PAPER NO. 224

OPTIMIZATION OF HYDRO-ELECTRIC PROJECTS

BY

ENGR. CH. ALTAF-UR-REHMAN

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1. INTRODUCTION

Hydroelectric installations are of appreciable size and extent and involve large expense. The design must be on overall basis. All alternative need to be examined and specifically for large catchment to ensure that the works not only meet present and future requirements but optimize the sites. Following is obviously necessary:

i) Ensure that components of structures are designed relevant to each other and to the whole development.
ii) That initial development do not prejudice the ultimate development of not only the site but overall catchment development.

The civil works component account for most of the cost of an hydroelectric project and provide motive power for the generator and therefore their design involves decision which govern the design and operation of the generating equipment.

If the load demand need only part of the capability of a site and leave the further development to the demand , it be considered that the demolition and replacement of an hydroelectric installation is not economical owing to the size and cost of engineering works and their long life.

The initially planned development was different for both Ghazi Barotha and Chashma Hydel Projects. In each case State-of-Art concerns lead to the presently implemented schemes. Projects like Mangla and Tarbela were affected by State-of-Art of design turbines. Warsak dam hydrological data was scanty the time of design.

In the light of above the constructed and being constructed Hydro Electric Projects are examined.

2) GHAZI BAROTHA HYDRO-POWER PROJECT (Reference -1)

The project as recommended after examining the various options comprised:-

i) A barrage about 7 km downstream of Tarbela Main Embankment Dam to create a pond for diversion of releases from Tarbela Power Station, Tunnels 4 and 5 and Spillways. The pond allows some re-regulation when releases from Tarbela are low to meet peak demand.

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ii) 52 km long concrete lined power channel with a capacity of 2000 cumecs as Tarbela 10 day releases are above 2000 cumecs for about 40 percent of the time.

iii) Power installation close to the confluence of the Haro with Indus with a 1450 MW power house to provide about 7700 GWH of power annually.

The project as being constructed has a reduced capacity of the power channel of 1600 cumes on the plea of limited experience of such large canals. Although the generation capability remains as 1450 MW, the annual generation will be about 6,700 GWH. At one time twin canals were suggested for 2000 $M^{3/Sec}$. The project as now is the ultimate development.

3) CHASHMA HYDRO-POWER PROJECT (Reference -2)

The Chashma development was planned as 12 Units for total discharge of 3000 cumecs. The as being constructed has 8 Units of 23 MW each. Also the rapid loss of reservoir capacity from 0.87 MAF to 0.300 MAF would require augmentation and the site capability of raising to 661 SPD from the present 649 SPD conservation level has to be exploited.

There was great resistance to this project mainly that the barrage will have belas close to its gates and in case of floods may be damaged. Also the off-taking canals i.e. Chashma Right Bank Canal & Chashma Jhelum Link may not provide desired supplies efficiently. This has been proposed to be cared by having a dredger. It has yet to be seen what will be the problem by not operating the barrage for 8-9 months in a year. The 12 units initially planned have been limited to 8 units. Finally the substructure was planned to be constructed for 12 units at least the substructure and now it is not to be so.

The overall project capability has not been utilized and myopic view of only the present project has been considered.

4) MANGLA POWER GENERATION

Mangla Power works were installed in 4 phases as Units 1-4 (year 1967 to 1969), Units 5-6 (1973-1974), Units 7-8 (1981) & Units 9-10 (1993). The characteristics of the units are as per **Table-1**. The characteristics of the turbines are recounted to better understand the installations.

The hydraulic characteristics of any hydraulic turbine can be referred to its specific speed ns which is an index to its capability. Any turbine can be operated under various heads and at each head it will run over a range of speeds but the best efficiency is at one particular speed which corresponds to the environment of smooth entry of water into the revolving runner and to minimum friction losses in the passage. Specific speed is the speed in rpm at which turbine will operate at maximum efficiency for full guide vane opening under a head of one foot with its geometry reduced to generate one horse power.

$$ns = \frac{n}{\sqrt{H}} \times \sqrt{\frac{N}{\sqrt[4]{H}}} = \frac{n}{H}\sqrt{\frac{N}{\sqrt{H}}}$$

n is speed of turbine in rpm, operating under Head H in feet and Out put N in b.h.p.

