2001 for Nachtigal I,
2010 for Memvé Elé 1,
2015 for Nachtigal II,
2017 for Memvé Elé 2, and
2021 for Nachtigal III.

The analysis summary is shown in Fig. 5.11 and Tables 5.4 and 5.5. The associated development time line is illustrated in Fig. 5.12.

5.6 Sensitivity Test of Optimized Project Scheme

The sensitivity analysis was made for the net-benefit based DTS optimization. Its concern is how the project optimality changes when fuel cost and also construction cost vary. The variation range of both of fuel cost and construction cost is assumed from 10% increase to 10% decrease with 5% intervals.

The fuel cost change effects energy values. The energy value is originally assumed as:

Energy value = (Fuel cost + Variable O&M cost) x Adjustment factor
= (0.0734 + 0.0030) x 1.007 = US $0.0769/kWh (primary energy), and
= (0.0325 + 0.0006) x 1.028 = US $0.0340/kWh (secondary energy).

Therefore, the fuel cost change yields the following energy values:

Unit: US $/kWh

	10% up	5% up	Original	5% down	10% down
Primary Energy Value	0.0843	0.0806	0.0769	0.0732	0.0695
Secondary Energy Value	0.0374	0.0357	0.0340	0.0323	0.0306

The change of construction costs are similarly assumed from 10% cost increase to 10% cost decrease with 5% intervals.

Using those increased or decreased values, 25 cases (five fuel cost cases x five construction cost cases) come up for the sensitivity test. The conclusion is rather simple such that all of 25 cases show similar development timing and development order for the South Interconnection Network, that is, the order of Nachtigal I – Memvé Elé 1 – Nachtigal II – Memvé Elé 2 – Nachtigal III or Nachtigal I – Memvé Elé 1 – Memvé Elé 2 – Nachtigal II – Nachtigal III. It can be said that the project optimization is not very sensitive to construction costs and fuel prices as long as changes of those values are within 10%; in any case the development order of Nachtigal I – Memvé Elé 1 will yield the advantageous net benefit for the system.

The net benefits of four outstanding cases are shown below:

when construction cost increases 10% and fuel price decreases 10%, Bill. F. CFA 307.3 or
Mill. US $1,135.8 (N1 - M1 - N2 - M2 - N3),
when construction cost decreases 10% and fuel price decreases 10%, Bill. F. CFA 361.2 or
Mill. US $1,334.9 (N1 - M1 - M2 - N2 - N3),
when construction cost increases 10% and fuel price increases 10%, Bill. F. CFA 370.8 or
Mill. US $1,370.4 (N1 - M1 - N2 - M2 - N3), and
when construction cost decreases 10% and fuel price increases 10%, Bill. F. CFA 424.7 or
Mill. US $1,569.3 (N1 - M1 - M2 - N2 - N3).

Recall that the net benefit is F. CFA 365.8 billion or US $1,351.8 million based on original construction cost and fuel price without any cost increase or decrease.

Table 5.1 Classification of Project Alternatives

Alternatives	Notes
1. ***Dam Alignment Alternatives, A(i)*** (See Fig. 6.1)	
A(1) Dam length = 1,765 m	Small Scale Development using runoff from only Ntem river
A(2) Dam length = 3,930 m	Large Scale Development using all of runoff from Ntem, Biwome, and Ndjo'o rivers
2. ***Waterway Alternatives, W(l)*** (See Fig. 6.1)	Headrace Channel Length = 2,480 m for all of W(1), W(2), and W(3)
W(1) No headrace tunnel; headpond equipped Tailrace tunnel length, Ltr = 2 x 1,450 m	TWL = 336.0 m
W(2) No headrace tunnel; headpond equipped Tailrace tunnel length, Ltr = 4 x 340 m	TWL = 345.2 m
W(3) Headrace tunnel length, L = 1,740 m; no headpond Tailrace tunnel length, Ltr = 4 x 160 m	TWL = 336.0 m
3. ***Full Supply Level Alternatives, H(k)***	
H(k) Full supply level varies from EL. 398 m to EL. 388 m with a 2-m interval. (k = -2, -1, 0, 1, 2, 3)	Associated dam crest elevations are from EL. 401 m to EL. 391 m with a 2-m interval.
4. ***Plant Discharge Alternatives, Q(j)***	
Q(j) Varies from 350 m3/s to 650 m3/s or approximately from 90% to 170% of the mean runoff	The optimization referrers to following 7 plant discharge series: Q(1) = 350 m3/s, Q(2) = 400 m3/s, Q(3) = 450 m3/s, Q(4) = 500 m3/s, Q(5) = 550 m3/s, Q(6) = 600 m3/s, and Q(7) = 650 m3/s

* There exist 252 Project Alternatives combining the above alternative parameters.

Table 5.2 Project Costs (Dam Alignment: A(1), Waterway Route: W(1))

Project Features and Work Descriptions	Q'ty Unit	Unit Price (FCFA)	Plan 1		Plan 2		Plan 3		Plan 4		Plan 5	
			Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)
I Preparatory Works (20% of II)				**7,059.7**		**6,814.5**		**7,225.1**		**7,727.1**		**8,260.3**
II Civil Works				**35,297.9**		**34,072.1**		**36,125.2**		**38,635.0**		**41,301.2**
1. River Diversion				222.0		222.0		222.0		222.0		266.4
Coffering & coffer removal	m3	3,100	71,600	222.0	71,600	222.0	71,600	222.0	71,600	222.0	85,920	266.4
2. Main Dam				2,108.1		2,604.0		2,604.0		2,604.0		3,892.4
Common excavation	m3	1,100	262,400	288.6	262,400	288.6	262,400	288.6	262,400	288.6	341,660	375.8
Riprap	m3	2,500	60,900	152.3	75,900	189.8	75,900	189.8	75,900	189.8	118,480	296.2
Transition	m3	4,200	41,200	173.0	49,300	207.1	49,300	207.1	49,300	207.1	74,730	313.9
Filter	m3	4,200	69,800	293.2	84,800	356.2	84,800	356.2	84,800	356.2	130,330	547.4
Impervious	m3	2,000	492,500	985.0	673,200	1,346.4	673,200	1,346.4	673,200	1,346.4	1,145,570	2,291.1
Foundation treatment	m	40,000	5,400	216.0	5,400	216.0	5,400	216.0	5,400	216.0	1,700	68.0
3. Spillway				5,740.7		6,485.7		6,485.7		6,485.7		8,321.4
Common Excavation	m3	1,100	6,000	6.6	5,800	6.4	5,800	6.4	5,800	6.4	5,800	6.4
Rock Excavation	m3	3,500	19,500	68.3	17,400	60.9	17,400	60.9	17,400	60.9	16,500	57.8
Concrete	m3	71,000	79,800	5,665.8	90,400	6,418.4	90,400	6,418.4	90,400	6,418.4	116,300	8,257.3
4. Intake				3,850.4		3,688.4		3,772.8		3,849.8		4,372.0
Common Excavation	m3	1,100	536,400	590.0	509,500	560.5	515,000	566.5	520,500	572.6	519,200	571.1
Rock Excavation	m3	3,500	134,300	470.1	126,900	444.2	129,000	451.5	131,000	458.5	130,500	456.8
Concrete	m3	71,000	39,300	2,790.3	37,800	2,683.8	38,800	2,754.8	39,700	2,818.7	47,100	3,344.1
5. Headrace Channel				5,429.1		4,769.8		5,003.1		5,431.5		5,031.5
Common excavation	m3	1,100	767,000	843.7	721,100	793.2	767,000	843.7	810,700	891.8	767,000	843.7
Rock excavation	m3	3,500	426,000	1,491.0	406,800	1,423.8	426,000	1,491.0	444,900	1,557.2	426,000	1,491.0
Riprap	m3	2,500	28,000	70.0	28,000	70.0	28,000	70.0	28,000	70.0	28,000	70.0
Transition	m3	4,200	53,000	222.6	53,000	222.6	53,000	222.6	53,000	222.6	53,000	222.6
Soil embankment	m3	2,000	272,000	544.0	271,000	542.0	272,000	544.0	272,900	545.8	272,000	544.0
Concrete	m3	71,000	31,800	2,257.8	24,200	1,718.2	25,800	1,831.8	30,200	2,144.2	26,200	1,860.2
6. Headpond Dam				467.5		564.1		564.1		564.1		771.8
Common excavation	m3	1,100	84,000	92.4	97,000	106.7	97,000	106.7	97,000	106.7	119,200	131.1
Riprap	m3	2,500	13,830	34.6	15,810	39.5	15,810	39.5	15,810	39.5	19,800	49.5
Transition	m3	4,200	5,600	23.5	6,200	26.0	6,200	26.0	6,200	26.0	7,500	31.5
Filter	m3	4,200	18,900	79.4	21,400	89.9	21,400	89.9	21,400	89.9	26,600	111.7
Impervious	m3	2,000	90,800	181.6	119,000	238.0	119,000	238.0	119,000	238.0	166,000	332.0
Foundation treatment	m	40,000	1,400	56.0	1,600	64.0	1,600	64.0	1,600	64.0	2,900	116.0
7. Penstock Intake				3,207.2		2,890.4		3,079.5		3,566.8		4,130.3
Common excavation	m3	1,100	46,900	51.6	40,000	44.0	45,000	49.5	50,000	55.0	45,000	49.5

Table 5.2 Project Costs (Dam Alignment: A(1), Waterway Route: W(1))

Project Features and Work Descriptions	Q'ty Unit	Unit Price (FCFA)	Plan 1		Plan 2		Plan 3		Plan 4		Plan 5	
			Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)
Rock excavation	m3	3,500	35,416	124.0	30,222	105.8	34,000	119.0	37,778	132.2	34,000	119.0
Concrete	m3	71,000	42,700	3,031.7	38,600	2,740.6	41,000	2,911.0	47,600	3,379.6	55,800	3,961.8
8. Penstocks				371.9		345.5		371.9		390.1		371.9
Common excavation	m3	1,100	6,500	7.2	5,100	5.6	6,500	7.2	8,000	8.8	6,500	7.2
Tunnel excavation	m3	7,000	14,600	102.2	13,200	92.4	14,600	102.2	15,900	111.3	14,600	102.2
Tunnel concrete	m3	75,000	3,500	262.5	3,300	247.5	3,500	262.5	3,600	270.0	3,500	262.5
9. Power Station				4,919.2		4,480.3		5,040.1		5,600.1		5,161.3
Common excavation	m3	1,100	35,200	38.7	32,000	35.2	36,000	39.6	40,000	44.0	36,900	40.6
Rock excavation	m3	3,500	6,500	22.8	5,900	20.7	6,700	23.5	7,400	25.9	6,800	23.8
Shaft excavation	m3	6,000	186,000	1,116.0	169,400	1,016.4	190,500	1,143.0	211,700	1,270.2	195,100	1,170.6
Concrete	m3	71,000	52,700	3,741.7	48,000	3,408.0	54,000	3,834.0	60,000	4,260.0	55,300	3,926.3
10. Surge Tunnel / Chamber				1,160.3		1,076.8		1,160.5		1,237.7		1,160.6
Common excavation	m3	1,100	2,800	3.1	2,600	2.9	3,000	3.3	3,300	3.6	3,100	3.4
Shaft excavation	m3	7,000	43,600	305.2	38,800	271.6	43,600	305.2	48,500	339.5	43,600	305.2
Concrete	m3	71,000	12,000	852.0	11,300	802.3	12,000	852.0	12,600	894.6	12,000	852.0
11. Tailrace Tunnels				5,904.0		5,246.5		5,904.0		6,554.4		5,904.0
Tunnel excavation	m3	7,000	264,000	1,848.0	234,700	1,642.9	264,000	1,848.0	293,400	2,053.8	264,000	1,848.0
Tunnel concrete	m3	78,000	52,000	4,056.0	46,200	3,603.6	52,000	4,056.0	57,700	4,500.6	52,000	4,056.0
12. Tailrace Outlet				1,917.4		1,698.5		1,917.4		2,128.6		1,917.4
Common excavation	m3	1,100	80,400	88.4	71,400	78.5	80,400	88.4	89,300	98.2	80,400	88.4
Rock excavation	m3	3,500	187,600	656.6	166,700	583.5	187,600	656.6	208,400	729.4	187,600	656.6
Soil embankment	m3	2,000	4,000	8.0	3,500	7.0	4,000	8.0	4,400	8.8	4,000	8.0
Concrete	m3	71,000	16,400	1,164.4	14,500	1,029.5	16,400	1,164.4	18,200	1,292.2	16,400	1,164.4
III Hydro-mechanical Equipment				7,260.3		7,250.2		7,668.8		8,088.2		8,944.4
1. Spillway				1,874.2		1,853.8		1,853.8		1,853.8		2,098.6
Spillway Gates	ton	2,400,000	529	1,269.6	471	1,130.4	471	1,130.4	471	1,130.4	504	1,209.6
Sand Sluice Gate	ton	2,400,000	113	271.2	146	350.4	146	350.4	146	350.4	193	463.2
Stoplogs	ton	2,400,000	138	330.0	154	369.6	154	369.6	154	369.6	176	422.4
Monorail Crane	kg	2,510	1,355	3.4	1,355	3.4	1,355	3.4	1,355	3.4	1,355	3.4
2. Intake				1,447.2		1,541.4		1,675.8		1,810.2		2,051.6
Trash Racks	ton	1,800,000	94	169.2	103	185.4	116	208.8	129	232.2	142	255.6
Intake Gates	ton	3,000,000	271	813.0	297	891.0	334	1,002.0	371	1,113.0	442	1,326.0
Rakes	-	L.S.		125.0		125.0		125.0		125.0		125.0
Stoplogs	ton	2,400,000	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Table 5.2 Project Costs (Dam Alignment: A(1), Waterway Route: W(1))

Project Features and Work Descriptions	Q'ty Unit	Unit Price (FCFA)	Plan 1		Plan 2		Plan 3		Plan 4		Plan 5	
			Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)	Quantity	Amount (Mill. FCFA)
Desilting System	ton	5,000,000	68	340.0	68	340.0	68	340.0	68	340.0	69	345.0
3. Penstok Intake				1,488.1		1,541.4		1,675.8		1,810.2		2,162.6
Trash Racks	ton	1,800,000	98	176.3	103	185.4	116	208.8	129	232.2	142	255.6
Intake Gates	ton	3,000,000	282	846.9	297	891.0	334	1,002.0	371	1,113.0	479	1,437.0
Rakes	-	L.S.		125.0		125.0		125.0		125.0		125.0
Stoplogs	ton	2,400,000	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Desilting System	ton	5,000,000	68	340.0	68	340.0	68	340.0	68	340.0	69	345.0
4. Penstock				1,519.0		1,486.8		1,531.6		1,577.8		1,675.8
Penstock	ton	1,400,000	1,085	1,519.0	1,062	1,486.8	1,094	1,531.6	1,127	1,577.8	1,197	1,675.8
5. Powerhouse				294.0		261.0		294.0		327.0		318.0
Draft Gates	ton	3,000,000	98	294.0	87	261.0	98	294.0	109	327.0	106	318.0
6. Tailrace				637.8		565.8		637.8		709.2		637.8
Outlet Gates	ton	3,000,000	139	417.0	123	369.0	139	417.0	154	462.0	139	417.0
Stoplogs	ton	2,400,000	92	220.8	82	196.8	92	220.8	103	247.2	92	220.8
IV Electro-mechanical Equipment				33,225.0		31,925.0		33,625.0		37,525.0		37,625.0
1. Generating equipment	unit	L.S.		20,100.0		18,800.0		20,500.0		24,400.0		24,500.0
2. Transmission line system	m	42,400	285,000	13,125.0	285,000	13,125.0	285,000	13,125.0	285,000	13,125.0	285,000	13,125.0
V Engineering Services (10% of I + II + III + IV)				8,284.3		8,006.2		8,464.4		9,197.5		9,613.1
VI General Expenses (1% of I + II + III + IV)				828.4		800.6		846.4		919.8		961.3
VII Contingencies (20 % of I + II + III + IV + V + VI)				18,391.1		17,773.7		18,791.0		20,418.5		21,341.1
Grand Total				110,346.7		106,642.3		112,746.0		122,511.2		128,046.4

Exchange Rate: US$1 = FCFA270.6

	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Full Supply Level (m)	390.0	392.0	392.0	392.0	394.0
Tail Water Level (m)	336.0	336.0	336.0	336.0	336.0
Maximum Plant Discharge (m3/s)	450.0	400.0	450.0	500.0	450.0
Installed Capacity (MW)	4 x 48.2	4 x 44.5	4 x 50.3	4 x 54.75	4 x 51.8

Table 5.3 Assumptions for Development Scale and Timing Optimization

Items	Memvé Elé Plan 1		Memvé Elé Plan 2		Memvé Elé Plan 3	
	Memvé Elé 1	Memvé Elé 2	Memvé Elé 1	Memvé Elé 2	Memvé Elé 1	Memvé Elé 2
Hydro Plant Features						
1. Values to be Optimized	Total Net Present Value of the South Interconnection Ntework					
2. Price Level	1993 price level without inflation of construction cost nor interest during construction					
3. Project Cost (1993 price level)	Mill. FCFA 84,967 (Mill. US$ 313.99)	Mill. FCFA 25,380 (Mill. US$ 93.79)	Mill. FCFA 82,115 (Mill. US$ 303.45)	Mill. FCFA 24,528 (Mill. US$ 90.64)	Mill. FCFA 86,814 (Mill. US$ 320.82)	Mill. FCFA 25,932 (Mill. US$ 95.83)
4. Cost Disbursement	3, 15, 30, 40 & 12% in 5 years	50%, 50% in 2 yeras	3, 15, 30, 40 & 12% in 5 years	50%, 50% in 2 yeras	3, 15, 30, 40 & 12% in 5 years	50%, 50% in 2 yeras
5. Guaranteed Power	96.4 MW	96.4 MW	89.0 MW	89.0 MW	100.6 MW	100.6 MW
6. Energy Output (Primary) (Secondary)	320 GWh/year 392 GWh/year	2 GWh/year 384 GWh/year	336 GWh/year 342 GWh/year	3 GWh/year 386 GWh/year	342 GWh/year 402 GWh/year	3 GWh/year 396 GWh/year
7. Monthly Rate of Energy Output (%)	3.70, 2.89, 4.10, 7.64, 10.19, 9.25, 5.00, 2.99, 7.05, 17.75, 20.29, 9.15 in January-December order					
8. Project Life	50 years for civil; 35 years for metal and electrical					
9. O&M Costs	0.5% of capital cost for civil; 2% of capital cost of metal and electrical					
Alternative Plant Features						
10. Alternative Thermal Plant	Gas-Turbine Generators for primary energy and Oil-fired for secondary					
11. Power Output	96.4 MW	96.4 MW	89.0 MW	89.0 MW	100.6 MW	100.6 MW
12. Energy Output (Primary) (Secondary)	320 GWh/year 392 GWh/year	2 GWh/year 384 GWh/year	336 GWh/year 342 GWh/year	3 GWh/year 386 GWh/year	342 GWh/year 402 GWh/year	3 GWh/year 396 GWh/year
13. Project Life						
14. Economic Construction Cost (US$1131/kW)	Mill. US$109.03	Mill. US$109.03	Mill. US$100.66	Mill. US$100.66	Mill. US$113.78	Mill. US$113.78
15. O&M Cost (US$22.6/kW/year)	Mill. US$2.18	Mill. US$2.18	Mill. US$2.01	Mill. US$2.01	Mill. US$2.27	Mill. US$2.27
16. Variable Cost	Mill. US$37.94	Mill. US$13.21	Mill. US$37.47	Mill. US$13.35	Mill. US$39.97	Mill. US$13.69

US$1.00 = FCFA270.6 assumed.

