CHAPTER 5

METEOROLOGY AND HYDROLOGY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 5 Meteorology and Hydrology

5.1 General

(1) Meteorology

The island of the Sri Lanka belongs to the tropical monsoon climate zone and is influenced by two monsoons. Seasons in the country consist of southwest monsoon, northeast monsoon, and two inter monsoon periods which are called intermonsoons. The rainfall pattern is strongly influenced by the direction of these monsoons. The southwest monsoon takes place from May to September pouring much rainfall in the southwest part of Sri Lanka. The northeast monsoon takes from December to February giving precipitation in central part and arid area of north and northeast part of Sri Lanka.

The land of Sri Lanka is further subdivided to three zones, i.e. the wet zone, intermediate zone, and dry zone. Wet zone is the area where annual rainfall has more than 2,000 mm. Dry zone is defined where the annual evaporation exceeds the annual rainfall. Intermediate zone is transition zone between the wet and the dry zones. The southwest part of Sri Lanka belongs to wet zone, north and northwest part is in dry zone, and intermediate zone is mainly laid on the central part of Sri Lanka. The isohyet graph of monsoon and intermonsoon periods are shown in **Figure 5.1-1**.

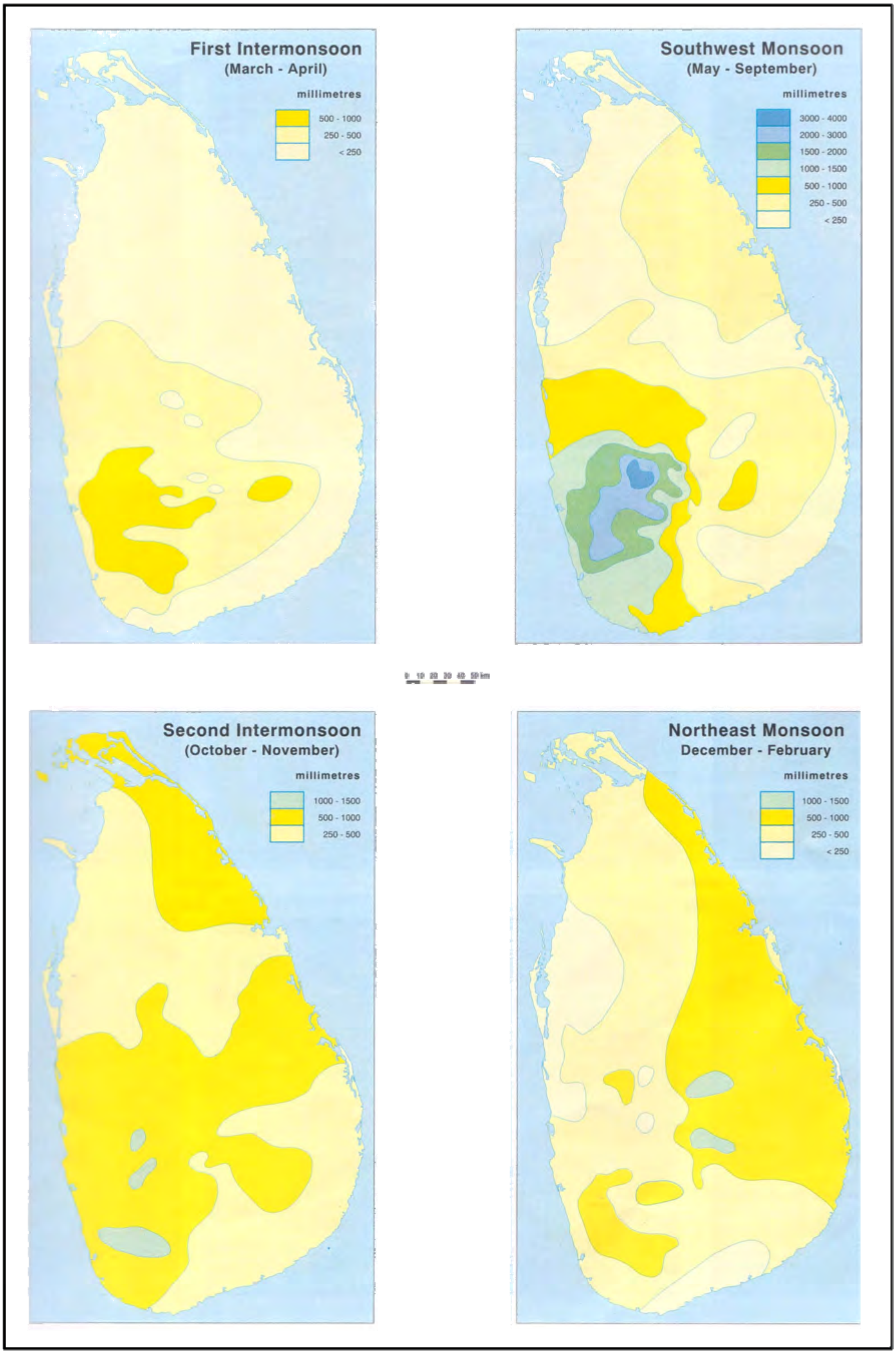
There is a central mountainous area above the elevation of 750 m called as the Central Highlands in the central part of the country. In the Central Highlands, the southwest monsoon gives rainfall at the southwest part, while the northeast monsoon pours precipitation at northeast part.

The Southwest monsoon period is called as “Yala” season which is from April to August, and, the northeast monsoon is called as “Maha” season which takes place from September to March.

(2) Climate in the Mahaweli River Basin

The Mahaweli river is originating in the southwest part of the Central Highlands, flowing through the northeast part of Sri Lanka island, and effluent to the Trincomalee bay. The general plan of the Mahaweli river basin is shown in **Figure 5.1-2**. The Mahaweli river basin is the largest in Sri Lanka with the total catchments area of 10,327 km^2 and river length of 335 km. There are many irrigation tanks and reservoirs located within the Central Highlands and peneplains of the basin to serve hydropower, irrigation and water supply.

The upstream part of the Mahaweli river basin is subject to southwest monsoon, and the middle part of the Central Highlands, where the Victoria Dam is located, is influenced by both monsoons. The downstream part of the basin is dry in southwest monsoon period and receives rainfall spontaneously in northeast monsoon period.



Source: The National Atlas of Sri Lanka

Figure 5.1-1 Isohyet in Monsoon Season

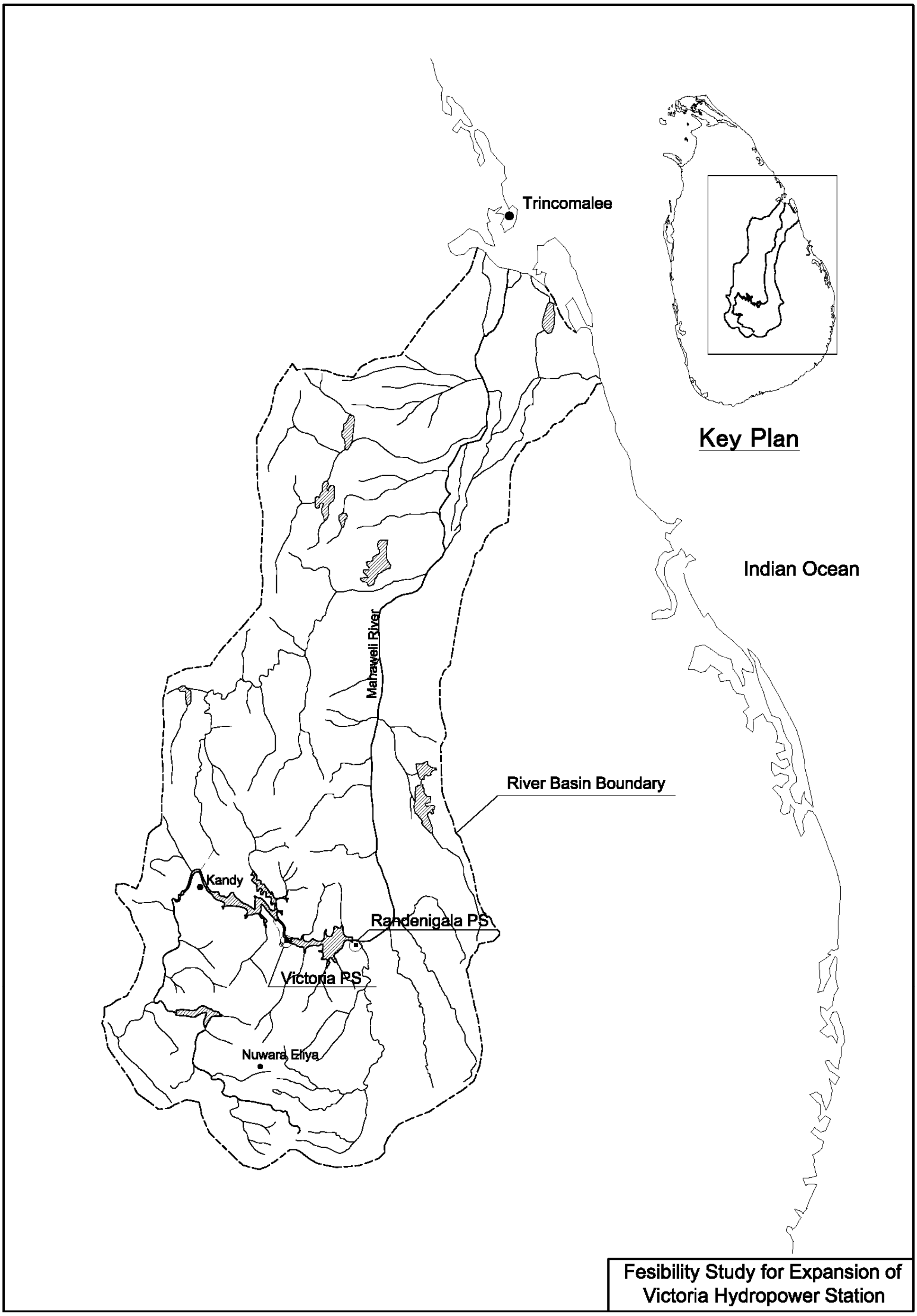


Figure 5.1-2 General Plan of the Mahaweli River Basin

5.2 Meteorology and Discharge Measurement in the Project Area

(1) Rainfall Measurement

There are eight rainfall gauging stations nearby the project area operated by the Meteorological Department. At the hydropower stations of the Victoria and the Randenigala, CEB also measures the rainfall. The list of the rainfall stations and locations of the rainfall stations are shown in **Table 5.2-1** and **Figure 5.2-4**, respectively.