The total horse of unit must be decided and number of units. A suitable speed is specified. For the Francis turbine . The lower speed will be better as having flatter efficiency curve than higher speed type . Also there are significantly lower friction assess and much lesser abrasion which depends on type of sediment, and that period the sediment in PPM is high.

Francis turbine occupies smaller space and has higher efficiency near the full head experience concerning newly , installed turbines is not available until few years of operation.

It is interesting that as designed units 1-4, 5-6 and 7-8 are same i.e. 13800 rated output, design head of 295 feet and speed 1667 rpm, however as can be seen in **Table-2** (also refer Figure-1) the units 5 &6 generate 125 MW /unit at reservoir levels of 1202 to 1180 whereas the other units give 115 MW/Unit. At 295 feet design head, unit 5-6 give 103.5 MW/Unit while 7-8 give 97 MW/Unit. At lower heads unit 5-6 i.e at RL 1100 it is 82.5 MW/Unit while 7-8 produce 75 MW/Unit. At minimum level there is difference of 6 MW/Unit. The present cost of installation of a 6 MW installation would run to $36 million and additional revenue will be Rs. 0.5 million per year.

There are other limitations viz. more generation by releasing more flows during May to August 20th for an average year and may be for April through for wet year see **Table-3** but the draft tubes tailrace dimensions cannot be altered. The other aspect is the Mangla 2nd Phase to 1250 reservoir level, the generation will be the same as for 1202 reservoir level.

5) TARBELA POWER STATION

Tarbela units 1-10 have generation capacity of 175 MW/unit at a speed of 136.4 rpm at head of 417/378 feet. At maximum head units 5-10 produce 8 MW/unit extra to unit 1-4. The problem of draft tube limitation of raising Tarbela by 30 feet (possibly) are identical to Mangla power station (Refer Table also refer Figure-2). The tunnel 4 is yet to be utilized for power generation. It can be seen in Table-5 that even in an average year outflows for Tarbela from May (20-30) to October (10-20) are much more.

6) RECOMMENDATIONS

It is necessary to alter the runner dimension on refurbishment when undertaken. It is being advertised that the generation capability can be augmented by 10-40% (Reference-3).

7) WARSAK POWER STATION

Warsak Power Station has 6 units of 40 MW each at 136.3 rpm under a head of 144 feet. The total releases are 22,800 cusecs. Refer Figure-3. Kabul river at Warsak has more than

40,000 cusecs flows for nearly 5 months and extra generation is possibly by reactivation of diversion tunnel and installating 4-5 more units of 40 MW.

Warsak maximum reservoir level were restricted so that back water does remain within Pakistan. It could now be possible to increase the reservoir level by 30 feet by raising the dam height. It would then be possible to also care for the recurrent abrasion of installations due to large sand component inflows and decrease the stoppages necessary for repairs.

8) FINDINGS AND RECOMMENDATIONS

I. The generation capability of both Ghazi Barotha and Chashma Hydel is under utilized.

II. Mangla and Tarbela generation can be increased on refurbishment.

III. Warsak has additional capability for more units.

9. REFERENCES

1. Ghazi Barotha Hydro Power Project, Pakistan Hydro Consultants Volume-I, August 1991.

2. Chashma Hydro Power Project, Feasibility Study HEPO and GTZ, Volume-2, July 1987.

3. A Procedure for Upgrading by Runner Replacement Swarop, International Water Power and Dam Construction, September 1995.

