 11 for Poonch river, 12 for Kanshi river and 7 for Khad river.

The following conclusions can be made from sediment simulations based on the results:

(i) As the minimum drawdown level is raised the elevation of the top of the delta rises and the time for the delta to reach the dam increase.

(ii) Raising the maximum conservation level does not create a higher-level delta in the upper reaches. In all the simulations carried out, sediment deposition occurs initially along the topset slope.

(iii) The sediment deposition up to year 2002 had occurred at a rate of about 0.03 BCM per year while deposit rates for future years are shown in Table-6.

Table-6 Prediction of Sediment Deposition (BCM)/Year

Simulation Conditions	2007-2022 (15 years)	2022-2037 (15 years)	2037-2087 (50 years)
No raising with minimum draw down level 317 m.	0.037	0.026	0.021
Raising with minimum draw down level 317 m.	0.038	0.031	0.024

Raising with minimum draw down level 323 m.	0.039	0.035	0.023
Raising with minimum draw down level 329 m.	0.040	0.040	0.022
Raising with minimum draw down level 335 m.	0.041	0.041	0.023

(iv) The results show that raising the maximum conservation level to 379 m would only marginally increase the amount of deposition.

(v) With the raised Mangla the predicted annual sediment deposition increased gradually as the minimum draw down level was raised to 323 m, 329 m and 335 m.

(vi) In most options tested, the reservoir would ultimately achieve a state of equilibrium with large quantities of sediments being passed through the outlet works.

SEDIMENT FLUSHING/DREDGING

By raising of conservation level of Mangla reservoir by 12.20 m (El. 366.37 m to El. 378.56 m), a volume of 3.58 BCM would be added to the remaining available capacity. This additional capacity is projected to be depleted in about 80 years. Thus, raising of the dam is one of effective measures to enhance the useful life of the reservoir.

As a part of the engineering studies for raising of the dam, other possible measures such as dredging and flushing have been given due consideration particularly as a long term strategy. World-wide experience of these practices is very limited on large reservoirs. The simulation have been carried out in the raised Mangla condition.

The results can be interpreted as follows:

(i) Sediment deposition with sluicing is initially significantly less (about 30-35%) when compared with the sediment deposition without sluicing.

(ii) The delta is predicted to advance towards the dam at a very high rate with all the sluicing regimes, generally reaching the dam within 5 years of the start of sluicing.

LIQUEFACTION POTENTIAL

The risk of liquefaction of sediments deposited in the Mangla reservoir is being systematically investigated by a comprehensive programme of field investigations and laboratory testing, followed by detailed geotechnical analysis.

Twelve (12) boreholes of 12 m to 41 m depth have been drilled in the lake. In the boreholes, standard penetration tests (SPT) and vane shear tests have been carried out at close intervals. The locations of the boreholes have been carefully selected, so as to provide adequate information about the topset, foreset and bottomset zones of the sub-aqueous sediments Fig-6.

The studies are not conclusive. Mangla delta being relatively fine is considered to be not prone to liquefaction.

CONCLUSIONS

i) Reservoir capacity at Tarbela and Mangla is being lost at the rate of about 0.132 BCM and 0.038 BCM per year respectively.

ii) In both reservoirs, the pivot point of delta is advancing towards the dams and at present it is at 10.6 Km and 7.9 Km upstream of Main dam at Tarbela and Mangla respectively.

iii) At Tarbela sediments deposit in live storage zone when reservoir remains well above El. 420 m.

iv) Erosion, reworking and advancement of delta accelerates at Tarbela when reservoir level drops to El. 402 m. Consequently sediments are deposited in dead storage zone.

v) Flushing of sediments at Tarbela through the existing tunnels during low reservoir level is on the average 7% of total incoming sediment. This is increasing with the passage of time.

vi) Presently adopted policy of progressively raising of minimum reservoir level when necessary might be maintained at Tarbela. This has advantage of keeping the delta away with one major disadvantage of loss of active storage at faster rate.

vii) The remedial action in terms of dredging & excavation and disposal of upstream deposits are not economical.

viii) Action plan recommended for Tarbela Reservoir Sediment Management by the Consultants M/s TAMS/H.R. Wallingford are not practicable and WAPDA has strong reservations against their implementations.

ix) Studies for sediment flushing with the existing outlets should continue at Tarbela.

x) With the raised Mangla, the annual sediment deposition shall increase gradually as the minimum draw down level shall be raised to 323 m, 329 m and 335 m.

xi) The additional capacity at Mangla shall extend the life of the reservoir for another 80 years.

xii) At Mangla the delta is predicted to advance towards the dam at a faster rate when the flushing is started.