Energy Value: US$0.0769/kWh for primary, US$0.034/kWh for secondary.

Table 5.3 Assumptions for Development Scale and Timing Optimization

Items	Memvé Elé Plan 4		Memvé Elé Plan 5		Plan of Nachtigal		
	Memvé Elé 1	Memvé Elé 2	Memvé Elé 1	Memvé Elé 2	Nachtigal 1	Nachtigal 2	Nachtigal 3
Hydro Plant Features							
1. Values to be Optimized	Total Net Present Value of the South Interconnection Ntework						
2. Price Level	1993 price level without inflation of construction cost nor interest during construction						
3. Project Cost (1993 price level)	Mill. FCFA 94,334 (Mill. US$ 348.61)	Mill. FCFA 28,178 (Mill. US$ 104.13)	Mill. FCFA 90,944 (Mill. US$ 336.08)	Mill. FCFA 27,165 (Mill. US$ 100.39)	Mill. FCFA 84,209 (Mill. US$ 311.19)	Mill. FCFA 14,581 (Mill. US$ 53.88)	Mill. FCFA 8,395 (Mill. US$ 31.02)
4. Cost Disbursement	3, 15, 30, 40 & 12% in 5 years	50%, 50% in 2 yeras	3, 15, 30, 40 & 12% in 5 years	50%, 50% in 2 yeras	3, 15, 30, 40 & 12% in 5 years	50%, 50% in 2 yeras	50%, 50% in 2 yeras
5. Guaranteed Power	109.5 MW	109.5 MW	103.6 MW	103.6 MW	133.4 MW	66.7 MW	54.1 MW
6. Energy Output (Primary) (Secondary)	337 GWh/year 450 GWh/year	2 GWh/year 397 GWh/year	433 GWh/year 333 GWh/year	0 GWh/year 407 GWh/year	395 GWh/year 349 GWh/year	0 GWh/year 246 GWh/year	0 GWh/year 188 GWh/year
7. Monthly Rate of Energy Output (%)	3.70, 2.89, 4.10, 7.64, 10.19, 9.25, 5.00, 2.99, 7.05, 17.75, 20.29, 9.15 in January-December order				3.39, 2.15, 1.84, 2.33, 3.79, 5.69, 9.01, 12.27, 18.30, 21.84, 13.45, 5.93 in January-December order		
8. Project Life	50 years for civil; 35 years for metal and electrical						
9. O&M Costs	0.5% of capital cost for civil; 2% of capital cost of metal and electrical						
Alternative Plant Features							
10. Alternative Thermal Plant	Gas-Turbine Generators for primary energy and Oil-fired for secondary						
11. Power Output	109.5 MW	109.5 MW	103.6 MW	103.6 MW	133.4 MW	66.7 MW	54.1 MW
12. Energy Output (Primary) (Secondary)	337 GWh/year 450 GWh/year	2 GWh/year 397 GWh/year	433 GWh/year 333 GWh/year	0 GWh/year 407 GWh/year	395 GWh/year 349 GWh/year	0 GWh/year 246 GWh/year	0 GWh/year 188 GWh/year
13. Project Life	15 years						
14. Economic Construction Cost (US$1131/kW)	Mill. US$123.84	Mill. US$123.84	Mill. US$117.17	Mill. US$117.17	Mill. US$150.88	Mill. US$75.44	Mill. US$61.19
15. O&M Cost (US$22.6/kW/year)	Mill. US$2.47	Mill. US$2.47	Mill. US$2.34	Mill. US$2.34	Mill. US$3.01	Mill. US$1.51	Mill. US$1.22
16. Variable Cost	Mill. US$41.22	Mill. US$13.65	Mill. US$44.62	Mill. US$13.84	Mill. US$42.23	Mill. US$8.36	Mill. US$6.39

US$1.00 = FCFA270.6 assumed.

Energy Value: US$0.0769/kWh for primary, US$0.034/kWh for secondary.

Table 5.4 Development Timing of South Interconnection Network

Net Benefit		1st	2nd	3rd	4th	5th	Deficit Year	Plan
1	1,243.0	Nachtigal I 2001	Memvé Elé 1 2008	Nachtigal II 2013	Memvé Elé 2 2019	Nachtigal III 2021	2023	Plan3
2	1,314.7	Nachtigal I 2001	Memvé Elé 1 2008	Nachtigal II 2015	Nachtigal III 2019	Memvé Elé 2 2021	2023	Plan3
3	1,315.1	Nachtigal I 2001	Memvé Elé 1 2008	Memvé Elé 2 2015	Nachtigal II 2018	Nachtigal III 2021	2023	Plan3
4	1,314.6	Nachtigal I 2001	Nachtigal II 2008	Memvé Elé 1 2015	Memvé Elé 2 2018	Nachtigal III 2020	2023	Plan3
5	1,351.5	Nachtigal I 2001	Nachtigal II 2010	Memvé Elé 1 2015	Nachtigal III 2019	Memvé Elé 2 2021	2023	Plan3
6	1,351.8	Nachtigal I 2001	Nachtigal II 2010	Nachtigal III 2015	Memvé Elé 1 2018	Memvé Elé 2 2021	2023	Plan3
7	1,351.4	Memvé Elé 1 2001	Nachtigal I 2010	Nachtigal II 2015	Memvé Elé 2 2018	Nachtigal III 2020	2023	Plan3
8	1,324.9	Memvé Elé 1 2001	Nachtigal I 2010	Nachtigal II 2013	Nachtigal III 2018	Memvé Elé 2 2021	2023	Plan3
9	1,323.9	Memvé Elé 1 2001	Nachtigal I 2010	Memvé Elé 2 2013	Nachtigal II 2018	Nachtigal III 2020	2023	Plan3
10	1,303.9	Memvé Elé 1 2001	Memvé Elé 2 2010	Nachtigal I 2013	Nachtigal II 2016	Nachtigal III 2020	2023	Plan3

Deficit Year denotes the first year when electricity deficit will occur even after full Memvé Elé and full Nachtigal Projects are put into the South Interconnection Network.

Plans 1 to 5 denote the Memvé Elé's development schemes as follows:

Plan 1	Q = 450 m3/s	FSL = 390 m
Plan 2	Q = 400 m3/s	FSL = 392 m
Plan 3	Q = 450 m3/s	FSL = 392 m
Plan 4	Q =500 m3/s	FSL = 392 m
Plan 5	Q = 450 m3/s	FSL = 394 m

Electricity demand based on Medium Growth Scenario by Microscopic Method.
This table shows the best 10 development cases of Plan 3.

Table 5.5 Development Scale and Timing Optimization

Unit: $1,000,000

Dvelopment 0123456			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.0	-8.2	HC[1]
1997	-63.9	-39.7	HC[1]
1998	-136.8	-77.2	HC[1]
1999	-195.0	-100.1	HC[1]
2000	132.2	61.7	HC[1] TR[1]
2001	52.6	22.3	
2002	56.2	21.7	
2003	60.1	21.1	
2004	64.3	20.5	
2005	68.8	19.9	
2006	-70.1	-18.4	HC[2]
2007	236.9	56.7	HC[2] TR[2]
2008	85.7	18.6	HC[3]
2009	-25.4	-5.0	HC[3]
2010	-183.7	-33.0	HC[3]
2011	-308.0	-50.4	HC[3]
2012	583.3	86.7	HC[3] TR[3]
2013	317.7	42.9	
2014	339.8	41.7	
2015	363.4	40.6	
2016	959.6	97.4	TR[1]
2017	271.2	25.0	HC[4]
2018	723.0	60.7	HC[4] TR[4]
2019	425.1	32.4	HC[5]
2020	856.3	59.4	HC[5] TR[5]
2021	635.7	40.1	
2022	679.8	39.0	
2023	1,641.0	85.5	TR[2]
2024	777.7	36.8	
2025	831.7	35.8	
2026	889.5	34.8	
2027	951.4	33.9	
2028	2,713.4	87.8	TR[3]
2029	1,088.3	32.0	
2030	1,163.9	31.1	
2031	2,809.4	68.3	TR[1]
2032	1,331.4	29.4	
2033	1,423.9	28.6	
2034	2,792.0	51.0	TR[4]
2035	1,628.8	27.0	
2036	675.1	10.2	HR[1] TR[5]
2037	1,863.1	25.6	
2038	4,497.2	56.1	TR[2]
2039	2,131.1	24.2	
2040	2,279.3	23.5	
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	42,450.0	1,243.0	

Dvelopment 0134526			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.0	-8.2	HC[1]
1997	-63.9	-39.7	HC[1]
1998	-136.8	-77.2	HC[1]
1999	-195.0	-100.1	HC[1]
2000	132.2	61.7	HC[1] TR[1]
2001	52.6	22.3	
2002	56.2	21.7	
2003	40.6	14.2	HC[3]
2004	-40.3	-12.8	HC[3]
2005	-154.9	-44.9	HC[3]
2006	-245.4	-64.6	HC[3]
2007	389.8	93.3	HC[3] TR[3]
2008	198.1	43.1	
2009	211.9	41.9	
2010	226.6	40.8	
2011	242.4	39.6	
2012	259.2	38.5	
2013	166.8	22.5	HC[4]
2014	509.3	62.6	HC[4] TR[4]
2015	351.3	39.2	
2016	868.9	88.2	TR[1] HC[5]
2017	647.0	59.7	HC[5] TR[5]
2018	141.3	11.9	HC[2]
2019	849.6	64.8	HC[2] TR[2]
2020	594.3	41.2	
2021	635.7	40.1	
2022	679.8	39.0	
2023	1,939.0	101.0	TR[3]
2024	777.7	36.8	
2025	831.7	35.8	
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,017.5	32.9	
2029	1,088.3	32.0	
2030	2,133.9	57.0	TR[4]
2031	2,809.4	68.3	TR[1]
2032	1,331.4	29.4	
2033	2,386.4	47.9	TR[5]
2034	1,522.9	27.8	
2035	3,676.0	61.0	TR[2]
2036	-502.4	-7.6	HR[1]
2037	1,863.1	25.6	
2038	5,313.7	66.3	TR[3]
2039	2,131.1	24.2	
2040	2,279.3	23.5	
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	43,890.2	1,314.6	

Dvelopment 0314526			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.2	-8.3	HC[3]
1997	-65.3	-40.6	HC[3]
1998	-139.7	-78.9	HC[3]
1999	-199.3	-102.2	HC[3]
2000	194.4	90.7	HC[3] TR[3]
2001	71.2	30.2	
2002	76.2	29.4	
2003	81.5	28.6	
2004	87.1	27.8	
2005	71.3	20.7	HC[1]
2006	-17.4	-4.6	HC[1]
2007	-143.8	-34.4	HC[1]
2008	-243.1	-52.9	HC[1]
2009	364.0	72.0	HC[1] TR[1]
2010	226.6	40.8	
2011	242.4	39.6	
2012	259.2	38.5	
2013	166.8	22.5	HC[4]
2014	509.3	62.6	HC[4] TR[4]
2015	351.3	39.2	
2016	1,055.0	107.1	TR[3] HC[5]
2017	647.0	59.7	HC[5] TR[5]
2018	141.3	11.9	HC[2]
2019	849.6	64.8	HC[2] TR[2]
2020	594.3	41.2	
2021	635.7	40.1	
2022	679.8	39.0	
2023	727.1	37.9	
2024	777.7	36.8	
2025	1,877.1	80.8	TR[1]
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,017.5	32.9	
2029	1,088.3	32.0	
2030	2,133.9	57.0	TR[4]
2031	3,319.6	80.7	TR[3]
2032	1,331.4	29.4	
2033	2,386.4	47.9	TR[5]
2034	1,522.9	27.8	
2035	3,676.0	61.0	TR[2]
2036	89.3	1.3	HR[3]
2037	1,863.1	25.6	
2038	1,992.6	24.9	
2039	2,131.1	24.2	
2040	5,144.2	53.0	TR[1]
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	44,447.2	1,351.4	

Dvelopment 0341526			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.2	-8.3	HC[3]
1997	-65.3	-40.6	HC[3]
1998	-139.7	-78.9	HC[3]
1999	-199.3	-102.2	HC[3]
2000	194.4	90.7	HC[3] TR[3]
2001	71.2	30.2	
2002	76.2	29.4	
2003	81.5	28.6	
2004	87.1	27.8	
2005	93.2	27.0	
2006	99.7	26.2	
2007	106.6	25.5	
2008	8.3	1.8	HC[4] HC[1]
2009	130.8	25.9	HC[4] TR[4] HC[1]
2010	-151.5	-27.2	HC[1]
2011	-271.2	-44.4	HC[1]
2012	473.3	70.4	HC[1] TR[1]
2013	307.2	41.5	
2014	328.5	40.4	
2015	351.3	39.2	
2016	1,055.0	107.1	TR[3] HC[5]
2017	647.0	59.7	HC[5] TR[5]
2018	141.3	11.9	HC[2]
2019	849.6	64.8	HC[2] TR[2]
2020	594.3	41.2	
2021	635.7	40.1	
2022	679.8	39.0	
2023	727.1	37.9	
2024	777.7	36.8	
2025	1,524.8	65.7	TR[4]
2026	889.5	34.8	
2027	951.4	33.9	
2028	2,296.4	74.3	TR[1]
2029	1,088.3	32.0	
2030	1,163.9	31.1	
2031	3,319.6	80.7	TR[3]
2032	1,331.4	29.4	
2033	2,386.4	47.9	TR[5]
2034	1,522.9	27.8	
2035	3,676.0	61.0	TR[2]
2036	89.3	1.3	HR[3]
2037	1,863.1	25.6	
2038	1,992.6	24.9	
2039	2,131.1	24.2	
2040	4,178.8	43.1	TR[4]
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	43,127.8	1,323.9	

Table 5.5 Development Scale and Timing Optimization

Unit: $1,000,000

Dvelopment 0132456			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.0	-8.2	HC[1]
1997	-63.9	-39.7	HC[1]
1998	-136.8	-77.2	HC[1]
1999	-195.0	-100.1	HC[1]
2000	132.2	61.7	HC[1] TR[1]
2001	52.6	22.3	
2002	56.2	21.7	
2003	40.6	14.2	HC[3]
2004	-40.3	-12.8	HC[3]
2005	-154.9	-44.9	HC[3]
2006	-245.4	-64.6	HC[3]
2007	389.8	93.3	HC[3] TR[3]
2008	198.1	43.1	
2009	211.9	41.9	
2010	226.6	40.8	
2011	242.4	39.6	
2012	259.2	38.5	
2013	47.4	6.4	HC[2]
2014	549.8	67.5	HC[2] TR[2]
2015	363.4	40.6	
2016	959.6	97.4	TR[1]
2017	271.2	25.0	HC[4]
2018	723.0	60.7	HC[4] TR[4]
2019	425.1	32.4	HC[5]
2020	856.3	59.4	HC[5] TR[5]
2021	635.7	40.1	
2022	679.8	39.0	
2023	1,939.0	101.0	TR[3]
2024	777.7	36.8	
2025	831.7	35.8	
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,017.5	32.9	
2029	1,088.3	32.0	
2030	2,626.8	70.2	TR[2]
2031	2,809.4	68.3	TR[1]
2032	1,331.4	29.4	
2033	1,423.9	28.6	
2034	2,792.0	51.0	TR[4]
2035	1,628.8	27.0	
2036	675.1	10.2	HR[1] TR[5]
2037	1,863.1	25.6	
2038	5,313.7	66.3	TR[3]
2039	2,131.1	24.2	
2040	2,279.3	23.5	
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	43,887.5	1,314.7	

Dvelopment 0312456			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.2	-8.3	HC[3]
1997	-65.3	-40.6	HC[3]
1998	-139.7	-78.9	HC[3]
1999	-199.3	-102.2	HC[3]
2000	194.4	90.7	HC[3] TR[3]
2001	71.2	30.2	
2002	76.2	29.4	
2003	81.5	28.6	
2004	87.1	27.8	
2005	71.3	20.7	HC[1]
2006	-17.4	-4.6	HC[1]
2007	-143.8	-34.4	HC[1]
2008	-243.1	-52.9	HC[1]
2009	364.0	72.0	HC[1] TR[1]
2010	226.6	40.8	
2011	242.4	39.6	
2012	259.2	38.5	
2013	47.4	6.4	HC[2]
2014	549.8	67.5	HC[2] TR[2]
2015	363.4	40.6	
2016	1,145.8	116.3	TR[3]
2017	271.2	25.0	HC[4]
2018	723.0	60.7	HC[4] TR[4]
2019	425.1	32.4	HC[5]
2020	856.3	59.4	HC[5] TR[5]
2021	635.7	40.1	
2022	679.8	39.0	
2023	727.1	37.9	
2024	777.7	36.8	
2025	1,877.1	80.8	TR[1]
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,017.5	32.9	
2029	1,088.3	32.0	
2030	2,626.8	70.2	TR[2]
2031	3,319.6	80.7	TR[3]
2032	1,331.4	29.4	
2033	1,423.9	28.6	
2034	2,792.0	51.0	TR[4]
2035	1,628.8	27.0	
2036	1,266.8	19.1	HR[3] TR[5]
2037	1,863.1	25.6	
2038	1,992.6	24.9	
2039	2,131.1	24.2	
2040	5,144.2	53.0	TR[1]
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	44,444.5	1,351.5	