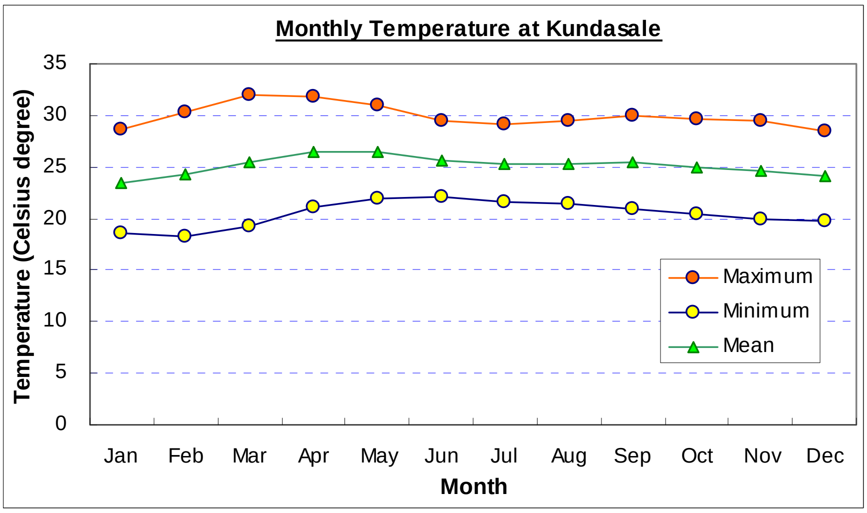
Table 5.2-1 List of Rainfall Gauging Station nearby the Project Area

Sta. No.	Station Name	Latitude			Longitude		
Rainfall gauging station operated by Meteological Department							
M146	GALPHELA	07	21	13	80	42	14
M191	HOPE ESTATE	07	06	31	80	44	20
M238	KANDAKETIYA	07	10	20	81	00	25
M283	KOBANELLA	07	21	15	80	50	21
M470	DELTOTA	07	10	04	80	41	52
M631	WOODSIDE ESTATE	07	15	52	80	49	39
	KUNDASALE	07	16	12	80	40	48
	MAHABERIYATENNA -DIGANA	07	16	12	80	45	36
Rainfall gauging station at dam site							
	VICTORIA	07	15	00	80	46	48
	RANDENIGALA	07	12	07	80	53	33

Source: Department of Meteorology, Sri Lanka

The monthly average rainfall measured at rainfall stations is shown in **Figure 5.2-5.** According to the record, the average annual rainfall at the Victoria dam is 1,375 mm. In general, the middle of the Central Highlands where the Victoria Dam is located is in the intermediate zone and is subject to both monsoons. However, according to the rainfall records, the project area receives more rainfall in the northeast monsoon period than that in southwest period.

There is a meteorological measurement station, the Kundasale meteorological station, located adjacent to the Victoria Hydropower Station. The monthly mean, maximum and minimum temperatures measured at the Kundasale station is shown in **Figure 5.2-1**. The annual mean temperature of the station is 25.1ºC with small variation through the year. The monthly maximum temperature varies from 29 to 32ºC. The monthly minimum temperature varies from 18 to 22ºC.



Source: Department of Meteorology, Sri Lanka

Figure 5.2-1 Temperature Measured at Kundasale Meteorological Station

(2) Discharge Measurement

The Polgolla diversion weir is located 20 km upstream of the Victoria Dam. The part of flow of the Mahaweli river is diverted to the Sudu river, a tributary of the Mahaweli river, at the weir for irrigation purpose. The released water from the weir to the downstream is flowing into the Victoria reservoir. Therefore, the inflow to the Victoria reservoir depends on the release from the Polgolla diversion weir. The weir is operated, and discharge data of the weir are managed by MASL. According to the records from 1985 to 2006, the average annual volume of inflow to the Polgolla weir is 1,949 MCM, annual average of 878 MCM was diverted to the Sudu river and the rest of 1,071 MCM is released to the Mahaweli river. The location of the Polgolla weir is shown in **Figure 5.2-2**, and the release record from 1985 to 2006 at the Polgolla weir is shown in **Figure 5.2-3**.

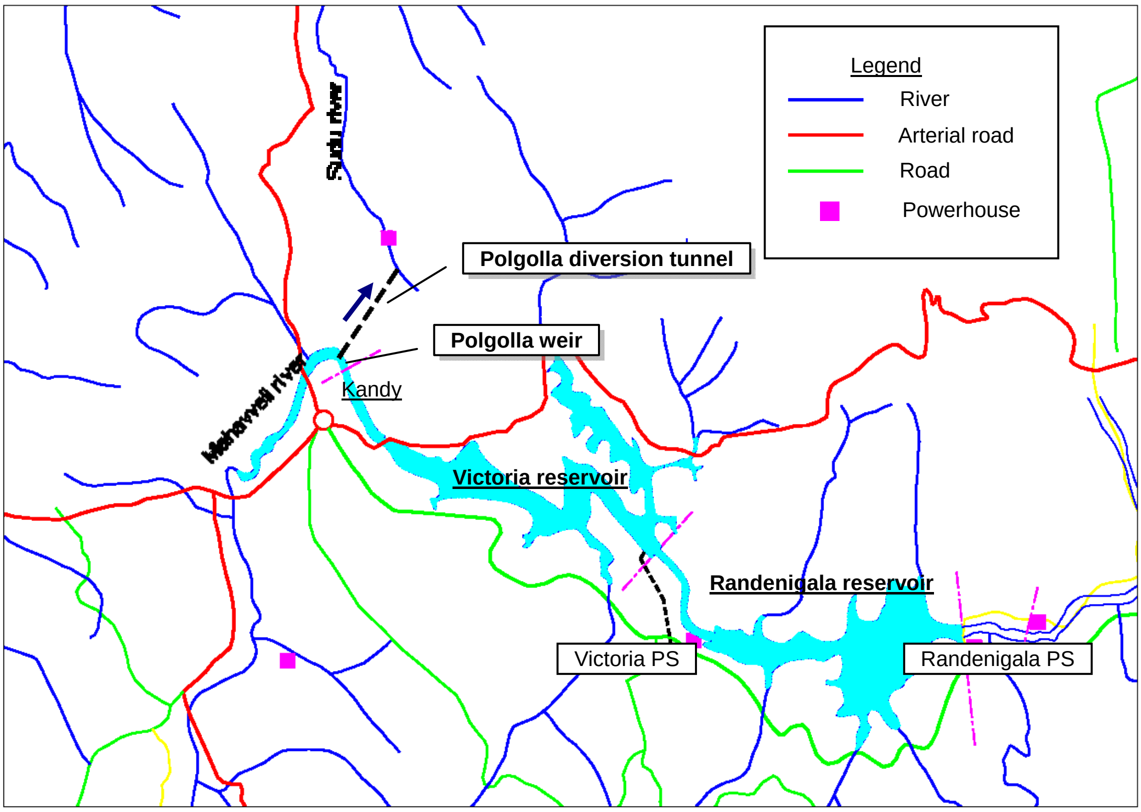
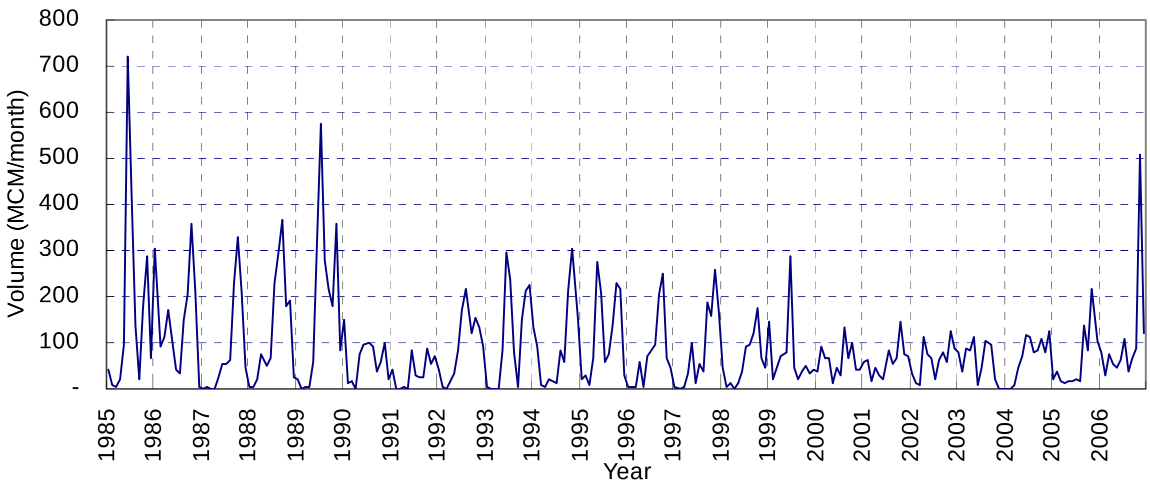
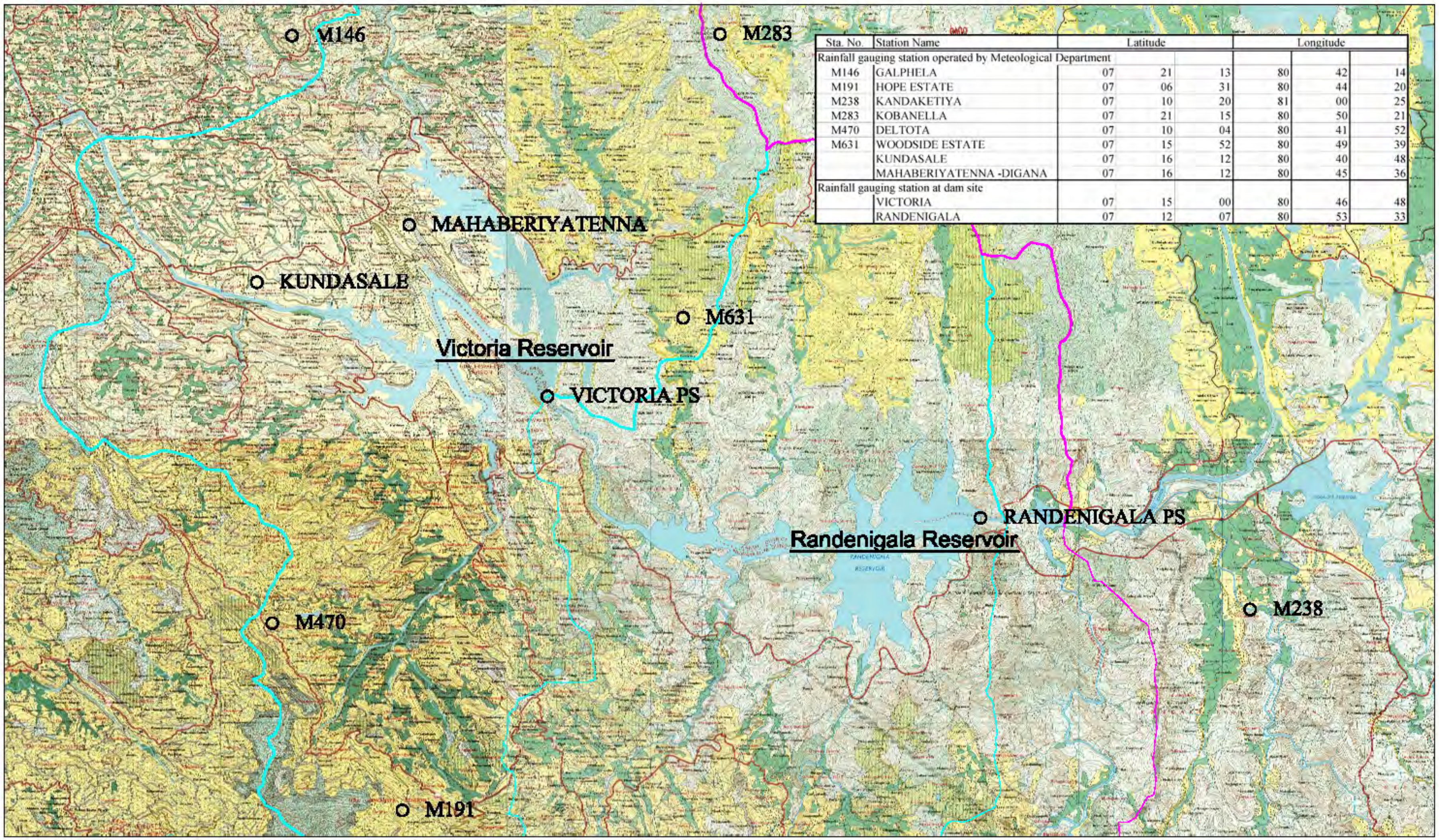


