In the subject survey, no faults were identified with the exception of the minor fault with drag in the Caledonia area. However, one portion of the NE-SW trending lineament accompanied by shear zone is possibly a fault with slight displacement.

3.2.5 Siting of Structures in Relation to Geostructure

The relationship of major project structures to the above described geostructural setting is as follows.

Caledonia Dam Site

Caledonia dam is sited on the unnamed minor anticline which plunges upstream of the site. In general, anticline structures easily fissure and crack and hence readily form valleys and rivers. As a result, dams are often situated at such structures.

Rock at the Caledonia dam site is largely hard, compact charnockite with compressive strength of 1,200-1,800kg/cm^2. However, Lugeon testing performed during boring yielded high values. This fact suggests that fissures have formed along the anticlinal axis. As a result, appropriate foundation treatment such as curtain grouting and consolidation grouting must be performed for dam construction.

Requiring particular attention is the need for detailed survey of the apparently consolidated minor fault at the right bank at the site. The purpose of such survey would be to know the direction and to determine whether foundation treatment is necessary, and if so, the most appropriate method. Also, two faults with NW-SE trending and NE-SE trending are estimated at the saddle on the left bank. Weathering extends to deep level, as much as 30m at some points, and foundation treatment is necessary.

Caledonia Headrace Tunnel

The headrace tunnel route from Caledonia dam to Caledonia power station is planned along the St. Clair syncline. As few fissures are present in the syncline structure, it is well suited for tunnel. No special problems are accordingly anticipated in tunnel excavation.

Caledonia Power Station

The site for the Caledonia power station was selected to avoid the anticlinal axis in the vicinity.

Talawakelle Intake Dam

The Talawakelle intake dam site is situated on the minor anticline within the aforedescribed Talawakelle structure bend. This anticline plunges gently downstream of the site. A number of fissures with good continuity were observed along the anticlinal axis. Rock is outcropped for about 300m downstream of the dam site; however, on the upstream side this outcropping abruptly disappears. As weathered rock is thickly distributed on both banks at the site, appropriate excavation and water seepage prevention works will be necessary.

Talawakelle Headrace Tunnel

The main headrace tunnel from Talawakelle intake dam to the Talawakelle power station is approximately 13km long. The route passes through the Talawakelle structure bend and intersects the Belton-Meddecombra anticline and parallel NW-SE trending lineament. Care will be required during construction as the anticline structure and lineaments are areas of heavy cracking. The route subsequently runs parallel to the NE-SW trending lineament, separated by a distance of 400m, and intersects the Pundal Oya syncline. The route then turns northwest and follows the Pundal syncline axis which has formed large-scale, gentle folding. As excavation along this northwest oriented segment of the route is through stable rock of the syncline axis, no special problems in construction are anticipated. Also, the shear zones at NE-SW trending lineaments intersected by this segment of the route are expected to be about 10m wide. However, as outpour of groundwater often occurs at such shear zones, appropriate countermeasures may be required.

Talawakelle Power Station

Talawakelle power station is planned for construction within a broad syncline structure. As almost all excavation is to be within level gneiss (khondalite), no special problems are expected. Bedding is highly stratified, and the danger of rock burst is anticipated to be minor.

Others

In addition to the above structures, a total of 13.5km of 2.2m diameter tunnel is planned for diversion from the Devon Oya to the south, the Nanu Oya in the east, as well as the Pundal and Puna rivers in the north. Of this, the Puna Oya diversion tunnel intersects the Rambota anticline running along the Puna Oya. Weathered zone accompanying fissures occuring along the anticline axis is anticipated to extend to deep level. Water outpour at fissures is possible.

Diversion canals from the Nanu and Devon rivers intersect a minor folding axis. However, as this folding structure is small, no special problems in construction are anticipated.

As discussed above, sites for Project structures have been carefully selected to avoid synclines to the extent possible, which generally exhibit heavy cracking. Although long tunnel segments are envisaged under the Project, tunnel routes intersect large-scale synclines at only two locations. The remainder of tunnel routing is through ground of stable geology, and overall no particular problems are expected in construction.

3.3 Meteorology and Hydrology

3.3.1 Meteorology

Locations of hydrologic and meteorologic stations in the Project area and its vicinity, and periods covered by existing data are as set out in APPENDIX II.

Sri Lanka is an island country situated in the northern Indian Ocean at northern latitudes of 5°55'-9°50' and eastern longitudes of 79°42'-81°53'. The country covers a total area of 65,635km^2 comprised of mountainous regions in the south central portion and lowland area in the north.

Due to Sri Lanka's close proximity to the equator, there is little variation in sunshine or temperature throughout the year; rather, the largest variation occurs in rainfall. The rainfall pattern is determined by fluctuations in the prevailing winds which are affected by the atmospheric pressure nearby.

The climate of Sri Lanka can be broadly divided into the southwest monsoon, the northeast monsoon, and the transition period or thunderstorm season. The southwest monsoon prevails from May to September and the northeast monsoon from December to February, with a transitional thunderstorm season from March to May. Thunderstorms also occur during the transition from the southwest to northeast monsoon from October to November. In Sri Lanka, the seasons are designated as Maha from October to March, and Yala from April to September; Maha corresponds to the northeastern monsoon period and Yala to the southwest monsoon period.

Rainfall distribution varies locally in Maha and Yala season. Rainfall carried by the northeastern monsoon in Maha season originates from low pressure systems and is distributed throughout the country; rainfall carried by the southwestern monsoon in Yala season on the other hand, clearly tends to be concentrated in the southwestern part of the country, and is particularly heavy on the southwestern slopes of the central and southern mountains range from elevations of 600 to 1,200m. Accordingly, annual rainfall in southwestern Sri Lanka is greater than in the north, east and southeast.

There are several climatic classifications used for the climate of Sri Lanka; however, the classification based on rainfall and dividing the country into a Dry Zone, Wet Zone and Intermediate Zone as presented in FIG.3.3-1 is the most widely used. The Project area and catchment area are located in the eastern end of the Wet Zone and thus subject to abundant rainfall.

Long-term meteorological observations have been carried out in Nuwara Eliya (EL.1,896m) and Kandy (EL.477m) and the meteorological patterns of the same are shown in FIG.3.3-2 and 3.3-3, respectively. Both sites are characterized by southwestern and northeastern monsoon rainfall distribution and the number of days on which lightning occurs in the thunderstorm season is also substantial.

The difference in the rainfall patterns for Nuwara Eliya and Kandy are due to the fact that rainfall in Nuwara Eliya is most predominant during the southwestern monsoon versus rainfall in Kandy which is greatest during the northeastern monsoon from October to December. This is due to Kandy's location in the northern part of the central mountain region.

Due to differences in elevation, temperature varies greatly between Nuwara Eliya and Kandy. In Nuwara Eliya average daily maximum temperature varies only slightly from 21.9°C in April to 18.5°C in July, while average daily minimum temperature is 7.7°C in February and 13.3°C in June. According to data for the last 65 years, the maximum temperature recorded was 27.3°C in May 1966 and the minimum temperature was -2.7°C in February 1914.

In Kandy, on the other hand, average daily maximum temperature fluctuates from 31.1°C in March to 27.2°C in July and average daily minimum temperature ranges from 17.9°C in February to 21.4°C in May and June. Based on data for the past 91 years, the maximum temperature recorded was 36.5°C in March 1948 and the minimum was 10.2°C in February 1939.

Relative humidity at both sites is comparatively high, usually exceeding 80%.

Monthly rainfall pattern for the existing Kotmale dam and vicinity is presented in FIG.3.3-4. Long-term average monthly rainfall data over a 39 year period from 1940 to 1978 is used, and indicates a fairly wide variation in rainfall given the relatively limited 600km^2 area.

As mentioned above, the Project area is situated in the eastern edge of the Wet Zone. As can be seen in FIG.3.3-4, rainfall within the Project area is correspondingly greatest at the southwestern sides. The 39 year average for annual rainfall from 1940 to 1978 ranges from 2,048mm at Nawara Eliya to 5,236mm at Watawala. Mean annual rainfall for 19 points in and around the Kotmale catchment is 2,847mm.

3.3.2 Rivers and Daily Discharge

The Kotmale Oya is an upstream tributary of the Mahaweli Ganga which comprises the largest catchment area in Sri Lanka. The name Kotmale applies to that portion of river which flows from the confluence of the Agra and Dambagastalawa rivers at Caledonia down to its conjunction with the Mahaweli Ganga.

The Kotmale Oya originates near Nuwara Eliya, Holton Plane and the maximum elevation of the catchment area is over EL. 2,500m. After flowing past the confluence at Caledonia, the Kotmale flows in a northwesterly direction and is joined by the Nanu Oya at Talawakelle. Near St. Clair Falls, it flows north and is joined by the Pundal and subsequently the Puna Oya, after which it flows west. About 9km south of Gampola it flows into the Mahaweli Ganga.

The catchment area of the Kotmale Oya is 555km^2 at the Morape gauging station. The majority of this area is mountainous, over EL. 1,000m. Although tea estates are numerous, woods and grassland occur at elevations above EL. 1,800m.

The river profile of the Kotmale Oya and right bank tributaries as presented in FIG.3.3-5 shows an average riverbed slope of about 1/90 from the Agra Oya beyond Caledonia to Talawakelle. The slope increases sharply to 1/35 from there to the existing Kotmale dam, especially past Talawakelle where numerous falls occur beginning with St. Clair Falls which has a drop of 90m. The river section is V-shaped to U-shaped. The majority of streams which flow into the Kotmale are also characterized by a steep gradient and there are many waterfalls in the catchment area.

Discharge observations for the Kotmale Oya have been carried out at Caledonia (183.0km^2), Talawakelle (287.2km^2), and Morape (554.57km^2).

Gauging systems at these stations are reliable, and recording with automatic water stage recorder is presently being carried out. Data at the above points are compiled and analyzed under the Hydrological Crash Programme.

Discharge data required for the present Study are those for Kotmale Oya at the proposed Caledonia dam site and the proposed Talawakelle diversion dam site, and for intake sites on Nanu, Pundal, Puna, Devon, etc. rivers which are tributaries of Kotmale Oya. Long term data is available for the Talawakelle site only. If specific discharge ($m^3/s/100km^2$) based on daily discharge for both Caledonia and Talawakelle is compared the specific discharge correlation is about to 1:1. On the basis of these results, Kotmale Oya discharge at the proposed Caledonia dam site will be determined from the catchment area ratio on the basis of discharge at the Talawakelle site for which long-term discharge is available.

In regards to discharge and water stage for tributaries of the Kotmale Oya, the Irrigation Department has started measurement from July 1986 at the request of CECB in response to the Team's recommendation. The available data is, however, still insufficient. Consequently, due to the fact that, rainfall patterns and amount for tributaries (with the exception of Devon Oya) located on the right bank of the Kotmale Oya and the catchment at Talawakelle are relatively similar, and the fact that the Devon Oya catchment is adjacent to the Talawakelle catchment, the discharge for tributaries is calculated from catchment area ratio based on data from the Talawakelle discharge gauging station.

For the period for which there is no data at Talawakelle, data were supplemented using data at Morape, and the daily discharge for the 30 year period from 1951 to 1980 to serve as the base for hydropower development planning was formulated. Data supplementation from Morape is based on a correlation established through HCP as presented in APPENDIX-II.

The 30 year monthly average discharge based on daily discharge is as shown in the following table.

TABLE 3.3-1 30-YEAR MONTHLY MEAN DISCHARGES OF KOTMATE OYA AT TALAWAKELLE (1951-80)

Catchment Area: 297km2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year Mean
Discharge (m^3/s)	11.20	8.18	6.94	9.46	15.13	24.21	24.11	22.20	20.68	24.46	22.85	17.16	17.26
Specific Discharge ($m^3/s/100km^2$)	3.77	2.75	2.34	3.18	5.09	8.15	8.11	7.47	6.96	8.23	7.69	5.77	5.81

A 30-year period daily discharge hydrograph is presented in FIG.3.3-6. Seasonal runoff pattern for the Kotmale Oya as seen from the hydrograph, is characterized by abundant water period from June to August, and discharge recession period from November to March. This pattern is clearly controlled by monsoon rainfall. Discharges from May to September during the southwest monsoon period are generally larger than that from December to February during the northwest monsoon.

The discharges of Kotmale Oya thus have relatively high seasonal variation, and this variation exhibits a certain regular pattern. From this runoff pattern, a reservoir to seasonally regulate river discharge is judged advantageous for hydropower generation.

The specific discharge ($m^3/s/100km^2$) duration curve of the Kotmale Oya at Talawakelle for the 30-year period (1951-80) is presented in FIG.3.3-4. The key values are as follows:

95-day discharge : 6.5 $m^3/s/100km^2$

185-day " : 4.1 "

275-day " : 2.6 "

355-day " : 1.7 "

Average " : 5.8 :

TABLE 3.3-2

1951-80 MONTHLY AVERAGE DISCHARGE OF KOTMALE OYA AT TALAWAKELLE

Discharge Data for 1951-1980

Unit : m³/s

** DMDS0004:1951-80 Kotmale Oya Daily Discharge at Talawakelle(297.2km2). Data from HCP-1 Vol.19 and Vol.5 and Reviced. **

Main Catchment:297.20km2, Trib.Catchment(km2)/Max.Div.(m3/s)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Year
1951	14.5161	12.1071	6.4839	9.4000	7.7419	98.7333	32.4194	17.8387	19.0667	25.3226	28.2667	10.3548	23.4466
1952	15.7742	9.4483	6.2258	13.3667	47.8387	35.1000	24.9032	18.9032	27.2333	26.8065	11.8667	8.9677	20.5820
1953	8.2581	4.7500	9.3548	16.6667	9.6452	16.5667	25.5161	19.7419	22.0000	22.1935	26.7000	17.5806	16.6356
1954	18.5161	14.7857	7.0645	11.0333	10.4516	12.3333	14.4839	28.4194	19.3667	34.0968	17.2000	23.7742	17.6795
1955	23.7097	17.1429	14.0000	17.9000	42.9032	78.7333	40.3548	19.9677	18.7667	19.5161	20.9000	12.2258	27.1836
1956	9.9355	7.3448	8.4194	8.0333	9.2581	53.3667	23.6774	22.2903	20.3000	24.5806	28.5000	15.3871	19.2322
1957	8.9032	6.8929	5.9677	4.5667	10.4516	21.2000	25.4516	13.0323	11.2000	10.9355	26.3667	70.5484	18.0740
1958	25.7419	10.0357	11.3226	9.8667	11.1290	20.5333	20.0323	19.4194	10.6667	23.4194	22.0667	12.3871	16.4438
1959	8.0323	6.0000	4.8710	9.1333	9.9677	49.9000	39.3226	16.7419	15.0333	20.6452	19.1667	12.3871	17.6329
1960	10.0000	14.7931	8.8710	13.0000	12.6129	17.5333	22.4194	25.8710	41.2333	30.9032	31.8333	13.5484	20.1858
1961	8.6452	7.7500	6.3548	7.9333	22.1613	14.5000	15.8065	26.3871	13.8000	12.7742	14.8667	11.7097	13.6137
1962	8.4839	6.6786	5.6452	6.4667	20.1290	11.4667	22.0000	15.4839	26.5667	24.2581	14.9667	10.5806	14.4521
1963	11.5806	8.7143	6.2903	10.4333	8.7097	11.8667	13.9355	12.3548	14.5333	28.2581	20.5000	21.0645	14.0603
1964	12.8065	8.7586	7.2258	6.3333	6.2258	6.5333	15.4516	21.9355	25.3000	12.6452	23.7333	10.3226	13.1038
1965	6.5484	7.0000	5.5161	12.7000	33.1935	20.4333	10.2258	19.5484	12.8333	20.2581	19.2000	16.3548	15.3753
1966	10.0968	6.6786	7.6452	9.5667	7.2903	7.2667	8.7742	9.7742	25.8333	25.7419	18.7667	10.5806	12.3479
1967	8.0000	7.4643	6.9677	6.8333	5.9677	9.2667	14.6774	10.8387	9.4000	32.6452	24.5000	22.1613	13.2822
1968	9.1936	6.0345	5.9677	5.5000	10.0645	12.5667	38.9355	34.6774	28.4667	25.4516	19.0333	12.0968	17.4044
1969	8.3226	6.0357	5.3548	9.8667	15.1935	25.5333	15.0645	10.2258	23.1333	21.7419	13.6333	18.6452	14.4247
1970	15.7419	14.8214	8.2258	11.4000	10.3871	12.7333	15.2903	29.8710	12.6000	22.4194	18.3000	20.6129	16.0685
1971	14.0323	7.7857	6.4839	13.8333	11.5700	17.7000	24.2581	27.3548	49.0000	28.0645	13.6667	19.4839	19.4868
1972	7.8065	5.6562	4.5161	6.6667	23.7419	7.8667	43.2258	22.4516	16.6000	39.7742	34.2333	21.2258	19.5902
1973	8.8710	6.3214	4.7097	5.7333	4.5161	6.3667	8.3548	29.7097	9.6667	9.8710	14.0333	14.9355	10.3041
1974	9.2903	7.0000	6.0968	8.0333	13.4516	22.6000	57.8710	42.9032	34.2333	23.5161	10.0333	10.3226	20.5753
1975	12.1935	6.4643	8.6129	10.6000	9.4516	58.9333	17.3871	31.0645	34.3333	35.2581	47.5333	18.9677	24.2219
1976	11.1290	5.8276	4.6129	9.4667	5.5807	4.9000	11.3226	10.6774	8.0333	11.7419	19.2000	10.1613	9.3962
1977	6.5806	5.6786	5.2258	8.6000	12.8387	20.7000	36.7419	19.8065	9.8000	37.2581	22.9667	12.1290	16.6274
1978	7.6129	5.8571	10.8710	4.8333	39.0000	21.4333	37.9677	48.8710	20.7667	27.3548	51.1667	18.4194	24.6658
1979	7.1613	6.6071	4.6129	9.4000	14.0968	20.3333	32.5161	22.1290	30.3667	36.1935	36.2333	26.6452	20.6000
1980	8.6452	5.0690	4.7097	6.6667	8.3226	9.2333	14.8710	17.6774	10.1667	20.1290	16.1000	11.2258	11.1066
Ave./T	11.2043	8.1804	6.9409	9.4578	15.1298	24.2078	24.1086	22.1989	20.6767	24.4591	22.8511	17.1602	17.2594