Table-1
TARBELA DAM PROJECT SALIENT FEATURES

LOCATION	Distt. Haripur, River Indus
RESERVOIR	
Length	96 km
Maximum Depth	137 m.
Area	60,000 Acres
Gross Storage	14.34 BCM
Live Storage	11.95 BCM
Dead Storage	2.39 BCM
Mean Annual Inflow	79 BCM
MAIN EMBANKMENT DAM	
Length at crest	2743 m
Max. Height	143 m
AUXILIARY DAM-1	
Length at crest	713 m
Maximum height	105 m
AUXILIARY DAM-2	
Length at crest	292 m
Maximum height	67 m
SERVICE SPILLWAY	
Gates	7 Nos.
Discharge Capacity	17,417 CMS
Ogee level	455 m
AUXILIARY SPILLWAY	
Gates	9 Nos.
Discharge Capacity	22515 CMS
Ogee level	455 m
RIGHT BANK TUNNELS	
Four tunnels each with length of	731 to 823 m
Tunnel 1, 2 & 3 dia	13.25 m
Tunnel 4 dia	10.9 m
LEFT BANK TUNNEL	
Length	1120 m
Dia of concrete lined portion	13.7 m
POWE PLANT:	
Units 1-10 @ 175 MW each	1750 MW
Units 11-14 @ 432 MW each	1728 MW

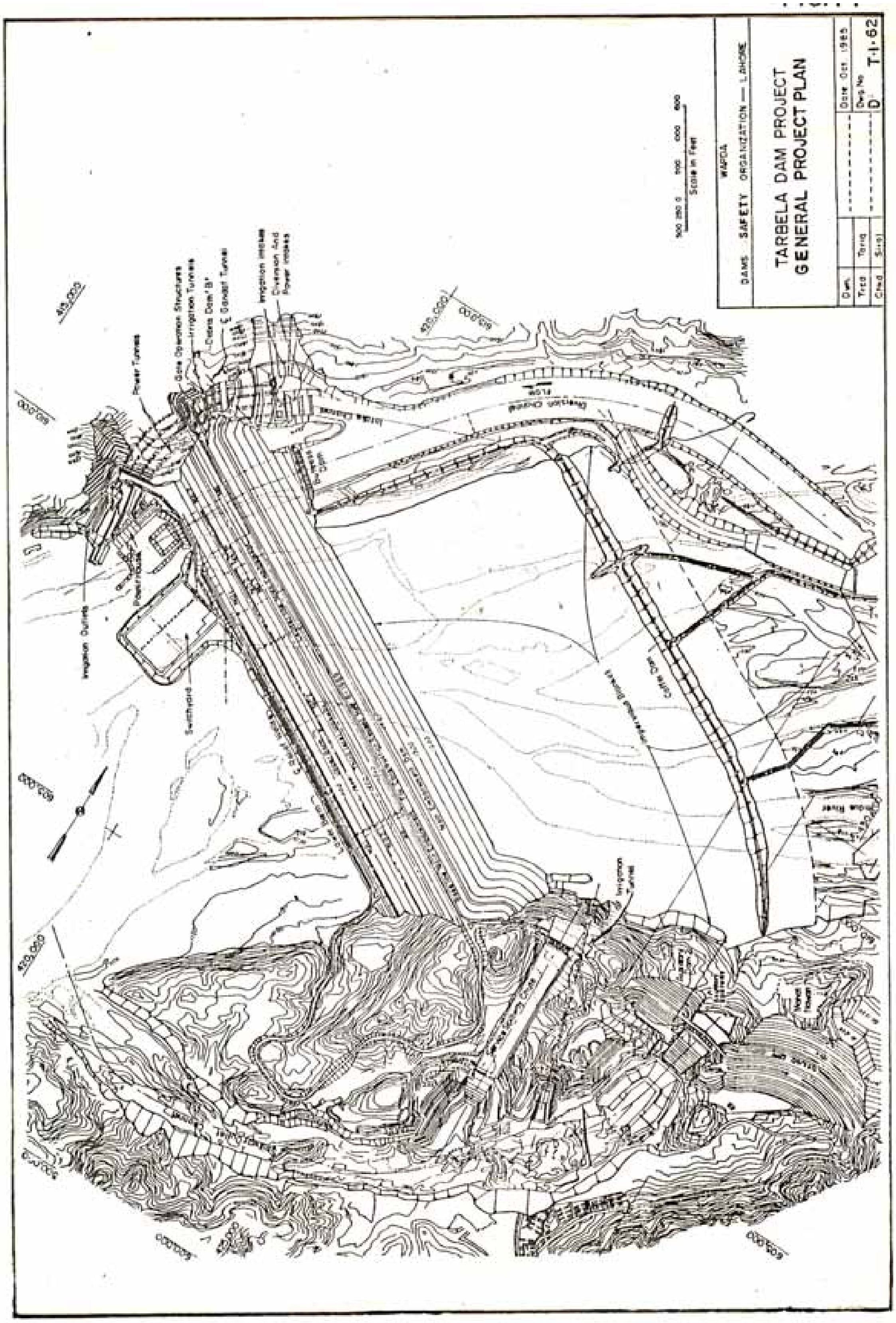
Table-2
INFLOW AT TARBELA GREATER THAN AVERAGE (79 BCM) 1974–2005