Figure 5.2-2 Location of Polgolla Diversion Weir



Source: MASL

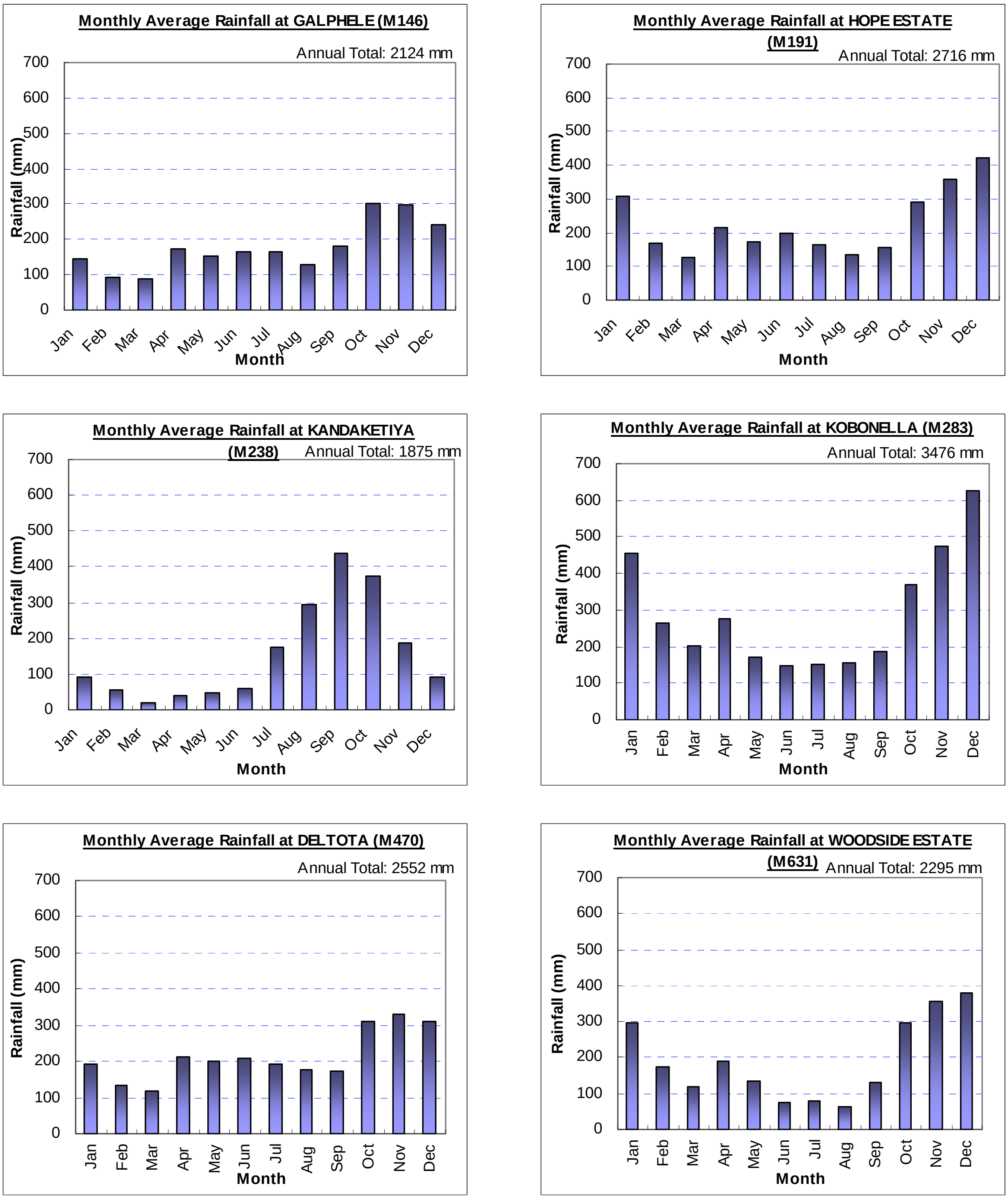
Figure 5.2-3 Polgolla Diversion Release Record



Sta. No.	Station Name	Latitude			Longitude		
Rainfall gauging station operated by Meteological Department							
M146	GALPHELA	07	21	13	80	42	14
M191	HOPE ESTATE	07	06	31	80	44	20
M238	KANDAKETIYA	07	10	20	81	00	25
M283	KOBANELLA	07	21	15	80	50	21
M470	DELTOTA	07	10	04	80	41	52
M631	WOODSIDE ESTATE	07	15	52	80	49	39
	KUNDASALE	07	16	12	80	40	48
	MAHABERIYATENNA -DIGANA	07	16	12	80	45	36
Rainfall gauging station at dam site							
	VICTORIA	07	15	00	80	46	48
	RANDENIGALA	07	12	07	80	53	33

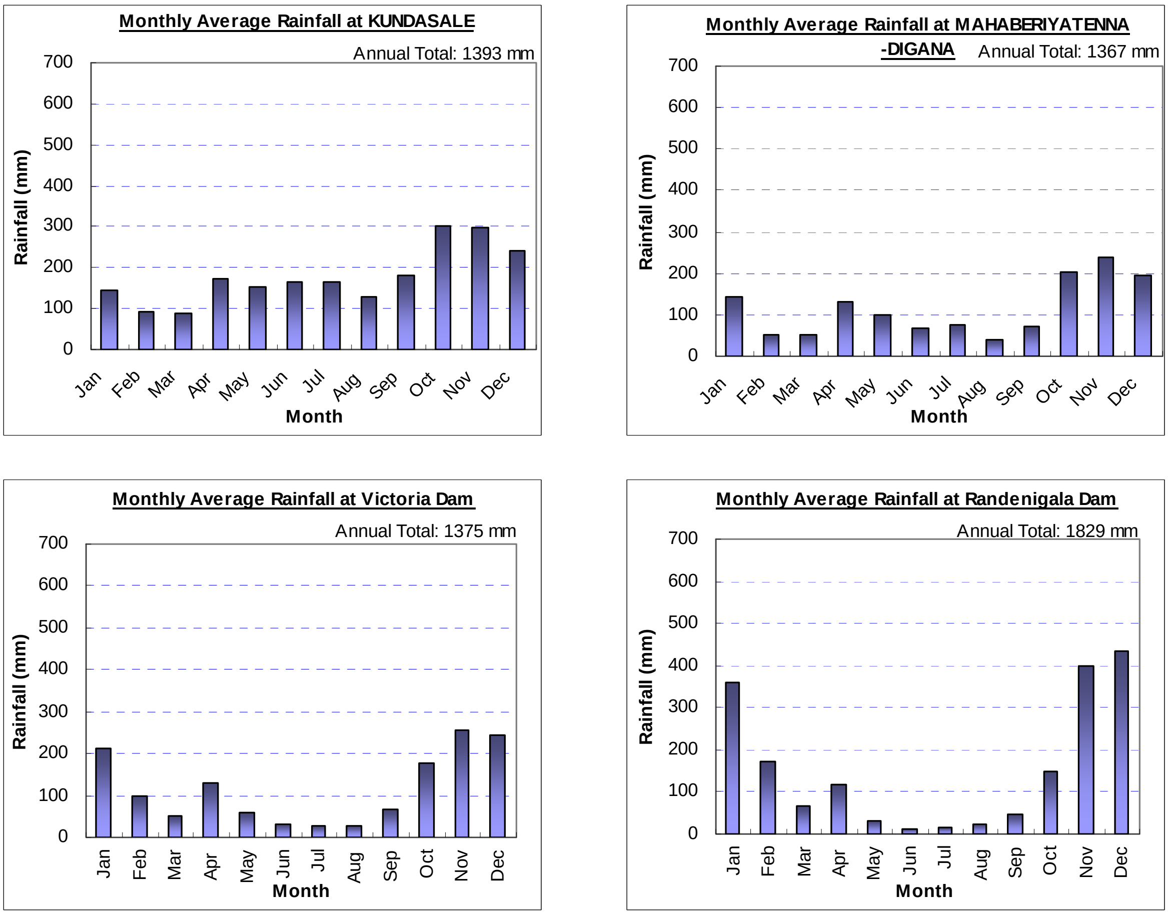
Source: Department of Meteorology, Sri Lanka

Figure 5.2-4 Location Map of Rainfall Gauging Station



Source: Department of Meteorology, Sri Lanka

Figure 5.2-5(1/2)
Monthly Average Rainfall Record Measured at Vicinity of the Victoria Dam (1/2)



Source: Department of Meteorology, Sri Lanka

Figure 5.2-5(2/2)
Monthly Average Rainfall Record Measured at Vicinity of the Victoria Dam (2/2)

5.3 Water Resources Development of the Mahaweli River

(1) Water Resources Plan of the Mahaweli River

The master plan of the Mahaweli river development was prepared as the "Mahaweli Ganga Development Project" under UNDP/FAO assistantship in 1968. The master plan involved development of 365,000 ha irrigation area and development of 500 MW of hydropower. The Sri Lankan government commenced to undertake the development scheme in 1968 according to the master plan. In 1977, the master plan was revised, and "Accelerated Mahaweli Development Programme" (AMDP) was issued. AMDP recommended developing 204,000 ha of irrigation area and 470 MW of hydropower with five large dams (Kotmale, Victoria, Randenigala, Maduru Oya, Moragahakanda). In early 1980s, the Sri Lankan government undertook the construction of the four dams, which are Kotmale dam, Victoria dam, Randenigala dam, and Maduru Oya dam.