3.3.3 Flood Discharge

The design flood hydrograph for Caledonia and the design flood peak discharge at Talawakelle were determined according to the synthetic unit hydrograph method.

Design rainfall for determining design flood hydrograph was developed as a centralized hydrograph based on probable rainfall intensity. For the Caledonia site hydrograph, Probable Maximum Flood (PMF) was assumed from Probable Maximum Precipitation (PMP).

PMF hydrograph at Caledonia is presented in FIG. 3.3-8 (Details are given in APPENDIX-II).

Flood peak discharges at Caledonia are presented in the following table.

PROBABLE FLOOD PEAK DISCHARGES AT CALEDONIA

Catchment Area: 175.2km2

Return Period (Year)	50	100	200	500	1,000	10,000	PMF
Peak Discharge (m3/s)	933	1,108	1,202	1,330	1,429	1,913	2,527
Specific Peak Discharge ($m^3/s/km^2$)	5.3	6.3	6.9	7.6	8.2	10.9	14.4

Probable peak discharges at the Talawakelle diversion dam site ($297km^2$) have also been developed in the same manner, at $1,363m^3/s$ for 50-year return period probability and at $1,584m^3/s$ for 100-year return period.

3.3.4 Water Quality

Results of water qulity test for samples from Caledonia and Talawakelle on the Kotmale Oya are presented below. The sample is of muddy water taken during high discharge (about 20m^3/s at Talawakelle) period on August 22, '86; values are still well within to acceptable limits for the generating equipment. Ordinary water quality is assumed better than this, and no problems are envisaged.

WATER QUALITY TEST RESULTS

Item	Unit	Caledonia	Talawakelle	Acceptable Range
Turbidity	NTU	2.0	2.4	<10
PH (25°)		7.0	6.9	6.5~8.5
Total Hardness	mg/ℓ	12.4	10.9	<200
Total Residue	mg/ℓ	36	28	<500
Chloride	mg/ℓ	5.5	4.9	<200
Sulphate	mg/ℓ	4.1	7.4	<150
Total Iron	mg/ℓ	0.56	0.92	<1

The above test results also indicate that the subject water is also potable. The water is also clearly suitable for use in cement preparation.

CHAPTER IV

PLAN FORMULATION

CHAPTER IV

PLAN FORMULATION

4.1 Planning Approach

4.1.1 Maximum Development of Hydropower Potential

Hydropower potential in Sri Lanka is somewhat limited, estimated at about 2,000MW. Of the 2,000MW, 1,115MW has already been developed or is the target of projects currently under construction. The hydropower potential still untapped is accordingly small at about 900MW which is not enough for future development of the country. The development plan under the present Project is hence formulated in accordance with a basic policy that the Project area's hydropower potential is to be maximally developed as far as technically and economically feasible.

The general approach to hydropower development is to construct a reservoir in upstream area at high elevation, and to utilize water regulated at the reservoir at a powerstation located downstream. A reservoir is planned at Caledonia which is the upstream-most site suited for dam construction, and resultant water resources and available head are to be developed effectively.

The optimum scale of the reservoir will be determined on the basis of comparative analysis for cost effectiveness. However, a larger scale is preferable from the following point of view:

- to effectively utilize water resources by minimizing overspilling
- to provide capacity to regulate seasonal variation of discharges and to obtain larger firm energy

Furthermore, in order to fully develop the area's hydropower potential, discharge from tributaries will be utilized as far as economically feasible by diversion into the reservoir and regulating pond.

Precipitous terrain and the resultant high head available for hydropower development, coupled with abundant water resources, are outstanding characteristics of the area. It is planned to develop the head as effectively as possible, and care was taken not to allow idle head between hydropower stations.

4.1.2 Peaking Station Planning

Present generation capacity in Sri Lanka consists of hydropower : 715MW, gas turbine : 120MW and diesel : 80MW. The present power supply system in the country is thus reliant principally on hydropower, with thermal fired playing a subsidiary role. Hydropower stations are presently used to supply base load and middle-peak load, with peak load supplied by gas turbine and diesel units. In other words, almost all ordinary electric supply is met by hydropower stations; and gas turbines and diesel equipment are kept as stand-by units.

However as stated earlier, the untapped hydropower potential in the country is limited at 900MW. Of this, sites with comparatively larger development scale, besides the present Project, are only Uma Oya and Kukule. Furthermore, these capacities are not extremely large, at less than 200MW at each site. Accordingly, in the Long Range Generation Transmission Plan, large scale thermal stations are proposed to be introduced after 1993.

The power supply system in the early 21st century will therefore shift to primarily thermal, with hydropower subsidiary, and after that the portion supplied by thermal is projected to rapidly increase further. These larger scale thermals are for base load supply, and cannot be operated to meet a sharp peak demand. Accordingly large scale peaking capacity is expected to be required after the year 2000.

The existing Kelanitissa gas turbine(120MW) and the Sapugaskanda diesels (80MW) as well as 40MW diesels scheduled to be introduced from 1991 can be considered to supply for this peak load: the Kelanitissa gas turbine, however, will be obsolete from 1998. In addition, from the year 2000, evening peak for lighting is assumed at 700MW for 4 hours (total load is about 1,800MW as presented in FIG-4.1-1) and the above diesels are not enough to meet this demand. It is accordingly deemed appropriate to supply middle and peak load by hydropower stations, while Sapugaskanda diesels, 120MW in the year 2000, will provide for extreme sharp peak during that time.

The Team compared hydro stations, both existing and under construction, for peaking suitability. It was shown that the Upper Kotmale station has a high peaking suitability since a high head is obtained by a relatively short waterway, and the scheme exhibits a low per kW construction cost (Detailed discussions in APPENDIX-III).

Peaking stations require relatively larger maximum turbine discharge and hence unused spill water can be minimized, which means effective utilization of water resources. However if maximum turbine discharge is increased, cost for civil structures including waterway and electro-mechanical facilities will also increase. Accordingly, the optimum generation scale will be determined not only on the basis of economic evaluation for the Project itself, but also taking into consideration the necessity for a peak power station in Sri Lanka, as stated above.

4.1.3 Future Raising of the Existing Kotmale Dam

Kotmale dam was completed in 1985 at the downstream portion of the Project area with a height of 87m and an effective storage capacity of 155MCM. The Kotmale reservoir is presently used for mainly hydropower generation. However, it is considered necessary to double the storage capacity by raising the dam about 30m, to insure stable irrigation water to the central and northern part of the country.

Accordingly, all facilities of the existing Kotmale project were planned, designed and constructed taking the future raising of Kotmale dam into consideration. Land acquisition and compensation for the reservoir flooding area under the said project were also considered on the basis of this future increase in dam height.

The development plan under the present Project is accordingly formulated with a premise that the Kotmale dam will be raised in the future. As such, the power station at Talawakelle planned under the Project will be such that it can be operated even after the raising of Kotmale dam. In addition, since the timing of the raising is unclear, the present plan was developed to avoid idle head even before the raising.

4.1.4 Downstream Water Release

Kotmale Main Course

There is no major intake nor water utilization facility which will be affected by the present Project for 30km between the existing Kotmale reservoir upto the proposed Caledonia dam site. Only St. Clair Falls with a drop of 90m located 2km downstream of the Talawakelle dam and a microhydro generation facility for a tea factory at Yoxford 5km further downstream will be influenced.

The team examined compatibility of St. Clair Falls with the present hydropower development scheme; however, the Falls will unavoidably disappear with implementation of the Project. In other words, preservation of the Falls would mean abandonment of the Project. With regard to the microhydro station, it can be operated with water from the downstream catchment of the Talawakelle dam. Accordingly, no river maintenance flow for the Kotmale main course was taken into account.

Devon Oya

Water of the Devon Oya will be diverted by a 4km long diversion tunnel to the Talawakelle pond and will be used for power generation at the Talawakelle power station with a head of 470m.

Regulated water will be released to maintain Devon Falls during the daytime as would be required. Accordingly, 2/3 of annual discharge is considered as available for the purpose of power generation.

Other Tributaries

No downstream release is considered for Nanu Oya the water of which will be diverted to the Caledonia reservoir, or for the Pundal and Puna rivers whose waters will be diverted to the Talawakelle pond. The reason for this is that there is no major water use to be affected by the Project on these rivers. A town development is proposed at the downstream area of the Puna Oya. However, the scale will be small and required water can be easily supplied by small creeks flowing downstream of the proposed intake.

4.2 Determination of Development Mode

4.2.1 Review of Existing Development Proposals

The following development plans were prepared prior to the present feasibility study.

(1) 4 Step Development Proposal prepared by FAO (1968)

Site	Installed Capacity (MW)	Annual Energy (GWh)
1. Agra	5.1	20.0
2. Tillicoultry	11.4	40.7
3. Talawakelle	40.0	132.0
4. Yoxford	43.5	138.0
Total	100.0	330.7

(2) 2 Step Development Proposal prepared by CEB (1985)

Site	Installed Capacity (MW)	Annual Energy (GWh)
1. Caledonia	50	100
2. Talawakelle	180	466
Total	230	566

The Team reviewed these proposals using 1/10,000 aerophoto map and through field reconnaissance at the beginning of the present study. Thorough review and study were made on already identified sites i.e. Wavahena, Yoxford, Logie, Tillicoultry, Agra, East Holyrood, Palmerston, Wangie etc. for appropriateness as dam construction sites and as components of the hydropower development for the region.

Study results showed that these proposals are all very preliminary based on inch-mile mapping.

4.2.2 Development Mode Determination

At an early stage of the Study, comparative study was made on how to develop the head of 660m along 30km of the Kotmale Oya main course between the downstream existing Kotmale reservoir (NHWL: EL703) and the upstream Caledonia dam site (possible maximum NHWL: EL1,365m). The study was made using inch-mile mapping, 1/10,000 scale mapping, field reconnaissance results and collected data. The objective of the comparative analysis was to identify which proposal would realize the maximum development of hydropower potential, and also be economically feasible.

The potential for hydropower generation is in proportion to the product of catchment area and head. Development potential index obtained by multiplying the catchment area and head was employed for comparison. In addition, the fact that installed capacity per one power station is generally bigger in the case of lesser development steps, and number of units is small as number of power stations is less, results in greater cost effectiveness was also taken into account. Nevertheless, to maximally develop an area's hydropower potential, a larger number of intakes and resultant larger number of power stations are generally required.

The results of comparison are as tabulated in TABLE 4.2-1; details are presented in APPENDIX III. These results show that as a result, the 2-step proposal with two power stations at Caledonia and Talawakelle proved to have the highest development potential. Plan No.7 (3-step development) and Plan No.8 (4-step development) clearly appear to be disadvantageous because of their lower development potential index value and obvious high costs compared to 2-step development.

In addition, reservoir type 1-step development was found to be economically advantageous even though the development potential index is somewhat on the small side. Of the two proposals for reservoir type 1-step development, Plan No.5 with a reservoir at Lindula has unfavorable geological conditions for dam construction; and furthermore, the Lindula plan is economically inferior to Plan No.4 with a reservoir at Caledonia.

TABLE 4.2-1 COMPARISON OF DEVELOPMENT POTENTIAL INDEX

Plan No.	Intake Site	Type 1/	Catchment Area (km2)								Head (m)			Development Potential Index (m·km2)
			Kotmale	Nanu 1	Nanu 2	Devon	Pundal	Puna 1	Puna 2	Total	Intake W.L.	Tailrace W.L.	G. Head	
1	Caledonia	P	175.2	64.0	-	-	18.0	8.2	17.2	282.6	1,310	703	607	171,538
2	Lindula	P	190.0	79.2	-	-	19.6	8.9	17.5	315.2	1,255	703	552	173,990
3	Talawakelle	P	297.2	-	-	16.3	21.3	10.1	18.5	363.4	1,200	703	497	180,610
4	Caledonia	Re	175.2	16.5	43.3	-	17.2	-	16.6	268.8	1,365	703	662	177,946
5	Lindula	Re	190.0	64.0	-	-	18.0	-	17.2	289.2	1,310	703	607	175,544
6	Caledonia	Re	175.2	16.5	43.3		-	-	-	235.0	1,360	1,200	160	37,600
	Talawakelle	P	297.2	-	-	16.3	21.3	10.1	18.5	363.4	1,200	703	497	180,610
	Total													218,210 2/
7	Caledonia	Re	175.2	16.5	43.3					235.0	1,360	1,200	160	37,600
	Talawakelle	P	297.2	-	-	16.3				313.5	1,200	960	240	75,240
	Yoxford	P	365.0	-	-					365.0	960	703	257	93,805
	Total													206,645
8	Caledonia	Re	175.2	16.5	43.3	-				235.0	1,360	1,200	160	37,600
	Talawakelle	P	297.2	-	-	16.3				313.5	1,200	960	240	75,240
	Yoxford	P	365.0	-	-	-				365.0	960	800	160	58,400
	Wevahena	P	398.0	-	-	-				398.0	800	703	97	38,606
	Total													209,846

Note: 1/ Re: Reservoir, P: Daily Regulation Pond
2/ Development Potential Index for 2-Step Development is the highest value

Plan No.3 Talawakelle-Kotmale run-of-river scheme with a regulating pond presents the highest benefit and cost ratio (APPENDIX III), although it is not considered for further study since the plan develops only a very limited hydropower potential in the area, and hence runs counter to the basic philosophy behind the subject Project.