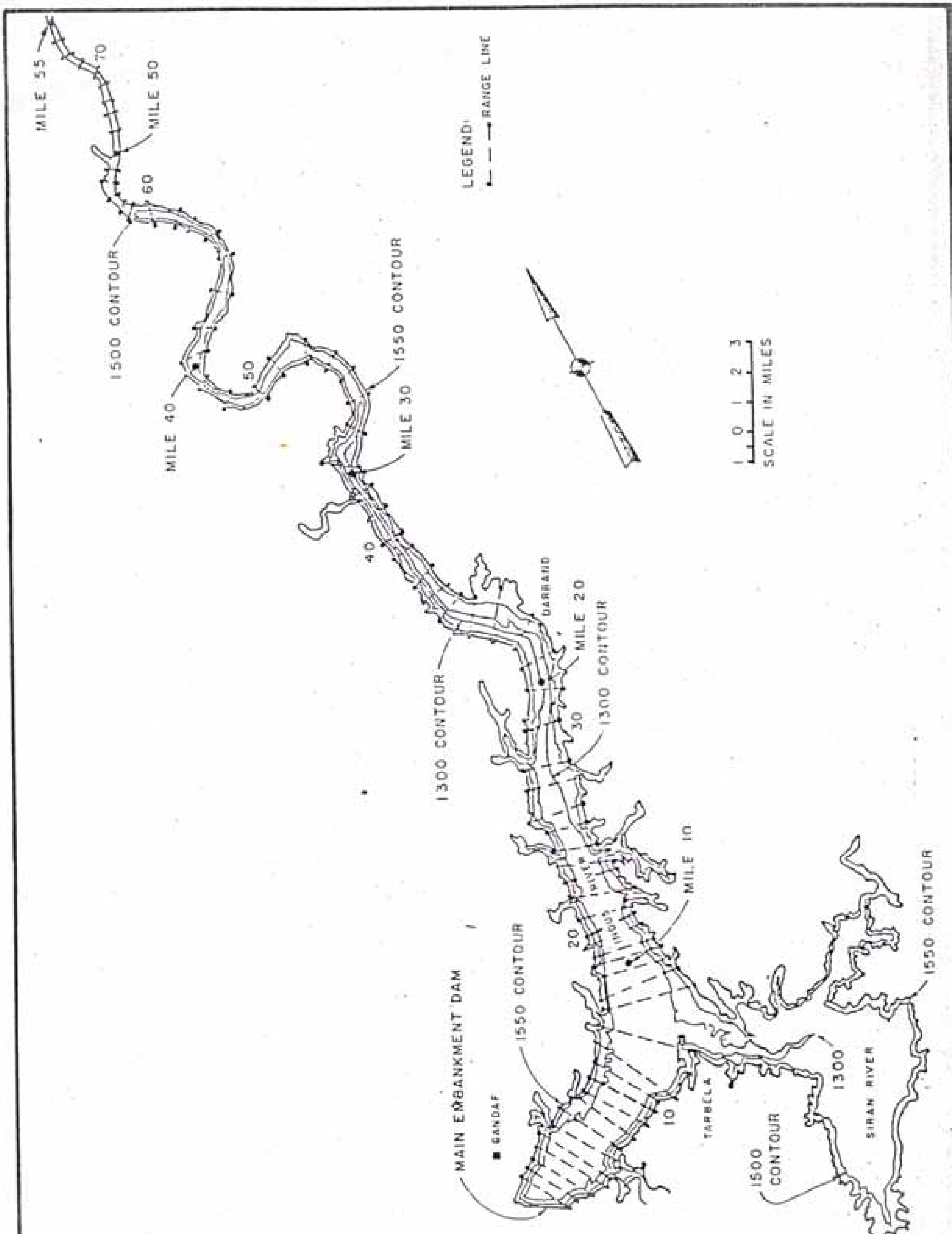
Year	Inflow (BCM)
1978	85.081
1988	89.222
1990	88.484
1991	84.639
1992	80.815
1994	91.268
1996	85.325
1998	80.047
1999	80.432
2005	81.470