Dvelopment 0341256			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.2	-8.3	HC[3]
1997	-65.3	-40.6	HC[3]
1998	-139.7	-78.9	HC[3]
1999	-199.3	-102.2	HC[3]
2000	194.4	90.7	HC[3] TR[3]
2001	71.2	30.2	
2002	76.2	29.4	
2003	81.5	28.6	
2004	87.1	27.8	
2005	93.2	27.0	
2006	99.7	26.2	
2007	106.6	25.5	
2008	8.3	1.8	HC[1] HC[4]
2009	130.8	25.9	HC[1] HC[4] TR[4]
2010	-151.5	-27.2	HC[1]
2011	-271.2	-44.4	HC[1]
2012	473.3	70.4	HC[1] TR[1]
2013	307.2	41.5	
2014	328.5	40.4	
2015	351.3	39.2	
2016	851.6	86.5	HC[2] TR[3]
2017	711.8	65.7	HC[2] TR[2]
2018	486.5	40.8	
2019	425.1	32.4	HC[5]
2020	856.3	59.4	HC[5] TR[5]
2021	635.7	40.1	
2022	679.8	39.0	
2023	727.1	37.9	
2024	777.7	36.8	
2025	1,524.8	65.7	TR[4]
2026	889.5	34.8	
2027	951.4	33.9	
2028	2,296.4	74.3	TR[1]
2029	1,088.3	32.0	
2030	1,163.9	31.1	
2031	3,319.6	80.7	TR[3]
2032	1,331.4	29.4	
2033	3,213.6	64.6	TR[2]
2034	1,522.9	27.8	
2035	1,628.8	27.0	
2036	1,266.8	19.1	HR[3] TR[5]
2037	1,863.1	25.6	
2038	1,992.6	24.9	
2039	2,131.1	24.2	
2040	4,178.8	43.1	TR[4]
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	43,129.3	1,324.4	

Dvelopment 0345126			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.2	-8.3	HC[3]
1997	-65.3	-40.6	HC[3]
1998	-139.7	-78.9	HC[3]
1999	-199.3	-102.2	HC[3]
2000	194.4	90.7	HC[3] TR[3]
2001	71.2	30.2	
2002	76.2	29.4	
2003	81.5	28.6	
2004	87.1	27.8	
2005	93.2	27.0	
2006	99.7	26.2	
2007	106.6	25.5	
2008	35.0	7.6	HC[4]
2009	274.0	54.2	HC[4] TR[4]
2010	154.8	27.8	
2011	77.2	12.6	HC[1] HC[5]
2012	177.1	26.3	HC[1] HC[5] TR[5]
2013	-161.7	-21.8	HC[1]
2014	-306.5	-37.7	HC[1]
2015	606.1	67.7	HC[1] TR[1]
2016	1,161.8	118.0	TR[3]
2017	432.9	40.0	
2018	141.3	11.9	HC[2]
2019	849.6	64.8	HC[2] TR[2]
2020	594.3	41.2	
2021	635.7	40.1	
2022	679.8	39.0	
2023	727.1	37.9	
2024	777.7	36.8	
2025	1,524.8	65.7	TR[4]
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,705.3	55.2	TR[5]
2029	1,088.3	32.0	
2030	1,163.9	31.1	
2031	4,884.2	118.7	TR[3] TR[1]
2032	1,331.4	29.4	
2033	1,423.9	28.6	
2034	1,522.9	27.8	
2035	3,676.0	61.0	TR[2]
2036	89.3	1.3	HR[3]
2037	1,863.1	25.6	
2038	1,992.6	24.9	
2039	2,131.1	24.2	
2040	4,178.8	43.1	TR[4]
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	42,711.0	1,303.9	

Table 5.5 Development Scale and Timing Optimization

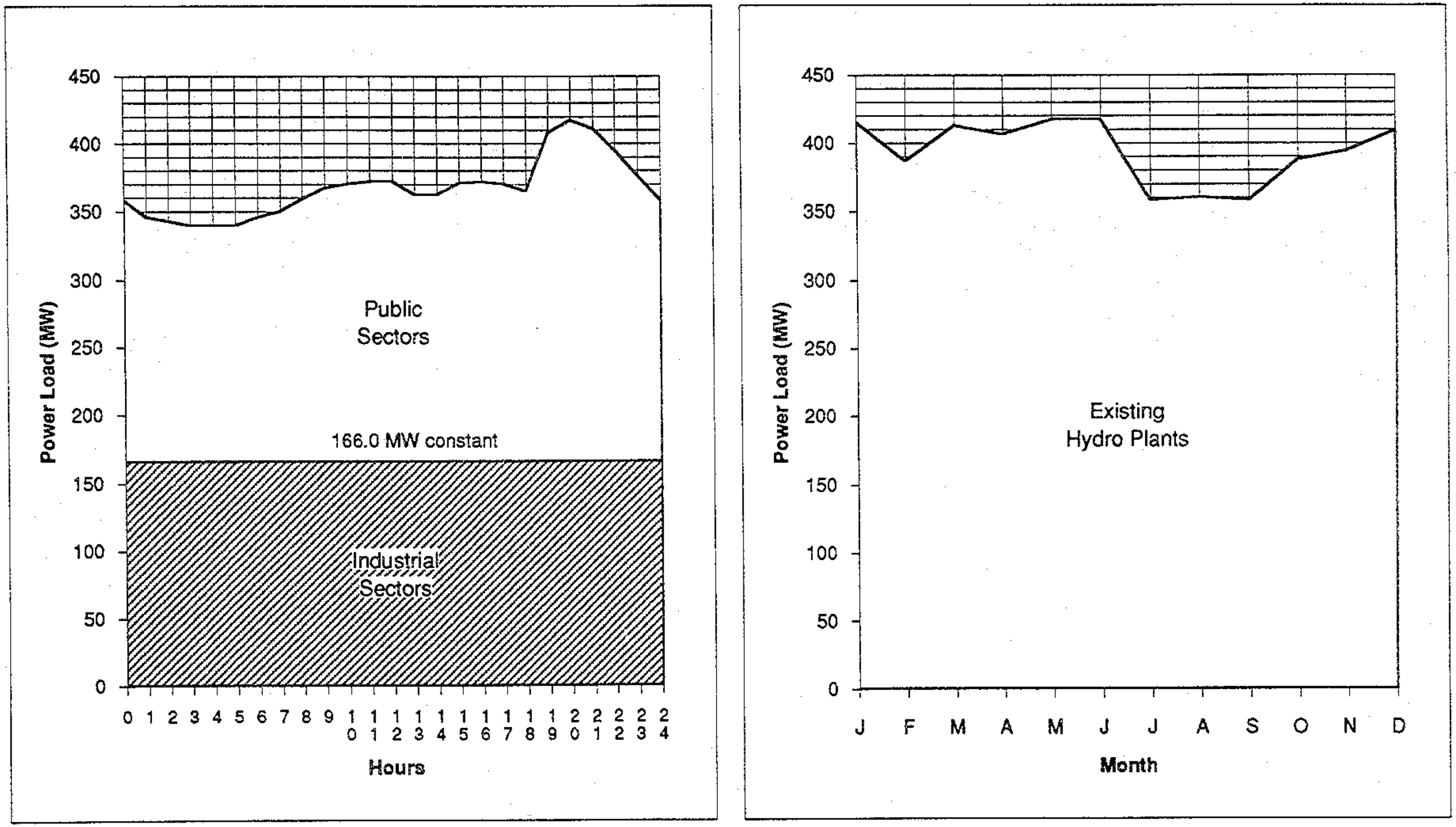
Unit: $1,000,000

Dvelopment 0134256			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.0	-8.2	HC[1]
1997	-63.9	-39.7	HC[1]
1998	-136.8	-77.2	HC[1]
1999	-195.0	-100.1	HC[1]
2000	132.2	61.7	HC[1] TR[1]
2001	52.6	22.3	
2002	56.2	21.7	
2003	40.6	14.2	HC[3]
2004	-40.3	-12.8	HC[3]
2005	-154.9	-44.9	HC[3]
2006	-245.4	-64.6	HC[3]
2007	389.8	93.3	HC[3] TR[3]
2008	198.1	43.1	
2009	211.9	41.9	
2010	226.6	40.8	
2011	242.4	39.6	
2012	259.2	38.5	
2013	166.8	22.5	HC[4]
2014	509.3	62.6	HC[4] TR[4]
2015	351.3	39.2	
2016	665.5	67.6	HC[2] TR[1]
2017	711.8	65.7	HC[2] TR[2]
2018	486.5	40.8	
2019	425.1	32.4	HC[5]
2020	856.3	59.4	HC[5] TR[5]
2021	635.7	40.1	
2022	679.8	39.0	
2023	1,939.0	101.0	TR[3]
2024	777.7	36.8	
2025	831.7	35.8	
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,017.5	32.9	
2029	1,088.3	32.0	
2030	2,133.9	57.0	TR[4]
2031	2,809.4	68.3	TR[1]
2032	1,331.4	29.4	
2033	3,213.6	64.6	TR[2]
2034	1,522.9	27.8	
2035	1,628.8	27.0	
2036	675.1	10.2	HR[1] TR[5]
2037	1,863.1	25.6	
2038	5,313.7	66.3	TR[3]
2039	2,131.1	24.2	
2040	2,279.3	23.5	
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	43,891.7	1,315.1	

Dvelopment 0314256			
Year	Bare(B-C)	PV(B-C)	Notes
1993	0.0	0.0	
1994	0.0	0.0	
1995	0.0	0.0	
1996	-12.2	-8.3	HC[3]
1997	-65.3	-40.6	HC[3]
1998	-139.7	-78.9	HC[3]
1999	-199.3	-102.2	HC[3]
2000	194.4	90.7	HC[3] TR[3]
2001	71.2	30.2	
2002	76.2	29.4	
2003	81.5	28.6	
2004	87.1	27.8	
2005	71.3	20.7	HC[1]
2006	-17.4	-4.6	HC[1]
2007	-143.8	-34.4	HC[1]
2008	-243.1	-52.9	HC[1]
2009	364.0	72.0	HC[1] TR[1]
2010	226.6	40.8	
2011	242.4	39.6	
2012	259.2	38.5	
2013	166.8	22.5	HC[4]
2014	509.3	62.6	HC[4] TR[4]
2015	351.3	39.2	
2016	851.6	86.5	HC[2] TR[3]
2017	711.8	65.7	HC[2] TR[2]
2018	486.5	40.8	
2019	425.1	32.4	HC[5]
2020	856.3	59.4	HC[5] TR[5]
2021	635.7	40.1	
2022	679.8	39.0	
2023	727.1	37.9	
2024	777.7	36.8	
2025	1,877.1	80.8	TR[1]
2026	889.5	34.8	
2027	951.4	33.9	
2028	1,017.5	32.9	
2029	1,088.3	32.0	
2030	2,133.9	57.0	TR[4]
2031	3,319.6	80.7	TR[3]
2032	1,331.4	29.4	
2033	3,213.6	64.6	TR[2]
2034	1,522.9	27.8	
2035	1,628.8	27.0	
2036	1,266.8	19.1	HR[3] TR[5]
2037	1,863.1	25.6	
2038	1,992.6	24.9	
2039	2,131.1	24.2	
2040	5,144.2	53.0	TR[1]
2041	2,437.8	22.8	
2042	2,607.2	22.2	
Sum	44,448.7	1,351.8	

- HC: Construction of hydro plant - HR: Replacement of hydro plant
- TR: Replacement / construction of thermal plant

[0] Present System
[1] Memvé Elé 1 (FSL=392.0 m, MOL=336.0 m, Q=225 m3/s)
[2] Memvé Elé 2 (FSL=392.0 m, MOL=336.0 m, Q=225 m3/s)
[3] Nachtigal I
[4] Nachtigal II
[5] Nachtigal III
[6] Dummy