The comparison of 2-step and 1-step proposals is as follows:

	2-Step (Plan No.6)	1-Step (Plan No.4)
Installed Capacity (MW)	248	214
Annual Energy (GWh)	809	664
Construction Cost (Rs.million)	9,800	7,920
B/C	1.38	1.20
B-C (Rs. million)	309	336
Energy Cost (Rs./kWh)	1.24	1.22

As presented above, the 2-step proposal has a large advantage in maximum development of hydropower potential, but B/C (investment effectiveness) is slightly favorable in the case of 1-step development. Much importance was attached by the Sri Lankan side to the maximum development of potential upon discussion with the Sri Lankan officials concerned regarding the study results, and hence the 2-step proposal was ultimately selected.

The plan for detailed study which includes aerophoto mapping, topographical survey, geological investigations, and other field investigations was then prepared and conducted for the selected 2-step proposal. The optimum development scale was thereafter accordingly determined to obtain the best combination for various reservoir scales, turbine discharges, etc.

4.3 Definition of Energy

Annual Generated Energy

The annual generated energy in this Report is defined by reducing 5% losses accrued by actual reservoir operation for a 30-year period simulation based on optimum operation according to mass curve.

Firm Energy

Firm energy is defined as annual energy which is available with 98% probability. Namely, of the 360 months for the 30-year simulation period, the monthly energy which is available for 98% of the time, namely 353 months, is multiplied by 12 to obtain annual firm energy.

Secondary Energy

Secondary energy is obtained by subtracting the firm energy from the annual generated energy.

4.4 Evaluation Criteria

Various evaluation criteria are employed for comparative study and optimization study of hydropower development, namely, per kW and per kWh construction costs, energy cost, benefit/cost ratio (B/C), net incremental annual benefit (B-C), internal rate of return (IRR). Under the present study, B/C and B-C are selected as evaluation criteria for use in various comparative analysis and optimization studies. Study on energy cost and economic and financial analysis based on internal rate of return will be made for the finally proposed plan and appropriateness of development will be judged.

Least cost alterative method is applied to estimate benefit (B) which is used for B/C, B-C and internal rate of return calculation. Namely, construction cost and operation and maintenance cost of the thermal stations which are quantitatively and qualitatively on a par with the envisioned hydropower station are considered as a benefit of hydropower.

For the least cost alternative to a large scale hydropower station such as this Project, coal-thermal or oil-thermal is commonly applied. However, since the Upper Kotmale Project is characterized by peak generation, 5 hours of firm operation (98% dependable), it is judged most preferable to apply diesel as the alternative from the viewpoint of quantitative and qualitative equality.

Accordingly, peak generation supply under the present Project will be evaluated on the basis of alternative diesel. Namely, for Output (kW) and Firm Energy (GWh) which correspond to supply for peak load, a diesel station was considered as an alternative. On the other hand, for Secondary Energy, fuel costs of oil thermal stations which are to be introduced before the Project are considered as alternatives because as mentioned above, the secondary energy of hydropower will save fuel consumption at oil thermal stations.

With regard to the Secondary Energy of the Project, full amount is considered effective for fuel cost reduction in oil thermal generation since there will be abundant thermal generation which can effectively be replaced by generation under the Project. This is because generation by oil thermal will be 3.283GWh in 1997, 5.419GWh in 2000, and will continue to increase.

Economic internal rate of return based on coal and oil thermal as alternatives is also obtained as reference for comparison to other projects worldwide.

Power values of diesel and coal thermal stations which are proposed by CEB to be introduced in the future are calculated as presented in TABLE 4.3-1 and 4.3-2.

Cost (C) is obtained by adding annualized capital cost and O/M cost. Economic cost calculated by multiplying overall conversion factor of 0.86 (refer to 8.1.2) to the financial cost is applied for capital cost. Capital recovery factor to obtain annualized cost is based on 50 year facility life and discount rate at 10%. Operation and maintenance cost is determined at Rs.4.5/kW/mo.

TABLE 4.4-1 kW AND kWh ADJUSTMENT FACTOR FOR ALTERNATIVES

Item	Hydropower	Diesel	Oil Thermal	Coal Thermal
Facility Scale (MW)	248	20	200	200
Transmission Loss (%)	1.0	0.5	0.5	3.0
Auxiliary Use (%)	0.3	0.0	0.0	0.0
Forced Outage (%)	0.3	15.0	15.0	18.0
Annual Maintenance (%)	2.0	8.22	11.0	11.0
kW Adjustment Factor	-	1.2424	1.2812	1.3623
kWh Adjustment Factor	-	0.9920	0.9920	1.0176

Note : Auxiliary Use rate is zero for diesel, oil and coal since net heat value is adopted

: Calculations for diesel are as follows:

$$\text{kW Adjustment Factor} = \frac{(1-0.010)\times(1-0.003)\times(1-0.003)\times(1-0.020)}{(1-0.005)\times(1-0.000)\times(1-0.15)\times(1-0.0822)} = 1.2424$$

$$\text{kWh Adjustment Factor} = \frac{(1-0.010)\times(1-0.003)}{(1-0.005)\times(1-0.000)} = 0.9920$$

TABLE 4.4-2 POWER VALUE

Item	Unit	Diesel	Oil Steam	Coal Steam
Facility Life	Yr	20	25	25
Capital Recovery Factor at 10% Discount Rate		0.1175	0.1102	0.1102
Construction Cost 1/	Rs.10^6	248×1.2424 =308MW @13,641/kW 4,201	248×1.2812 =318MW @27,915/kW =8,877	248×1.3623 =338MW @33,163/kW =11,209
Annualized Capital Cost	Rs.10^6/Yr	4,201×0.1175 =493.6	8,877×0.1102 =978.2	11,209×0.1102 =1235.2
Annual kW cost 2/	Rs./kW/Yr	493.6/.248 1,990	978.2/.248 =3,944	1235.2/.248 =4,981
Annual Energy 2/	GWh	809	809	809
Plant Factor	%	809/.308/8,760 30.0	809/.318/8,760 29.0	809/.353/8,760 26.2
Net Heat Value	kcal/kWh	2,520	4/ 2,480	4/ 2,533
Fuel Cost	Rs./m.kcal	331	331	192
"	Rs./kWh	0.834	0.821	0.486
O & M Costs	Rs./kW/yr	Rs.10/month/kW ×12=120	Rs.7/month/kW ×12=84	Rs.12/month/kW ×12=144
"	Rs.10^6/Yr	120×308MW =37.0	84×318MW 26.7	144×338MW 48.7
"	Rs./kWh	37.0/809 =0.046	26.7/809 =0.033	48.7/809 =0.060
kW Value	Rs./kW	1,990+120×0.8 =2,086	3,944+84×0.8 =4,011	4,981+144×0.8 5,096
Firm kWh Value	Rs./kWh	0.834+0.046×0.2 =0.843	0.821+0.033×0.2 =0.828	0.486+0.060×0.2 =0.498
Second. kWh Value	"	0.834	0.821	0.486

1/: Unit construction cost data are provided by CEB
2/: Annualized kW cost is obtained from the capital cost of alternative facilities divided by 248MW of the Upper Kotmale Project.
3/: 248MW and 809GWh are for Upper Kotmale
4/: The values are for 200MW scale

4.5 Formulation of Optimum Development Plan

In section 4.2.2 it was determined to adopt a two step development consisting of Caledonia and Talawakelle power schemes. In this section, the optimum plan for this two step development approach is determined.

4.5.1 Selection of Sites for Caledonia and Talawakelle Dams

Caledonia dam and Talawakelle dam are the major components of the subject hydropower scheme, and the sites for these structures were determined on the basis of studies on aerophotography, topo-mapping (1:63360, 1:10000 and 1:5000), river profile, and field surveys, e.g. site reconnaisance, geologic surface survey, etc. for the 554km^2 of the Project area.

As shown in the river profile in FIG-3.3-5, the length of the Kotmale Oya from the starting point of the existing Kotmale reservoir (EL. 703m) to the Caledonia dam (riverbed elevation: 1300m) site is 28km. Elevation differential is 597m. Of this, river length from the Kotmale reservoir to the Talawakelle dam site is 18.5km, elevation differential is 487m and riverbed gradient is 1/38. River length from Talawakelle dam to Caledonia dam is 9km, elevation differential is 110m and river gradient is 1/82.

The confluence of the Agra and Dambagastalawa rivers is located 800m upstream from the Caledonia dam site. For 3-4km above this confluence point, river gradient is a gentle 1/100, which allows ready securement of good reservoir capacity. On this basis, the Caledonia dam site is suitable for creation of a reservoir.

At the Caledonia dam site, topographical and geological conditions are good as river width is narrow, and rock is outcropped in the riverbed. The site is the optimum for dam construction within the Project area. However, there exists a saddle at about 500m from the river on the left bank, with bottom elevation of EL. 1350m and bottom width of 50m. Accordingly, if full water level is set above EL.1,350, construction of a saddle dam will be necessary.

The span at the top of the saddle is relatively large, and geologic conditions at the bottom are not favorable. As extensive foundation improvement works would be necessary, the maximum height for a saddle dam is considered to be 15m.

Consequently, the maximum value for normal high water level for the Caledonia reservoir is assumed at EL. 1365m. On this basis, study for optimum normal high water level of Caledonia reservoir was carried out for three cases: EL. 1365m, EL. 1360m, and EL 1355m (see section 4.5.6).

As seen in the river profile, the Talawakwelle dam site was selected at the upperstream-most edge of the river section which exhibits steep, sharply fluctuating river gradient. Talawakelle dam is principally designed to perform daily regulation, by means of regulating pond, of the tailwater from Caledonia power station and discharge from the residual catchment ($62.2km^2$) interlying between the Caledonia and Talawakelle dams. These water resources are to be effectively utilized for power generation at the Talawakelle power station.

In addition to the above described residual catchment, the Talawakelle pond will also perform daily regulation of discharge diverted from the Devon Oya ($24.5km^2 \times 2/3 = 16.3km$) which presently empties into the Kotmale at the left bank 5km downstream of the Talawakelle dam, as well as discharge diverted from the Pundal ($21.3km^2$) and Puna ($28.6km^2$) rivers located along the headrace route.

Necessary reservoir capacity to perform the above described daily regulation is 1MCM in the dry season. However, in order to minimize spillover during the wet season, a technically applicable capacity of 2MCM was selected.

On the basis of topographical and geological factors, the Talawakelle dam site was selected at a point 1km below the confluence of the Nanu Oya in order to secure a reservoir capacity of 2MCM. The site is a favorable one with rock outcropping occuring in the riverbed. National highway A7 runs along the left bank, and the town of Talawakelle is located in the vicinity. Due to topographical restrictions, and the need to minimize inundation of property, reservoir normal high water level is determined at 1,200m (details are presented in APPENDIX-III).

Major features of the two dam sites are as follows:

	Caledonia Dam	Talawakelle Dam
Catchment Area (km^2)		
Direct Catchment	175.2	297.2
Indirect Catchment	59.8	66.2
Total	235.0	363.4
Riverbed Elevation (m)	1300.0	1190.0

4.5.2 Selection of Power Station Site and Type, and Main Headrace Route

Three points are fixed for the subject hydropower plan as presented in the previous section: Caledonia dam, Talawakelle dam, and the existing Kotmale reservoir. The optimum locations and routes for the headraces, power stations and tailraces connecting these components were subsequently determined.

A comparative study of three possible alternatives for both the Caledonia and Talawakelle power generating schemes was carried out. These alternatives are set out below (details are presented in APPENDIX-III).

For each of the above cases, cost effectiveness was compared on the basis of costs calculated from preliminary design. Technical evaluation was likewise performed, with particular attention to geologic features. For the Talawakelle scheme, future raising of the existing Kotmale dam was also taken into consideration. On the basis of comparative study, C-2 route option for Caledonia power scheme was deemed as optimum. For Talawakelle, T-2 was considered best.

	Head/Tailrace Length	Tributary Diversion Length (excluding Devon)
(1) Caledonia Scheme		
C-1 Route: left bank intake, left bank feed, surface power station	7,570m	
C-2 Route: right bank intake, direct feed, underground power station	5,150m	
C-3 Route: right bank intake, right bank feed, surface power station	5,750m	
(2) Talawakelle Scheme		
T-1 Route: direct route, underground power station	13,470m	10,200
T-2 Route: detour route, underground power station	13,100m	5,250
T-3 Route: detour route, surface power station	13,100m	5,250

4.5.3 Selection of Tailrace Outlet Location and Tailwater Level

In selecting tailwater level, care was taken to eliminate dead head occuring between Caledonia power station, Talawakelle power station and Kotmale reservoir. Tailrace outlet sites were determined so as to avoid effects of silting at the Talawakelle regulating pond and Kotmale reservoir.

The tailwater level for the Caledonia power station was set at EL. 1,198.0m which is 2.0m below the full water level for Talawakelle regulating pond. Tailwater outlet site was selected at a point 2km above the Talawakelle dam site.

Tailwater level for the Takawakelle power scheme was determined at EL. 703m, which is the normal high water level for the existing Kotmale reservoir. The existing Kotmale reservoir is intended to be utilized in coordination with the Victoria (effective reservoir capacity: 668MCM) and

Randenigala (effective reservoir capacity: 797MCM) power schemes downstream, and at present serves principally for power generation.

According to the 30 year operation simulation under the Water Management Programme of the Mahaweli Development Authority, operation of the Kotmale reservoir at high reservoir water level is indicated as optimum for the integrated Mahaweli water utilization scheme. This plan calls for maintenace of the reservoir at full water level for 60% of the year.

On the other hand, extension of the tailrace for 3km in order to establish outlet elevation at EL. 696.0m (the average water level of the existing Kotmale reservoir), would result in increased energy (secondary energy) of only 3GWh per year.

Consequently, a tailwater level of EL. 703m is optimum in terms of cost effectiveness for the Talawakelle power station. Tailrace outlet for the Talawakelle power station was selected at the optimum location in terms of topography and geology. In determining tailwater level for Talawakelle, the fact that Kotmale dam height will be raised 30m in the future was also taken into consideration.

4.5.4 Tributary Diversion

The special feature of the subject hydropower plan is the use of high head. Consequently, it is advantageous to divert discharge from available tributaries into the Caledonia reservoir and Talawakelle regulating pond.

Discharge ponded in the Caledonia reservoir is seasonally regulated, and converted into effective firm discharge for utilization at both the Caledonia and Talawakelle power stations. Discharge ponded in the Talawakelle regulating pond is regulated daily, and used for peak power generation. Discharge of $1m^3/s$ diverted to the Caledonia power station creates 1,256kW of power from a head of 144m; in the case of Talawakelle power station $1m^3/s$ discharge produces 4,082kW of power utilizing effective head of 468m.

Tributaries from which diversion is possible, and diversion features are indicated below.

MAJOR FEATURES OF INTAKE FROM TRIBUTARIES

Tributary	Intake Sites	Catchment Area (km2)	Diversion Canal Length (km)	Maximum Discharge (m3/s)
Caledonia Reservoir				
Nanu	2	59.8	4.1	6.4
Talawakelle Regulating Pond				
Devon	1	24.5 1/	4.2	3.3
Pundal	1	21.3	-	3.6
Puna	2	28.6	5.2	4.5

1/ In the case of the Devon Oya, no diversion is to be made for 8 hrs during the day in order to preserve Devon Falls. Consequently, actual catchment available for diversion is 24.5km2 x 2/3 = 16.3km.

Maximum diversion discharge is governed by minimum construction cross-section of headrace tunnel (2.2m x 2.2m unlined tunnel) and canal gradient. Maximum diversion discharges indicated above are 87-91% of yearly discharge. Assuming 88% average discharge utilization rate, yearly diversion is calculated at 96.4MCM for Caledonia and 106.7MCM for Talawakelle per year. Addition power which may subsequently be produced by this supplemental discharge is 33.6GWh for Caledonia and 120.8GWh for Talawakelle.