Table-3
TARBELA RESERVOIR
Sediment Inflow, Outflow & Trapped (MST) Trap Efficiency (%)

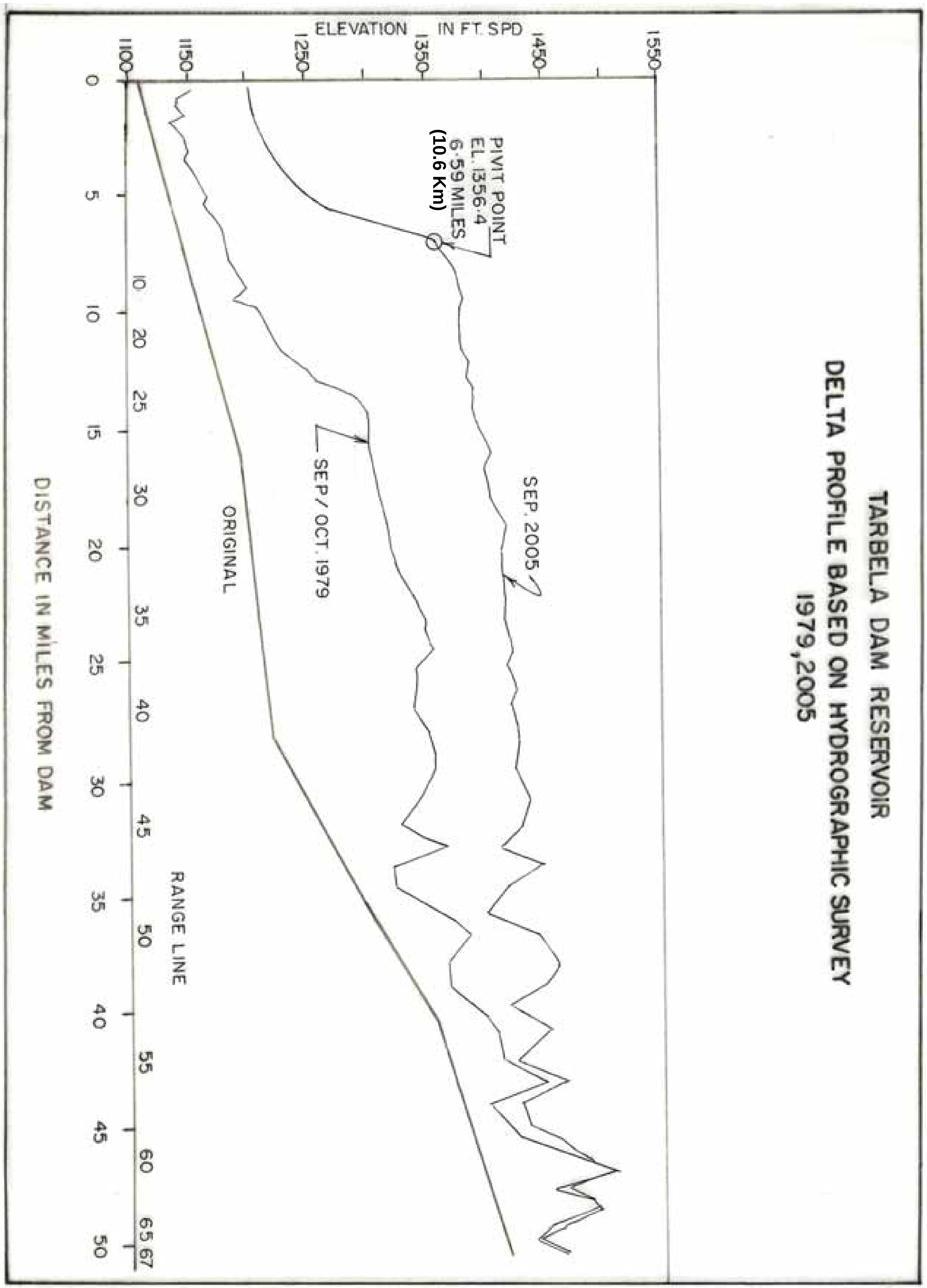
Water Year (Oct-Sep)	Inflow	Outflow	Trapped	Trap%
1980-81	40.6081	3.7659	36.842	91
1981-82	214.77	3.831	210.939	98
1982-83	81.6663	8.2165	73.450	90
1983-84	96.6063	3.7711	92.836	96
1984-85	186.564	5.03	181.534	97
1985-86	189.039	7.503	181.536	96
1986-87	220.759	8.629	212.130	96
1987-88	158.978	6.934	152.044	96
1988-89	272.094	4.924	267.170	98
1989-90	148.26	10.522	137.738	93