The operation rule of the Mahaweli river basin water resources facilities after completion of the above dams were determined in the study "Mahaweli Water Resources Management Project" in 1985 under Canadian International Development Agency (CIDA) assistantship. This study recommended the operation rule of principal reservoirs such as the Victoria reservoir in the Mahaweli river basin.

The current reservoirs and irrigation tanks are laid as a series of cascade on the Mahaweli river. The current water resources facilities in the Mahaweli river are shown in **Figure 5.3-2**.

The water resources management of the Mahaweli river will be reviewed in the study on the "Dam Safety and Water Resources Planning Project" (DSWRPP) under the World Bank assistantship. The project has been undertaken since 2008. The outline of the DSWRPP is described in the next section.

(2) Dam Safety and Water Resources Planning Project (DSWRPP)

DSWRPP is the project assisted by the World Bank and consists of the following four components.

- Component 1: Dam Safety and Operational Efficiency (US$52 million)
- Component 2: Hydro-meteorological Information System (US$8 million)
- Component 3: Multi-sectoral Water Resources Planning (US$6.5 million)
- Component 4: Project Management and Monitoring (US$5.5 million)

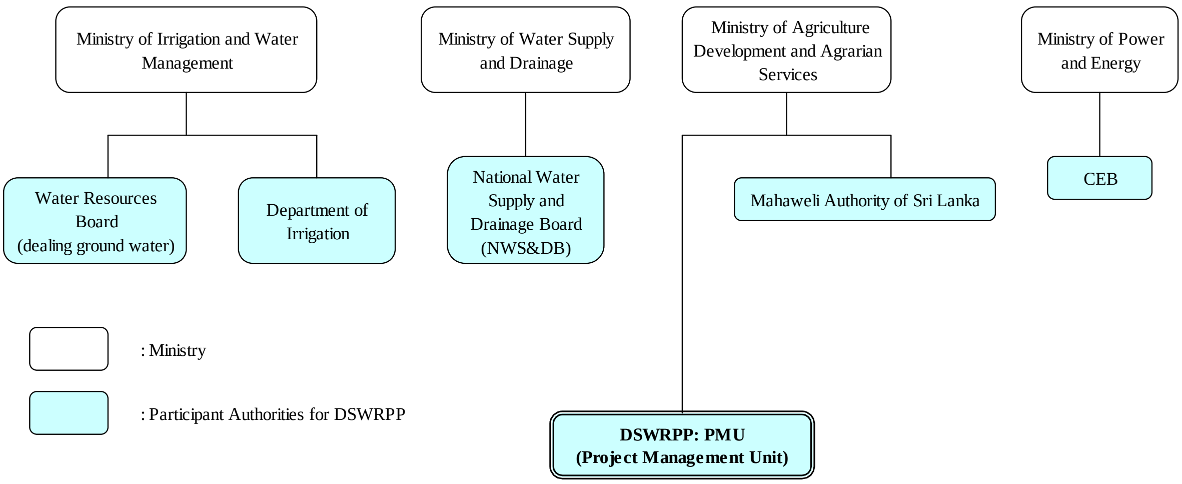
The total project cost is US$72 million in which US$66 million is financed by the World Bank and the rest of US$6 million is funded by the Sri Lankan government.

Component 1 consists of the rehabilitation of the existing 32 large dams in Sri Lanka. For the Victoria dam, the component will examine rehabilitation of the dam operating facilities and evaluation of dam structure behavior using measurement data recorded by the monitoring instruments in the dam body. Component 2 involves establishing hydrological information system, and component 3 will review and revise the water resources management in the principal river in Sri Lanka. Component 4 is operation and coordination of the DSWRPP components.

The study of the component 3 may affect the operation of the Victoria reservoir. The main scheme of component 3 is to develop national water-use plan for rivers other than the Mahaweli river and optimization of water resources of the Mahaweli river for preparation of "New Mahaweli Water Resources Development Plan." The national water-use plan will be developed under supervision by Department of Irrigation, and the optimization study on the Mahaweli river will be supervised by MASL. The review of the water management of the Mahaweli river basin will include assessment of the operation policy for the diversion at the Polgolla weir.

The principal authorities involved in the DSWRPP are; Water Resources Board, Department of Irrigation, National Water Supply and Drainage Board, Mahaweli Authority of Sri Lanka (MASL) and CEB. Among these five authorities, four authorities except Water Resources Board have their own dams. Each authority will supervise construction works on their dams.

The coordination of the project within DSWRPP scheme is made by Project Management Unit (PMU) under the Ministry of Agriculture Development and Agrarian Services. PMU is responsible for giving project guideline to the entities, procurement of consultants and materials, and reporting progress to the World Bank. PMU office is located in the MASL building, however, PMU is independent to MASL. Organization of the DWSRPP is shown in **Figure 5.3-1**.

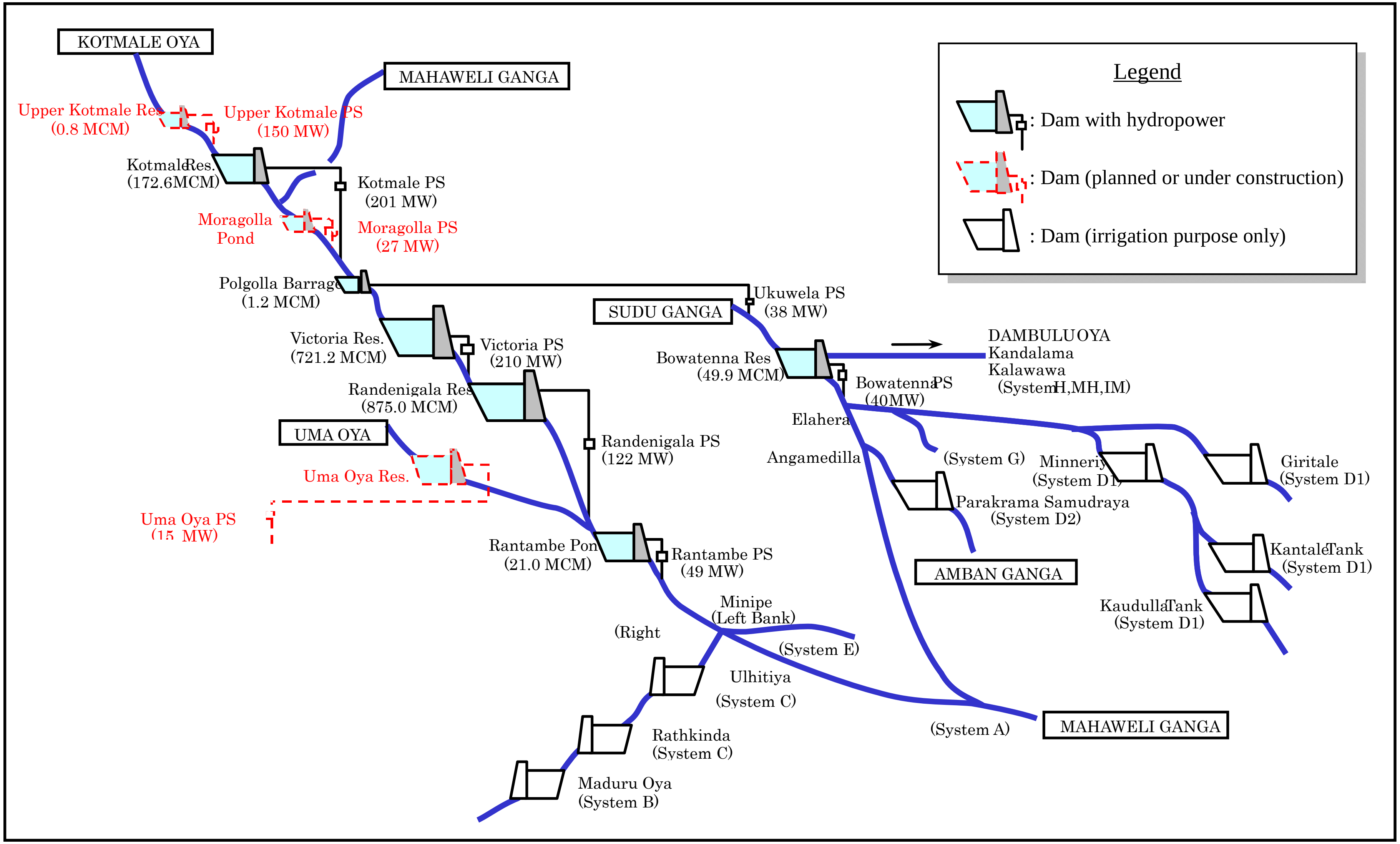


Source: Project Management Unit, DSWRPP

Figure 5.3-1 Related Organization of DSWRPP

Regarding the water resources development plan of the Mahaweli river, "New Mahaweli Water Resources Development Plan", a schedule as of late February 2009 is as follows;

- Selection of consultant will finish after two months
- The development plan will be prepared two years after commencement (completed in late April 2011)



Source: CEB

Figure 5.3-2 Dams and Reservoirs in the Mahaweli River Basin

5.4 Discharge at Project Site

The inflow to the Victoria reservoir is a total of the release at Polgolla weir and inflow from the residual basin between the Polgolla weir and the Victoria dam. The inflow from the residual basin is not measured, but it can be estimated by the difference between the total discharge from the Victoria dam and release at the Polgolla weir.