4. Warsak Dam, 2nd Periodic Inspection Report, NESPAK 1987.

TABLE-I

Sr. No.	Name Plate Data	TARBELA				MANGLA				WARSAK	
		Unit 1-4	Unit-5-8	Unit-9-10	Unit-11-14	Unit-1-4	Unit-5-6	Unit-7-8	Unit-9-10	Unit-1-4	Unit-5-6
1	Number of Units	4	4	2	4	4	2	2	2	4	2
2	Year of Commissioning	1977	1982	1985	1992-93	1967-68-69	1973-74	1981	1993	1961	1980-80
3	Capacity of each Units MW	175	175	175	432	100	100	100	100	40	40
4	Total Capacity of Power Station				(T) 3478				1000		240
5	Cost Per (K.W.)	737.5	4103	3423	6341	1033	1578	1578	P	1625	1179
6	River / Canal	Indus River	Indus River	Indus River	Indus River	Jhelum River	Jhelum River	Jhelum River	Jhelum River	Kabul River	Kabul River
7	Total Discharge Through Turbine	67000	67000	67000	1500			36400			22800
8	Lengthy of Power Channel (ET)	2640	2640	2640	2640			612.30			
9	Total Cost of Projects Rs. Million	516	2872	1198	10957			1262.80		260	283.10
	TURBINES							(1-8)			
1	Type	Vertical Francis	Vertical Francis	Vertical Francis	Vertical Francis	Vertical Francis	Vertical Francis			Vertical Francis	
2	Manufacture	Hitachi Japan	D.E.W. Ltd. Canada	D.B.S. Canada	D.B.S. Canada	Mitsubishi Japan	CKD Blanskd	A.C.E. Belgium	CKD Blansko	Dominion	Engg.
3	Rated Output H.P.	275000/23900	275000/239000	275000/239000	365000	138000					5500
4	Net Head F.T.	417/378	417/378	417/378	270 ft.	295	295	295			144
5	Speed R.P.M.	136.40	136.40	136.40	90.90	166.66	166.66	166.67			136.30
6	Rate Discharge for one Unit cusecs	7600	7600	7600	1500	4550	4515	4500			3800
	A.C. GENERATOR										
1	Type	Umbrella	Umbrella	Umbrella	Vertical						
2	Manufacture	Hitachi Japan	Hitachi Japan	Hitachi Japan	Semen's Germany	Hitachi Japan	Czechoslovakia	Hitachi Japan	Skoda Pezen	Canada	General Elect
3	Volts	13800	13800	13800		13200	13200	13200	13200	11000	11000
4	P.F.	0.85	0.95	0.95	0.90	0.80	0.80	0.80	0.80	1.00	1.00
5	Cycles Per Second	50	50	50	50	50	50	50	50	50	50
6	Rated Output K.V.A.	23764/20588	184210		480000	125000	125000	125000	130000	40000	40000
7	No. of Poles	44	44	44		36	36	36	36	44	44
8	AMPS	8614				5467	5465	5465	5467	2100	2100
	EXCITERS										
1	Rated Output K.V.A.				1260	600	600	600			
2	Voltage (Volts)				460	440	440	440	485	250	250
3	Current (AMPS)				2740	1364	1364	1364	1298	640	640

TABLE -2
MANGLA POWER STATION
ACTUAL CAPABILITY OF GENERATING UNITS AT VARIOUS LEVELS DURING 1994-95

Sr. No.	H.R.L S.P.D. (FT.)	Net Head Ft.	UNITS CAPABILITY (ME)				Total Capacity MW	Discharge Per MW cfs	Total Discharge Cfs
			1-4	5-6	7-8	9-10			
1	1202	356	460	250	230	230	1170	38.46	45000
2	1200	354	460	250	230	230	1170	38.46	45000
3	1195	349	460	250	230	230	1170	38.46	45000
4	1190	344	460	250	230	230	1170	38.46	45000
5	1185	340	460	250	230	230	1170	38.46	45000
6	1180	335	460	250	230	230	1170	38.46	45000
7	1175	329	456	245	225	230	1156	38.96	45000
8	1170	325	454	239	220	230	1143	39.37	45000
9	1169	323	452	236	218	228	1134	39.68	45000
10	1165	319	450	230	215	227	1122	40.11	45000
11	1160	314	437	223	210	226	1096	41.05	45000
12	1155	310	430	217	205	220	1072	41.98	45000
13	1150	304	420	212	200	216	1048	42.94	45000
14	1145	298	412	208	198	212	1030	43.30	44600
15	1140	295	404	202	194	207	1007	44.29	44600
16	1135	292	390	196	188	200	974	45.97	43800
17	1130	286	376	190	282	194	942	45.43	43800
18	1125	200	366	187	178	190	921	45.93	42300
19	1120	275	356	184	174	187	901	46.95	42300
20	1115	269	346	177	168	180	871	48.56	42300
21	1110	264	334	170	162	179	859	50.06	42000
22	1105	260	326	167	155	168	816	51.47	42000
23	1100	255	317	165	150	163	795	53.83	42000
24	1095	249	305	163	147	156	771	53.70	41400
25	1090	249	290	160	144	151	745	53.30	41200
26	1085	239	281	153	140	145	719	56.19	40400
27	1080	235	269	144	136	138	697	58.84	40400
28	1075	230	259	140	132	135	666	60.31	40200
29	1070	225	247	134	128	131	640	61.72	39500
30	1065	220	238	126	122	126	621	63.72	39000
31	1060	215	226	122	116	120	584	66.78	39000
32	1055	211	214	110	111	115	556	69.89	39000
33	1050	206	202	112	106	108	528	73.86	39000