(a) Daily Load Pattern in May 1993

(b) Yearly Peak Load Pattern in 1993

Fig. 5.1 Peak Load Patterns

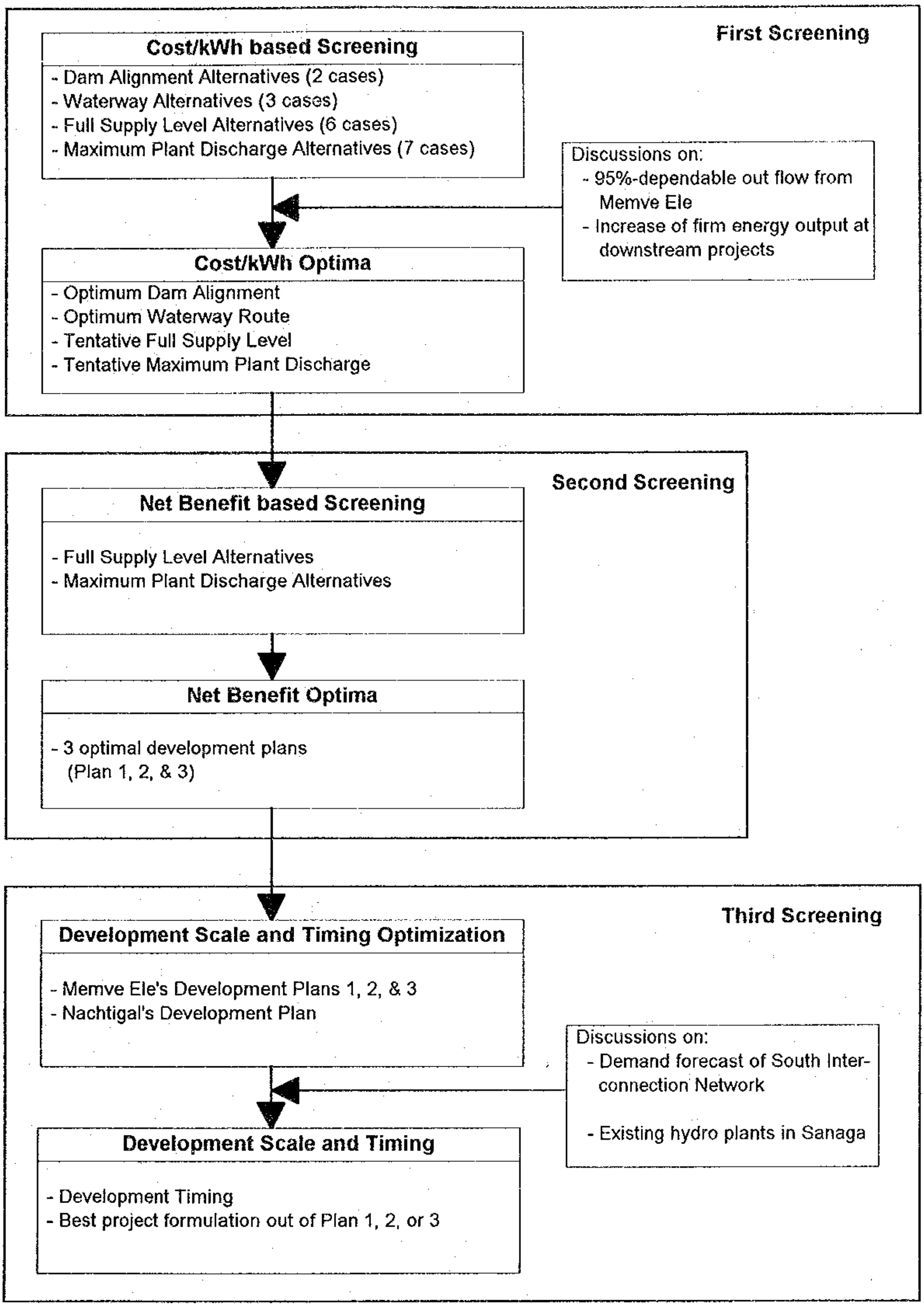


Fig. 5.2 Flow of Project Formulation

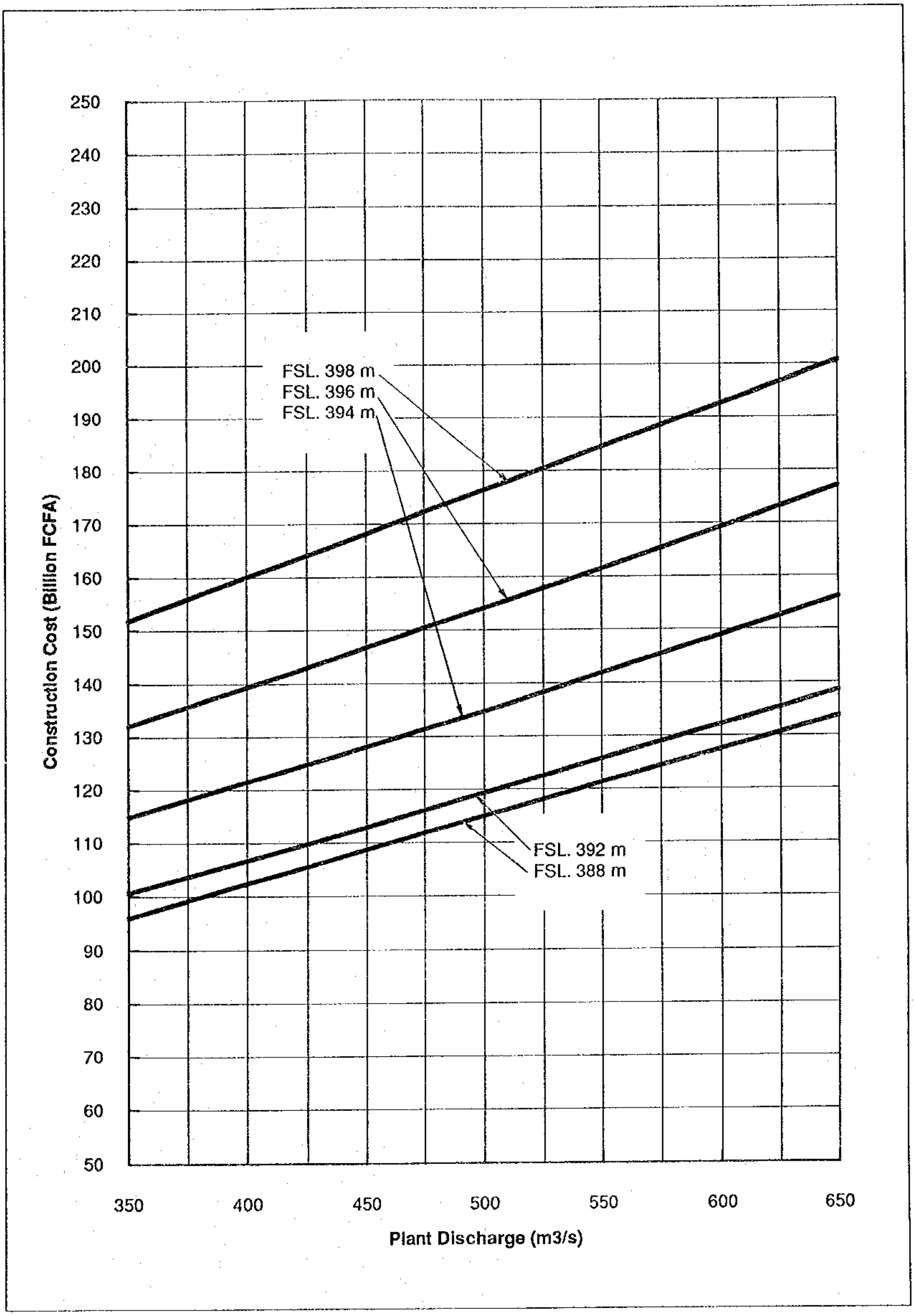


Fig. 5.3 Project Cost Curves

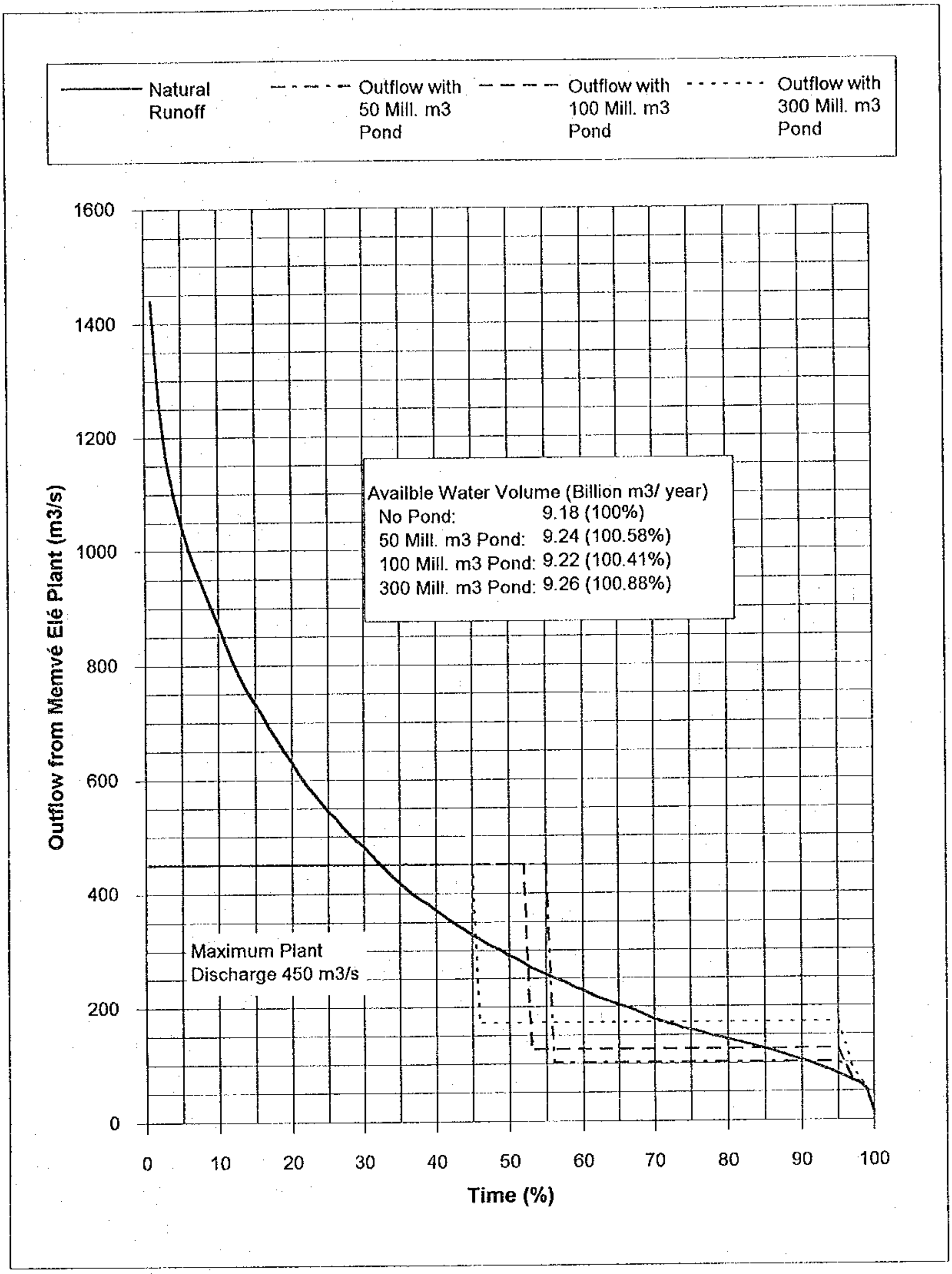


Fig. 5.4 Duration Curves of Outflow from Memvé Elé Plant

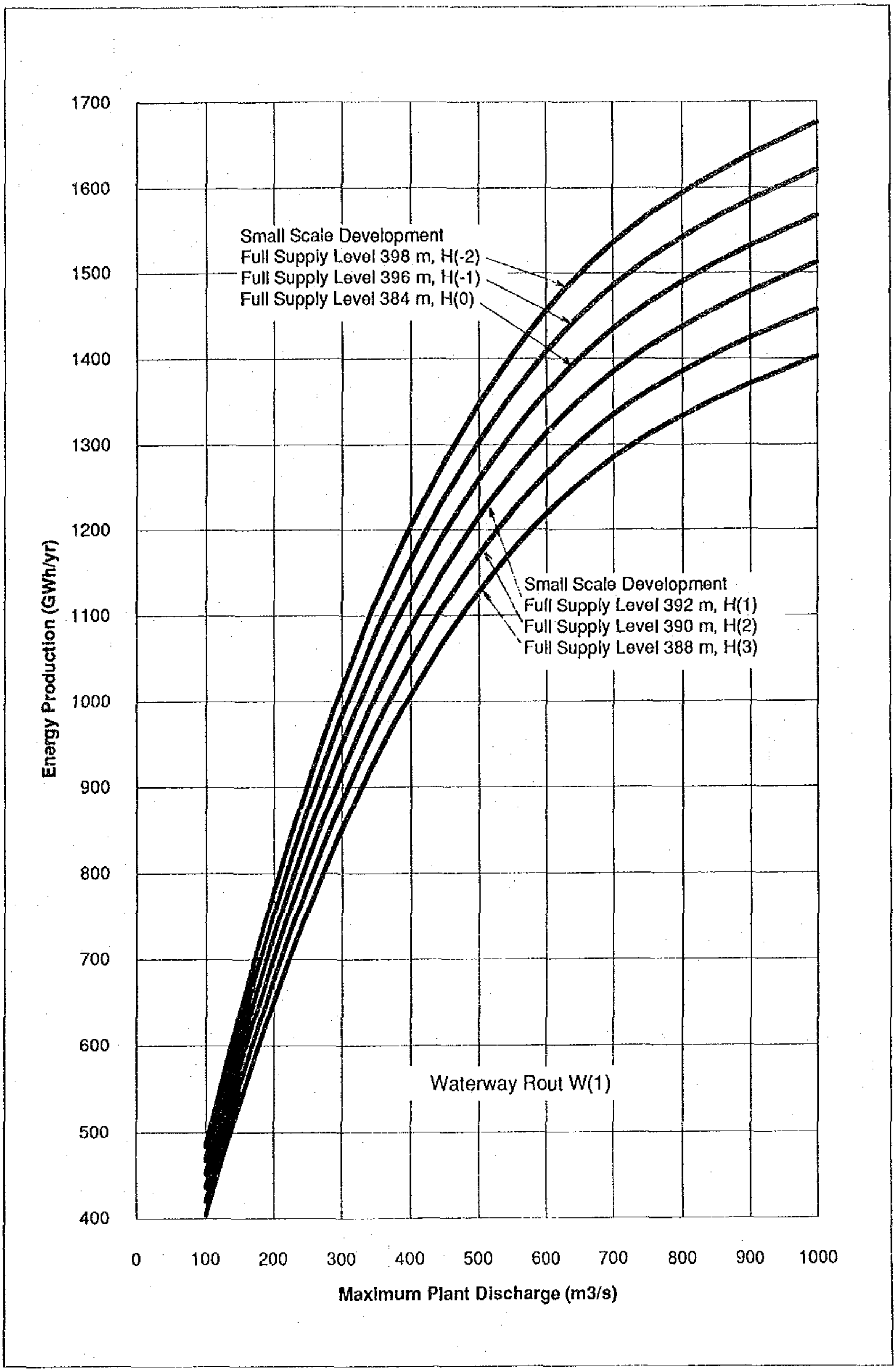


Fig. 5.5 Possible Energy Production

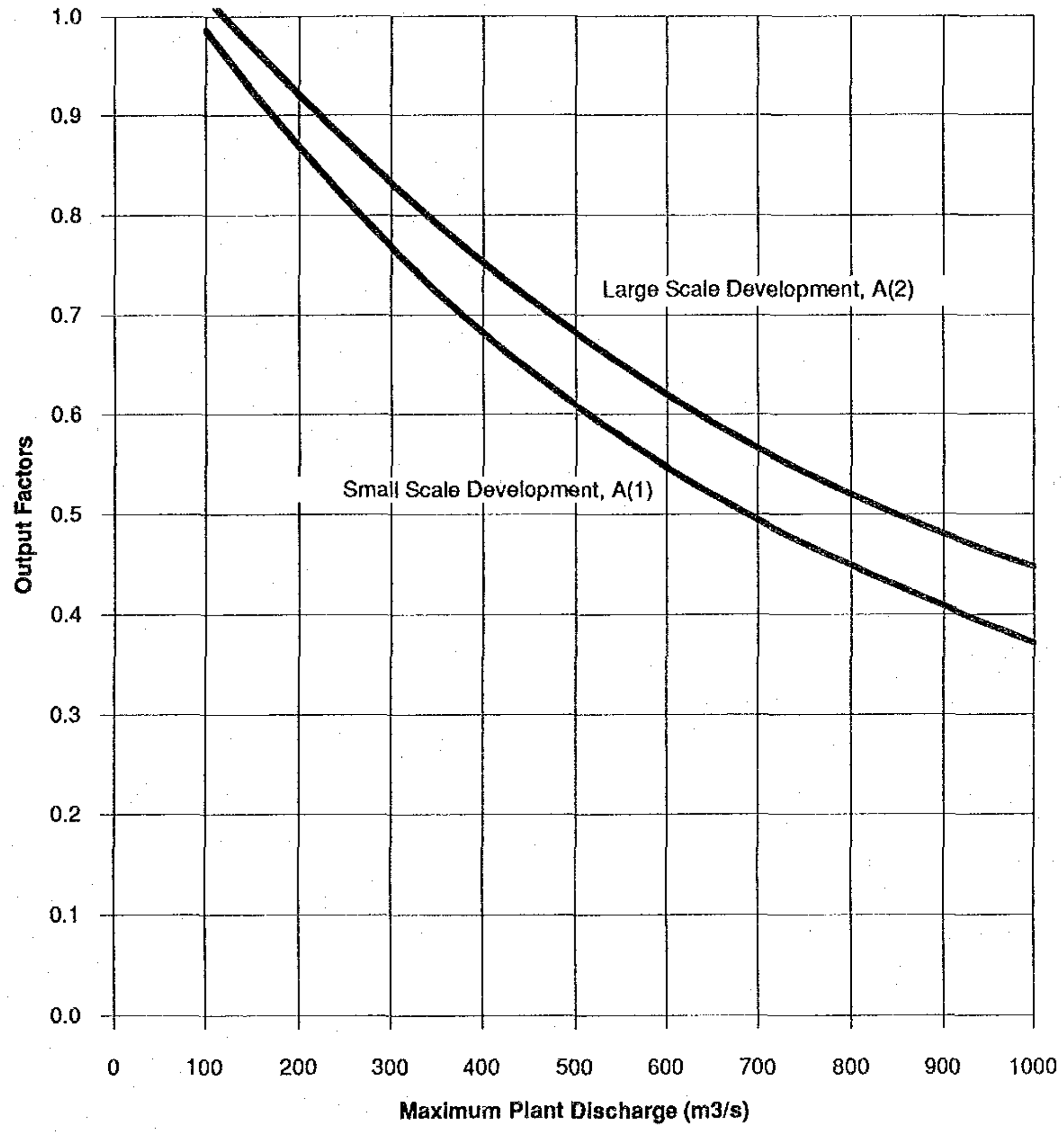
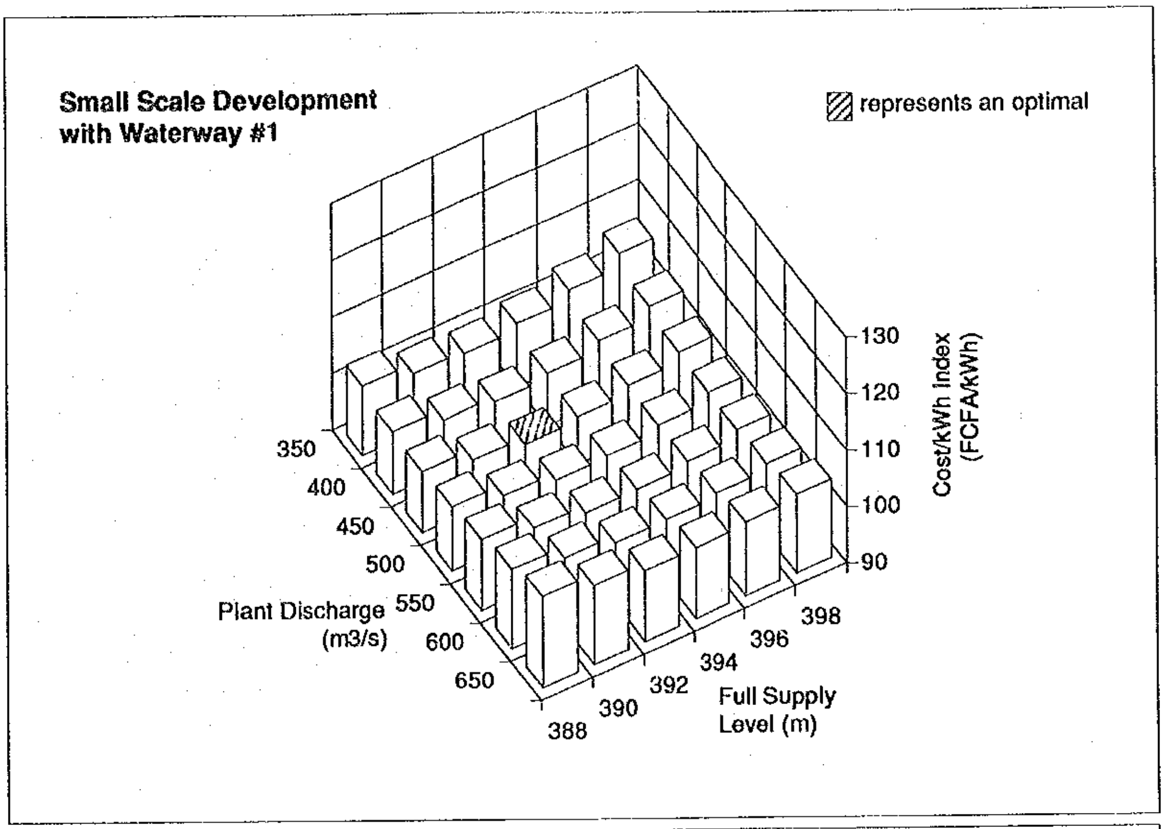


Fig. 5.6 Output Factors



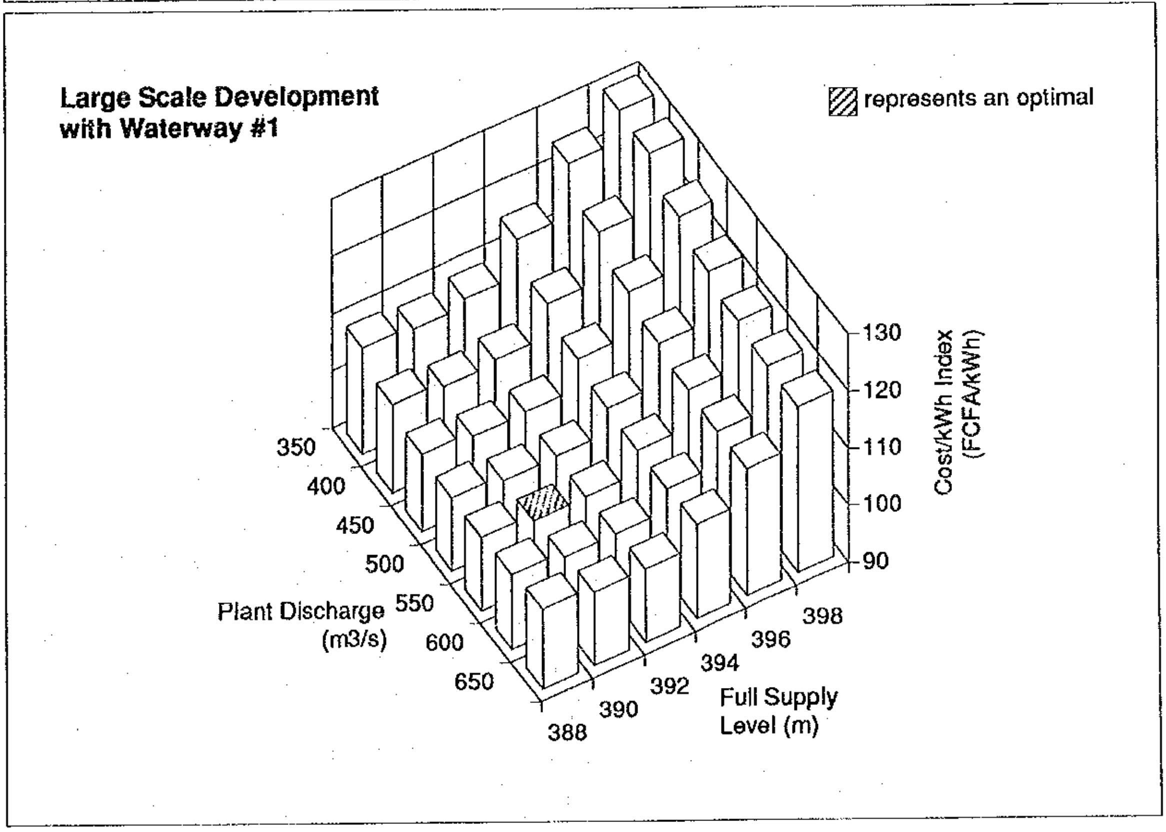
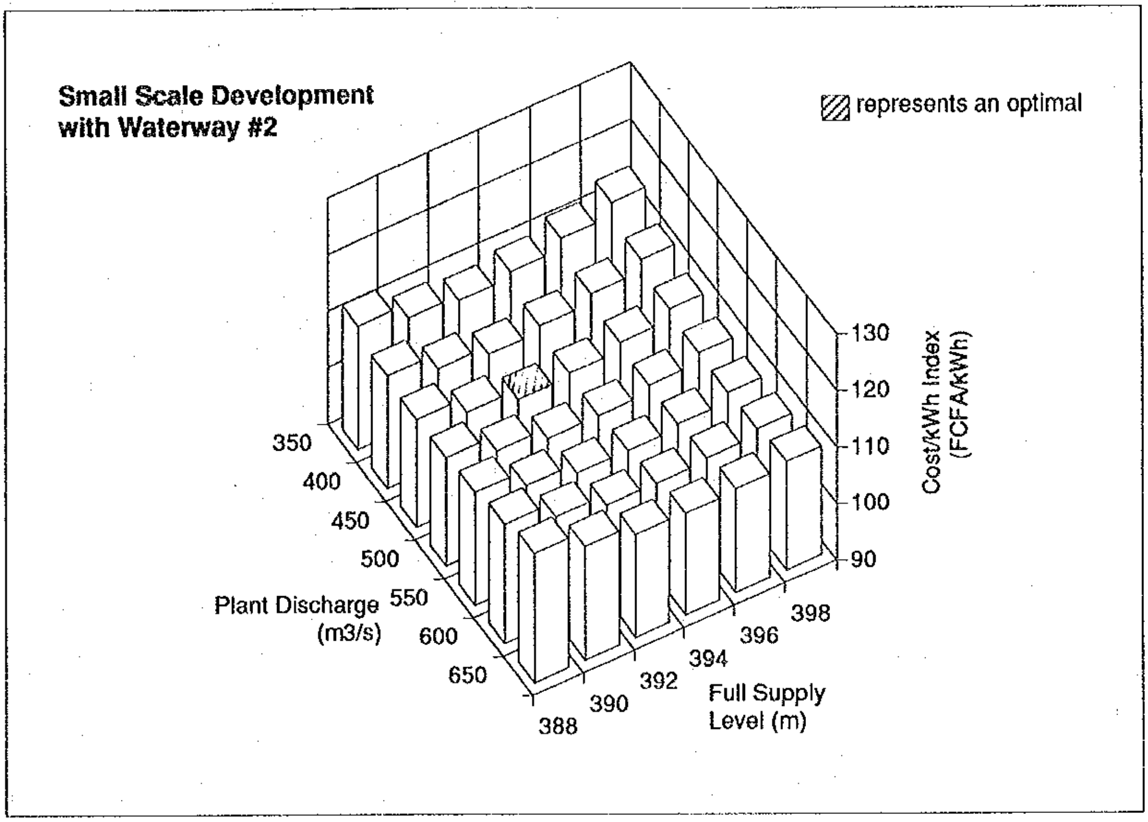