The water balance of the Victoria reservoir is shown in **Figure 5.4-1**. According to the discharge data from 1985 to 2006, Polgolla weir received 1,949 MCM of water annually, and 878 MCM was diverted to the Sudu river and the rest of 1,071 MCM is released to downstream and flowing to the Victoria reservoir. While, the total annual discharge at the Victoria reservoir was 1,532 MCM. The difference between the Polgolla weir release and the total release at the Victoria dam is the inflow from the residual basin. The difference is 461 MCM (= 1,532 MCM – 1,071 MCM) and is the annual inflow volume from the residual basin (the estimation method is attached to Appendix-II).

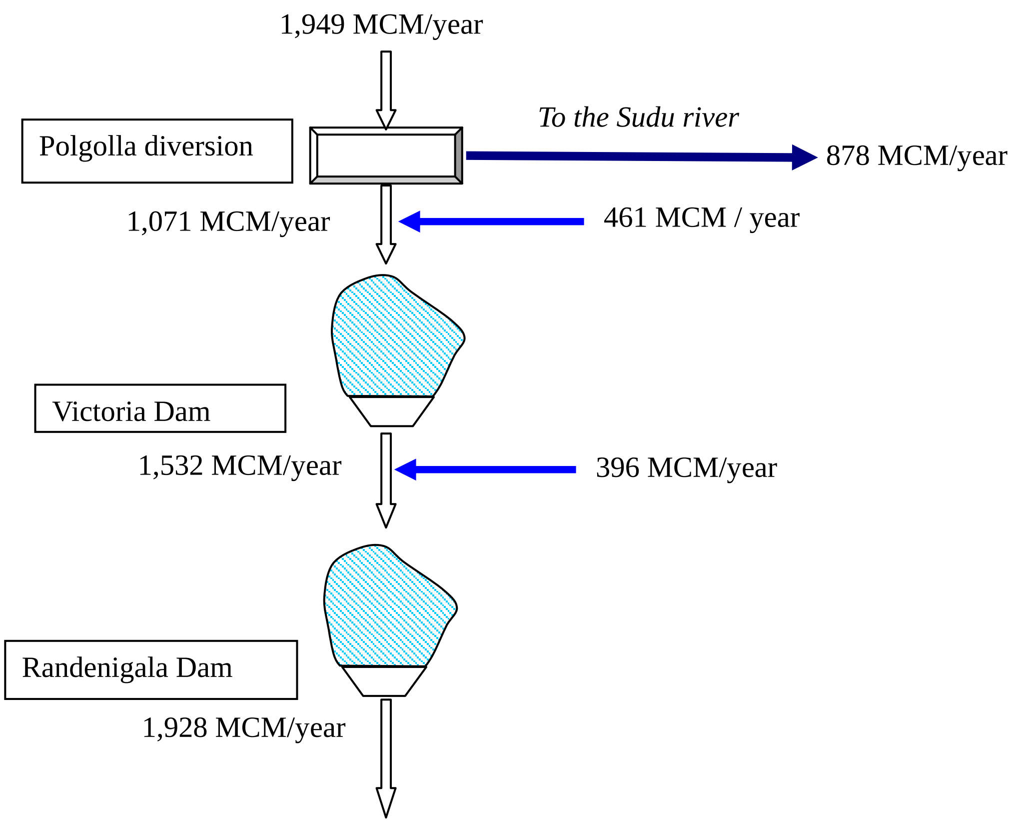
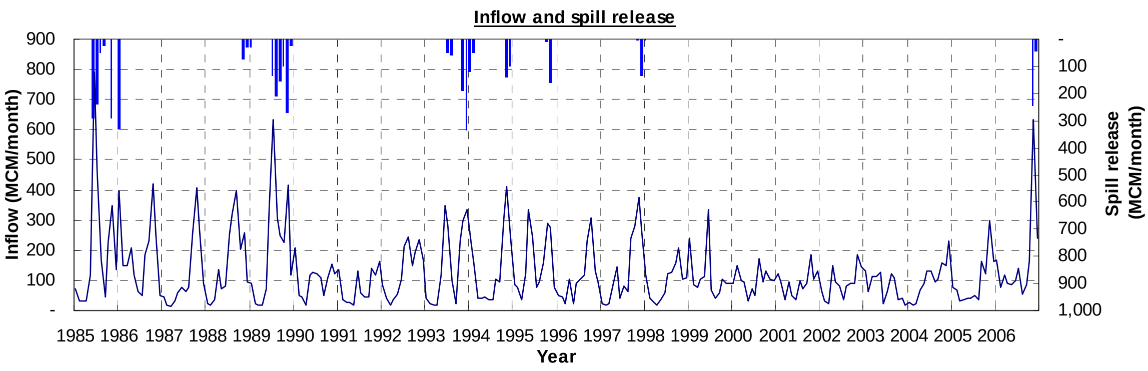


Figure 5.4-1 Water Balance of Victoria and Randenigala System

Of 1,532 MCM of the total annual discharge, 178 MCM per annum was released from spillway or bottom outlet. The inflow and discharge record of the spillway or bottom outlet is shown in **Figure 5.4-2**. The monthly inflow into the Victoria reservoir is tabulated in **Table 5.4-1**. The rest of 1,354 MCM/year was used for the hydropower generation and is equivalent to 42.9 m^3/s.



Source: Victoria Dam Operation Office, MASL

Figure 5.4-2 Inflow to Victoria Reservoir and Spill Release from the Victoria Dam

Table 5.4-1 Inflow to Victoria Reservoir

(Unit: MCM)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1985	72	30	31	31	117	789	464	168	45	227	347	133	2454
1986	395	149	150	209	118	61	51	183	229	418	252	51	2266
1987	42	17	14	32	59	74	64	77	255	404	266	90	1394
1988	22	17	37	135	73	82	254	323	396	201	259	95	1895
1989	88	22	17	20	74	339	630	305	247	225	417	118	2503
1990	208	51	46	18	117	127	121	109	51	109	153	121	1233
1991	136	34	26	26	19	131	59	44	44	141	115	163	939
1992	87	39	18	36	55	105	211	243	150	194	235	164	1535
1993	40	23	18	17	115	347	279	99	23	229	297	334	1822
1994	224	157	40	40	43	36	36	102	96	307	410	237	1728
1995	87	75	36	122	334	244	77	95	157	290	277	75	1867
1996	48	44	24	104	24	90	103	115	229	308	129	95	1314
1997	23	18	21	83	142	40	81	62	240	277	375	263	1625
1998	116	40	33	20	34	60	123	126	157	206	102	108	1124
1999	240	85	77	106	113	335	68	39	56	102	91	91	1404
2000	90	150	97	96	33	72	48	170	93	132	104	100	1183
2001	123	93	36	94	48	38	100	70	90	183	105	128	1109
2002	62	32	24	148	97	82	38	80	92	91	184	142	1073
2003	132	64	115	114	126	23	62	120	109	37	41	20	963
2004	25	17	22	67	89	133	130	93	103	159	150	228	1215
2005	75	68	30	38	41	39	49	34	161	121	295	160	1112
2006	166	78	117	91	86	98	139	54	87	161	631	239	1948
Average	114	59	47	75	89	152	145	123	141	206	238	143	1532

[Supplementary]

The discharge data at the Polgolla diversion and at the Victoria dam provided by MASL were recorded with the actual operation from 1985 to 2006. Therefore, the discharge data given by the MASL is credible for using in the Study.

While there were studies in which the inflow to the Polgolla diversion and that to Victoria reservoir were estimated with a certain method besides actual discharge records in the Mahaweli River. Those studies were "Victoria Scheme Mahaweli Development Project Phase I Pre-F/S" in 1978, and "Mahaweli Water Resources Management Project" in 1985.

The average of the estimated inflow at the Poglolla and at the Victoria dam is summarized below.

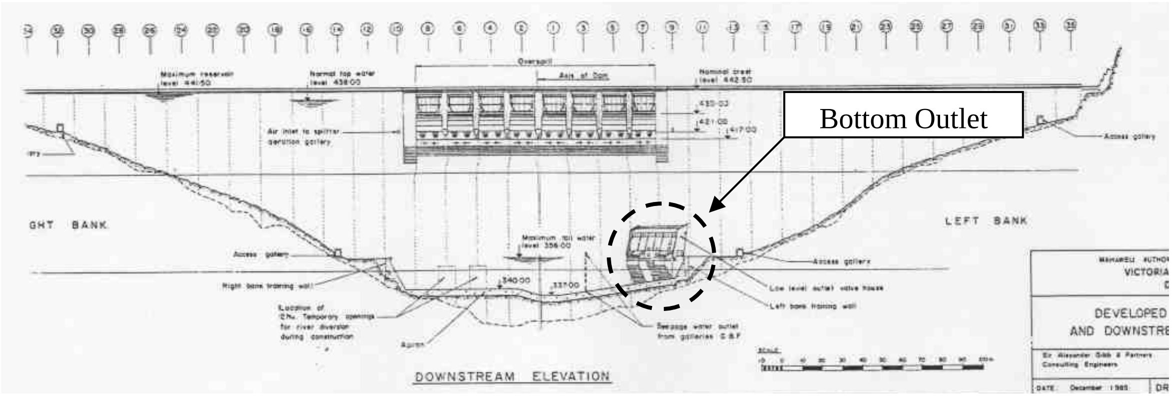
Table 5.4-2 Recorded Inflow Data and Estimated Inflow Data in the Past Studies

Studies	Quantity (MCM/year)	Data source
Victoria Expansion F/S, JICA (2008)		
Inflow at Polgolla Diversion	1,949	Operation record given by MASL.
Diversion at Polgolla	878	- ditto -
Incremental flow at Victoria	461	461 = 1532 – (1949 – 878)
Total Inflow into Victoria Reservoir	1,532	Operation record given by MASL.
Mahaweli Water Resources Management Project, CIDA (1985)		
Inflow at Polgolla Diversion	2,141	Data measured and estimated by NEDECO (1979)
Diversion at Polgolla	947	Operation record
Incremental flow at Victoria	784	Estimated (method unknown)
Total Inflow into Victoria Reservoir	1,978	1978 = 2141 – 947 + 784
Victoria Scheme Mahaweli Development Project Phase I Pre-F/S, UK (1978)		
Inflow at Polgolla Diversion	2,294	Measured data and estimated by multivariate lag-one Markov model.
Diversion at Polgolla	n/a	Diversion quantity was not stated because the study of diversion quantity was out of scope in the study.
Incremental flow at Victoria	1,026	1026 = 3320 – 2294
Total Inflow into Victoria Reservoir	3,320	This figure is **before** deducting the diversion quantity at Polgolla weir.