Construction cost for these diversions is estimated at Rs.401.9 million, the same per additional kWh is Rs.2.6/kWh. (Details are presented in APPENDIX III.)

4.5.5 Number of Turbine/Generator Units

Minimizing of numbers of turbine/generator units per power station reduces construction costs and is hence cost-effective. However, in determining optimum numbers of such equipment, it is necessary to take into consideration the scale of Sri Lanka's overall power supply system, as well as conditions affecting equipment transport.

For the subject Project, the following comparative study was carried out.

Site	Installed Capacity (MW)	Comparative Study
Caledonia	44	1-unit vs 2-unit
Talawakelle	204	2-unit vs 3-unit

Operation start-up for the Project is scheduled for 1997. At that time, Sri Lanka's total power supply system is planned to be 1,893MW (hydropower: 1,363MW; thermal: 530MW).

On the basis of this projected power supply capacity, it is applicable to install one unit (44MW) of turbine/generator at Caledonia, and two units (102MW x 2) at Talawakelle. In the event that one unit at Talawakelle (102MW) were to malfunction, it would have only a 5.4% effect on the overall power supply system. This loss could easily be covered by back-up capacity.

However, keeping units under 70MW capacity is desirable for reasons of transportation. Consequently, three units (68MW x 3) are proposed for Talawakelle. Unit capacities at the downstream schemes of Kotmale and Victoria are 70MW and 67MW, respectively, supporting the fact that units of this size can be moved successfully into the area.

From a standpoint of system operation, single unit capacity of 68MW at Talawakellle approximates the single unit capacities of 67MW at Victoria, 70MW at Kotmale and 61MW at Randenigala, thereby permitting effective system coordination through smooth substitute operation in the event of equipment breakdown at any of these power stations.

Thus number of turbine/generator units to be adopted is one at Caledonia and three at Talawakelle.

4.5.6 Optimum Development Scale

Optimization Procedure

The Project represents a two step development, consisting of the Caledonia and Talawakelle hydropower schemes. Caledonia power station utilizes the head existing between Caledonia reservoir and Talawakelle regulating pond. Discharge to be used at the Caledonia power station is the seasonally adjusted discharge from Caledonia reservoir.

The Talawakelle power station utilizes the head between the Talawakelle regulating pond and the existing Kotmale dam. Talawakelle regulating pond is to be fed by the tailwater from Caledonia power station as well as runoff from the residual catchment area of the Kotmale Oya between the Caledonia and Talawakelle dams. These water resources are regulated daily at the Talawakelle pond, and utilized to generate peak power.

If diversion from Nanu Oya is included, yearly discharge at the Caledonia dam site is 413MCM. If reservoir size is maximized and discharge utilized as uniformly as possible throughout the year, firm energy increases. However, dam cost also increases. Increase of maximum discharge results in an increase in facility capacity, and wasted spill from the reservoir can be prevented. Nevertheless, with larger discharge, tunnel construction cost is greater and generating equipment is more expensive.

In order to determine the optimum development scale, the following three parameters were examined interchanging various values, and B/C and B-C for each alternative compared.

-- Effective capacity at Caledonia reservoir

-- Maximum discharge at Caledonia power station

-- Maximum discharge at Talawakelle power station

Basic Conditions

Basic criteria for comparative study were set as follows:

(1) As discussed previously, the normal high water level for Caledonia reservoir as permitted by topographical and geologic conditions at the site is 1365.0m. Effective reservoir capacity at water level of EL 1365.0m is 45.5MCM. This represents 11% of annual discharge at the site, including diversion of Nanu Oya discharge.

(2) As discussed earlier, power stations at both Caledonia and Talawakelle are intended for response to peak demand. However, for the purpose of optimum scale study, this was not set as a precondition. However, firm operating time was

assumed at 4~8 hours per day, and the power stations are not considered to be capable of responding to base load supply.

(3) Components of benefit are, firm energy, and secondary energy. Regarding values for the above components, diesel is adopted as the alternative facility for output and firm energy, secondary energy is determined in terms of fuel savings for oil-fired generation as presented in 4.4 (Evaluation Criteria) and is expressed as kWh.

Study Results

Results of comparative study are given below, and details are presented in *APPENDIX III*).

Various reservoir capacities result in the following firm discharge values (determined independently of maximum turbine discharges for power stations):

Dam Height (m)	Full water Level (EL m)	Effective Storage Capacity (MCM)	Firm Daily Average Discharge at Caledonia P/S (m^3)	Firm Daily Average Discharge at Talawakelle P/S (m^3)
65	1355	18.0	6.0	8.5
70	1360	30.0	6.7	9.2
75	1365	44.5	7.5	10.0

For effective capacity for Caledonia dam, the possible combinations for maximum discharges of $30m^3/s$, $35m^3/s$ and $40m^3/s$ at Caledonia power station and maximum discharges of $45m^3/s$, $50m^3/s$ and $55m^3/s$ at Talawakelle power station were studied and benefit-cost ratio and net annual incremental benefit were compared.

(1) Normal High Water Level of Caledonia Reservoir

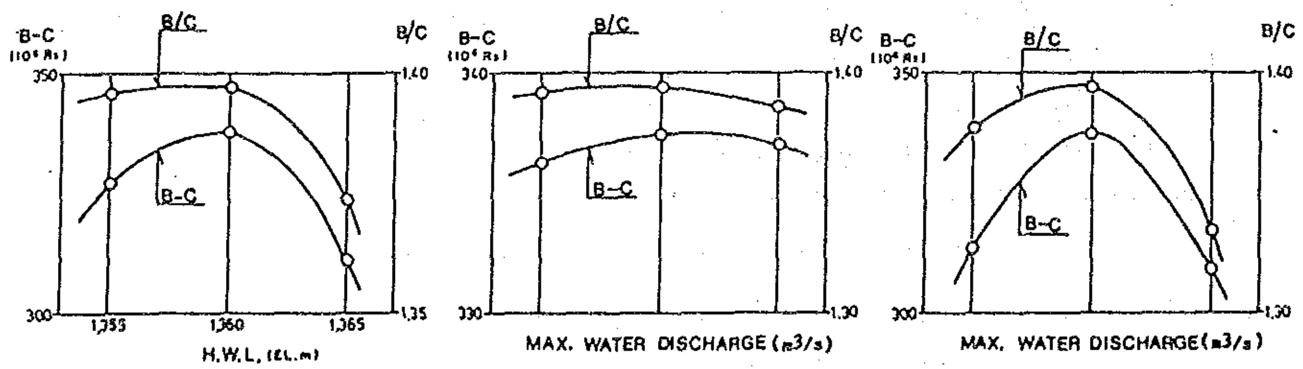
Three cases, EL. 1,355m, EL. 1,760m and EL. 1,365m, for the normal high water level of the Caledonia reservoir were selected for comparison. The optimum elevation is determined assuming the maximum turbine discharges for the Caledonia power station and Talawakelle power station at $35m^3/s$ and

50m3/s, respectively. Results are presented in TABLE 4.5-2 below.

As the figure below shows, B/C and B-C for EL. 1,360m are highest, and for this reason EL. 1,360m was selected as optimum.

TABLE 4.5-1 OPTIMIZATION OF CALEDONIA RESERVOIR N.H.W.L.

N.H.W.L.	ELm	1,355			1,360			1,365		
Scheme		Caled.	Talaw.	Total	Caled.	Talaw.	Total	Caled.	Talaw.	Total
Max.Turbine Q	m^3/s	35	50		35	50		35	50	
Max.Output	MW	39	204	243	44	204	248	47	204	251
Annual Energy	GWh	117	668	785	135	674	809	143	678	821
Firm Energy	GWh	60	299	359	76	331	407	89	396	485
Second Energy	GWh	57	369	426	59	343	402	54	282	336
Construction Cost	$Rs.10^6$	3,920	5,640	9,560	4,160	5,640	9,800	4,650	5,640	10,290
B	$Rs.10^6$	1,160			1,191			1,207		
C	$Rs.10^6$	833			854			896		
B-C	$Rs.10^6$	327			337			311		
B/C		1.391			1.394			1.346		



(2) Maximum Turbine Discharge of Caledonia Power Station

Discharges of $30m^3/s$, $35m^3/s$ and $40m^3/s$ are compared for the Caledonia power station for EL. 1,360.0m at the Caledonia reservoir, and assuming the maximum turbine discharge of Talawakelle at $50m^3/s$. $35m^3/s$ was selected as optimum as shown below.

TABLE 4.5-2 OPTIMIZATION OF MAXIMUM TURBINE DISCHARGE FOR CALEDONIA P/S

Max.Turbine Q m^3/s	30			35			40		
Scheme	Caled.	Talaw.	Total	Caled.	Talaw.	Total	Caled.	Talaw.	Total
Max.Turbine Q m^3/s	30	50		35	50		40	50	
Max.Output MW	38	204	242	44	204	248	50	204	254
Annual Energy GWh	133	671	804	135	674	809	136	676	812
Firm Energy GWh	76	331	407	76	331	407	76	331	407
Second Energy GWh	57	340	397	59	343	402	60	345	405
Construction Cost Rs.10^6	4,060	5,640	9,560	4,160	5,640	9,800	4,340	5,640	9,980
B Rs.10^6	1,176			1,191			1,205		
C Rs.10^6	845			854			870		
B-C Rs.10^6	331			337			335		
B/C	1.392			1.394			1.385		

(3) Normal High Water Level of Talawakelle Pond

The required capacity of the Talawakelle pond varies depending upon maximum discharges at Caledonia and Talawakelle power stations. However, the capacity was set at a larger size considering future sedimentation, and hence it is assumed that a high water level of EL. 1,200m is optimum.

TABLE 4.5-3 OPTIMIZATION OF MAXIMUM TURBINE DISCHARGE FOR TALAWAKELLE P/S

Max.Turbine Q m^3/s	45			50			55		
Scheme	Caled.	Talaw.	Total	Caled.	Talaw.	Total	Caled.	Talaw.	Total
Max.Turbine Q m^3/s	35	45		35	50		35	55	
Max.Output MW	44	184	228	44	204	248	44	225	269
Annual Energy GWh	135	671	806	135	674	809	135	676	811
Firm Energy GWh	76	331	407	76	331	407	76	331	407
Second Energy GWh	59	340	399	59	343	402	59	345	404
Construction Cost Rs.10^6	4,160	5,400	9,560	4,160	5,640	9,800	4,160	6,470	10,630
B Rs.10^6	1,145			1,191			1,235		
C Rs.10^6	832			854			926		
B-C Rs.10^6	313			337			309		
B/C	1.376			1.394			1.333		

(4) Maximum Turbine Discharge of Talawakelle Power Station

For maximum turbine discharges at Talawakelle power station, 45, 50, and $55m^3/s$ were compared for a fixed Caledonia reservoir high water level of EL. 1,360m, and a maximum turbine discharge at Caledonia power station of $35m^3/s$.

As the results below show, $50m^3/s$ yields the highest B/C and B–C values, and was therefore selected as the optimum discharge.

Optimum Plan

The optimum development plan obtained above is summarized in the following table.

TABLE 4.5-4 OPTIMUM DEVELOPMENT PLAN

	Unit	Caledonia	Talawakelle	Total
Reservoir/Pond				
Water Levels				
N.H.W.L.	EL.m	1,360.0	1,200.0	
L.W.L.	EL.m	1,341.0	1,193.0	
Standard Water Level	EL.m	1,353.0	1,198.0	
Storage Capacity				
-Gross	MCM	45.7	2.6	
-Effective	MCM	30.0	2.0	
Power Generation				
Rated Head	m	144	468	
Max. Turbine Discharge	m^3/s	35	50	
Installed Capacity	MW	44	204	248
Annual Generated Energy	GWh	135	674	809
-Firm Energy	GWh	76	331	407
-Secondary Energy	GWh	59	343	402
Operation Time				
-Firm Condition	Hr.	4.6	4.5	4.5
-Average	Hr.	8.9	9.5	9.4

CHAPTER V

FACILITY PLANNING

CHAPTER V

FACILITY PLANNING

5.1 Major Features of the Project

Major features of the project are as outlined below:

(1) Caledonia Scheme

Catchment and Reservoir

Catchment area	
Direct	: 175.2km^2
Trans-diversion	: 59.8km^2
Ponding area	: 2.25km^2
Storage capacity	
Gross	: 45.70 MCM
Sedimentation volume	: 8.76 MCM
Dead (incl.Sedimentation)	: 15.70 MCM
Effective	: 30.00 MCM
Flood water level (P.M.F.)	: EL.1,363.5m
Normal high water level	: EL.1,360.0m
Standard water level for Generation	: EL.1,353.0m
Low water level	: EL.1,341.0m

Dam

Type	: Concrete gravity
Height	: 70m (above bedrock)
Crest length	: 270m
Dam volume	: 250,000m^3
Slope gradient : Upstream	: above EL.1,325.0m : vertical
"	: below EL.1,325.0m : 1:0.3
Downstream	: 1:0.76
Elevations	
Non-overflow portion	: EL.1,365.0m
Overflow portion	: EL.1,360.0m
Bedrock	: EL.1,295.0m
Saddle dam	: Rockfill; 24m(H) x 145m(L)
Spillway	: Free Overflow Type (gateless) Design peak discharge (PMF); 2,530m3/s Max. discharge 2,470m^3/s 180m(W) x 3.5m(H)
Bottom Outlet	: Hollow jet valve; D=1,500mm

Headrace and Tailrace

Intake	: Inclined(45°) 6.4m(W)×33.2m(H) 1-span roller gate; 3.9m×3.9m
Headrace tunnel	: Concrete lined circular type D=3.9m; L=2,982m
Trans-diversion tunnel (Nanu Oya)	: Unlined; D-shaped type D=2.2~2.4m; L=4,130m
Surge shaft	: Portal type; 14.0m(dia)×53.4m(H)
Penstock	: Underground; inclined(48°) dia.:4.1m~3.2m; 1-line; L=213m
Tailrace tunnel	: Concrete lined circular type D=3.9m; L=2,168m

Powerhouse, etc.

Powerhouse	: Underground 16.0m(L)×23.0m(W)×25.2m(H)
Turbine	: Vertical shaft francis; 1-unit Capacity: 45,700kW Rated head: 144m (H_{max}: 151m) Rated discharge: 35m^3/s
Generator	: Vertical 3-phase synchronous; 1-unit Capacity: 52,600kVA Rated voltage: 11kV Rated current: 2,760A Power factor: 0.85 Rated frequency: 50Hz
Transformer	: Outdoor, three phase, oil immersed, air cooled type; 1-unit Capacity: 52,600kVA Rated voltage: 11/132±5%kV
Transmission Line	: Overhead line; 132kV×1cct to Nuwara Eliya - Laxapana line

(2) Talawakelle Scheme

Catchment and Regulating Pond

Catchment area	
Direct	: 297.2km^2
Trans-diversion	: 66.2km^2
Storage capacity	
Gross	: 2.6 MCM
Effective	: 2.0 MCM
Normal high water level	: EL.1,200.0m
Standard water level for Generation	: EL.1,198.0m
Low water level	: EL.1,193.0m
Usable water depth	: 7.0m

Dam

Type	: Concrete gravity
Height	: 20.0m
Dam length	: 102.0m

Discharge Facilities

Control gate	: Roller gate 8.0m(B)×12.0m(H); 3-span

Headrace and Tailrace

Intake	: Tower type; 8.0m(dia)×15.0m(H) 1-span roller gate; 4.4m×4.4m
Headrace tunnel	: Concrete lined circular type D=4.4m; L=13,066m
Trans-diversion	
Puna Oya	: Unlined; D-shaped tunnel D=2.2m; L=5,250m
Pundal Oya	: Concrete lined Vertical shaft D=10.0m; H=58.0m
Devon Oya	: Unlined; D-shaped tunnel D=2.2; L=4,170m
Surge shaft	: Portal type; 15.0m(dia)×92.8m(H)
Penstock	: Underground; inclined(48°) dia:4.7m~3.4m Upper portion: 1-line; L=684.0m Lower portion: 3-line; L=50.0m
Tailrace tunnel	: Concrete lined, a circular type D=4.4m; L=460m

Powerhouse, etc.