TABLE -3
MANGLA RESERVOIR OUTFLOWS
(ALL FIGURES IN 1000*CUSECS)

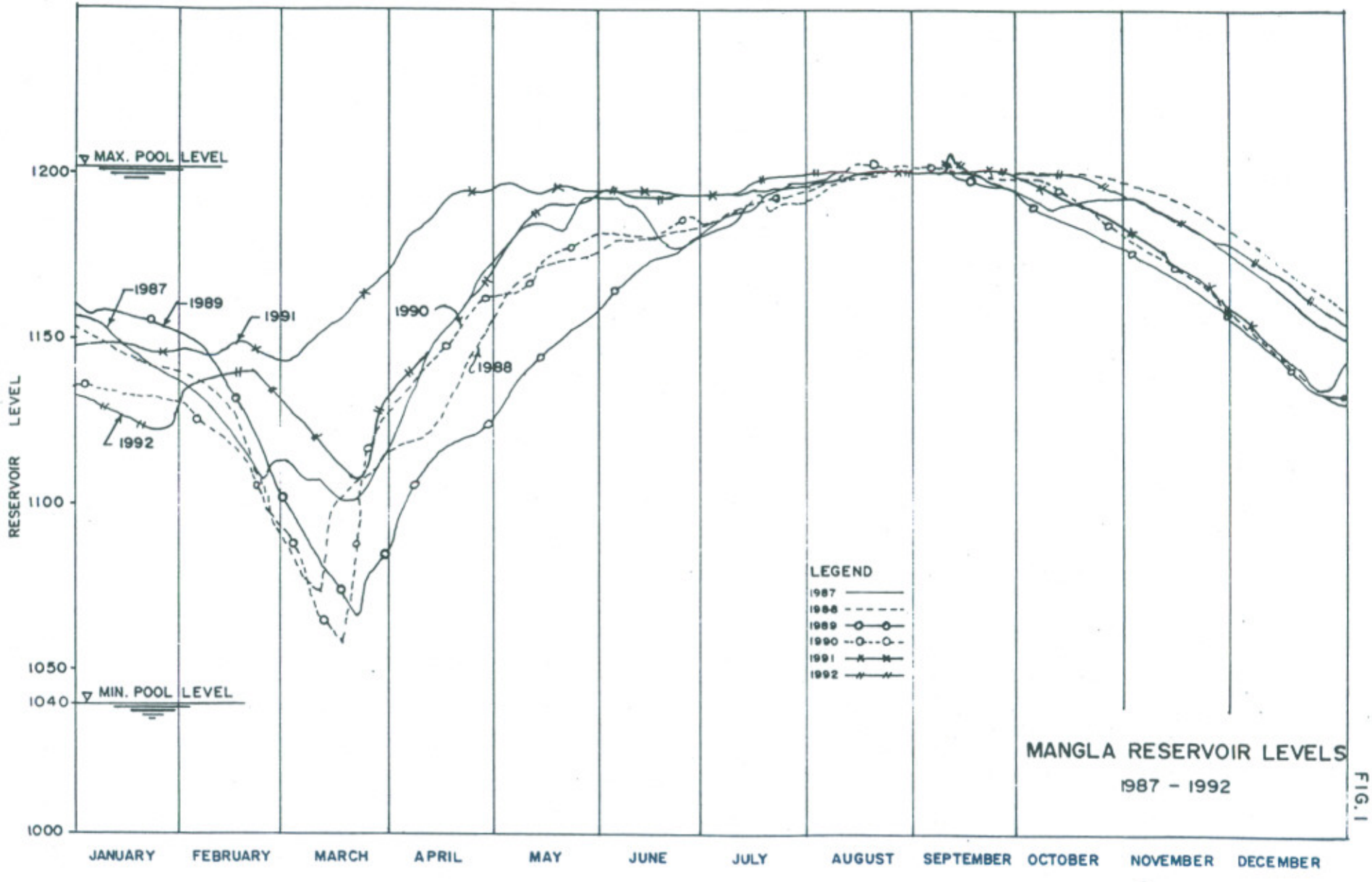
Period	POST TARBELA (1976-77 TO 1997-98			Last Year 1998-99	Current Year 1999-2000
	Maximum	Minimum	Average		
APR-1	43.5	11.5	27.9	40.0	
2	62.0	14.6	29.3	43.3	
3	85.3	18.1	36.8	54.0	
MAY-1	81.5	24.1	43.1	55.0	
2	93.3	30.4	52.2	70.0	
3	95.2	26.7	56.7	60.0	
JUNE-1	112.2	25.9	55.7	65.0	
2	128.6	20.4	52.4	40.0	
3	124.1	13.1	51.7	35.0	
JUL-1	199.3	14.7	55.4	40.0	
2	96.8	10.8	48.3	67.5	
3	96.8	10.8	50.5	48.7	
AUG-1	118.4	9.6	50.4	20.7	
2	61.8	10.4	39.9	16.7	
3	96.4	11.9	38.0	13.3	
SEP-1	72.5	13.4	34.1	16.0	
2	141.2	19.9	32.4	18.7	
3	50.2	163.3	26.6	22.0	
OCT-1	33.0	21.2	28.2	20.1	
2	30.4	15.7	26.1	20.0	
3	32.9	15.0	24.0	18.0	
NOV-1	30.0	17.0	24.8	21.3	
2	30.0	17.0	26.0	19.6	
3	31.1	17.0	26.6	28.4	
DEC-1	31.7	17.0	26.6	36.6	
2	39.9	17.0	26.2	27.5	
3	28.2	13.2	21.1	17.1	
FEB-1	27.6	9.7	14.9	15.0	
2	27.3	9.0	15.8	10.0	
3	24.9	9.0	17.3	12.3	
JAN-1	44.9	13.3	23.3	13.0	
2	59.8	14.5	29.4	25.9	
3	75.0	13.7	30.5	27.3	
MAR-1	75.0	14.3	30.4	30.0	
2	75.0	13.7	30.3		
3	60.2	14.9	29.4		
Kharif - TO (MAF)	**23.667**	**7.598**	**15.788**	**14.462**	
Rabi - TO	**10.959**	**7.476**	**9.016**		
Annual-To (MAF)	**33.015**	**16.405**	**24.804**		