As shown in the table above, the averages of the estimated inflow in the both studies are larger than that of measured data. Further, the details and assumption of the hydrological studies to derive the inflow data set is unknown. Therefore the data sets presented in the past studies are not used in the Study and the discharge record from 1985 to 2006 given by MASL is used.

5.5 Sedimentation

The bottom outlet is provided in the dam body to discharge sediments in the reservoir. The location of the bottom outlet is shown in **Figure 5.5-1**. The bottom outlet is opened before opening spillway gates during flood operation. According to the dam operation office, the discharging operation usually takes 2 to 3 hours, until the color of the water changes from brown to normal water color, and the bottom outlet is closed. The annual record of discharge from the bottom outlet is shown in **Table 5.5-1**.



Source: Victoria Dam Operation Office, MASL

Figure 5.5-1 Bottom Outlet at Victoria Dam

Table 5.5-1 Spill Release Record at Bottom Outlet and Spillway

	Bottom Outlet Release	Spillway release
	MCM	MCM
1987	0.00	0.00
1988	0.00	104.00
1989	0.00	878.00
1990	0.00	61.00
1991	0.00	0.00
1992	0.00	0.00
1993	0.48	620.00
1994	7.89	424.00
1995	95.14	108.00
1996	1.22	0.00
1997	0.00	141.00
1998	0.03	3.97
1999	0.00	0.00
2000	0.00	0.00
2001	0.00	0.00
2002	0.00	0.00
2003	0.00	0.00
2004	0.00	0.00
2005	0.00	0.00
2006	1.27	288.99
2007	0.01	0.00
Average	5.05	125.19

Source: Victoria Dam Operation Office, MASL

As shown in **Table 5.5-1**, the quantity of the discharge from the bottom outlet is relatively small compared to the reservoir capacity, except 95.14 MCM was released from the bottom outlet in 1995.

According to the dam operation office, sedimentation in the reservoir is not an issue for dam operation. The sedimentation level was surveyed after the construction of Victoria dam and it was confirmed that sedimentation volume in 1995 (10 years after completion) was 1.1% of total reservoir volume. In 2005, the sedimentation of the large reservoirs including the Victoria was briefly examined. The report concluded that the sedimentation in the Victoria reservoir was not significant and no additional countermeasures were needed. Therefore, the sedimentation will be relatively small compared with the reservoir capacity, thus it will not affect the expansion project.

CHAPTER 6

OPTIMIZATION OF THE DEVELOPMENT PLAN

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 6 Optimization of the Development Plan

The objective of the optimization of the development plan is to select the best option among the alternative options, and to optimize the capacity and number of units, and to determine the normal intake water level for the selected option. In this chapter, the methodology, procedure and result of the comparative study of the alternative options are described in **Section 6.1**, and the optimization of expansion plan is described in **Section 6.2**.

6.1 Comparison Study of Alternative Options

The expansion of the Victoria Hydropower Station is composed of a headrace tunnel, a surge tank, penstock(s), and a powerhouse. The water intake was already constructed for the purpose of future expansion of the hydropower facilities during the construction of the existing Victoria dam and hydropower station completed in 1985. One possible option of expansion plan is simply to place these components nearby the existing hydropower facilities, so as referred to as "Basic Option" in the Study. Besides this "Basic Option", following additional two alternatives are envisaged and examined in the Study.

a) To install expansion powerhouse further downstream of the existing powerhouse to increase an effective head (downstream option), and
b) To install pumped storage power station using the Victoria reservoir as an upper reservoir and the Randenigala reservoir as a lower reservoir (pumped storage option).

The comparison study of alternative options is to evaluate each option and to select the best option among the three candidate options.

6.1.1 Alternative Options

(1) Basic Option

The basic option is to place an expansion powerhouse nearby the existing hydropower facilities.

(2) Downstream Option

The downstream option is to place the surface type powerhouse 2 km downstream from the existing powerhouse. Placing the powerhouse in the downstream expects to gain an additional hydraulic head for hydropower generation.

The location of the powerhouse is selected by avoiding expansion plant from being placed on deposited material which is described in **Section 7.2**. Study Team also examined the scenario in which places the new powerhouse in 1 km downstream from the existing powerhouse. This scenario selected underground type powerhouse to avoid deposit material. This underground type and surface type downstream option are compared, and the detail of the comparison study is given in **Appendix-II**.

(3) Pumped Storage Option

The pumped storage option is the pumped storage power plant, using total head of 190 m between the Victoria and the Randenigala reservoirs.

General plan of the alternative options are shown in **Figure 6.1.1-1**.

	Headrace Tunnel Length (km)	Penstock Tunnel Length (km)
Basic Option	5.1	0.7
Downstream Option	8.7	0.4
Pumped Storage Option	9.1	1.8

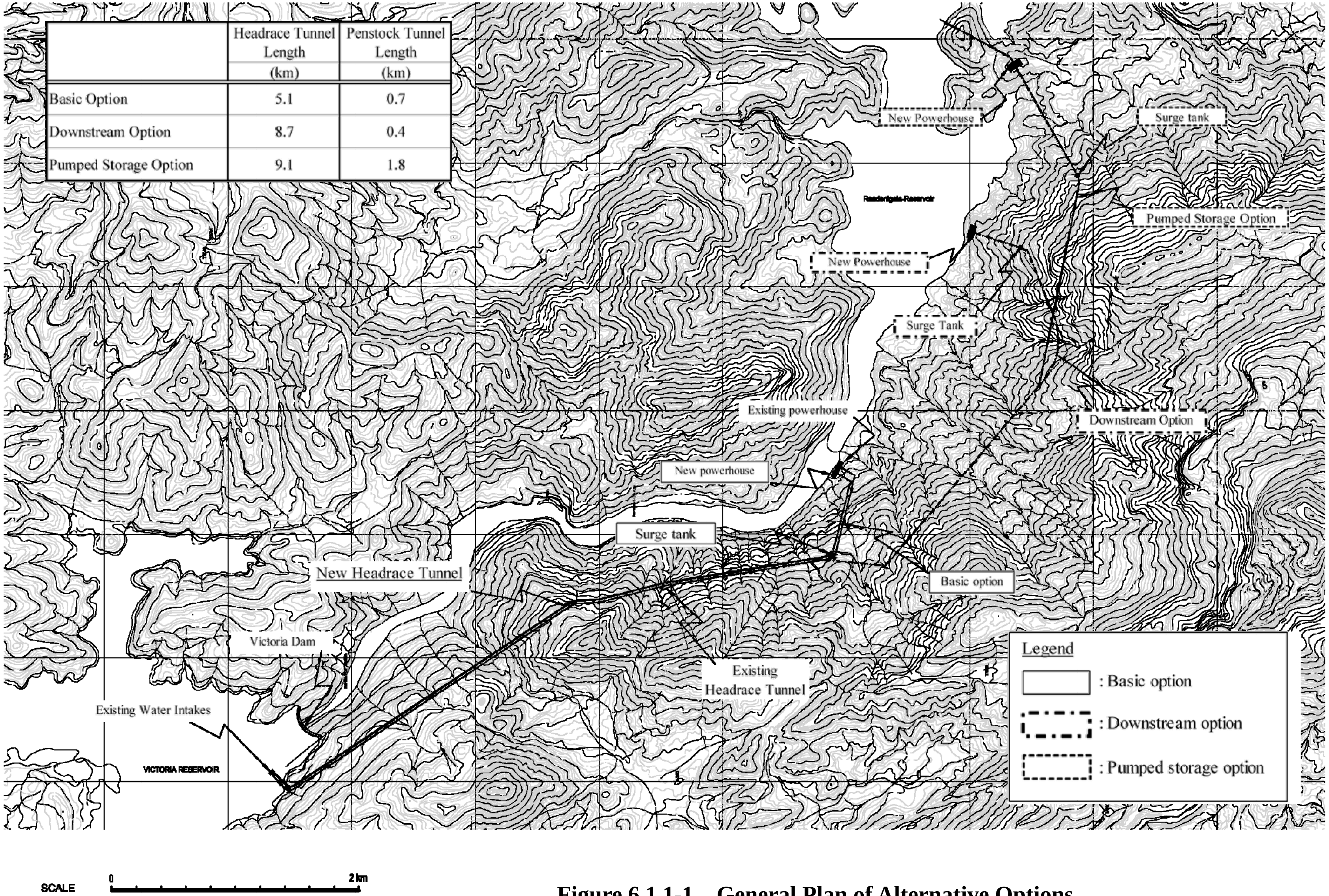


Figure 6.1.1-1 General Plan of Alternative Options

6.1.2 Comparison Method

To formulate the optimum plan among each alternative, Study Team considers (1) economic aspect, (2) construction aspect, and (3) environmental impacts as considered for a feasibility study on hydropower projects.

(1) Economic Aspect

Benefit (B) is annual cost calculated form construction and Operation & Maintenance (O&M) costs of an alternative thermal plant, and cost (C) is annual cost calculated from construction and O&M costs of the new hydropower facilities. The optimal option is determined as that with the maximum B/C.

(2) Construction Aspect

By recognizing the constraints of each alternative, Study Team examines the construction methods for each option and economical impacts to the region due to the limitation of water supply for irrigation and potable water in downstream during construction, if any.

(3) Environmental Impact

Study Team recognizes impacts on the natural and social environment for all alternatives and their countermeasures.

The flow chart of the comparative study is delineated in **Figure 6.1.2-1**.