Powerhouse	: Underground 16.0m(L)×55.0m(W)×23.0(H)
Turbine	: Vertical shaft francis; 3-unit Capacity: 69,700kW ×3-unit Rated head: 468m (H_{max}: 470m) Rated discharge: 50m^3/s; 16.67m3/s×3-unit
Generator	: Vertical 3-phase synchronous; 3-unit Capacity: 80,000kVA ×3-unit Rated voltage: 11kV Rated current: 4,200A Power factor: 0.85 Rated frequency: 50Hz
Transformer	: Outdoor, three phase, oil immersed, air cooled type; 3 unit Capacity: 80,000kVA×3 Rated voltage: 11/220±5%kV
Transmission Line	: Overhead line; 220kV×2cct; L=18.5km to existing Kotmale switchyard

5.2 Caledonia Dam

The Caledonia dam is to be located at a point 800m below the confluence of the Agra and Dambagastalawa rivers at the upper reaches of the Kotmale Oya. The dam is to be of concrete gravity type, 70m in height with crest length of 270m. The reservoir to be created will have an effective capacity of 30,000,000m^3 with a Normal High Water Level of EL.1,360m. Various studies made to determine the features of the dam are presented below.

5.2.1 Dam Site

Two candidate locations, upstream and downstream alternatives, were studied in detail for the Caledonia dam site. Locations of alternative sites are presented in Fig-5.2-1. Topographical and geological conditions at and around the candidate sites are summarized as follows:

i) A bottleneck shaped landslide scar is located on the right bank between upstream and downstream locations.

ii) Colluvial deposits from landslide collapse are thickly deposited at the right bank of the upstream location.

iii) Fresh bedrock outcrops are found on the riverbed at the upstream location.

iv) At the left bank of the upstream location weathered rock thickness is small at 2~3m. Outcroppings of bedrock fall into the class C_L~C_H.

v) Topography in the vicinity of the downstream location is steeper than at the upstream site, and outcropping of bedrock is relatively extensive.

vi) A fault runs parallel to the dam axis at the downstream location, forming a waterfall with 5m head below the site.

vii) Talus deposits consisting principally of boulders are distributed on the left bank slope at the lower location.

viii) The riverbed at the downstream location is 10m lower than at the upstream location.

In the event that the downstream location is selected, the following would apply:

i) As the landslide zone on the right bank would be inundated, there is a danger of landsliding.

ii) As the dam body would be situated on a fault, large scale fault treatment would be necessary to prevent water seepage as well as to ensure sufficient foundation bearing capacity.

iii) Dam height would be 10m higher than that at the upstream site.

iv) A curved portion would result in the stilling basin.

In the event that the upstream location is selected, the following would apply:

i) Dam alignment could be selected so as to avoid landslide zone.

ii) No curved portion would result in the stilling basin.

iii) Large fault treatment would not be necessary.

iv) Dam height would be less than that for downstream.

On the basis of the above, the upstream site was finally selected considering technical and economical advantageousness.

5.2.2 Dam Type

Bedrock of the dam site consists of a very hard formation of charanockite, with relatively minor jointing and schistocity. Dam foundation accordingly puts no particular constraints on selection of dam type. On the basis of topographical features at the site, either a concrete gravity type or fill type is considered appropriate.

As for dam type, concrete gravity and the concrete membraned rock fill were compared in detail. The drawings for the concrete gravity dam are presented in the Design Drawings, the same for the rock fill dam are shown in APPENDIX-IV.

A condition of the area's topography which requires special attention for the planning of the dam is the existence of a saddle at the left bank. This saddle is located 500m south of the proposed dam site.

The bottom elevation is EL.1,350m and bottom width is 50m. Since Normal High Water Level of the reservoir was determined at EL.1,360m, a saddle dam in the case of a concrete gravity dam, or a spillway in the case of a rock fill dam, would be necessary at the saddle.

Comparative studies were made on both types of dam for the case of Normal High Water Level of EL. 1,360m, and construction costs were estimated. As a result construction cost for the case of concrete gravity is 24% less than that for the rock fill case as shown below, the concrete gravity type was finally selected for the Caledonia dam.

CONSTRUCTION COSTS BY DAM TYPE

Unit: Rs. million

	Concrete Gravity	Rockfill
Diversion Works	100	150
Dam Body	1,120	860
Spillway	(included in dam body)	500
Total	1,220	1,510

5.2.3 Allocation of Reservoir Capacity

The proposed allocation of capacity for the Caledonia reservoir is presented in FIG.5.2-2.

Sedimentation Capacity

Specific sediment inflow is assumed at $500m^3/km^2$/year based on sedimentation at the existing Kotmale reservoir and considering the condition of catchment of the Caledonia dam. The design sedimentation capacity was calculated at 8.76MCM from this specific sediment inflow, catchment area of $175.2km^2$ and design period for sedimentation of 100-years. A capacity from the riverbed of EL.1,295m up to an elevation of EL.1,333.5m was allocated for sedimentation.

Effective Capacity

A capacity 30.0MCM from the lowest intake level of EL.1,341m to the Normal High Water Level of EL.1,360m was allocated for effective capacity for generation.

Gross Capacity

The gross storage capacity is 45.7MCM including 15.7MCM of dead capacity from the riverbed at EL.1,295m to the lowest intake water level at EL.1,341.0m.

5.2.4 Crest Level Elevation

Crest Level Elevation

Crest level elevation was determined in accordance with standards determined by the International Committee on Large Dams. Additional heights for each design flood water level, surcharge water level and normal high water level are added to these water levels based on the following formula and the crest level elevation of non-overflow portion is determined from the highest value.

The following formula for a dam with non-gated spillway is adopted to determine the crest level elevation of non-overflow portion.

for Normal High Water Level:

$$Hh + hw + he \text{ (if } hw + he < 2 \text{ then } hw + he = 2)$$

for surcharge water level:

$$Hs + hw + \frac{he}{2} \text{ (if } hw + \frac{he}{2} < 2 \text{ then } hw + \frac{he}{2} = 2)$$

for design flood water level:

$$Hd + hw \text{ (if } hw < 1 \text{ then } hw = 1)$$

Where,

Hh: Normal High Water Level (EL. m)

Hs: surcharge water level (EL. m)

Hd: design flood level (EL. m)

hw: wind wave height (m)

he: earthquake wave height (m)

Surcharge and design flood levels are determined on the basis of reservoir flood routing calculations. The surcharge level adopts a flood with a return period of 1000 year while design flood level is obtained from probable maximum flood (P.M.F.).

Wind wave height

Wind wave height is determined by the following calculation according to SMB method:

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

Where, V: design wind velocity (=36m/s)

F: the longest fetch (=2,250m)

Earthquake wave height

The height of wave action by earthquake is calculated by Satoh's formula as follows:

$$he = \frac{1}{2}\frac{K\tau}{\pi}(gH_0)^{1/2}$$

Where, K: design seismic coefficient at normal high water level

τ: cycle (=1 second)

H_0: reservoir depth at normal high water level (normal high water level - foundation elevation)

g: gravity acceleration (=9.8m/s^2)

Wind wave height and earthquake wave height are added following the formula presented above to normal high water level of EL.1360.0m, surcharge level of EL.1362.4m and design flood level of EL.1363.5m as follows:

NON-OVERFLOW PORTION CREST LEVEL ELEVATION FOR VARIOUS WATER LEVELS

Reservoir Water Level (El. m)	Normal High Water Level EL.1,360.0	Surcharge Level (1000-year) EL.1,362.4	Design Flood Level (PMF) EL.1,363.5
Wind Wave Height (m)	1.5	1.5	1.5
Earthquake Wave Height (m)	0.4	0.2	-
Additional Height (m)	2.0	2.0	1.5
Lowest Crest Elevation (m)	EL.1,362.0	EL.1,364.4	EL.1,365.0

On the basis of the above calculated heights, the required lowest crest elevation is to be EL.1,365.0m determined from design flood water level.

5.2.5 Temporary Diversion Works

River diversion methods during dam construction include diversion tunnel and half closure coffering. For the following reasons, the diversion tunnel method is to be selected.

From an economical point of view, river closing cost alone (Rs.60 million) is cheaper than the cost for diversion (Rs.100 million). However for the case of half closure coffering, the overall construction period is prolonged and the total cost will resultingly be higher due to cost for concrete placement equipment. Total period of construction is shorter in the case of diversion tunnel than the same for the half closure method, since dam excavation is possible at the same time for all points.

Work space can be amply secured in the case of diversion tunnel, while in the case of half closure, restriction of space will be a constraint for dam construction. Ample space will also result in safer construction works in the case of diversion tunnel.

Tunnel length is shorter if it is routed along the left bank since the river curves leftward after the dam site. Furthermore, a landslide zone is located on the right bank at the dam site, and 70m downstream from the stilling basin a fault is located which forms a waterfall. Talus deposits (boulders, etc.) are distributed on the right bank slope at the dam site. Accordingly, the tunnel is to be constructed on the left bank. Intake and outlet of the tunnel are to be constructed at 120m upstream of the dam axis and 800m downstream of said axis, respectively. Tunnel discharge capacity is to be equivalent to flood discharge with a return period of 20 years ($840m^3/s$).

The section of tunnel is to be a standard horseshoe type with diameter of 7.2m. Bottom of the intake opening is to be at EL.1,302m, about 1.0m above the present riverbed . Tunnel length is to be 395m with a gradient of 1/30. The tunnel is to be lined with 70cm thick concrete for sections extending 150m from the inlet and 50m from the outlet. The remaining portion is to be rock bolted and lined by shotcrete.

5.2.6 Spillway

For the spillway of the proposed Caledonia dam, both crest gate type and free overflow type are conceivable. In the case of gated spillway: i) staff and power are needed for operation, ii) there is a possibility of gate misoperation, iii) preliminary release of stored water is required and this may result in invalid release causing reduction in generated energy reduction. On the other hand, in the case of free overflow type the above problems will not be raised.

In the case of the gated spillway type, the dam height can be 1.9m lower than the same for the free overflow type as presented in APPENDIX-IV. Accordingly, in the case of the gated spillway type, reduction of the cost for dam body and for reservoir flooding compensation occurs. Additional cost for the case of gated spillway is that for gate facilities. The cost reductions and increases which result from use of the gated spillway are compared and the details are presented in APPENDIX-IV. Cost reduction for the case of gated spillway is Rs.45 million while the additional cost for the same is Rs.60 million. Accordingly also from the economical view point, free overflow type was found to be more advantageous than the gated type.

The free-overflow type was finally selected for the spillway of the Caledonia dam. The design flood discharge is determined by reservoir routing adopting the probable maximum flood (PMF) hydrograph at the site.

In view of the topography at the dam site, crest length is to be 180m. As a result of reservoir flood routing calculations carried out in view of utilizing reservoir effectively, design flood can be reduced from 2,530m^3/s to 2,470m^3/s by a surcharge capacity of 10.3MCM.

Crest elevation:	EL.1,360.0m
Crest length:	180.0m
Overflow depth:	3.5m
Overflow discharge:	2,465m^3/s
Design flood level:	EL.1,363.5m
Surcharge capacity:	10.3MCM

Spillway is to consist of 15 spans, each 12m wide, with 3.5m high piers. Transition portion consists of lateral walls affixed to the dam body to steadily narrow water flow.

5.2.7 Foundation Treatment

Dam foundation treatment is aimed at increasing bearing capacity and impermeability. Extension and depth of foundation treatment were tentatively determined based on the results of Lugeon testing, core drilling and site inspection.

Consolidation Grouting

Consolidation grouting is to be conducted to relatively shallow depth over the entire dam foundation area to improve deformation in the loosened layer near the foundation surface. Grouting holes are to be spaced at 5m intervals, and are to be 7m in depth.

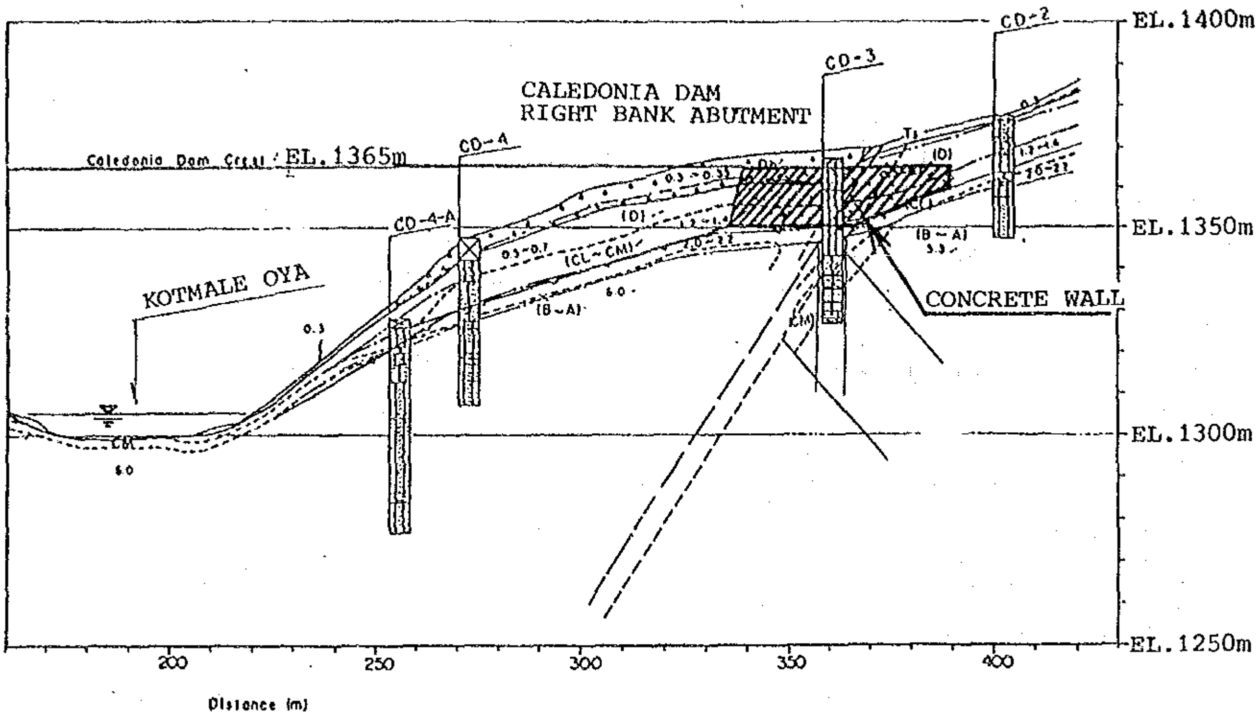
Curtain Grouting

By this procedure a continuous grout curtain is produced within the foundation rock to minimize to the extent possible seepage from the reservoir, and subsequent foundation destabilization. Grout holes are to be aligned along a single line at 1.5m interval, with a depth of 20m~70m. Location of grouting works is to be in the fillet at the upstream dam face and the dam gallery.

Seepage Prevention Wall

The result of the drilling CD-3 on the right bank abutment showed a existence of a highly fractured zone at elevations above EL.1,350.0m. The cores above EL.1,350.0m are clayed and recovery factor is low; Lugeon value at the second seismic velocity layer was over 30.

As curtain grouting cannot be applied for this portion, a 2.0m thick concrete wall is constructed to prevent seepage of water.



5.2.8 Stilling Basin

Type and design of the stilling basin will be determined on the basis of type and design of spillway, as well as conditions of hydraulics, geology, and topography of the dam site. Stilling basin type may be broadly classified into hydraulic jump, ski jump and free fall types.