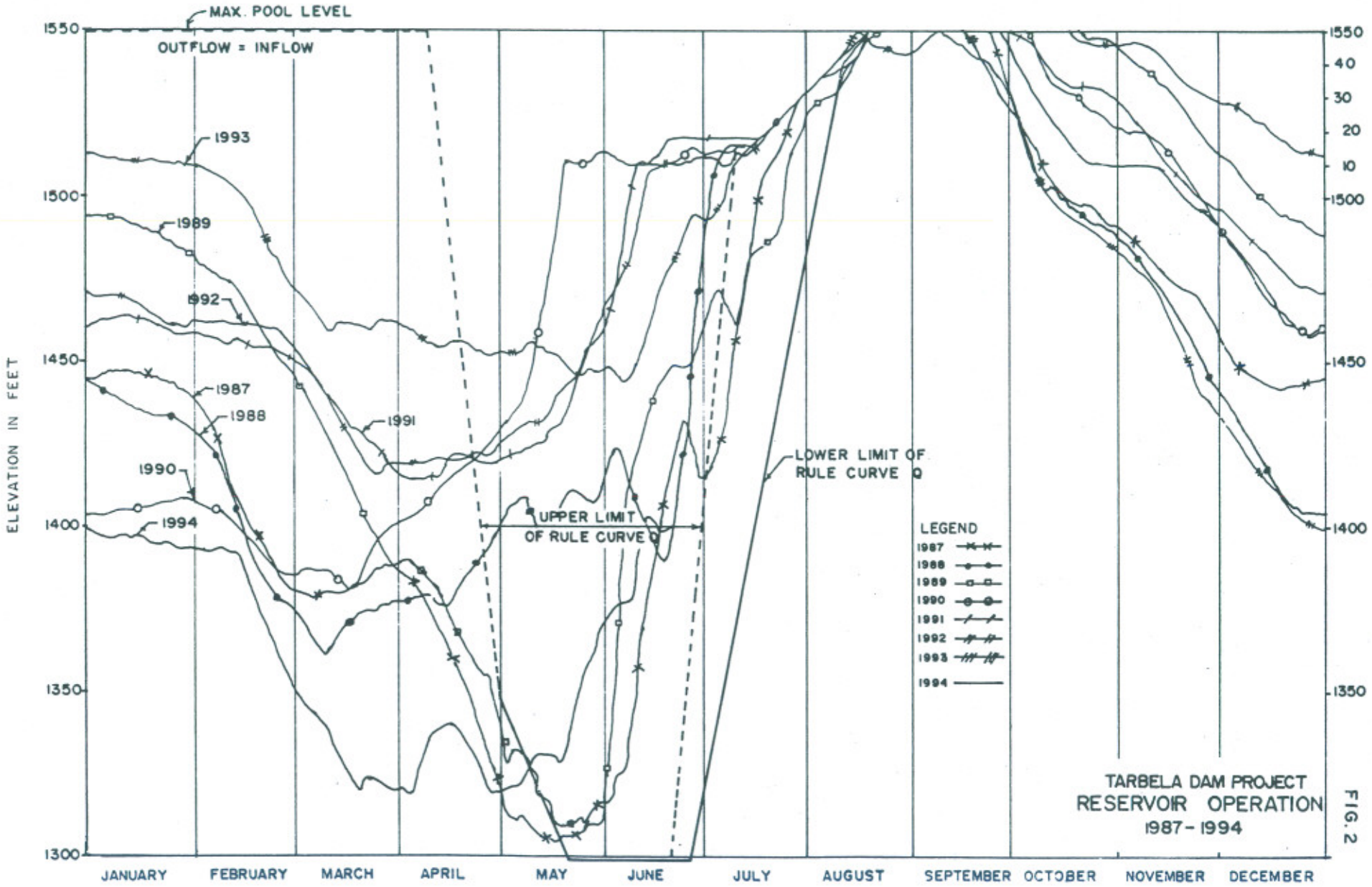
TABLE-4
TARBELA POWER STATION NO.1
CAPACITY PER MACHINE AGAINST VARING RESERVOIR LEVELS
DURING 1993-94 & 1994-95