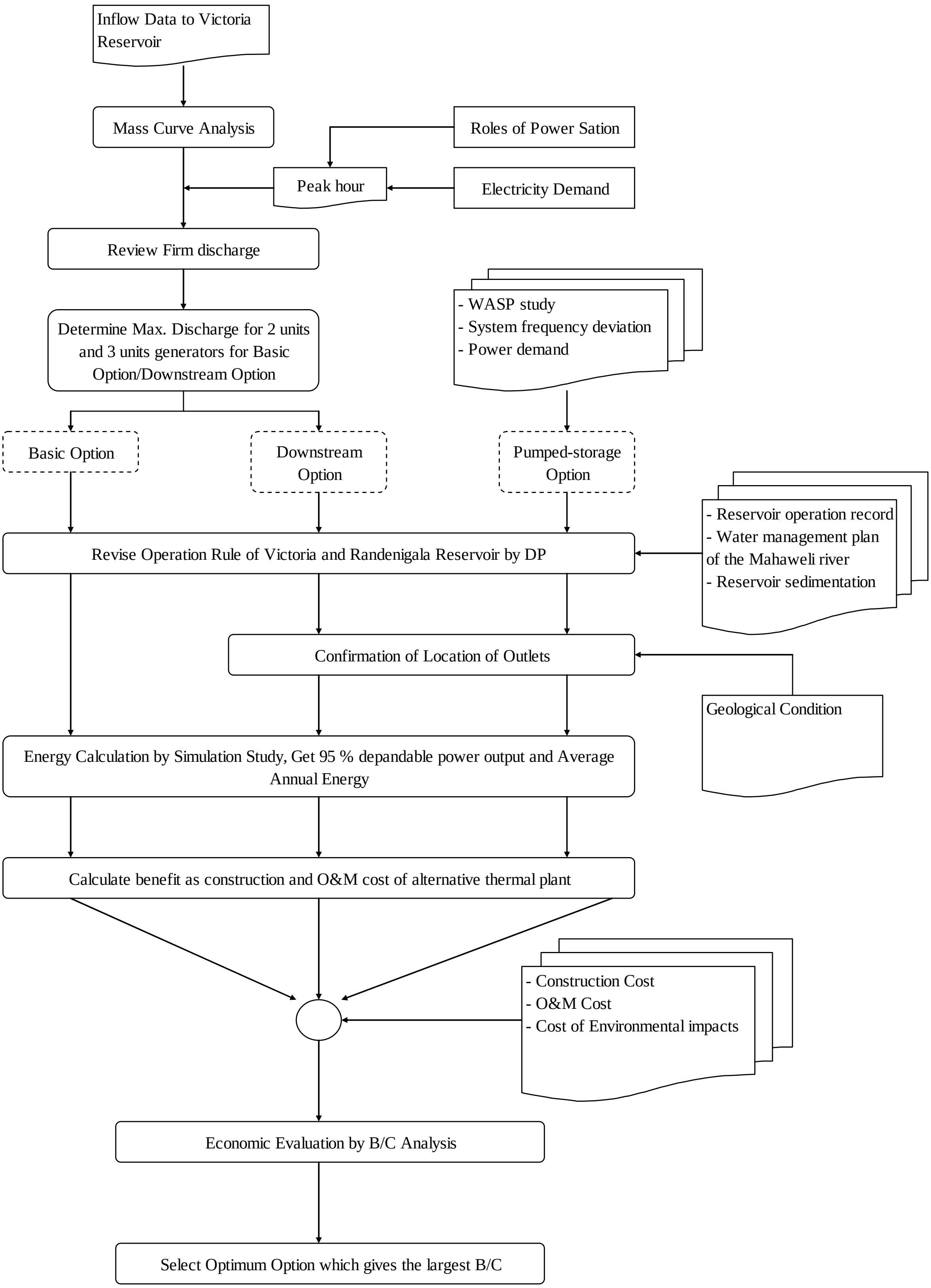


Figure 6.1.2-1 Flow Chart of Comparative Study for Alternative Options

6.1.3 Peak Duration

The storage capacity of the existing Victoria reservoir is over 700 MCM, therefore the operation of the Hydropower Station is possible for both peak or base load.

According to the records of the operation, the Victoria Hydropower Station has been operated not only for peak load but also for base load. It is confirmed for the Study that the Victoria Hydropower Station after the expansion is planned to be operated for peak load to cope with increasing peak demand load in the country.

The equivalent peak duration for the Hydropower Station after expansion is studied based on the daily and annual load curves.

In general there are two methods to examine equivalent peak duration of a reservoir type hydropower project; one is from the viewpoint of power demand, and the other is from aspect of hydropower planning. Because the former is adopted in the Study, the reason why only the former is adopted is mentioned in Appendix II.

(1) Monthly Records of Peak Load

The power demand records do not have remarkable seasonal changes, but the annual maximum demand was recorded in April, May, November, or December. **Figure 6.1.3-1** shows the peak power demand increases firmly year by year.

Table 6.1.3-1 and Figure 6.1.3-1 show monthly peak load in 2003 to 2007.

Table 6.1.3-1 Maximum Demand

(Unit: MW)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	1,413.9	1,434.9	1,455.8	1,454.9	1,453.6	1,455.6	1,450.0	1,445.8	1,491.3	1,491.7	1,483.6	1,515.6
2004	1,510.1	1,492.5	1,515.4	1,531.6	1,506.5	1,501.8	1,513.4	1,532.7	1,525.6	1,524.0	1,559.9	1,563.4
2005	1,583.8	1,625.5	1,646.1	1,644.7	1,748.2	1,642.1	1,633.4	1,682.8	1,716.1	1,724.9	1,673.0	1,711.2
2006	1,718.1	1,758.0	1,796.7	1,817.6	1,892.5	1,789.8	1,754.1	1,764.6	1,784.9	1,791.6	1,700.7	1,750.5
2007	1,788.1	1,799.6	1,837.1	1,800.6	1,829.6	1,803.5	1,814.6	1,816.9	1,802.6	1,805.9	1,840.1	1,835.3

Source: Monthly Review Report, CEB

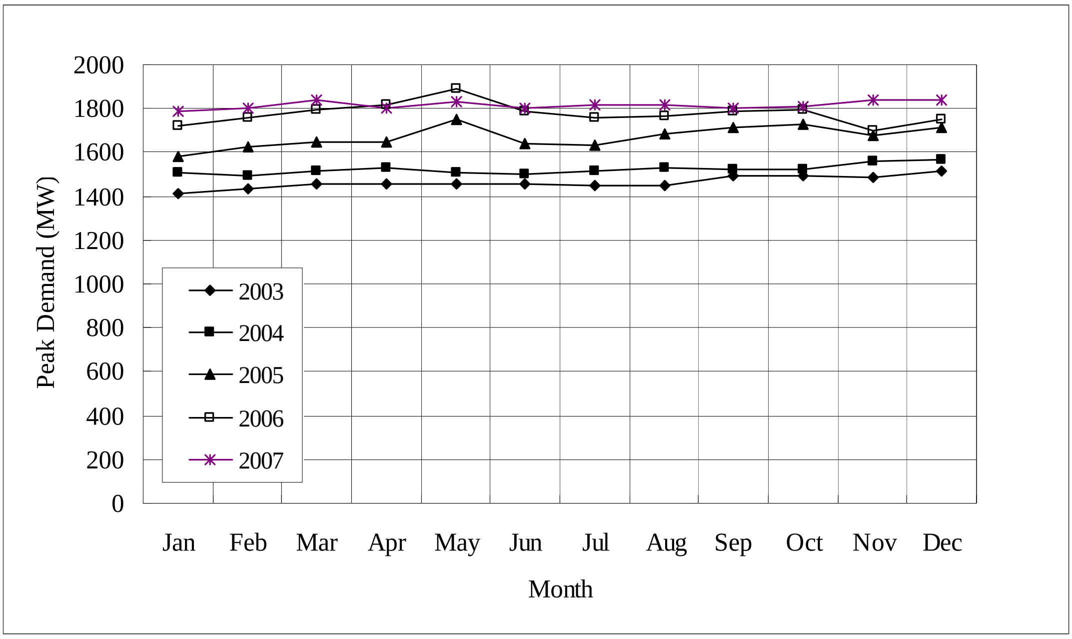


Figure 6.1.3-1 Maximum Demand

(2) Daily Load Pattern

The maximum peak load in the past is 1,922 MW recorded in the night on May 21, 2008. **Figure 6.1.3-2** shows the daily load curves on December 17, 2003 and May 21, 2008 on which the annual peak load was recorded respectively.

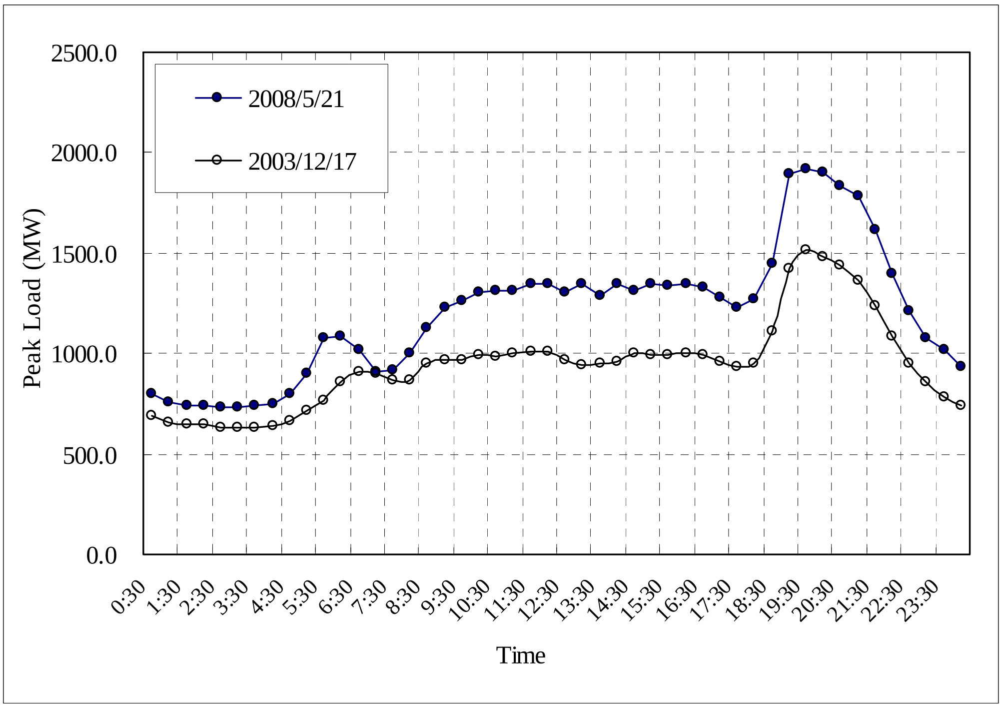


Figure 6.1.3-2 Daily Load Curve (2003/12/17 & 2006/5/15)

The daily load curve shows the peak which was recorded between 18:30 and 22:30 was caused due to typical domestic demand.