Fig. 5.7 Comparison of Cost/kWh (Waterway Case 1)



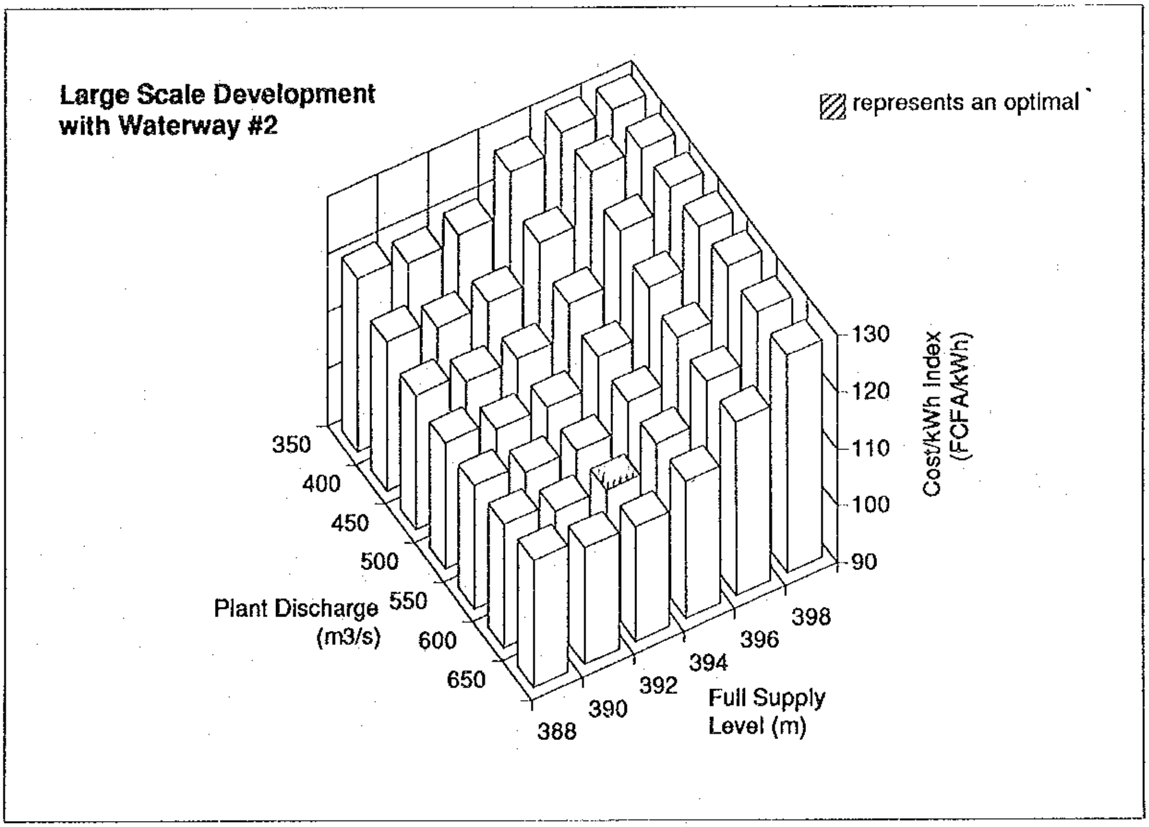


Fig. 5.7 Comparison of Cost/kWh (Waterway Case 2)

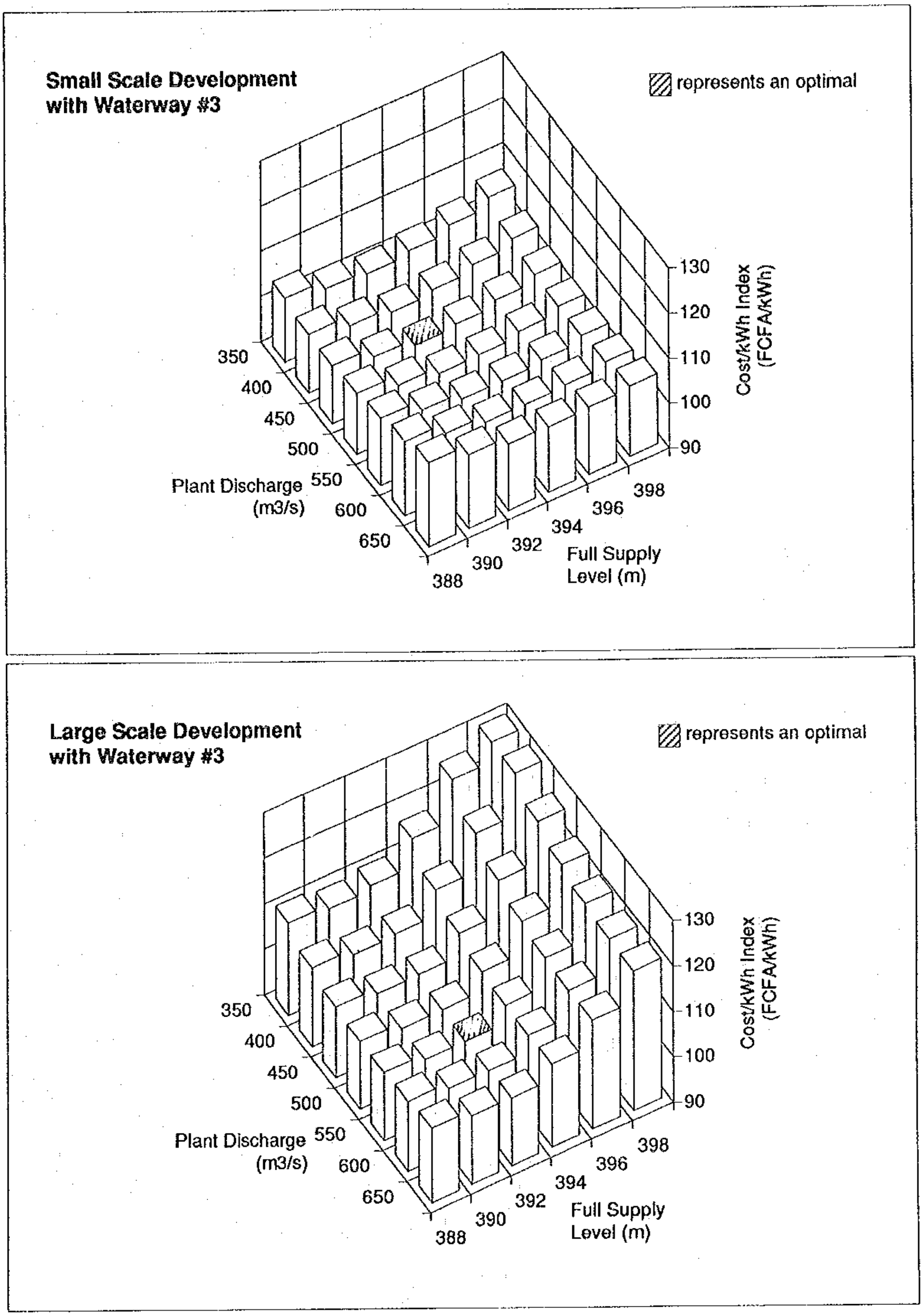
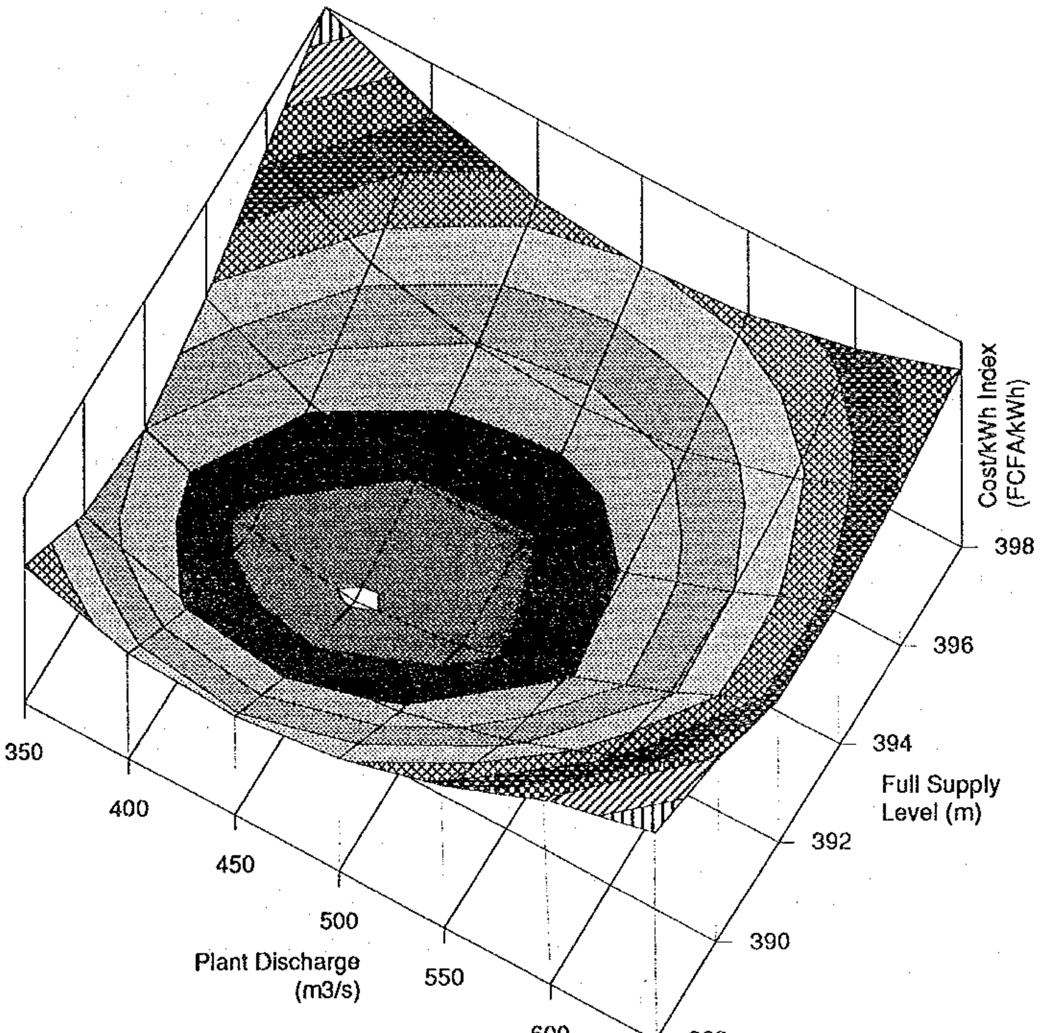


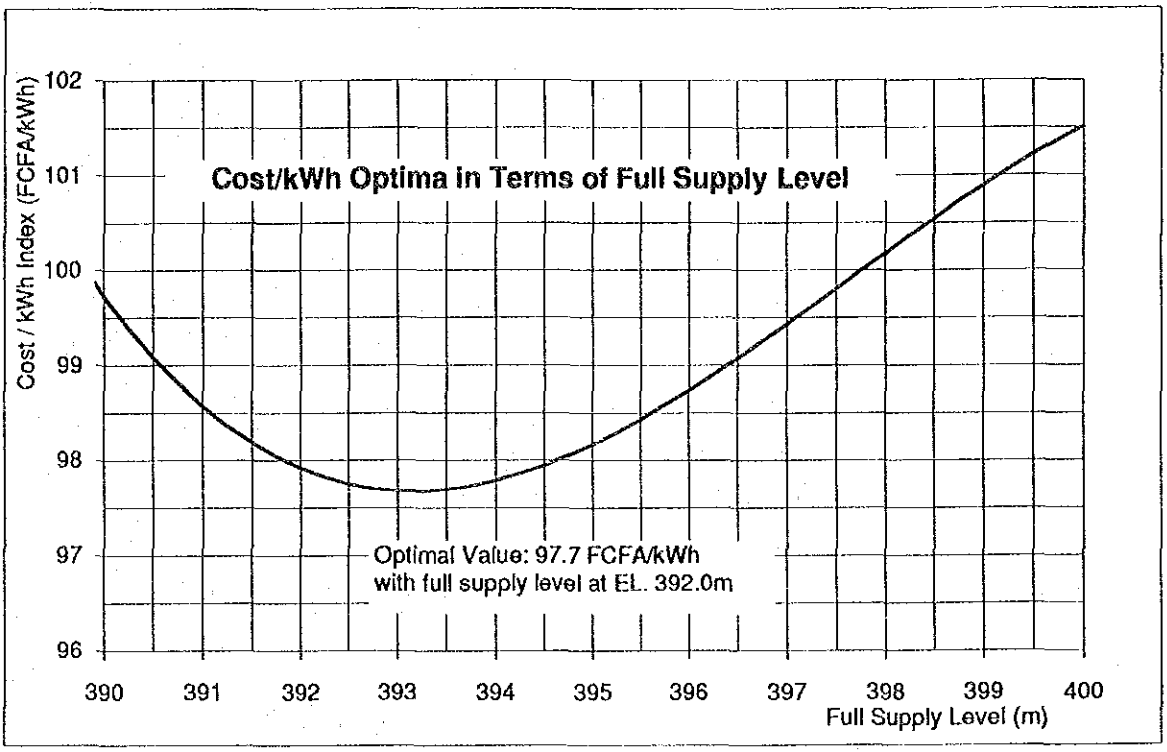
Fig. 5.7 Comparison of Cost/kWh (Waterway Case 3)

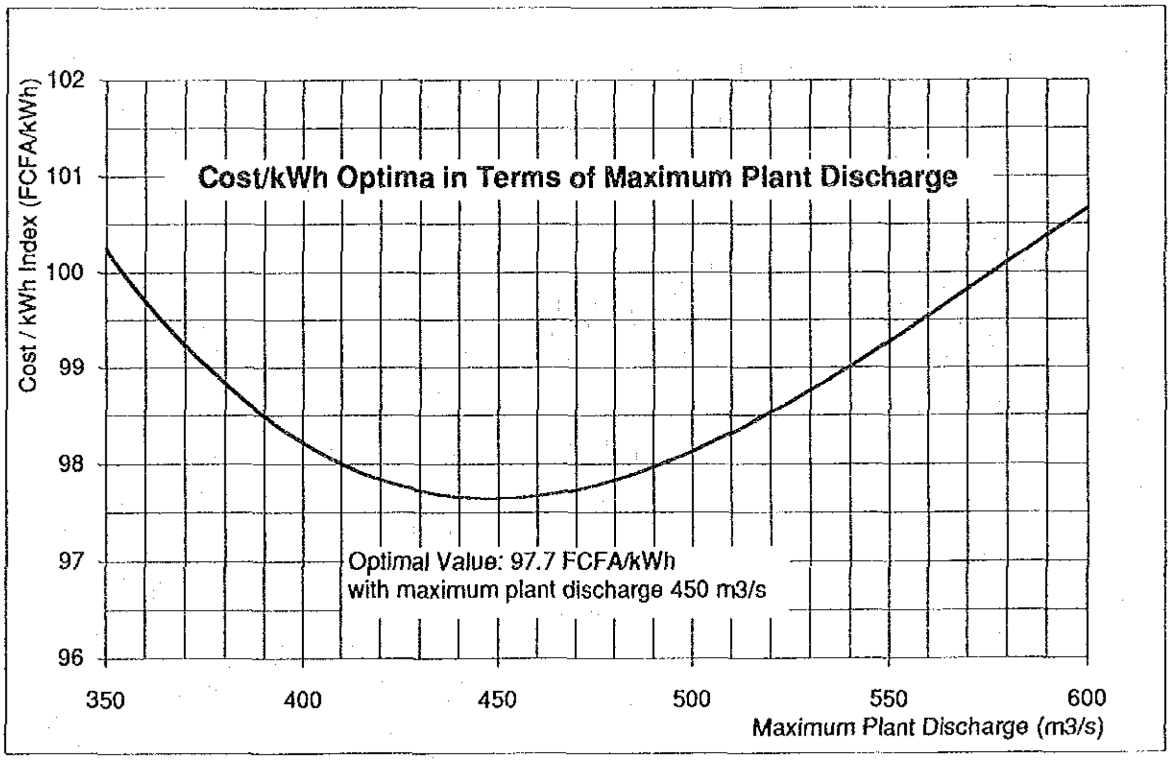
Small Scale Development with Waterway #1



Optimal Cost/kWh: 97.7 FCFA/kWh
Maximum Plant Discharge: 450 m3/s
Dam Crest Elevation: EL. 395.0 m
Full Supply Level: EL. 392.0 m
Waterway Case 1 (High head scheme equipped with headrace channel, headpond, penstocks, powerhouse, and tailrace tunnels)

Fig. 5.8 Cost/kWh Optima (1)





Both series of Cost/kWh optima based on Small Development with Waterway Case 1.