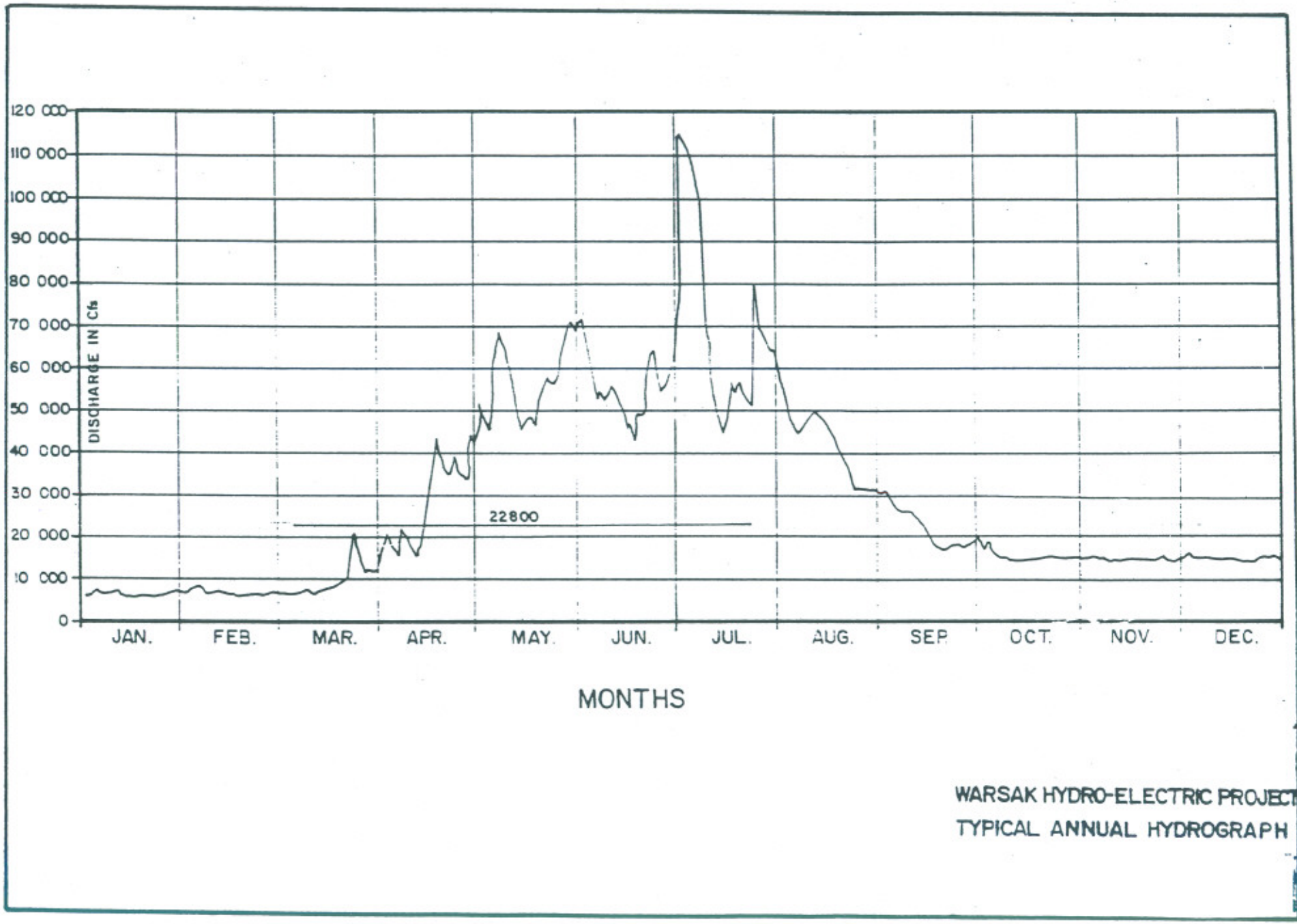
Sr. No.	HRL Ft. SPD	FRL Ft. SPD	Gross Head (Ft.) (HRL-TRL)	UNITS CAPABILITY (MW) PER UNIT			HRL Ft. SPD	FRL Ft. SPD	Gross Head (Ft.) (HRL-TRL)
				1-4	5-8	9-10			
1	1550	1117	433	204	212	212	2088	68800	33
2	1545	1117	428	201	207	207	2046	68600	34
3	1540	1117	423	199	205	205	2026	68600	34
4	1535	1117	418	198	203	203	2010	68100	34
5	1530	1117	413	194	201	201	1982	67800	34
6	1525	1117	408	191	200	199	1962	67400	34
7	1520	1117	408	188	197	196	1932	67100	35
8	1515	1116	399	186	192	194	1894	66800	35
9	1510	1116	394	183	187	186	1852	66400	36
10	1505	1116	389	178	182	182	1804	66000	37
11	1500	1116	384	176	179	179	1778	65600	37
12	1495	1116	379	174	176	174	1748	65200	37
13	1490	1116	374	172	174	172	1728	64900	38
14	1485	1116	360	168	169	168	1684	64400	38
15	1480	1115	365	165	166	164	1652	64000	39
16	1475	1115	360	162	163	161	1622	63600	39
17	1470	1115	355	159	159	158	1588	63100	40
18	1465	1115	350	155	156	155	1554	627700	40
19	1460	1115	345	153	153	153	1530	62200	41
20	1455	1115	340	150	150	150	1500	61800	41
21	1450	1114	336	147	147	147	1470	61300	42
22	1445	1114	331	143	146	143	1430	60900	43