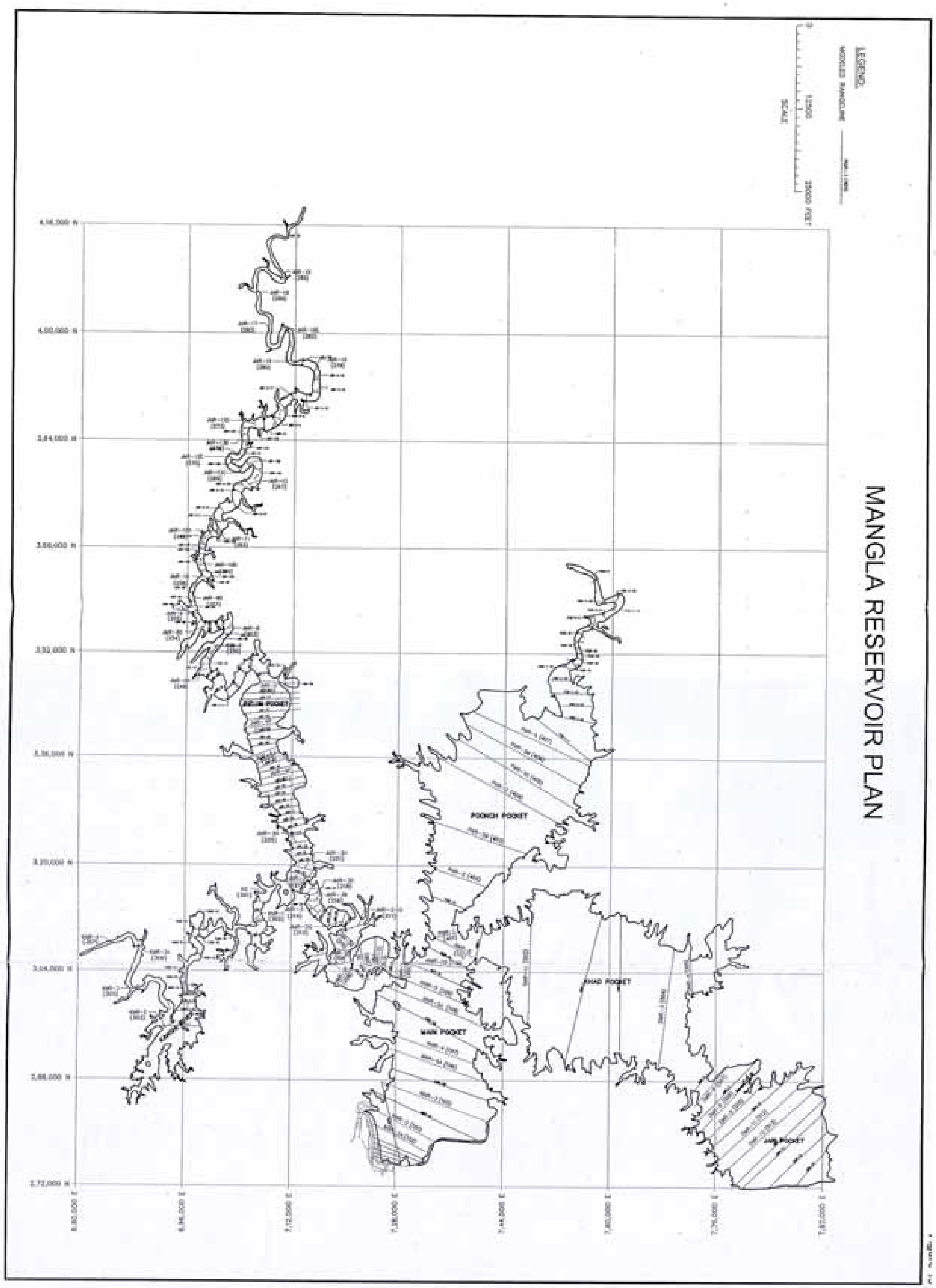
1990-91	271.831	6.47	265.361	98
1991-92	187.129	4.243	182.886	98
1992-93	153.2598	7.2821	145.978	95
1993-94	78.164	3.021	75.143	96
1994-95	278.649	12.767	265.882	95
1995-96	158.349	4.764	153.585	97
1996-97	187.096	3.958	183.138	98
1997-98	149.262	64.575	84.687	57
1998-99	203.386	104.126	99.260	49
1999-2000	139.738	11.094	128.644	92
2000-01	170.607	16.536	154.071	90
2001-02	101.649	4.214	97.435	96
2002-03	136.251	5.83	130.421	96
2003-04	99.614	10.91	88.704	89
2004-05	128.108	4.483	123.629	96
Total	4052.439	327.4	3725.039	92