Fig. 5.8 Cost/kWh Optima (2)

B-C_OPT.XLS

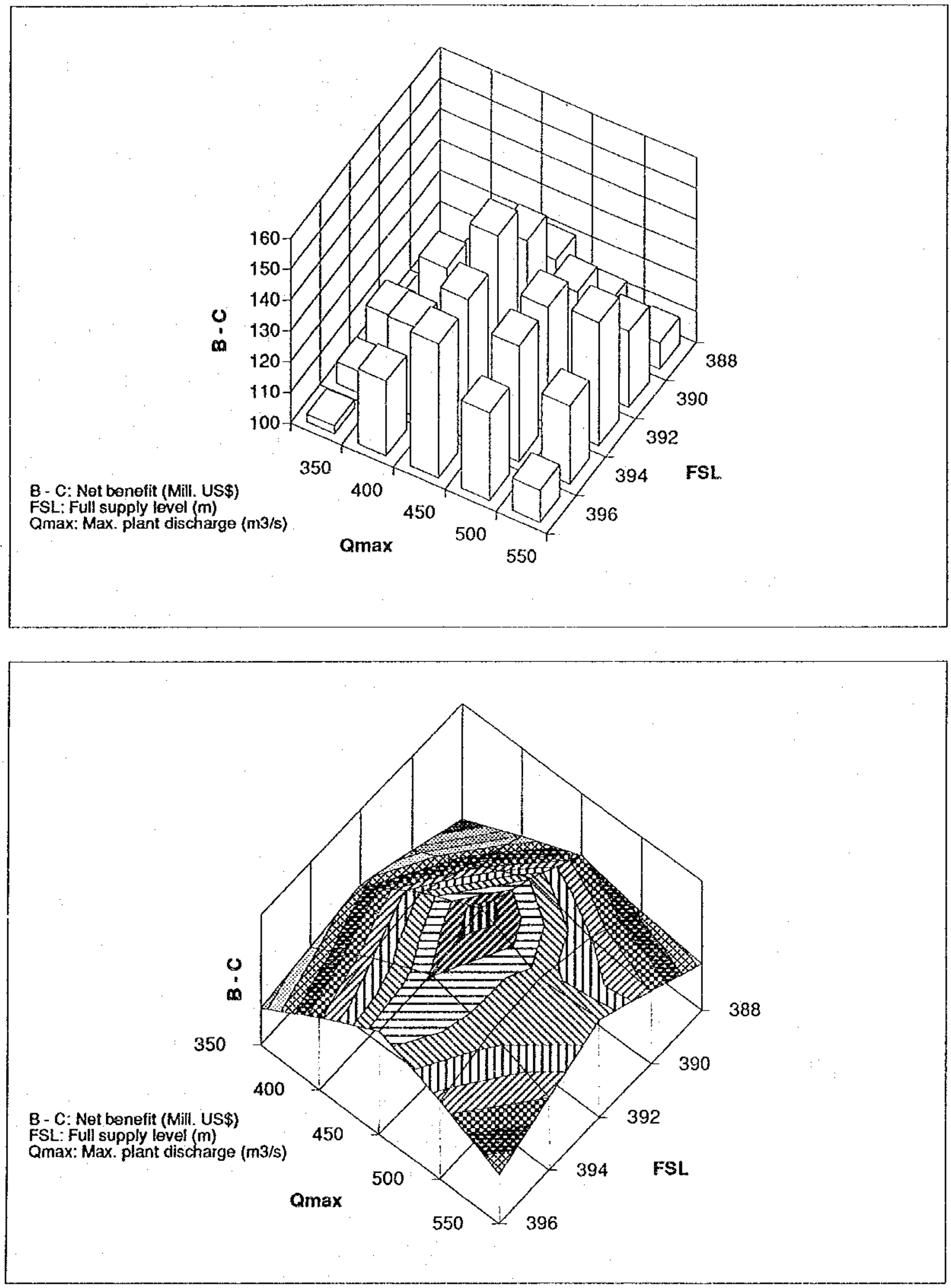
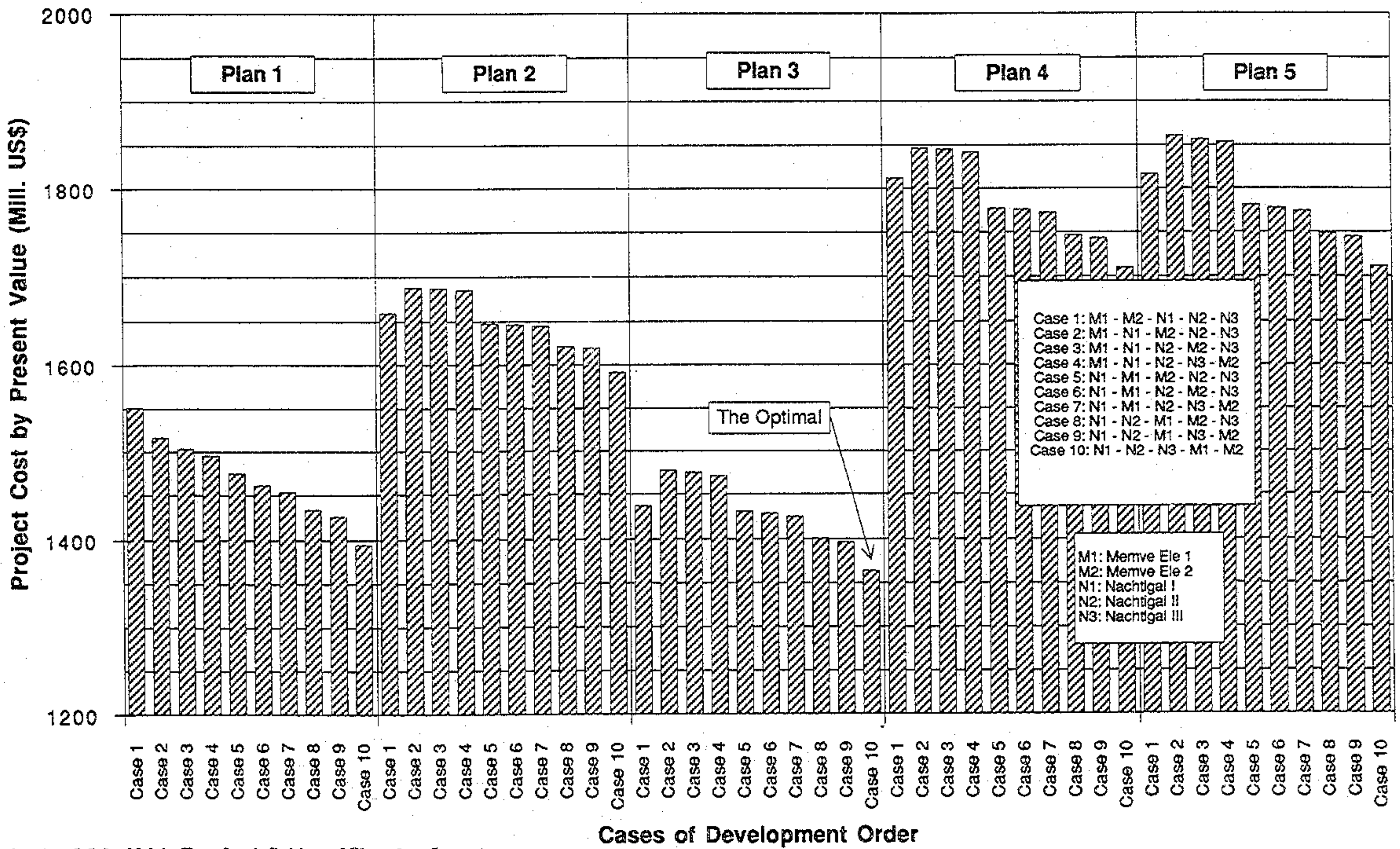
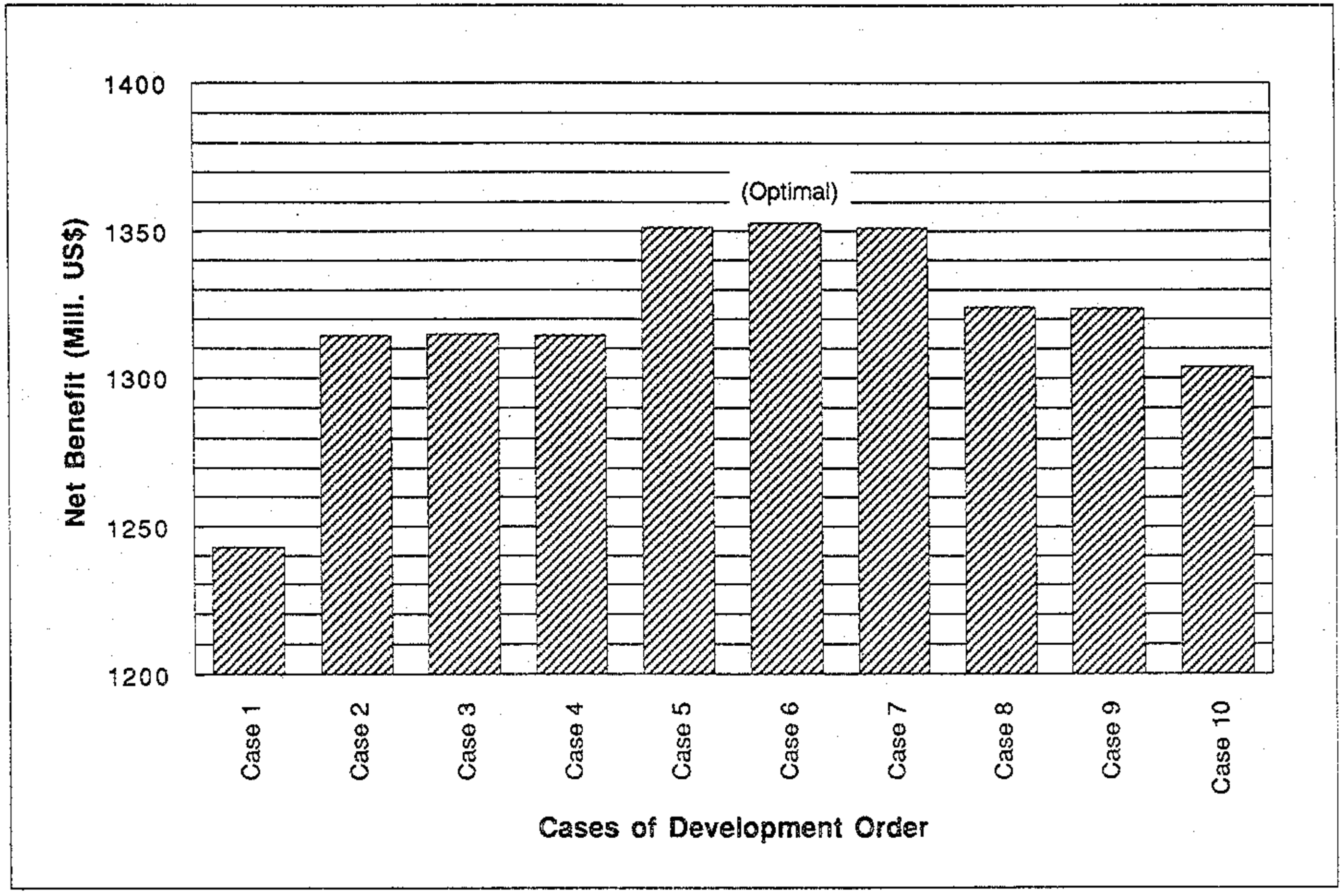


Fig. 5.9 Net Benefit Optima



See Section 5.5.3 of Main Text for definition of Plans 1 to 5.

Fig. 5.10 Least Cost Based DST Optimization



Case 1: M1 - M2 - N1 - N2 - N3
Case 2: M1 - N1 - M2 - N2 - N3
Case 3: M1 - N1 - N2 - M2 - N3
Case 4: M1 - N1 - N2 - N3 - M2
Case 5: N1 - M1 - M2 - N2 - N3
Case 6: N1 - M1 - N2 - M2 - N3 (Optimal)
Case 7: N1 - M1 - N2 - N3 - M2
Case 8: N1 - N2 - M1 - M2 - N3
Case 9: N1 - N2 - M1 - N3 - M2
Case 10: N1 - N2 - N3 - M1 - M2

M1: Memve Ele 1
M2: Memve Ele 2
N1: Nachtigal I
N2: Nachtigal II
N3: Nachtigal III

Full Supply Level	Maximum Plant Discharge		
	Q=400 m3/s	Q=450 m3/s	Q=500 m3/s
FSL. 390 m	-	Plan 1	
FSL. 392 m	Plan 2	Plan 3	Plan 4
FSL. 394 m	-	Plan 5	

Fig. 5.11 Net Benefit Based DST Optimization (Plan 3)

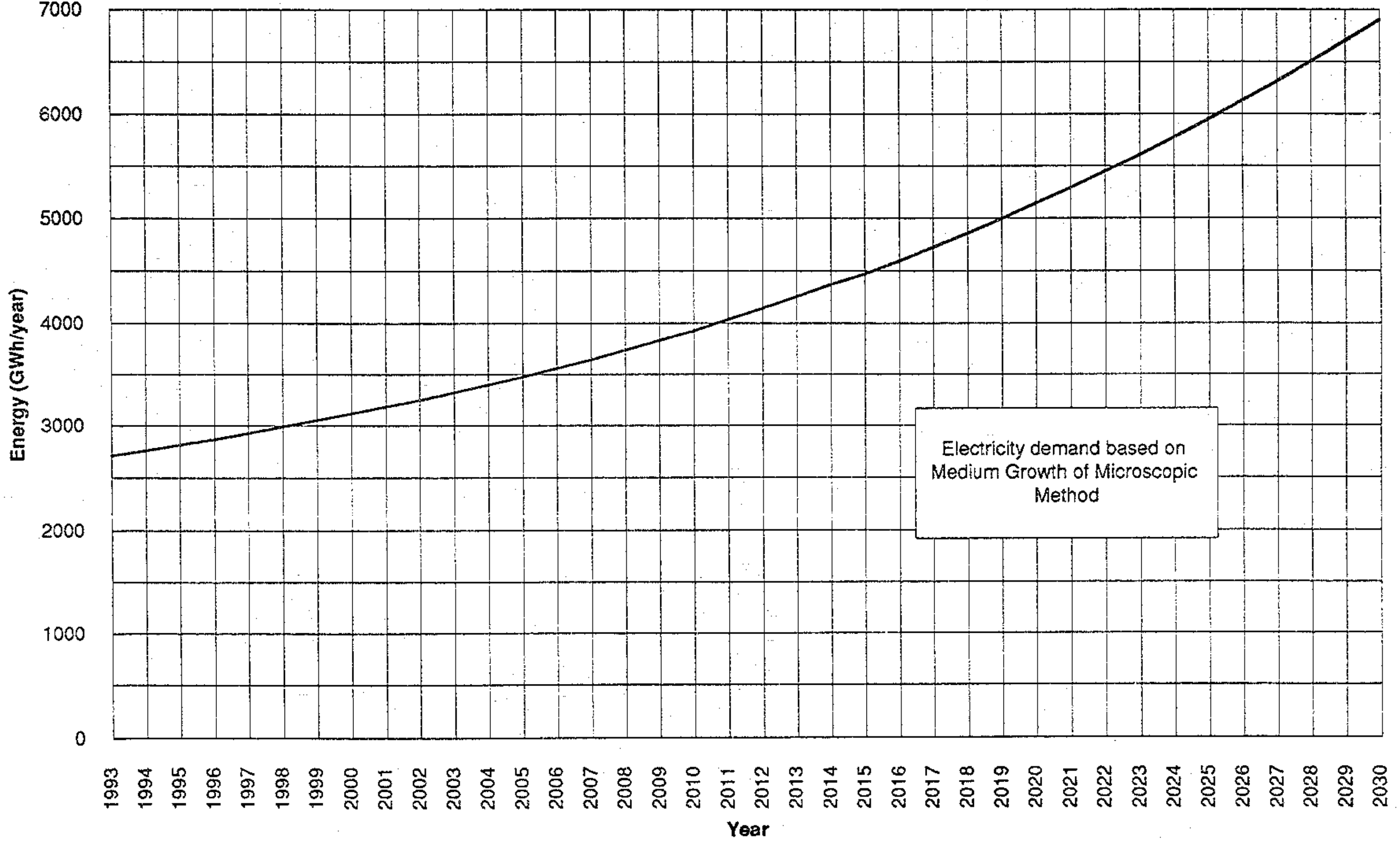


Fig. 5.12 Electricity Demand and Supply (1)

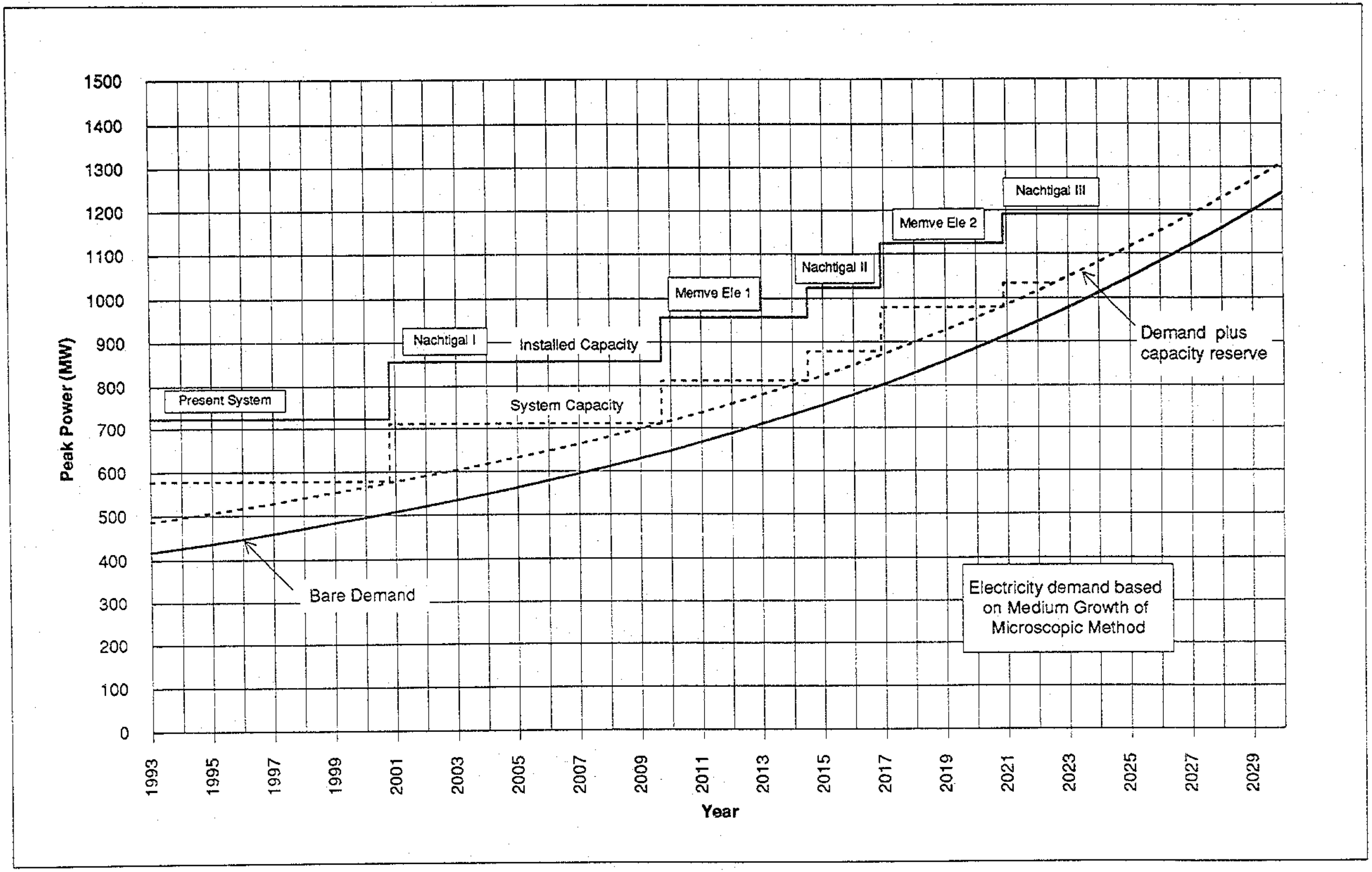


Fig. 5.12 Electricity Demand and Supply (2)

VI. BASIC DESIGN

6.1 Introduction

This chapter describes the basic design concepts and principal features of the main structures of the Memvé Elé Project. The design discussed here is, however, of a feasibility study level mainly to achieve a realistic estimate of construction cost for the project.