In view of the fact that the flood spillway for the subject dam is free-overflow type with wide crest, stilling basin is to be hydraulic jump type with apron and sill at the terminus of the stilling basin.

As spillway intake consists of lateral walls affixed to the dam main structure, stilling basin dimensions can be smaller than normally required for conventional straight line intake for flood spillway.

Maximum discharge for stilling basin is set at 2.465m3/s, the maximum release from spillway. Stilling basin width was determined at 40m considering connection to the downstream.

5.2.9 Release Structure

A structure is installed to release water required for Talawakelle power station while the Caledonia power station is not under operation. This will also be used for emergency release.

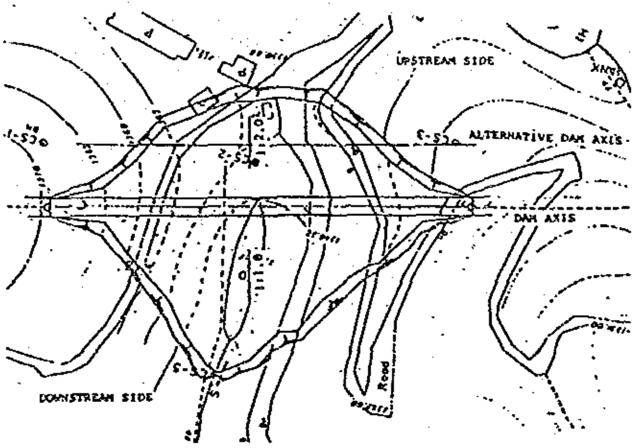
A screen will be installed at an inlet and hollow jet valve is installed at the downstream end to regulate discharge. Release pipe is to be installed maintaining the minimum distance of 3m from construction joints. Diameter of the valve is 1,500mm; the capacity was set at 40m3/s.

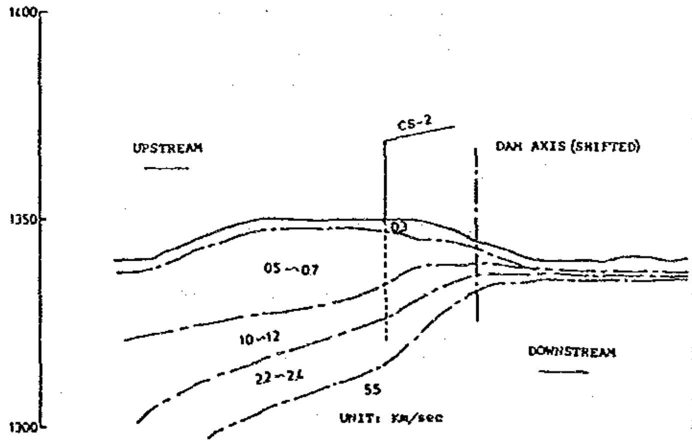
5.2.10 Saddle Dam and Seepage Prevention Wall

The elevation of the bottom of the saddle located in the left bank is EL.1,350m, 10m lower than the Normal High Water Level of EL.1,360m. Consequently, a saddle dam must be constructed.

Geology

Along the riverbed of the creek which flows from the bottom of the saddle and on a part of slope, outcrops of relatively good rocks better than C_M class are found. However, in most parts of the area clayed highly weathered rock (C_L to D class : seismic velocity 0.5-1.2km/s) are distributed with 3m to 30m thick. Bedrock is below this weathered rock; and the bedrock is inclined downward towards the upstream side.





The thickness of the highly weathered rocks on slopes and ridge portion is relatively hige at 10m to 20m. Talus deposit is found on the ridge slope at the saddle.

Cracks are found in all cores from drilling No.CS-1, CS-2 and CS-3. Geo-structural movement such as faulting is conceivable.

Dam Axis

Since the bedrock inclines downward at the upstream side, the dam axis was selected at 20m downstream from the bottom of the saddle to avoid a long slope and to limit the depth of water seepage prevention walls.

Dam Type

Construction costs for fill and concrete types were compared as follows. Cost is much cheaper in the case of fill type, Which was finally adopted for the saddle dam.

	Concrete	Fill
Crest length (m)	195	145
Dam height (m)	30	24
Dam volume (m^3)	46,00	80,000
Seepage prevention wall (m^2)	5,400	7,000
Construction cost (Rs. million)	178	100

Dimensions

Major dimensions of the saddle dam are determined as follows:

Type : Rockfill (zone type)

Height : 24m

Crest length : 145m

Dam volume : 80,000m^3

Slope : upstream 1:2.0, downstream 1:1.8

Non-overflow portion elevation : EL.1,366.0m

Bedrock elevation : EL.1,342.0m

Foundation Treatment

Joints and cracks are developed in the surface portion of highly weathered rocks which are found along the bottom of the saddle. Lugeon value show a high permeability and blanket grouting will be done for core basement to give an effective water tightness and bearing strength.

Grouting holes will be arranged in zigzag configuration, with an interval of 1m and depth of 5m to 10m.

Seepage Prevention Wall

The depth of the layer with Lugeon values over 30 is 25-45m deep at drilling hole CS-1 on the right bank of the creek at the saddle. At some other points, this layer seems to extend to much deeper level.

On the left bank of the creek at drilling hole CS-3, the depth of the layer with 5 to 15 Lugeon value is 5m to 15m. The highest elevation for the Lugeon value less than 5 is assumed at about EL.1,325m at drilling hole CS-3. The same elevation tends to increase toward the center of the saddle dam.

To ensure seepage prevention, concrete diaphragm wall is to be constructed to the level of EL.1,320m at the center of the saddle, EL.1,340m at left side and to the level of EL.1,330m at the right side. The structure for the concrete diaphram wall is presented in Plate No.03 of the design Drawings. The wall serves for seepage prevention by the ICOS method. Thickness of the wall is determined at 60cm considering the maximum water head of about 20m. Examples for concrete diaphram wall applied to seepage prevention at dams were presented in FIG. 5.3-4 (pp. F-37,38) of Progress Report No. 1, February 1986.

5.3 Talawakelle Intake Dam

Talawakelle dam is to be constructed on the Kotmale Oya at a point 1,000m downstream the confluence of the Nanu Oya. The dam is to be concrete, equipped with 3 movable gate spans. Dam height is 15m, length is 107m and effective reservoir capacity is 2.0MCM.

5.3.1 Dam Site

Two alternative candidate locations were considered. The upstream candidate site is located 600m below the confluence of the Nanu and Kotmale rivers. The downstream location is situated 1000m below the said point of confluence. As with the Caledonia dam site, bedrock is composed of charanockite. Talus deposits are distributed on both banks. Highly weathered rock is also in evidence on both banks.

Characteristics of the downstream alternative site are as follows:

Bedrock of C_H~B class is exposed in the riverbed, and foundation for pier and apron would have ample bearing capacity. Construction works are possible without interfering with transportation on national highway A7 between Talawakelle and Nuwara Eliya. River channel is straight indicating stability of river channel and riverbed.

On the other hand, upstream alternative site has the following characteristics;

A thick layer of riverbed deposits would make necessary piles and caisson works in foundation construction (refer to seismic prospecting results SL: TD-2). As a portion of national highway A7 would fall within the dam construction zone, completion of an alternate road is required in advance. The location of a school proximate to the dam site would necessitate careful safety measures and steps to limit noise during construction to the extent possible.

Scale of dam structures would be essentially the same for both locations. On the basis of the above factors, the downstream location is finally selected.

5.3.2 Dam Type

As mentioned above, charanockite is distributed at the site. As extremely hard bedrock outcrop of the class C_H~B appears in the riverbed, there would be no geological constraints for construction of a low concrete dam.

Required regulating capacity at Talawakelle pond is 2.0MCM, and effective drawdown for power generation is 7m. As regulating capacity is small, a concrete dam with movable weir type to allow for outflow where necessary is considered appropriate.

5.3.3 Structure

Elevation of non-overflow portion

Normal high water level was determined at EL.1,200.0m to provide necessary regulation capacity and also considering the relation with the tailrace water level of the Caledonia power stations. Elevation of non-overflow portion was subsequently determined at EL.1,202.0m considering 2.0m of freeboard.

Width of Movable Weir Portion

Width of movable weir portion was determined at 24m to maintain an area to discharge the design flood peak of 1,584m^3/s for a 100-year return period probability. The width is to be divided into 3-span with each 8m width.

Crest level evelation was set at EL.1,188m, 2m lower than the top elevation of sand prevention wall in order to facilitate smooth flush of sedimentation.

Pier width

Pier width was determined at 3m considering design load, overflow depth and overflow length. Piers are to be constructed of reinforced concrete. The top of the pier is to be equipped with a hoist, upstream side of the pier is to function as a support for the operation bridge.

Crest Gate

Since the crest gate is installed at the overflow portion and always under use, inspection and operation are limited. The roller gate or radial gate is commonly applied, both types have good water tightness and endurance, and are advantageous for maintenance and inspection, and thus technically there is no difference. In the case of radial gate, larger pier structures are required. With regard to the cost, the roller gate is slightly cheaper as compared below. For the present project, the roller gate which is common for the weir type diversion dam was adopted considering an economical approach.

	Unit Cost	Roller Gate	Radial Gate
Reinforced concrete for piers	Rs. 4,200/m^3	3,500m3: Rs. 14.7 million	4,500m3: Rs. 18.9 million
Gates	Rs. 186,000/t	250t: Rs. 46.5 million	250t: Rs. 44.6 million
Total		Rs. 61.2 million	Rs. 63.5 million

Since the main gate is to be used throughout the year, stop logs are installed in the upstream portion for maintenance and inspection of the main gate. This enables inspection during the ordinary use of the weir and prevents troubles during operation. In addition, a diesel generation is installed in case of power failure. A gate operation manual is also to be prepared and test operation will be done twice a year according to the manual, particularly prior to the flood season.

Accordingly, the possibility or occurrence of trouble in gate operation during the flood with 100 year return period seems very small. Design of the gate on the basis of the above case therefore seems too conservative. In the case that one gate out of three were to be inoperative, 1,360m^3/s of discharge, which corresponds to the 50 year return period flood at the site, can flow through the remaining two gates with an upstream water level of EL. 1,202m, or the elevation of the non-overflow portion of the gate.

Stop Log for Maintenance

Steel step log is installed for maintenance and inspection of the main gate since the main gate is to be used throughout the year.

River Protection Works

Since the Talawakelle pond will regulate inflow daily, 1-day water stage fluctuation will reach a maximum of 7m depth. River bank protection works by concrete block and stone riprap are considered on the left bank to protect the left bank's slope above where residential area is situated. The protection works are to be 15m high, 260m long and the slope is to be 30°.

5.4 Waterway and Power Station

5.4.1 Tunnel

Cross Section

Both the Caledonia and Talawakelle schemes have overall long tunnel, and both headrace and tailrace tunnels are pressure tunnel. The cost rates for tunnel construction in the overall waterway structure cost are high as shown below.

	Caledonia	Talawakelle
Headrace Tunnel (m)	2,982m	13,066m
Tailrace Tunnel (m)	2,168m	406m
Total	5,150m	13,470m
Rate of Cost Against Whole Waterway Structure	42%	57%

Although certain areas of quartzite and hornblende gneiss formation are evident and some topographies which suggest fracture zone are found, almost all the portion along the canal route is considered to consist of hard charanockite.

Pressure tunnels for hydropower stations are commonly lined. Although, the bedrock through which the tunnel passes is hard, bedding characteristic of charanockite are found. In the case of unlined tunnel, especially for the case of headrace tunnel, rock fragments are easily peeled off by water pressure fluctuation and water flow, and this will cause potential damage to invert concrete, steel pipe, valves, turbine runner, etc.

For the above reason, the entire surface of the tunnel is to be lined. Lining methods include concrete lining, shot-crete and steel pipe lining. For the subject tunnels, the concrete lining procedure is to be applied considering reliability, ease in construction and cost effectiveness.

A circular cross-section is commonly applied for pressure tunnels, since it is most advantageous in terms of resistance strength against water pressure and ground pressure. Circular tunnel is adopted for all headrace and tailrace tunnels for both Caledonia and Talawakelle schemes since these are all pressure tunnels.

Economically optimum diameter is to be determined comparing costs and benefit (generated energy). Construction cost is directly proportionate to tunnel diameter increase. On the other hand, head loss, is inversely proportional to diameter increase and thus, generated energy increases. The most economical tunnel diameter is accordingly determined to minimize the total of annualized capital cost and loss in benefit expressed by energy reduction due to head loss increase.

Annualized capital cost is calculated from tunnel construction cost and the cost of surge tank whose dimension is governed by tunnel diameter; head loss is friction loss of the tunnel. Capital recovery factor to calculate annualized cost, and energy value (GWh value) to obtain energy loss are as set out in section 4.3. Manning's roughness coefficient for the tunnel was assumed at 0.013 considering that lined surface will be good as a result of movable steel form use during concrete placement. FIG.5.4-1 shows the result of optimization study, the inner diameters are determined at 3.9m for Caledonia and 4.4m for Talawakelle.

Grouting

Low pressure and high pressure grouting will be conducted after concrete lining to strengthen the lined rock. Low pressure grouting serves to give tightness between concrete lining and rocks. Grouting will be made through grouting holes drilled at top of the tunnel to 10cm depth in the rock. Pressure will be 3-5kg/cm^2.

High pressure grouting consists of injection of cement milk in the rocks to improve their physical nature and to reduce tension stress which occurs in the concrete lining. This grouting will be made through 8 grouting holes around the circumference of the tunnel section every 3.0m along the tunnel axis, in a zigzag configuration. Grouting pressure is to be 10-15kg/cm^2.

Appurtenant Structures

Maintenance and inspection tunnels will be installed. A gallery will be installed in plug concrete of the access tunnel. Drainage facilities will be installed at the most downstream maintenance tunnel to drain water inside the headrace tunnel.

5.4.2 Intake Structure

Types of intake structure include inclined type for which inlet opening matches slope angle, tower type incorporating an intake tower in the reservoir, and intake type installed at the dam body.

Caledonia Intake

Topography at and around the proposed site for Caledonia intake consists of gentle slope of about 20°; top soil is thinly distributed and outcrops of bedrock are sometimes found. Usable water depth of the reservoir is 19m and thus inclined intake is more advantageous compared to the tower. Consequently, a 45° inclined intake with front side excavation (9,000m^3) has been adopted.

The bottom elevation of the intake was set at EL.1,331.8m, sediment inflow will be prevented by a submerged sill with an elevation of EL.1,335.5m installed at the front side of the intake. This elevation was determined considering the design sedimentation elevation of the Caledonia reservoir at EL.1,333.5m. The lowest water level of the reservoir is EL.1,341.0m thus intake water depth for the lowest water level is 9.2m. On this basis intake width is determined at 6.4m by overflow calculation.

A fracture zone is identified on the right bank near the Caledonia dam site and the present intake site has been determined to avoid this fracture zone. Bedrock at the intake site is good as mentioned above. Timing of construction works will have to take into account the fact that a quarry site is proposed on the right bank slope at a upper portion of the intake.

Talawakelle Intake

Talawakelle intake is sited on the right bank of the Kotmale Oya in upstream from the Talawakelle intake dam. The tower type and side spill type are conceivable. In the case of side spill type, a large scale concrete structure with a overflow width of 30m is required. Considering this, the tower type intake was applied with a morning glory intake with inner diameter of 8.0m. The minimum overflow depth is 4.0m and overflow crest elevation is EL.1,189m.

Submerged sill with a crest elevation at EL.1,190m is to be installed at the front side to prevent sediment inflow. Any deposited sediment occuring above EL.1,188m, the crest level elevation of the

Talawakelle dam, will be flushed out by opening gates during flood. Thus a 2m surplus is given to prevent sediment inflow into the intake.