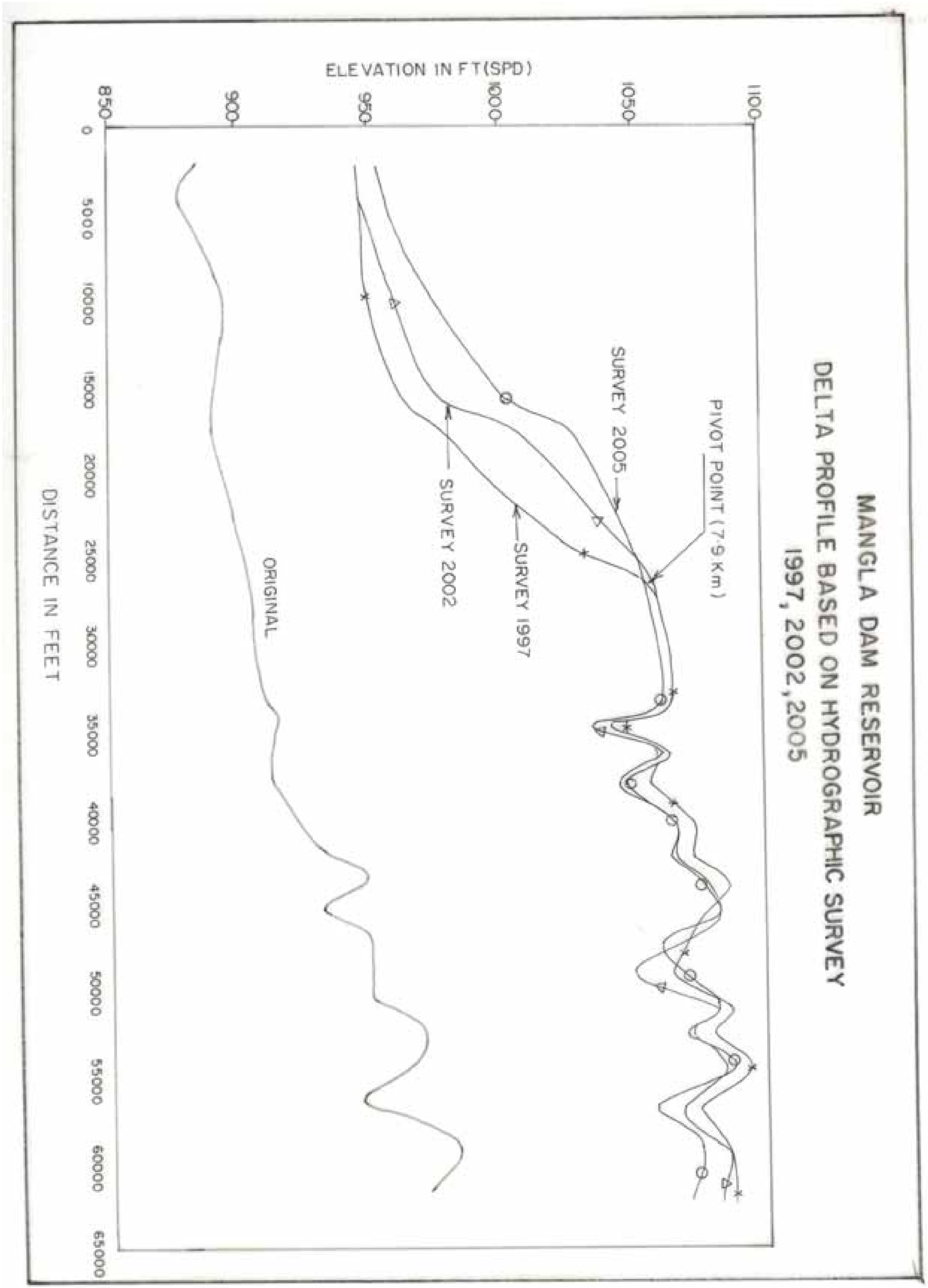

TARBELA DAM PROJECT
GENERAL PROJECT PLAN
WAPDA
DAMS SAFETY ORGANIZATION — LAHORE
Scale in Feet
T-1-62
Irrigation Outlets
Switchyard
Power Tunnels
Irrigation Tunnel
Indus River
Diversion Channel
FLOW