23	1440	1114	326	140	140	140	1400	60300	43
24	1435	1114	321	136	136	137	1362	59900	44
25	1430	1114	316	133	133	134	1332	59300	45
26	1425	1114	311	131	129	131	1302	58800	45
27	1420	1114	306	128	126	128	1272	58200	46
28	1415	1113	302	124	121	125	1230	57700	47
29	1410	1113	297	121	118	121	1198	57100	48
30	1405	1113	292	120	115	119	1178	56600	48
31	1400	1113	287	116	111	116	1140	56000	49
32	1395	1113	289	110	107	113	1094	55400	51
33	1390	1113	277	106	104	110	1060	54900	52
34	1385	1113	272	102	100	106	1020	54200	53
35	1380	1112	268	101	95	103	990	53700	54
36	1375	1112	268	99	92	98	960	53400	55
37	1370	1112	258	94	91	98	936	52500	56
38	1365	1112	253	91	87	94	900	52000	58
39	1360	1112	248	87	84	89	862	51400	60
40	1355	1112	243	83	80	84	820	50700	62
41	1350	1111	239	81	78	82	800	50100	63
42	1345	1111	234	78	74	78	764	49500	65
43	1340	1111	229	76	70	74	732	48900	67
44	1335	1111	224	74	67	72	708	48300	68
45	1330	1111	219	71	65	69	682	47700	70
46	1325	1111	214	69	62	67	658	47000	71
47	1320	1111	209	65	60	64	628	46300	74
48	1315	1110	205	61	56	61	590	45700	77
49	1310	1110	200	57	51	57	546	45000	82
50	1305	1110	195	54	40	55	522	44200	85