By installing the submerged sill, the intake crest is lowered to EL.1,189m, thus the intake structure is minimized by utilizing the larger overflow depth. This sill will function as a water prevention well during inspection.

Appurtenant Facilities

Screen is to be installed at the intake to prevent debris inflow to the tunnel, net opening interval is determined at 50mm. Design inflow velocity is set at about 60cm/s, to maintain required inflow even when a part of intake is blocked by floating debris. Intake crest shape is to be bellmouth to prevent air inflow. The roller gate with the same dimension as the tunnel will be installed for both intakes.

5.4.3 Surge Tank

Surge tanks include the simple type, differential type, portal type, chamber type, etc. For the reasons described below, the portal type is planned for the subject Project.

Although the simple type surge shaft is of uncomplicated construction and effectively absorbs water hammer, it requires a large area. The chamber type is more effective where water depth is great. On the other hand, both the differential and portal types feature a cross-sectional area nearly half that of the simple type, and accordingly have economical advantages.

Although water hammer pressure against the portal is considerable (with pressure transmitted into the canal) compared with the differential type it is simpler in design and construction is accordingly facilitated. In the case of the subject Project, due to favorable geology at the proposed site, the portal type surge shaft is deemed as sufficiently strong against water hammer and accordingly the most appropriate type for the Project.

Features of the surge tanks are as follows:

	Caledonia	Talawakelle
Type	Portal	Portal
Inner Diameter (m)	14.0m	15.0m
Height (m)	53.4m	92.8m

No topographical and geological constraints for Caledonia surge tank are found. On the other hand, Talawakelle surge tank has to be sited with a large depth from the ground surface, due to topographical reasons. Upper 35m portion of the tank is not required for surging purposes. This segment of the shaft is to be utilized for bringing in materials and equipment for penstock construction.

Advantageousness of installing an upper chamber to lower up-surge, and subsequently to increase catchment area of the tributary intakes by lowering intake elevation was studied. Since these tributaries have steep gradient and intake sites are determined from topography, catchment area will not significantly increase even though the intake elevation is lowered.

In addition, as mentioned above, the upper portion of the surge shaft will be utilized for penstock route access, and accordingly this portion of the shaft is to be excavated even though there is no need for it in terms of surging. Accordingly, a surge tank extending upward is more economical. Considering these reasons, an upper chamber will not be installed.

The surge tank is located where the diversion tunnel and penstock join. A single access tunnel installed at the surge tank would have to serve for transportation of machinery and materials and removal of excavated debris for both diversion tunnel and surge shaft construction. Furthermore, upper portion penstock steel would have to be transported by way of the surge shaft. Consequently, penstock construction and surge shaft construction would place constraints on one another.

Accordingly, two access tunnels, one for the diversion tunnel and the other for the surge shaft, are to be branched from the Caledonia access tunnel to avoid mutual interference during the construction period.

In the case of the Talawakelle scheme, the scale of construction works for the surge tank is large, and works for installation of the control gate are also to be performed. Furthermore, maximum segment length for the diversion tunnel is large and the resultant construction period is long. Considering these factors, the access tunnel for the Talawakelle surge shaft is planned to be facilitated separate to the access tunnel for the diversion tunnel. The access tunnel approaching the bottom of the surge shaft is to be used only for surge shaft works, and the access tunnel for the diversion tunnel will be installed about 600m upstream of the surge shaft. In this manner, construction works for the surge shaft and diversion tunnel can be performed without any mutual interference.

Pundal Oya intake shaft will function as a portal type sub-surge shaft. The topography at the Talawakelle surge shaft site exhibits an adverse slope to the neighbouring area and geological constraints were anticipated. Core drilling investigation, however, showed no abnormal conditions and this site was finally selected.

5.4.4 Penstock

As the power station is to be underground, the penstock will likewise be an underground structure. For the undergound penstock, either burying or installation within a concrete lined tunnel are possible. As geological conditions at the proposed penstock site are good and in view of economic considerations, penstock structure is to be of the buried type, with concrete backfilling between the excavated surface and pipe.

Excavation is to be manual. Where excavation is done manually, an angle of 48° is optimum (throwing off of excavated material is facilitated, etc.). In the case of mannual excavation and long incline simultaneous excavation of the penstock route in two or more sections will facilitate shorting of the construction period. At division points between sections, a level area should be prepared to receive the off-thrown excavated material from the upper section. The lower portion of the penstock tunnel shaft cross-section should be made wide enough to accommodate pipe transport by winch operated rail car.

In order to prevent loosening of rocks after excavation until concrete back filling completion, and also to prevent rock drop during construction, tunnel will be lined by shotcrete immediately after excavation.

Number of penstock line is one for both Caledonia and Talawakelle. In the case of Talawakelle, the single pipe trifurcates at the bottom portion.

The optimum diameter of penstock is determined in the same manner as for pressure tunnel. Namely, minimization of annualized capital cost total and energy loss due to head loss. As a result, the optimum average inner diameter is determined at 3.3m for Caledonia and 3.8m for Talawakelle (See FIG. 5.4-2).

The maximum design head at the end of the penstock is obtained as per below, supposing water hammer head in the case of load interception at 30% of hydrostatic pressure.

	Caledonia	Talawakelle
Average Inner Diameter (m)	3.3	3.8
Hydrostatic Water Head (m)	167	497
Water Hammer Head (m)	50	149
Surging Water Head (m)	7	13
Maximum Design Water Head (m)	224	659

Penstock material is to be rolled steels for welded structure, allowable stresses are determined as follows:

Tension stress:	2,400kg/cm2
Compression stress:	2,400kg/cm2
Shearing stress:	1,400kg/cm2
Bearing stress:	4,100kg/cm2

Bedrock around the penstock route is assumed very good, and a part of inner pressure is designed to be burdened by rocks to reduce penstock steel thickness. Since the coefficient of elasticity in the bedrock will not be uniform due to variation in rock quality and the existence and numbers of cracks, the rate of pressure to be borne by bedrock will be determined for each portion based on further detailed rock investigation.

In accordance with the geological investigation results obtained through the present study, 40% of inner pressure can be borne by the rock. For the present Study, an average 20% of inner pressure for Talawakelle penstock is assumed to be borne by bedrock for calculation of penstock steel quantities. For the Caledonia penstock, no pressure was considered to be borne by bedrock. However, materials were selected so as to sutisfy the condition that the stress is less than the material's yield point even in the case that full pressure is loaded to the steel.

5.4.5 Powerhouse and Tailrace

Due to topographical constraints, power stations are planned to be the underground type (refer to 4.5.2 in Chapter 4). To minimize excavation volume, compact power stations are planned. Dimensions of the powerhouse cavern are determine as follows considering scales of main and auxiliary equipment, ceiling crane beam length, etc.

Turbine installation elevations were determined as follows in order to prevent cavitation.

	Caledonia	Talawakelle
Height to turbine axis form tailrace water level	-4.5m	-9.0m

Power house cavern height was determined to sufficiently accommodate winching height of the overhead crane for equipment assembly and disassembly.

Deformation will occur in the arch portion and side wall by residual ground stress accompanied by cavern excavation. Faults and cracks at the excavation point will aggravate unstable condition of the excavated surface. In this light, shotcrete, anchor bolts, PC anchor, etc. works in conjunction with excavation will have to be done to prevent deformation and to reinforce and protect the arch portion where stress is to be concentrated.

According to the results of geological investigations, both the Caledonia and Talawakelle power station sites have very good bedrock and there is a possibility of applying concrete lining only for the arch portion as at the present Kotmale power station. However, it is common to apply concrete lining for the full section to shoulder partial deformation by the whole structure. For the present Project, both the Caledonia and Talawakelle power station caverns are planned to be fully lined by concrete. As the power station is situated underground, extreme care in design must be given to proper ventilation, and safe means of evacuation in emergencies (accidents, fire, etc.).

	Caledonia	Talawakelle
Area	16.0m×23.0m	16.0m×55.0m
Ceiling Height at Assembly Room	25.2m	23.0m
Crane Lift (from top of generator)	8.5m	10.0m

Since the Caledonia power station is equipped with one unit of turbine/generator, larger floor is required if the auxiliary equipment room is on the generator floor. Accordingly, without the auxiliary equipment room is located below the assembling room. On the other hand for the Talawakelle powerhouse, number of turbine/generator are three, and the auxiliary equipment room can be located between generators with requiring additional space. Auxiliary room ceiling and assembly room floor were set at the same elevation with the top of generator.

The following access tunnels are required. Half of access tunnel and inspection gallery is to be concrete lined, half is to be shotcrete lined.

	Caledonia	Talawakelle
Access Tunnel 5.0m (W)×5.0m (H)	600m	410m
Inspection Gallery 5.0m (W)×5.0m (H)	490m	670m
Cable Shaft	3.6m×2.6m 140m	4.6m×3.6m 230m

The tailrace is determined to have the same cross-sectional dimensions as the headrace since it is pressure tunnel. A tailrace surge shaft is to be included to reduce water hammer and facilitate smooth turbine operation.

Tailrace surge chamber of the Caledonia scheme is a room created by enlarging tailrace tunnel for 20m to 8m width and 19.0m height. Tailrace surge chamber for the Talawakelle scheme is three units of 2.4m diameter cylinder installed at the outlet gate of each turbine.

Outlet elevation of the Caledonia scheme is to be EL.1,193m, the low water level of the Talawakelle regulating pond, to avoid creation of idle head. Since the river gradient at the regulation pond is relatively gentle, larger tailrace tunnel will be required if the outlet is situated at the point with an elevation of EL.1,193m. The location of the outlet was thus determined at the upstream portion; 2,000m^3 of excavation is required for 100m along the river channel.

Outlet structure of the Talawakelle scheme is on the right bank of the Kotmale Oya. The outlet was sited to avoid this area and excavation along the river course is needed for 300m to site the outlet so as to avoid what is considered a potential landslide zone on the right bank.

5.5 Generating Equipment

5.5.1 General

Selection of generating equipment was made with consideration to the following basic considerations.

1) The Upper Kotmale Hydropower Project is to play a major role within the Sri Lanka power supply system.

2) Power station and switchyard facilities are to be constructed at high altitudes. The Caledonia power station is to be located at an elevation of EL.1,200m, and switchyard is at EL.1,300m. The Talawakelle power station is at EL.700m and switchyard at EL.1,000m.

   Design of facilities must take into account such factors as appropriate installation height for turbine to prevent cavitation caused by drop in atmospheric pressure; decreased insulation and air cooling effect for electrical equipment; potential output drop of diesel engine due to oxygen insufficiency; etc.

3) Facility design must take into account problems of equipment transport to the sites. As output at the Caledonia power station is 44MW, generating equipment is to consist of 1 unit. However, at Talawakelle where design output is 204MW, generating equipment are to be separated into 3 units.

5.5.2 Turbine and Governor

Turbine

Both the Caledonia and Talawakelle power stations are designed as peak stations. Full load operation is accordingly to be the common case for both stations and operation at partial load will not be often required. However, turbines are necessary which can respond safely to sharp increase in load. Also, since both stations are underground, equipment should be as compact as possible.

A vertical axis, francis type turbine is optimum for the Caledonia power station in view of the fact that rated effective head is 144m. Rated effective head at the Talawakelle power station is 468m, and either a pelton or francis turbine would be appropriate. In the case of a hydropower scheme where fluctuation in load is significant, a pelton turbine is advantageous over the francis due to low drop in efficiency at partial load. However, where equipment is designed to operate continuously at peak load as in the case of the subject Project, the francis type exhibits a higher absolute value for efficiency. In addition, future raising of the existing Kotmale dam would render a pelton turbine not operatable, and the vertical axis, francis type is accordingly recommended. A study for the case of future raising of the existing Kotmale dam is presented in APPENDIX III.

As shown in the table presented in APPENDIX III, there are numerous instances where the francis turbine, both as a pump turbine and as a normal turbine, has been adopted for projects where the effective head approximates 470m, and has performed both safely and effectively.

Principal specifications for turbines at both power stations are as follows:

Power Station:		Caledonia	Talawakelle
No. of Units:		1	3
Type:		Vertical francis	Vertical francis
Maximum Effective Head: Rated Effective Head: Minimum Effective Head:	m m m	151 144 130	470 468 463
Maximum Discharge:	m^3/s	35	16.7 (50/3)
Rated Output:	kW	45,700	69,700
Rated Speed:	rpm	375	600
Specific Speed:	m-kW	160	73

Governor

Governors are to be standard electric - oil pressure type. One governor is installed per turbine, and turbine regulation is performed by means of pressure oil supply system consisting of pressure oil pump, pressure oil tank, sump tank, distributing valve, etc.

Governor closing time is determined as shown in the following table based on factors of penstock pressure rise and speed rise at load rejection.

Power Station		Caledonia	Talakawelle
Pressure Rise:	%	30	30
Speed Rise:	%	45	45
Closing Time:	sec	4	8

Turbine Inlet Valve

The appropriate turbine inlet valve is selected on the basis of head and inlet diameter. Also, a bypass valve will be included for water-filling of the turbine casing.

At the Caledonia power station where intermediate head is available, a thruflow valve is to adopted. A spherical valve is to be utilized at Talawakelle where head is high.

Power Station	Caledonia	Talakawelle
Type of Valve:	Thruflow valve	Spherical valve
Diameter:	2,200mm	1,300mm

5.5.3 Generator and Excitor

Generator

The suspended type generator is to be adopted. This type of generator is connected directly to the turbine, and is equipped with a thrust bearing capable of withstanding turbine water thrust and supporting the weight of rotating parts of the turbine and generator. Generator cooling will be by water cooled air circulation.

Principal generator specifications for both power stations are as follows:

Power Station:		Caledonia	Talawakelle
No. of Units:		1	3
Type:		Vertical axis, 3 phase AC, synchronous	Vertical axis, 3 phase AC, synchronous
Capacity:	KVA	52,600	80,000
Power Factor:		0.85	0.85
Voltage:	KV	11	11
Frequency:		50	50
No. of Poles:	Hz	16	10
Rated Current:	A	2,760	4,200

Excitor

Excitors are to be of the static and brushless type which are easily maintained. A thyristor excitation system is presently common for large capacity generators; however, the brushless type will be the mainstream in the future.

Neutral Point Ground

The neutral point of the stator winding is to be grounded through the distribution transformer and resistor. However, as there is no appropriate grounding location within the underground type power stations, a grounding cable is to be connected to the switchyard at the surface.

5.5.4 Station Power Source

Power station AC source is as follows:

1) The power station transformer (11kV/400V) will draw 3 phase AC, 400V from the output terminal of the generator.

2) An emergency diesel generator (3 phase AC, 400V) will be installed at the switchyard to permit turbine operation when power is not available from the transmission grid.

3) 33kV distribution line will be connected to both Caledonia and Talawakelle power stations from Nuwara Eliya grid substation to supply electricity during construction. This 33kV distribution line will be retained as a power source for both stations.

4) A 220V storage battery will serve as DC source. Said battery will be recharged during normal power station operation.

5.5.5 Control and Protective Devices

Various control and protective devices will be installed at both the Caledonia and Talawakelle power stations. Control system will be the 1 man control type, with turbine and generator start-up and shut-down, output adjustment, and other major functions as well as gauging and monitoring being performed from the control room in the power station.

Security measures for turbine, generator, etc. will consist of warning systems and/or shut-down as the seriousness of danger may warrant. As the power stations are located underground, control rooms will be located as well on the surface in the vicinity of the station sites, from where monitoring and control of power station, switchyard and transmission line facilities may be performed.

The surface control room and power station will be connected by control and communications cables to permit turbine and generator start-up and shut-down, and indication and monitoring of principal turbine and generator functions at the surface control room. Monitoring of the Caledonia dam and Talawakelle dam operations is also performed at the control room.