Through the comparison and optimization study of project development scale described in the preceding Chapter 5, Plan Formulation, the following basic dimensions have been worked out for the project:

(1) Full Supply Level (FSL): EL. 392.0 m
(2) Minimum Operating Level (MOL): EL. 391.5 m
(3) Total installed capacity: 201.2 MW (50.3 MW x 4 units)
(4) Maximum plant discharge: 450 m3/sec
(5) Tail water level for the maximum plant discharge: EL. 336.0 m.

The project layout is shown in Figs. 6.2 and 6.3.

6.2 Main Civil Structures

6.2.1 River Diversion

Multi-stage river diversion by cofferdams will be applied for the purpose of diverting river flow during the period of the construction works of the main dam. The river diversion will be carried out at dry and low flow seasons (January - March). First stage cofferdams will be provided near the left abutment for construction of the dam and spillway section. Second stage cofferdams be on the islands, and third stage cofferdams be near the right abutment. Fig. 6.4 shows the coffer dam layout and typical section.

The recorded maximum flood with a peak discharge of 2,110 m3/sec was adopted as the design flood discharge for the diversion scheme. As the proposed dam has a length of 1,850 m and runs on flat islands, rivers and creeks, it is difficult to obtain exact rating curves of the rivers and creeks. The crest elevation of the cofferdam was assumed to be set at EL. 385 m from the limited hydrological data and the topography. It is therefore requested that further hydrological survey should be made in the detailed design stage to clarify this uncertainty.

The cofferdams are of dumped rockfill dams with an upstream inclined core. The embankment volume in each stage is as follows:

First stage cofferdams:	38,000 m3
Second stage cofferdams:	21,000 m3
Third stage cofferdams:	13,000 m3
Total:	72,000 m3

6.2.2 Main Dam

(1) Dam axis

Taking the geological conditions and the topographic conditions into consideration, two dam axes are proposed as given in Fig.6.1. The dam axis shown in purple on Fig. 6.1 is for the small scale dam plan, and that in red is for the large scale dam plan. Figs.6.3 and 6.5 depict the plan and profile of the small scale dam closing only the Ntem by adopting a homogeneous earthfill type, which is conceived to be one of promising dam types, whilst the large scale dam closes the Ntem, and its tributaries, the Ndjo' o and the Biwome.

Construction costs at two sites were compared by the earthfill type to select the optimal damsite as described in the preceding chapter. The small scale dam axis closing only the Ntem is selected as the optimal damsite of the Memvé Elé Project.

(2) Dam type

The topography and geology at the proposed damsite will allow the construction of either concrete gravity dam or fill type dam. However, the dam has a length of 1.85 km and the height is 20 m at maximum but mostly less than 10 m.

During the field investigation, borrow areas for the impervious materials were found in enough quantity near the damsite, resulting in the low construction cost of the earthfill dam. But, the rock quarries near the dam site is limited in quantity. Coarse concrete aggregate and filter material will be produced from quarry rocks.

The geological condition for the dam foundation is good at the left abutment, the river beds and the islands, but comes into question at the right abutment. The assumed rock line at the right abutment is lower than the riverbed and inclines towered the abutment direction, resulting in the thick overburden.

The earthfill dam is selected as the most suitable type for the Memvé Elé Project due to the following reasons:

- (i) Suitability for the construction of low dam with a long crest.
- (ii) Construction materials available.
- (iii) Poor geological aspect at the right abutment.
- (iv) Requirements of the foundation treatment are less intensive.

(3) Dam crest elevation

As demonstrated in Chapter 5, the proposed reservoir has FSL at EL. 392 m. In accordance with the *Design Criteria for Dams in the Ministry of Construction*, Japan, the crest elevation of dam should be design to be safe against the flood discharge, water wave by wind or earthquake and other allowance. The height of concrete dams can be determined from the table below, depending on existence of spillway gates. In case of embankment dams, one meter shall be added to the maximum value obtained from the table.

Existence of spillway gates	**Crest elevation of dam in m**		
Yes	Hm+hw+he+0.5	(hw+he<1.5	Hn+2)
	Hd+hw+0.5	(hw<0.5	Hd+1)
No	Hn+hw+he	(hw+he<2	Hn+2)
	Hd+hw	(hw<1	Hd+1)

where Hn: Normal high water level
Hd: Flood water level
hw: Wave height due to wind
he: Wave height due to earthquake

For the preliminary design of embankment dam in the Memvé Elé project, the dam crest is determined at EL. 395 m by adding a freeboard of 3 meters to FSL. 392 m. The proposed dam' s design is shown in Figs. 6.3 and 6.5.

(4) Zoning

The final output for the design of the main dam is shown in Fig. 6.5. The homogeneous type of dam must be provided with drains to prevent phreatic line from extending to the downstream slope. The layout of drains shall be determined according to the height of dams, pore pressure, amount of seepage and available material. The height of the proposed dam will be 20 m at the maximum section. Sloped and horizontal drains shown in Fig. 6.5 are mostly used to lower phreatic line in this scale of dams.

The embankment volume in each zone is as follows:

1) Impervious zone:	673,200 m3
2) Filter:	84,800 m3
3) Transition:	49,300 m3
4) Riprap:	75,900 m3
Total:	883,200 m3

(5) Foundation treatment

Grouting works will be carried out along the dam axis. Two rows of curtain grouting adopt 1.0 m spacing, and hole intervals in a row is 3.0 m. As to the right abutment where the rock line is lower than the river bed, a blanket by impervious materials may be applied for the upstream face of abutment.

6.2.3 Spillway

Two spillway sections are provided on the dam as shown in Figs. 6.5 and 6.6. One is located near the intake facilities at the left abutment. The spillway is of a movable weir for discharging flood and sedimentation. The location of spillway and the intake was determined to ensure a smooth inflow of water into the headrace channel and removal of sedimentation in front of the intake through the spillway gates and the sand flush gate. The other is called as an auxiliary spillway located near the right abutment. The spillway is of fixed weir having the crest elevation at EL.392.0 m same as the full supply level to release and control small inflow with keeping the water level constant at the full supply level. The location of spillways were selected by taking into account the following items:

1) A good quality of rock mass as bedrock with less deposits sediment.
2) A site where no potential scouring on the river bed and at the river bank.
3) A site where the river diversion work during construction is easy.
4) A section capable of allowing the flow of the design flood discharge even considering sedimentation in future should be deposited.

The spillway is designed to discharge the 10,000-year probable flood with a peak discharge of 3,450 m3/sec with a reservoir water level of EL. 392 m not counting the retention effect of the reservoir. The spillway near the left abutment consists of 1) five control gates being 11 m wide as discharge facilities for flood control, inspection, repair and maintenance, and 2) a sluice way as discharge facilities for sand removal from the entrance of the intake.

The spillway sections are provided with 11 m wide, 10.5 m high and 5 sets radial gates. The sill elevation of spillway gates is set at EL. 382 m. The sluice way to reduce the amount of stream bedload entering the intake is of 11 m wide and 13.5 m high radial gate. The sill elevation of sluice gate is at EL. 379.0 m, 3 m lower than the spillway crest.

A downstream apron and side walls are provided to protect the streambed and bank against erosion. The apron and side walls are of reinforced concrete anchored in rock by grouted anchor bars and have a drainage system beneath the apron.

The auxiliary spillway near the right abutment is of non-gated weir with the crest length of 100 m and piers for spillway bridges. If the inflow exceeds the turbine discharge and the water level becomes higher than FSL. 392.0 m, the auxiliary spillway releases extra water automatically. This guarantees the safety of dam against mal-operation of the spillway gates.

6.2.4 Waterway

(1) General

The waterway for power generation will be composed of an intake, a headrace channel, a head pond, a penstock intake dam, penstock lines, turbines, draft tunnels, access- surge tunnel, tailrace tunnels and a tailrace outlet.

The waterway is arranged in the left bank connecting the intake and the tailrace outlet through a semi-underground powerhouse. The route is selected so as to minimize its length and to gain water head as much as possible through the Memvé Elé waterfalls and the Gorges du Ntem. Plans and profiles of the waterway is shown in Figs. 6.7 and 6.8..

(2) Intake

The sluice way is provided in front of the intake to protect the headworks from accumulation of stream bedload, the head pond has a function as a desilting basin to catch suspended silt load for preventing turbines from abrasion. The intake structure is shown in Fig. 6.9.

The water level in the Ntem river will be controlled by the spillway and thus the location of intake was selected on the left bank to which a gut (flow line) approaches. The scouring sluice is installed adjacent to the intake.

The front of the intake is aligned with the edge of the natural river without projecting out or being set back from the edge of the river bank. If the intake projects out, it may be damaged by destructive forces during floods. If it is set back, eddies may be created, resulting in the inflow and deposition of suspended sediment contained in the flood water.

The intake sill is set at EL. 386 m which is 4.0 m higher than the crest of spillway to prevent the bedload in the river from entering the intake. Furthermore, a concrete slab provided in front of the intake leads to the sand flush gate.

The intake basin (forebay) is a gradually decreasing approach between the intake and the headrace channel for creating a smooth current of water taken in.

To prevent the inflow of suspended substances such as trash, a screen is installed in front of the intake. The screen consists of essentially flat steel bars placed parallel and space not greater than the smallest fixed opening of the water passage of turbine. The maximum flow velocity is about 0.6 m/sec in front of the screen. The screen has a inclination of one horizontal to three vertical to facilitate cleaning.

Four sets of intake gates with dimensions of 11.0 m wide and 6.5 m high is provided as a shut-off gates for dewatering the headrace channel and the head pond for inspection and maintenance. The gates are of fixed-wheel type operated by hydraulic hoist.

Ordinary type desilting basin is omitted as 1) the river is found to have a small sediment inflow and very low content of suspended load, the head for the power generation is relatively small, and 3) the rotating speed of turbine is low. However, a sand flushing gutter is provided in the bottom of the intake basin between the screen and the gates and led to a manual scouring sluice consisting of a sluice gate 1 m x 1 m and a 2 m dia. tunnel for flushing sand.

Just upstream of the intake gates, there are stoplog slots considering trouble of intake gates. Stoplogs provided for the spillway gates can be applied for this purpose.

(3) Headrace channel

The headrace channel conveys water from the intake to the head pond as shown in Fig. 6.10. The flow capacity of channel is equivalent to the maximum plant discharge 450 m3/sec. The cross section of channel selected is a trapezoid with a bottom width of 15 m and a side slope of 1:2.0 (vertical : horizontal). The longitudinal bottom slope of channel is 1/4,000. The flow velocity is with in the range between the minimum permissible velocity to prevent sedimentation 0.6 to 1.0 m/sec and the maximum velocity 4.0 m/sec. The channel is of concrete lining with a total length of 2.5 km. The plan and typical sections are illustrated in Fig. 6.10.

The headrace channel is aligned toward south-south-west direction, then turns to south-west direction at the one-third distance, runs on a foot of a hill, further turns to west direction at the middle distance and leads to the head pond crossing a ridge which is one of proposed quarry sites. In order to establish reliable foundation of the channel, the abovementioned alignment was determined. However, it is unavoidable to cross the swamp zone with a distance of 300 m at the beginning. Swamp-dozers and geotextile mats will be applied for the construction in the swamp area having low foundation bearing capacity.

Open and underground drains are provided to remove excess water from the ground surface and subsoil. Inspection roads are provided at the both banks of channel.

(4) Head pond

The head pond is to be created by constructing a small dam (penstock intake/dam) located in a swamp near by the Gorges du Ntem. As the headrace channel is rather long and the power plant is subject to large load demand, the pond is designed to have a capacity to keep the plant operation for more than 10 minutes with maximum turbine discharge without inflow from the intake.

The head pond has a function as a desilting basin to prevent Francis turbines from abrasion. Thus, it is recommended that the bottom of head pond be used as a rock quarry to increase the storage/sedimentation capacity.

An inspection road is provided around the pond and side ditches along the road collect rain water from ground and drain outside the pond. Also, access roads to the bottom of head pond will be considered for inspection and removal of sand as required on the long term basis.

(5) Penstock intake dam

The penstock intake dam is a combined type dam, consisting of earthfill dams at the both abutments and a concrete penstock intake structure at the center as shown in Fig. 6.11. The foundation condition is good with its shallow overburden.

Screens are provided at the penstock intake structure to prevent the floating debris in the headrace channel and the head pond from being drawn into the turbines.

Four intake gates of fixed-wheel type are provided at the entrance of the penstock to serve for emergency closure. It is also serve as a shut-off gate for unwatering the penstock and turbines.

Air-entraining vortices decrease turbine efficiency, pull floating debris onto the trashrack, and cause rough turbine operation. The invert elevation of intake is set at EL. 377.0 m to keep a depth more than two times of penstock diameter.

(6) Penstock lines

Four penstock lines connect the head pond with the powerhouse in the shortest distance, with vertical shafts of about 52 m and horizontal tunnels of 42 m. The penstocks are classified into encased steel liners having a diameter of 6.0 - 4.0 m. These are located in tunnels and shafts and fully encased in concrete or encased in a portion of the intake dam. The penstock profile is shown in Fig. 6.11.

(7) Draft tunnels

Four draft tunnels with a diameter of 6.0 m are constructed to connect the draft tubes with the access-surge tunnel. Each two draft tunnel joins just downstream of the access-surge tunnel. The distance between the center of units in the powerhouse and the surge tank is around 70 m.

(8) Access-surge tunnel

The length of tailrace tunnels is about 1.4 km and the velocity in the tunnel is around 3.6 m/sec. Under this hydraulic condition, it is necessary to provide tailrace surge tank/chamber in order to alleviate the water hammer caused by the sudden change of flow condition.

On the other hand, to economically excavate the bottom of the pit-type powerhouse, construction of an access tunnel may be needed. It will later serve as a tailrace surge chamber for Tailrace Tunnel No.2. So, the access-surge tunnel of 7 m wide and 6 m high is planned to connect the bottom of pit and the tailrace tunnels. The portal of tunnel must be above the maximum tail water level to maintain free release to the atmosphere.

An underground surge chamber of vertical shaft type will be separately constructed for the Tailrace Tunnel No. 1.

(9) Tailrace tunnel

Two tailrace tunnels connect the bifurcation just downstream of the surge tanks and the tailrace outlet in a total length of about 1.5 km having a circular section of 9.0 m in diameter.

The maximum discharges through the tunnels are 225 m3/sec each, being equivalent to the maximum discharges in two units operation.

(10) Tailrace outlet

At the end of the tailrace tunnels, a portal structure is provided with an elevated sill EL.334 m to maintain the minimum draft head and to prevent debris from entering into the tunnels as shown in Fig. 6.12. Outlet gates of fixed-wheel type are provided at the outlet structure as shut-off gates for unwatering the tailrace tunnel for inspection and maintenance.

The tailrace outlet bay will be provided downstream of the portal structure to smoothly lead the plant discharge to the Gorges du Ntem. The bay will be 10 m long with the bottom width of 42 m. The tailrace outlet is illustrated in Fig. 6.13.

6.2.5 Power Station

(1) General

The selected power station is located on the left bank of the Gorges du Ntem about 1.5 km downstream of the Memvé Elé waterfalls. The power station consists of a powerhouse and an outdoor switchyard. The powerhouse will house four units of vertical synchronous generators and Francis type hydraulic turbines as shown in Fig. 6.13.

(2) Powerhouse

The powerhouse is a semi-underground type (pit-type) with a reinforced concrete structure and is designed to house four 50 MW generating units. The dimensions are 32 m wide, 120 m long and 60 m high, determined essentially by the size of turbines and generators, the draft head and the area and height required for erecting and installing the generating equipment. The basic arrangement for the equipment and appurtenant structures in the powerhouse is shown in Fig. 6.13.

There is no denying the fact that a cavern powerhouse may be constructed instead of the pit powerhouse. However, the minimum sound rock cover over the cavern is almost same as the cavern width and very critical.

The powerhouse consists of a machine bay an erection bay, a space for a control room, an office, etc. at the tailrace side. The machine bay is divided into two at the longitudinal ends. Each machine bay is 42 m wide and 20 m long, considering the step-wise-development. The erection bay is provided at the middle of powerhouse and is 26 m wide and 29 m long. Beneath the erection bay and between the two machine bays, rock is remained as a rock strut to control the behavior of rock around the powerhouse side walls. The space for control room and office is 46 m wide and 30 m long.