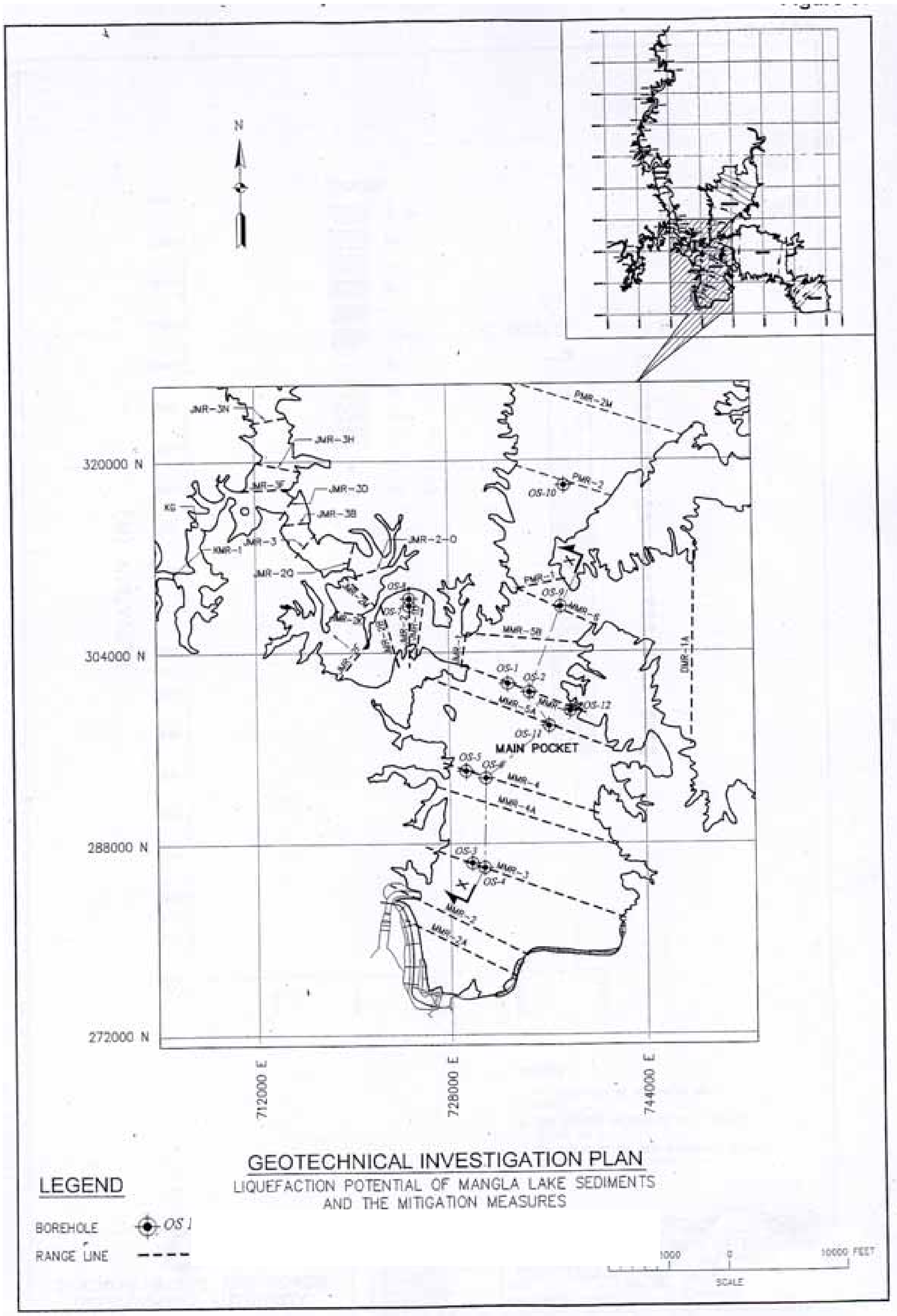


RESERVOIR SEDIMENTATION
SURVEY RANGE LINES


TARBELA DAM RESERVOIR
DELTA PROFILE BASED ON HYDROGRAPHIC SURVEY
1979,2005
ELEVATION IN FT. SPD
1100
1150
1250
1350
1450
1550
PIVIT POINT
EL. 1356.4
6.59 MILES
(10.6 Km)
SEP. 2005
SEP / OCT. 1979
ORIGINAL
RANGE LINE
10
20
25
30
35
40
45
50
55
60
65 67
0
5
10
15
20
25
30
35
40
45
50
DISTANCE IN MILES FROM DAM


MANGLA RESERVOIR PLAN
LEGEND
SCALE
POONCH POCKET
MAIN POCKET
KHAD POCKET
JARI POCKET


MANGLA DAM RESERVOIR
DELTA PROFILE BASED ON HYDROGRAPHIC SURVEY
1997, 2002, 2005
ELEVATION IN FT (SPD)
850
900
950
1000
1050
1100
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
60000
65000
DISTANCE IN FEET
PIVOT POINT (7·9 Km)
SURVEY 2005
SURVEY 1997
SURVEY 2002
ORIGINAL


PMR-2M
JMR-3N
JMR-3H
320000 N
PMR-2
OS-10
JMR-3F
JMR-3D
JMR-3B
KG
KMR-1
JMR-3
JMR-2-O
JMR-2O
PMR-1
OS-9
MMR-6
MMR-5B
304000 N
DMR-1A
OS-1
OS-2
OS-12
MMR-5A
OS-11
MAIN POCKET
OS-5
OS-6
MMR-4
MMR-4A
288000 N
OS-3
MMR-3
OS-4
MMR-2
MMR-2A
272000 N
712000 E
728000 E
744000 E
GEOTECHNICAL INVESTIGATION PLAN
LIQUEFACTION POTENTIAL OF MANGLA LAKE SEDIMENTS
AND THE MITIGATION MEASURES
LEGEND
BOREHOLE
RANGE LINE
1000
0
10000 FEET
SCALE

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