5.5.6 Crane

Water Supply and Water Drainage Facilities

In order to allow for assembly and disassembly of generating equipment, a crane with main hoist capacity of 120 tons and auxiliary hoist capacity of 10 tons will be installed at the Caledonia power station, and a crane with main hoist capacity of 130 tons and auxiliary hoist capacity of 10 tons at the Talawakelle power station.

Water supply facilities will be installed to convey water for generator air cooling and lubricant cooling systems, and turbine water stuffing system. Drainage facilities will be provided to remove water from penstock, casing and draft tube. Water for fire protection is also taken from the penstock.

5.5.7 Transmission to Switchyard

A vertical shaft will be constructed from the power station to the surface switchyard to house CV cable for transmission of generated energy to the primary transformer of the surface . In the case of the Caledonia power station, 11kV CV cable, 800mm2, 3 lines per phase, will be used. At Talawakelle, 11kV CV cable, 1000mm2, 4 lines per phase, will be adopted.

In addition to the above described method of transmission, it would also be conceivable to house the transformer within the underground power house, and transmit generated power to the surface switchyard by means of 132kV or 220kV cable. However, as voltage is high, this would require utilization of OF cable (oil filled cable) instead of the more easily handled CV cable. OF cable must be installed in spiral fashion within the vertical shaft, and due to the range limitation on allowable internal pressure, must be divided into several sections.

Also as an alternative to CV cable, it would be possible to connect the generator with the surface transformer by means of housing bus. Nevertheless, in comparison, CV cable is clearly advantageous in terms of cost effectiveness and maintenance.

The power station ventilation shaft would serve as the above described vertical shaft for CV cable.

5.6 Switchyard

5.6.1 General

The switchyard plan for the Project is formulated with consideration to the following criteria:

Common Conditions

As with the case of the aforedescribed generating equipment, the following factors will be considered: i) the subject hydropower plan occupies a major place within the overall power generation plan of Sri Lanka; ii) facilities are to be constructed at high altitude; and iii) design must reflect difficulties in transport of equipment and materials to the sites. Single line diagram for the overall upper Kotmale scheme is presented in Design Drawings. Facilities layout for the Caledonia and Talawakelle switchyards are also presented in the Design Drawings.

Gas insulated switchgear (GIS) which requires very small switchyard area has been recently developed. This type, however, is still expensive compared to the conventional type and operation and maintenance requires a higher technical level. Accordingly, for the present Study, the GIS has not been applied, and its possible utililzation should be studied in detail at the detailed design stage.

Caledionia Switchyard

The 49km transmission line (132kV, 2-circuit) connecting the Laxapana power station and Nuwara Eliya substation is to be completed in 1988. This transmission line passes in the vicinity of the Caledonia switchyard. Consequently, of this line, one circuit will be connected to the outdoor switchyard at Caledonia.

The Caledonia switchyard is located approximately 5km from both the Caledonia and Talawakelle dams. A 33kV distribution line from the switchyard will serve as the power source for operation, control and monitoring of intake gate, etc. at both dams.

Talawakelle Switchyard

The Talakawelle switchyard will transmit to the Kotmale switchyard by 2-circuit line the 204MW of power (stepped up to 220kV) generated at the Talakawelle power station.

Expansion of Kotmale Switchyard Facililties

Kotmale switchyard facililties must be rearranged in order to receive transmitted power from the Talawakelle switchyard. As shown in the Design Drawings, the transmission line from Talawakelle switchyard will be connected to the 2 bays, which are presently used for the Diyagama line, after the said Diyagama line is transferring to the southern bays.

Grounding

In considering switchyard sites, it is necessary to select locations where grounding resistance is low. Abnormal current resulting from earthing or lightning strike at transmission line and switchyard sites raises the ground potential. In order to protect personnel, and preserve the insulation of electrical equipment and circuits, appropriate grounding works will be implemented.

5.6.2 Bus

The Caledonia and Talakawelle switchyards will both constitute important components of the Sri Lankan power supply system. As a result, measures must be taken to ensure that effects to the overall grid resulting from accidents at either switchyard are minimized. Consequently, both switchyards will be of the double bus type. For the same reasons, expanded facilities at the Kotmale switchyard will also be double bus. In comparison with the single bus, the double bus requires more equipment and space, but is far more advantageous in terms of equipment inspection and utilization.

In Sri Lanka, it is common to apply 1½ system circuit breaker for 220kV transmission. In the case of 132kV transmission, standard type double bus is commonly applied. The 1½ system requires higher cost for additional facilities and for increase in required switchyard area. However this system is suitable from a viewpoint of maintenance for a switchyard where switching is often conducted.

The Talawakelle switchyard is located at the end of the national grid system and in addition it will generate for peak load supply. Accordingly, time not under operation is relatively long and switching actions are not performed so often. A standard type double bus can be applied in this light. However, for the Talawakelle switchyard, 1½ system circuit breaker was adopted due to its present utilization in Sri Lanka. The Caledonia switchyard is designed to be of standard type double bus system since it connects to 132kV transmission line.

5.6.3 Transformer and Switchgear

Insulation design for switchyard bus and other equipment will be compatible with the transmission line. Standard insulation strength (BIL) will be 900kV; abnormal voltage in the system in excess of this will be protected against by means of arrestor and discharge gap.

Main Transformer

It was determined after study to locate the main transformer at an outdoor switchyard. Although a 3 phase, single unit type would be more ideal, the weight of such equipment would be in excess of 50 tons for both the Caledonia and Talawakelle power stations, resulting in serious problems of transport.

Three units of single phase transformers for each switchyard is also conceivable, but precluded for reasons of cost effectiveness. Consequently, a specially designed 3 phase transformer which can be dismantled for transport (1 section per phase) and assembled at the site will be adopted. However, there are no technical constraints on application of single phase transformer.

Principal specifications for the primary transformer are as follows: (For reference, in the case of application of single phase transformers, three units each with rated capacity of 17,600kVA for Caledonia and nine units each with rated capacity of 26,700kVA of outdoor, oil immersed, air cooled type will be required.

Substation:		Caledonia	Talawakelle
No. of units:		1	3
Type:		outdoor, special 3 phase, oil immersed, air cooled type	outdoor, special 3 phase, oil immersed, air cooled type
Rated capacity:	kVA	52,600	80,000
Rated voltage:	kV	11/132	11/220
Connection:		delta/star (with neutral grounding device for secondary)	delta/star (with neutral grounding device for secondary)
Frequency:	Hz	50	50

Switchgear

For switchgear at both the Caledonia and Talawakelle switchyards, the recently widely used gas circuit breaker, which is compact and easy to maintain, will be adopted.

Breakers will be of sufficient breaker capacity. A grounding device is attached to part of the disconnecting switches to connect the no voltage portion to the ground when the circuit is open.

Steel Towers

In consideration of ease of transport and assembly, angle structure towers will be used. In order to protect switchyard equipment from lightning strikes, the overhead grounding wire, which serves as an effective arrester, will be adopted.

Grounding

In order to ground transformer equipment, equipment casings, steel towers, etc., ample copper wire mesh will be included in the switchyard foundation. This will also serve as a ground for the equipment of the underground power stations as well. Concrete and gravel will be used in the switchyard to protect workers from abnormal current.

Maintenance Track

One set of tracks will be installed at each switchyard for conveyance of main transformer in the case of repair.

5.7 Transmission and Distribution Facilities, Distribution Plan and Communication System

5.7.1 Transmission Line

New transmission line construction is not planned for the Caledonia switchyard as it will be connected to the proposed transmission line to be constructed in 1988. A 18.5km transmission line, however, is planned from the Talakawelle switchyard to the Kotmale switchyard.

The transmission plan for the Project will emphasize minimization of transmission loss, minimization of transmission line length, and location of facilities at sites where landsliding and other topographical and geological hazards are avoided. In addition to such basic design criteria, consideration will likewise be given to the following.

1) Ease of transport, erection and maintenance of equipment and materials.

2) The transmission line will run through the Wet Zone of Sri Lanka. Meteorological conditions along the route are as follows:

   Maximum temperature: 40°C (actual measurement at nearby weather station: 38°C)

   Minimum temperature: 0°C (without icing; actual measurement at nearby weather station: 38°C)

   Wind pressure: for transmission line: 970N/m^2

   for steel towers: 1640N/m^2

   (maximum wind velocity assumed at 40m/s; actual measured value: 36m/s)

   Earthquake coefficient (horizontal): 0.1G

   Annual days of thunderstorms (IKL): 80 days

3) There are existing 33kV distribution lines in the vicinities of both the Caledonia and Talawakelle power stations. However, as the capacity of these lines are insufficient as a power source for construction, a 33kV line will be constructed from Nuwara Eliya for both stations. This 33kV line will not be planned merely as a temporary facility, but rather as a long term one which can provide power to nearby villages along the route. The

33kV distribution line will be run from the Caledonia power station to the Caledonia dam and the Talawakelle dam for both construction and future operation of Caledonia and Talawakelle dams. This will also be used for start-up of the power stations and auxiliary use when the transmission line is not connected.

5.7.2 Transmission Voltage and Route

Transmission voltages used in Sri Lanka are 220kV and 132kV. A transmission voltage of 132kV is to be adopted for the the Caledonia switchyard as it is to be connected to the transmission line between Laxapana switchyard and Nuwara Eliya substation. As the Talawakelle switchyard will tie into the 220kV transmission line connecting with the Biyagama switchyard via the Kotmale switchyard, 220kV will be utilized there. Transmission route is presented in the Design Drawings.

The Caledonia switchyard will tie into one circuit of the two circuit line connecting the Nuwara Eliya substation and Laxapana switchyard. A two circuit transmission line is planned to connect the Talawakelle and Kotmale switchyards, as this line will bear a large portion of the load of the Sri Lankan power grid for a period following completion of construction.

5.7.3 Conductors and Steel Towers

Conductors

ACSR (aluminum cable steel reinforced), the standard utilized in Sri Lanka, will be adopted for the Project. A GOAT conductor ($300mm^2$), standard for Sri Lanka, will be used for the line from the Talawakelle switchyard to the Kotmale switchyard.

Armour rod and damper will be attached to counteract light wind vibration. In order to fix the line constant, each line will be crossed over at two locations.

Insulators

Insulators to be used are 250mm, disc-type suspension insulators, 12 nos. Salt pollution is not considered as a factor. As lightning frequently occurs in the Project area, arcing horns will be attached to the insulators to prevent insulator damage caused by the flashover arc of lightning surge.

Two insulator strings are required at tension points in consideration of tension strength, and one or two strings at suspension points depending on the interval between steel towers.

Overhead Ground Wire

In consideration of the high incidence of lightning in the Project area, two overhead ground wires will be installed to shield the transmission line from lightning strikes.

Galvanized steel wire $70mm^2$ will be used with a shield angle of 5°. As with the transmission line, dampers will be attached to prevent light wind vibration.

Steel Towers

In consideration of the mountainous terrain over which transmission line is routed and the importance of the lines to the overall Sri Lanka power grid, a structure of high mechanical reliability will be adopted. Angle steel towers will be used in view of their superior mechanical strength, and ease of transport and assembly. Standard interval between towers will be 355m. Every fifth tower will be a tension support, while other towers will serve as suspension supports. Tension supports will also be established wherever the line route curves, or intersects roads, rivers, etc.

A grounding rod or ground wire will be embedded for each steel tower to reduce ground resistance to less than 10ohm. The standard tower structure is shown in the Design Drawings.

5.7.4 Communication Facilities

General

Communication facilities are to consist of a telephone system, a data acquisition system, a maintenance system, and a dam communication system.

Communication systems comprise the nerve system of the power generating system and are essential to ensure stable power supply and prompt response to equipment fault. The communication systems also serve to collect information required for the smooth and efficient operation and management of hydropower facilities and equipment. In this light, the said communications systems must be highly reliable.

Telephone System

Telephone lines are designed to connect the Talawakelle, Caledonia and Kotmale power stations, the system control center and other power stations and switchyards for overall system control and administration of the power generating system.

A UHF wireless will connect the Caledonia and Talawakelle power stations. One or two relay stations will be located in between.

A transmission line carrier will be implemented along the new transmission line between the Talawakelle and Kotmale power stations to hook into the existing line carrier system at the Kotmale power station.

Data Acquisition System

All types of data and information from the Talawakelle and Caledonia power station will be transmitted by UHF wireless and power line carrier to the system control center. Transducers and transmitting and receiving equipment will be installed for this purpose. To facilitate transmission line maintenance, a VHF walky-talky will be used to communicate between the transmission line route and the power station. A base office for maintenance will be set up at the power station.

Wire telecommunication lines will be used for both the telephone system and data and information acquisition between the Caledonia power station and Talawakelle and Caledonia dams. The communication line will be strung from the dam distribution line poles.

5.8 Land Acquisition and Compensation

Land area under the Project requiring compensation due to its inundation by the Caledonia and Talawakelle reservoirs, or its acquisition for structure sites and resettlement encompasses 1,085ha as shown in TABLE 5.8-1. Of this, about 870ha belongs to national tea estates, and about 85ha comprises land cultivated primarily with vegetables and land occupied by residences of the local population. The remaining 130ha is wasteland, river and road area requiring no compensatory payment.

Houses, Public Facilities

Total numbers of residences, commercial establishments and public facilities within the Project area requiring compensation total approximately 1,000. Breakdown is presented in TABLE 5.8-2.

Resettlement

People who live in the area to be compensated for under the Project can be broadly divided into two categories i.e. tea labouers (and management staff) and residents engaged in other agricultural and commercial sectors. For these residents, cost for resettlement has to be considered in addition to compensation cost.

TABLE 5.8-1 BREAKDOWN OF COMPENSATION AND LAND ACQUISITION AREA

Unit: ha

Item	River, Road & Waste Land	Tea Field	Crop Field & Housing Lot	Total
Compensation for Innundation				
- Caledonia Reservoir	64	205	66	335
- Talawakelle Pond	26	3	5	34
(Sub-Total)	(90)	(208)	(71)	(369)
Land Acquisition for Civil Works				
- Caledonia Dam	6	27	3	36
- Talawakelle Intake Dam	2	13	1	16
- Calèdonia P/S and Tunnels	1	14	1	16
- Talawakelle P/S and Tunnels	9	60	6	75
- Transmission Lines	2	1	-	3
- Camp Sites	-	60	-	60
- Road Construction and Widening	20	27	3	50
(Sub-Total)	(40)	(202)	(14)	(256)
Land Acquisition for Resettlement				
- Land for 950 Twin Cottages of Tea Estate Labours	-	32	-	32
- Land for Other Estate Facilities	-	24	-	24
- Alternative Land for 400 Families	-	364	-	364
- Public Facilities	-	40	-	40
(Sub-Total)	(-)	(460)	(-)	(460)
Total	(130)	(870)	(85)	1,085

TABLE 5.8-2 COMPENSATION FOR DWELLINGS AND FACILITIES

No.	Facilities	Caledonia Dam Site		Talawakelle Dam site	Others (P.Stations, Camp Site, etc.)	Total Numbers
		Dambagas-talawa	Agra			
1	Factories	3	4	1	-	8
2	Estate Offices	2	5	-	-	7
3	Bungalows	16	-	-	-	16
4	Quarters	70	70	3	7	150
5	Twin Cottages	2	107	5	-	114
6	Lines	96	88	13	9	206
7	Workshops/Stores/ Sheds/Garages	37	14	9	-	60
8	Schools	4	5	- (High school is included under item 12)	-	9
9	Dispensaries/Maternity Wards/Nursery Schools/Baby Rooms	9	4	2	-	15
10	Hindu Temples/Buddhist Temples/Churches/ Mosques	9	13	2 (Excluding Talawakelle Temple)	2	26
11	Residences/Shops					
	1) Big Scale	2	13	12	4	31
	2) Medium Scale	8	93	50	18	169
	3) Small Scale	62	66	33	25	186
12	Other Important Facilities (Bank, Gov. Offices, Sports Club, etc.)	1	7	6	-	14
	Total	321	489	136	65	1,011