TABLE -5
TARBELA RESERVOIR OUTFLOWS
(ALL FIGURES IN 1000*CUSECS)

Period	POST TARBELA (1976-77 TO 1997-98			Last Year 1998-99	Current Year 1999-2000
	Maximum	Minimum	Average		
APR-1	55.2	14.8	30.7	39.7	
2	69.6	15.7	33.3	45.3	
3	79.4	19.1	45.9	44.7	
MAY-1	109.3	21.0	53.2	70.7	
2	142.9	38.0	63.3	89.9	
3	146.2	35.4	85.0	139.8	
JUNE-1	159.9	45.9	103.6	163.8	
2	248.4	37.7	126.9	126.4	
3	297.2	97.3	153.5	115.2	
JUL-1	317.3	97.8	174.0	172.2	
2	336.3	107.3	197.1	278.9	
3	320.3	67.1	510.2	230.1	
AUG-1	339.0	53.9	234.8	207.6	
2	300.3	110.5	201.8	191.0	
3	248.1	118.9	189.4	192.1	
SEP-1	230.2	87.9	145.9	162.1	
2	164.9	82.6	116.6	129.5	
3	142.5	62.6	95.5	106.3	
OCT-1	139.5	50.8	92.0	56.5	
2	95.3	37.1	63.8	72.4	
3	60.2	37.5	47.4	45.3	
NOV-1	59.0	28.0	44.9	41.2	
2	72.7	28.4	48.3	53.0	
3	64.7	29.7	49.8	72.3	
DEC-1	61.0	19.9	45.0	62.2	
2	55.2	22.6	38.8	45.1	
3	33.4	15.5	24.2	22.2	
FEB-1	31.4	4.5	18.9	11.1	
2	40.7	13.6	23.2	11.5	
3	35.0	15.4	25.1	8.8	
JAN-1	59.9	17.6	33.8	10.3	
2	63.3	23.7	46.4	61.5	
3	69.0	27.4	44.1	58.2	
MAR-1	67.3	17.3	41.6		
2	63.9	16.0	38.6		
3	57.4	9.0	30.4		
Kharif - TO (MAF)	**57.113**	**34.739**	**45.800**	**50.807**	
Rabi - TO	**17.033**	**12.826**	**15.096**		
Annual-To (MAF)	**72.634**	**16.405**	**60.896**		


MAX. POOL LEVEL
MIN. POOL LEVEL
1200
1150
1100
1050
1040
1000
RESERVOIR LEVEL
1987
1988
1989
1990
1991
1992
LEGEND
1987
1988
1989
1990
1991
1992
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
MANGLA RESERVOIR LEVELS
1987 - 1992
FIG. 1


MAX. POOL LEVEL
OUTFLOW = INFLOW
1993
1989
1992
1987
1988
1991
1990
1994
UPPER LIMIT OF RULE CURVE Q
LOWER LIMIT OF RULE CURVE Q
LEGEND
1987
1988
1989
1990
1991
1992
1993
1994
ELEVATION IN FEET
1550
1500
1450
1400
1350
1300
40
30
20
10
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
TARBELA DAM PROJECT
RESERVOIR OPERATION
1987 - 1994
FIG. 2



WARSAK HYDRO-ELECTRIC PROJECT
TYPICAL ANNUAL HYDROGRAPH

FIG. 3