The main units have a space of 25 m between centers to provide an area for installation and arrangement of turbines, its auxiliaries and other electrical equipment. The turbine center is set at EL. 326.5 m, about 7.5 m lower than the minimum tail water level EL. 334 m to secure draft head required.

(3) Outdoor switchyard

The outdoor switchyard is located in the right bank of the Gorges du Ntem and the dimensions of which are planned to be 200 m wide and 120 m long with the ground elevation of EL. 378 m as shown in Fig. 6.14.

6.2.6 Saddle Dam

There is a thin ridge near the existing road at Abem Melongo village at about 3 km distance from Nyabessan village. The top of ridge is about EL. 397 m and there is a spring at the foot of ridge. A saddle dam or blanket may be constructed on the ridge.

The dam will be designed as a homogeneous earthfill type, the upstream and downstream slopes of which are 1:3.0 (vertical : horizontal) and 1:2.5 (vertical : horizontal), respectively, considering the dam height of about 5m. The dam crest is about 300 m long or less and will be used as a relocation road.

6.2.7 Permanent Access Road

The project will require construction of access roads, relocation roads and haul roads. The access roads and relocation roads will be permanent use while the haul roads are for temporary use.

Permanent access roads to the damsite are comprised of the existing road connecting Nyabessan village and Ma'an, and newly constructed access road between Nyabessan village and the damsite and between the damsite and the power station. The existing road requires minor upgrading works for some portions prior to commencement of the construction works. The distance between the branch point at Nyabessan village and the damsite is approximately 1.0 km.

The following permanent access roads will be required for the Project:

From	To	Length (km)	Width (m)
Nyabessan Village	Damsite	1.0	6.0
Damsite	Powerhouse	3.0	6.0

6.3 Hydro-Mechanical Works

The major items of metal works to be supplied and installed in the project will be gates, trashracks, valves, and steel penstock pipes. The following are main features of the structures required for the project:

(1) Spillway gates (with 2 sets of stoplog)

Type:	Radial gate
Number:	5 sets
Dimensions:	11 m wide x 10.5 m high

(2) Sand flush gate

Type: Radial gate
Number: 1 set
Dimensions: 11 m wide x 13.5 m high

(3) Intake trashracks

Type: Fixed screen
Number: 14 sets
Dimensions: 10.0 m wide x 9.0 m high

(4) Intake gate

Type: Fixed-wheel gate
Number: 4 sets
Dimensions: 11 m wide x 6.5 m high

(5) Sluice gate in the intake (with 1 set of stoplog)

Type: Sluice valve
Number: 1 set
Dimensions: 1 m wide x 1 m high

(6) Penstock intake trashrack

Type: Fixed screen
Number: 8 sets
Dimension: 10 m wide x 18 m high

(7) Penstock intake gate (with 1set of stoplog)

Type: Fixed-wheel gate
Number: 4 sets
Dimensions: 6.0 m square

(8) Penstock line

Type: Embedded type
Number: 4 lanes
Dimensions: 6.0 - 4.0 m dia. x 95 m long

(9) Draft tube gate

Type: Slide gate
Number: 1 set
Dimensions: 6 m wide x 6 m high

(10) Tailrace outlet gates

Type:	Fixed-wheel gate
Number:	2 sets
Dimensions:	9 m wide x 9 m high

6.4 Generating Equipment

Basic design conditions of the generating equipment are summarized below:

- High water level of reservoir:	EL. 392.0 m
- Low water level:	EL. 391.5 m
- Maximum plant discharge:	450 m^3/s
- Tail water level for maximum plant discharge:	EL. 336.0 m
- Rated head:	52.3 m.

The layout of four units of generating equipment is determined taking account of the two-stage development. The Francis type turbines are selected because of head and discharge available for each unit turbines taking account of its performance and cost. The type of generators is selected to be the vertical-shaft umbrella type synchronous generator due to its rotational speed and capacities.

The single line diagram will be applied for unit system and high voltage synchronization system as shown in Fig. 6.15. The generator output is to be steeped up with unit transformer with double bus arrangement of 225 kV switchgear in outdoor switchyard. One 3,000 kVA local transformer is also provided for 30 kV local supply.

The principal features of the generating equipment of the Memvé Elé Power Station are outlined as follows:

a) Water turbine

- Number of units:	4 units
- Type:	Vertical shaft Francis
- Rated net head:	52.3 m
- Maximum plant discharge:	450 m^3/s
- Rated output:	251.6 MW for each
- Rated speed:	200 rpm
- Turbine efficiency:	0.895

b) Generator

- Number of units:	4 units

- Type: Three-phase synchronous generator of vertical shaft with static type exciter
- Rated capacity: 55,900 kVA
- Rated voltage: 11 kV
- Rated frequency: 50 Hz
- Rated power factor: 0.9
- Electrical output: 50.3 MW for each
- Generator efficiency: 0.975

c) Main transformer

- Number of transformers: 4 sets
- Type: Outdoor use with forced oil circulation and forced air-cooled
- Rated Capacity: 55,900 kVA
- Rated Voltage Ratio: 11/225 kV
- Rated Frequency: 50 Hz

d) 225 kV SF6 circuit breaker

- Rated voltage: 245 kV
- Rated continuous current: 1,600 A
- Rated rupturing current: 40 kA.

Major auxiliary equipment of the power station includes the following:

- one 200-ton overhead traveling crane with an auxiliary hoist for handling miscellaneous equipment, and
- one diesel engine generator for emergency power supply to auxiliary equipment.

The general layout of the powerhouse is shown in Fig. 6.14. The outdoor switchyard is illustrated in Fig. 6.18.

6.5 Transmission Line and Substation

6.5.1 Conductors and Overhead Earthwires

(1) Size of Conductor

Power conductors to be applied for the project will be Aluminum Conductor Steel Reinforced (ACSR) generally used for high tension transmission lines. The Memvé Elé 225kV transmission line will require double circuits taking account of the maximum output 201MW of the power station and the long transmission line distance.

Maximum Phase current is 450 amperes in case of 201MW output. From the point of corona critical voltage, diameter of the conductor for 225kV should be bigger than 20mm in rainy condition. Accordingly, minimum conductor for the project is ACSR 160 mm2, ACSR Panther in BS code or ACSR Lark in ASTM code.

Considering line voltage regulation and line energy losses on such long transmission line, conductor used for the project will be either ACSR 410 mm2, ACSR Deer (425 mm2) in BS, ACSR Condor (400 mm2) in ASTM or equivalent.

Technical particulars of the conductors are as follows:

Particulars of ACSR		410 mm2	Deer	Condor
Strand	(Al/mm+St/mm)	26/4.5 + 7/3.5	30/4.27 + 7/4.27	54/3.1 + 7/3.1
Section	(Aluminum)	413.4 mm2	429.6 mm2	402.8 mm2
	(Steel)	67.4 mm2	100.2 mm2	52.0 mm2
	(Total)	480.8 mm2	529.8 mm2	454.8 mm2
Diameter	(mm)	28.5	29.89	27.73
Unit weight (kg/m)		1.673	1.973	1.460
Ultimate strength (kg)		13,910	16,210	12,600
Current capacity (A)		840	860	840

(2) Size of Overhead Earthwire

Two overhead earthwires will be provided above the power conductors with the shield angle of 0 degrees for effective protection from lightning strokes to the power conductors. The earthwires will be of a galvanized steel stranded wire with a section of 70 mm2. Size of the wire are selected from its mechanical strength for keeping the sufficient shielding and for preventing reverse flashover from the earthwires to power conductors in the midspan so that sags of the wires should be less than 80% of that of power conductors under the condition of still air and the minimum temperature.

Technical particulars of the wire are as follows:

Nominal section: 70 mm2
Stranding: 7/3.5 mm
Calculated section: 67.35 mm2
Outside diameter: 10.5 mm
Unit weight: 0.533 kg/m
Ultimate tensile strength: 5,580 kg

(3) Sags of Poser Conductor and Overhead Earthwire

Tensions of power conductor and overhead earthwire vary under air temperature, their temperature due to current flow and wind pressure on them. Sags of power conductor and overhead earthwire are computed so that their tensions will not exceed their specified allowable mechanical strengths under any climatic condition.

The maximum tensions are usually limited by safety factors specified for their maximum working tension under the most severe condition and their everyday stress, Every stress of ACSR conductor is assumed to be that occurred on conductor at average conductor temperature in still air.

Sags of power conductor and overhead earthwire are computed under the following conditions referring to the local climatic condition.

(a) Most severe design condition: maximum wind pressure under min temperature
(b) Maximum wind pressure: 480 pa
(c) Maximum conductor temperature: 75 degrees centigrade
    Maximum earthwire temperature: 40 degrees centigrade
    Average conductor temperature: 25 degrees centigrade
    Average earthwire temperature: 25 degrees centigrade
    Minimum conductor temperature: 15 degrees centigrade
    Minimum earthwire temperature: 15 degrees centigrade
(d) Factor of safety
    max. working tension to UTS: more than 2.5
    everyday stress to UTS: more than 5.0
(e) Young's modulus of aluminum: 6,300 kg/mm2
    Young's modulus of steel: 21,000 kg/mm2
(f) Linear expansion coefficient
    aluminum: $23 \times 10^{-6}/°C$
    steel: $1.5 \times 10^{-6}/°C$

Computation of sags and tensions resulted in the maximum working tensions of power conductor and overhead earthwire to be 3,500kg and 1,450kg, respectively.

Maximum and minimum sags of power conductor at equivalent span 400m are as follows:

Span Length (m)	Maximum Sag (m)	Minimum Sag (m)
	Tension = 2,404kg	Tension = 2,789kg
50	0.22	0.19
100	0.87	0.75
200	3.48	3.00
300	7.83	6.75
400	13.92	12.00
500	21.75	18.75
600	31.32	27.00
700	42.63	36.75
800	55.68	48.00
900	70.47	60.75
1,000	87.00	75.00
1,500	195.75	168.75

6.5.2 Insulation

Insulation of the transmission line will be determined on such basic design philosophy that flashover should not be occurred by internally induced abnormal voltages.

(1) Insulator unit

Insulator unit to be employed will be a ball and socket type toughened glass or porcelain standard suspension insulator of 254mm in diameter and 146mm in spacing. Electrical and mechanical characteristics of each insulator unit will be as below:

(a) minimum flashover voltage	:	power frequency: dry:	78 kV
	:	power frequency: wet:	45 kV
	:	50% impulse: positive:	120kV

		:	50% impulse: negative:	125 kV
(b)	minimum withstand voltage	:	power frequency: dry:	70 kV
		:	power frequency: wet:	40 kV
(c)	electromechanical failing load	12,000 kg		

(2) Insulator set

Number of insulator unit per string will be determined so that

(a) withstand voltage for switching surge of an insulator set in wet condition should be higher than the crest value of switching surge induced in the system, and

(b) the power frequency withstand voltage of an insulator set in wet condition should be higher than the effective value of short time abnormal occurred on the line.

Insulator sets will be provided with arcing horns at both line and earth ends for protection of the sets from lightning strokes, for preventing arc cascading over insulator discs and for equalization of electric field charged on each insulator unit on the set. Following are insulation design of sets for solid neutral grounding system in the project.

Nominal system voltage	Vo	225 kV
Highest operating voltage	$V = 1.15Vo$	260 kV
Switching surge	$U = 2.8\ (\sqrt{2}/3)V$	595 kV
Insulation reduction factor	R	1.1
Short duration over-voltage factor	Ov	1.3
Require withstand voltage for		
switching surge	$Uo = U \times R$	645 kV
short duration over-voltage	$Uo' = (V/\sqrt{3})\ r \times Ov$	215 kV
Required Nos. of insulator unit per set	N	13
Withstand voltage of set for		
switching surge	more than U_0	725 kV
short duration over-voltage	more than U_0'	420 kV
Length of insulator set	$Z_0 = n \times 0.146$	1.898 m
Design horn gap	$Z = 0.85Z_0$	1.613 m
Impulse withstand voltage of horn gap	more than U_0	695 kV
Power frequency withstand voltage of horn gap	more than U_0	455 kV

Outline of insulator sets used for the project are illustrated in Fig. 6.16. Double insulator sets will be used for crossing section over major roads, wider rivers, other lines, etc.

(3) Minimum clearance of live parts to towers

Minimum electrical clearances of live parts to earthed structures are determined in insulation coordination. Spatial diagrams as drawn in Fig. 6.17 are generally used for keeping necessary clearance of live parts to earthed materials.

(a) The standard clearance is equivalent to the gap coordinated with lightning impulse flashover voltage of insulator sets. The gap is practically to be more than the value obtained from the experimented formula $L = 1.115\,Z = 0.021$ (m). Since Z is the designed horn gap of insulator set, the necessary clearance for the project is 1,800mm.

(b) The minimum clearance is required should be more than the gap (1,475 mm) coordinated with the minimum require withstand voltage for switching surge of insulator set. The value will be 1,500 mm for the minimum clearance for the transmission line.

(c) The maximum swing angle of insulator set is obtained in relation with horizontal and vertical loads working on insulator set. The horizontal load will be sum of maximum wing loads on insulator set and conductor on the equivalent span of 400 m. While the vertical load is sum of weights of insulator set and conductor. The maximum swing angle of insulator set is therefore calculated to be 38 degrees, say 40 degrees.

6.5.3 Towers

(1) Type of towers

Supports are of self-supporting and broad base galvanized steel lattice type with body and hillside extensions create on concrete foundations.

Towers will be classified into the following types, but other types may be required after field survey and profile design in the next stage.

(a) Type S: applying for tangential positions or angle points up to 2 degrees of horizontal angle deviation, provided with suspension type insulator sets.

(b) Type L: applying for positions of light horizontal angle deviation up to 15 degrees with tension type insulator sets.

(c) Type M: applying for positions of medium horizontal angle deviation up to 30 degrees with tension type insulator sets.

(d) Type H: applying for positions of heavy horizontal angle deviation up to 60 degrees with tension type insulator sets.

(e) Type T: applying for line terminating points and/or positions of heavy horizontal angle deviation up to 60 degrees with tension type insulator sets.

The hillside extensions are applied for each tower leg so that each leg is suited to the original land slope of the tower site and that excessive land cutting around its foundation and land collapse are prevented. General layouts of tower are shown on Fig. 6.17.

(2) Height of towers

Heights of towers are determined in the following practice:

$$H = Gc + Sg + Li + 2He + Hg$$

where, H = total height of standard tower (30.2 m for standard tower)
Gc = necessary ground clearance of the lowest power conductors (7.0 m)
Sg = maximum conductor sag (14.0 m)
Li = length of a suspension insulator set, but nil for tension type towers (2.0 m)
He = vertical spacing of conductor cross-arms (4.2 m)
Hg = vertical spacing between upper conductor cross-arms and overhead earthwire arm (3.0 m)

Towers will be provided with body extensions in a 3m step to the standard height for maintaining necessary ground clearance on various topographical locations besides the hillside extensions above stated.

(3) Design span

Towers will be designed under assumptions of the following basic, wind and weight spans.

Type of Tower		S	T	M	H	T
Basic Design Span	(m)	400	400	400	400	400
Wind Span (normal condition)	(m)	500	500	500	500	500
Wind Span (broken wire condition)	(m)	350	350	350	350	350
Weight Span (normal condition)	(m)	700	700	700	700	700
Weight Span (broken wire condition)	(m)	500	500	500	500	500

Those spans may slightly be modified on the basis of results of field survey and profile design.

(4) Design loads

Following loads will be applied for design of towers.

(a) Wind loads

- on the projected areas of power conductor and overhead earthwire	: 480 pa
- on the projected area of tower structures	: 1,200 pa
- on the projected area of insulator sets	: 720 pa

(b) Maximum working tensions

- power conductors	: 3,500 kg
- overhead earthwires	: 1,450 kg

(c) Vertical loads

- tower structures:	actual weights of tower structures and accessories
- power conductors:	weights of conductors of the specified weight span with accessories
- overhead earthwires:	weights of conductors of the specified weight span with accessories
- erection loads:	such loads as workers' weights on tower members, reaction of temporary backstays during stringing operation, etc.

(d) Horizontal angle effect

- Power conductor & overhead earthwires:
  horizontal component of maximum working tensions of conductors and earthwires due to the specified horizontal angle deviation

(5) Design conditions

(a) Assumed normal loading condition

Following loads are assumed to work simultaneously on a tower.

(i)	vertical loads:	as mentioned above
(ii)	transverse loads:	wind loads and horizontal angle deviation effects
(iii)	longitudinal loads:	wind loads and creation loads for all types of towers but together with maximum working tensions of power conductors and overhead earthwires for their termination for type T tower.

(b) Assumed broken-wire condition

Under the condition, any one power conductor or overhead earthwire will be assumed to be broken at the maximum working tensions besides the loads under the normal condition. In the case of type S, the pull of conductor or earthwire is assumed to be reduced to 70% of the respective specified maximum working tension with the reason that displacement of the suspension insulator set for the broken conductor or suspension hardwares for the broken earthwire will reduce the respective tension.

(c) Factor of safety

Following factor of safety will be assumed for tower design.

(i) more than 1.5 for the synthetic maximum load under the normal loading condition
(ii) more than 1.1 for the synthetic maximum load under the broken-wire condition, but 1.5 for the cross-arms

Those factors of safety will be taken for yield strength of tower steel materials and proved in the tower loading test to be carried out in the manufacturer' s testing station.

(6) Tower foundations

(a) Type of foundations

Standard foundations are of concrete pad and chimney type and are classified into the following types to apply for various soil conditions at each tower site.

Type of Foundation		Ultimate Bearing Capacity (t/m3)	Unit Weight of soil (t/m3)	Angle of Repose (degree)
Light	(L)	60	1.6	30
Medium	(M)	40	1.5	20
Heavy	(H)	20	1.4	10

(b) Design of foundations

Each type of foundations will be designed for resisting compression, uplifting and horizontal forces with the following safety factors.

(i) not less than 2.0 against the maximum working load under the normal condition, and

(ii) not less than 1.5 against the maximum working load under the broken-wire condition.

(7) Tower footing resistance

Published statistics indicate that approximately 95% of the lightning current to transmission lines are less than 100kA and 95% of the discharged current through a tower are not more than 50kA. For preventing the reversed flashover from towers to insulator sets, the footing resistance of towers should be less than 12 ohm obtained from withstand impulse voltage of insulator sets.

To reduce footing resistance, a grounding and will be installed on each foundation stub, and counterpoise earthwires will be added to towers whose resistance is still higher than 12 ohms.