According to the survey result of Study Team, constructions of large factories which will affect the load demand are not planed in future; therefore, the said domestic demand pattern is estimated to be continued in future.

(3) Load Duration Curve

1) Daily Load Duration Curve

Figure 6.1.3-3 shows daily load duration curve recorded on December 17, 2003 and on May 21, 2008 on which the annual maximum peak load was recorded. The peak duration is considered as 3 hours.

2) Annual Load Duration Curve

Figure 6.1.3-4 shows annual load duration curve in 2007. It is confirmed that the peak duration is 3 hours.

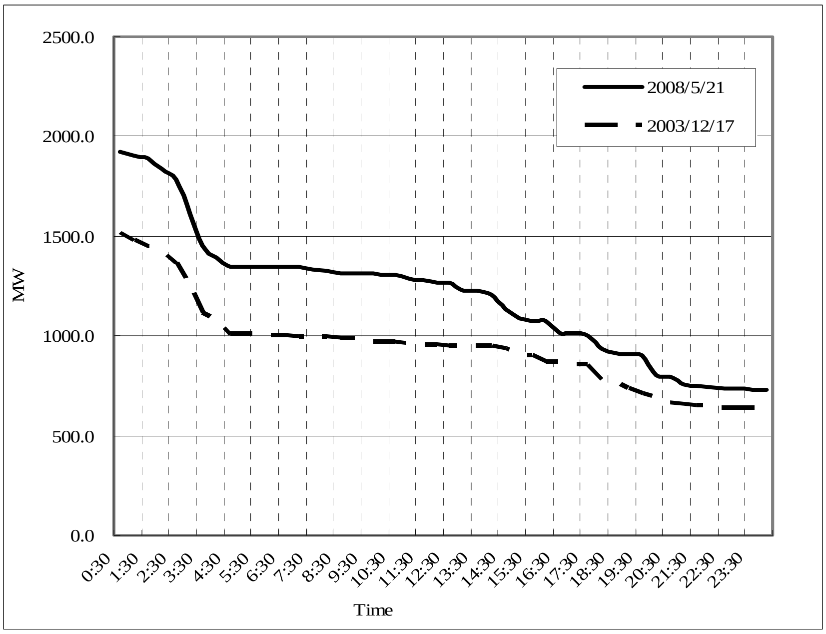


Figure 6.1.3-3 Load Duration Curve (2003/12/17 & 2005/5/21)

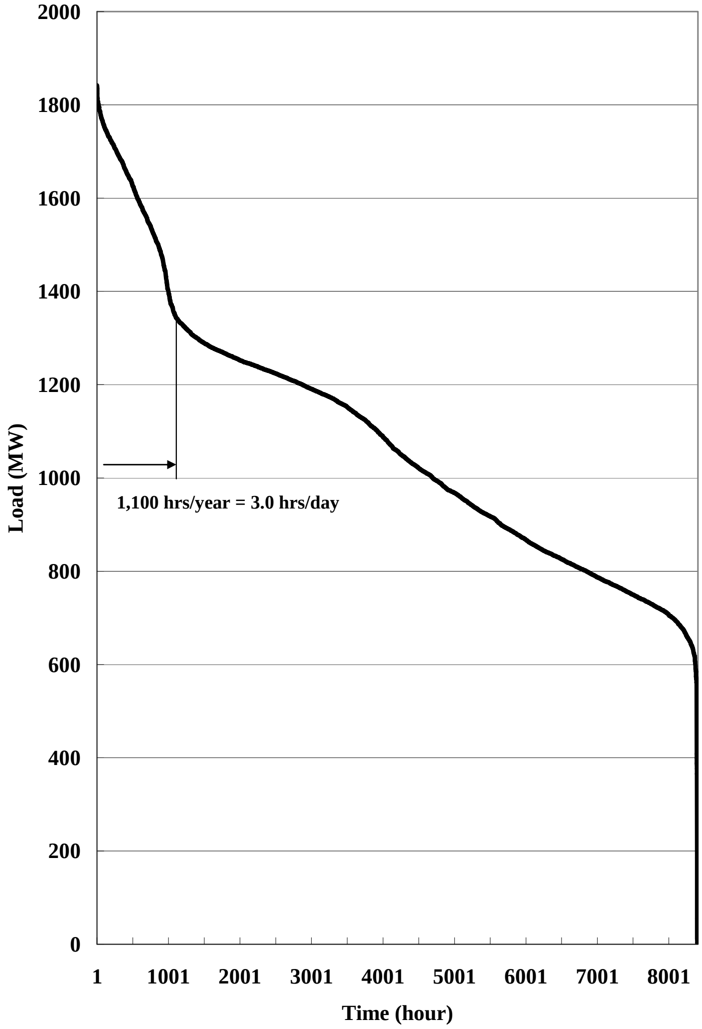


Figure 6.1.3-4 Annual Load Duration Curve in 2007

(4) Equivalent Peak Operation Hours

The peak duration in the country is estimated based on the daily and yearly load duration curve as shown in **Figure 6.1.3-3** and **Figure 6.1.3-4**, and estimated at 3 hours.

This duration pattern is the same as past duration curves and expected to be continued in the future. Therefore the equivalent peak operation hours of the Victoria Hydropower Station are estimated at 3 hours.

Based on the above result, CEB and Study Team, for the Study, agreed that the existing and expansion power plant will supply peak power, and that the equivalent peak duration for both the existing and expansion of Victoria Hydropower Station is fixed as 3 hours.

In general, there are two examination methods for the equivalent peak duration for a storage type hydropower project, namely that from the viewpoint of power demand and that from hydropower planning aspect. In the Study the former is only applied. Appendix-II includes explanatory notes why the former is applied to the examination in the Study.

6.1.4 Scale of Expansion

(1) Maximum Intake Discharge

The maximum intake discharge is determined by the capacity of the existing intake provided for expansion plan. In general, the velocity at the screen of the intake should be limited to less than around 1.0 m/s. Hence, this criterion limits the maximum discharge for expansion as 140 m^3/s, which is the same discharge with the intake of existing Victoria Hydropower Station.

(2) Water Available for Expansion Plant

The available discharge for the hydropower generation for the Victoria Hydropower Station is checked by the mass curve analysis. The data used for the mass curve analysis is a monthly inflow data set from 1985 to 2006. The data is sum of water release to downstream at Polgolla diversion weir given by MASL and residual flow between the Polgolla diversion weir and the Victoria dam.

In the mass curve analysis, the discharge for hydropower generation is determined so as that the reservoir water level is recovered to the full supply level once in several years.

The mass curve prepared for this analysis is shown in **Figure 6.1.4-1**.

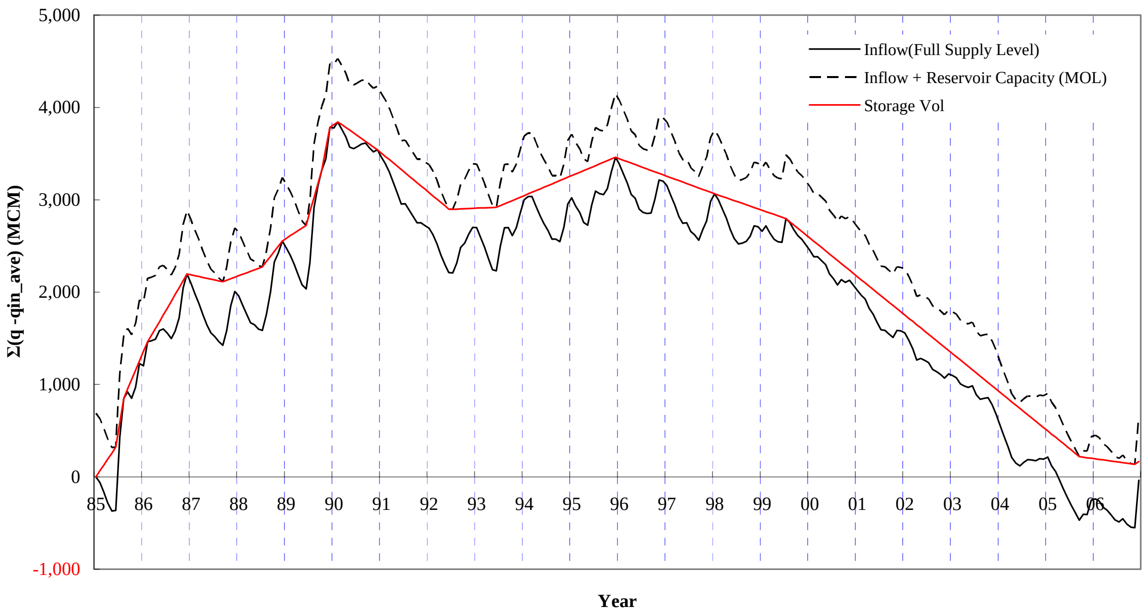


Figure 6.1.4-1 Mass Curve Analysis for the Victoria Hydropower

In planning of hydropower development, it is necessary to determine the firm discharge which is the available discharge for hydropower generation for 24 hours. The firm discharge is equivalent to the 95% dependable discharge of the outflow given in the mass curve analysis showing in **Figure 6.1.4-1**. The 95% dependable discharge is calculated as 35 m^3/s.

After determining the firm discharge, it is necessary to determine the maximum plant discharge. The maximum plant discharge is the maximum discharge of hydropower plant and is determined by the firm discharge and peak hours of generation. The relation among the maximum plant discharge, the firm discharge and peak hours is;

$$Q_{max} = Q_{firm} \times \frac{24}{T} \ (\mathrm{m^3/s})$$

Where,

Q_{max} : Maximum plant discharge ($\mathrm{m^3/s}$)

Q_{firm} : Firm discharge ($\mathrm{m^3/s}$)

T : Peak duration for Victoria Hydropower Station (hour(s))

As mentioned in **Section 6.1.3**, the peak hours appropriate for the Victoria Hydropower Station is 3 hours. In this case, the maximum plant discharge is;

$$Q_{max} = 35 \times \frac{24}{3} = 280 \ (\mathrm{m^3/s})$$

The maximum plant discharge for the existing hydropower generators is 140 $\mathrm{m^3/s}$. Therefore, the residual of 140 $\mathrm{m^3/s}$ is the available discharge for the expansion units. This means that the same amount of discharge used for existing power station is available for the expansion plant.

The concept of the relation of the maximum plant discharge and firm discharge is shown in **Figure 6.1.4-2**.

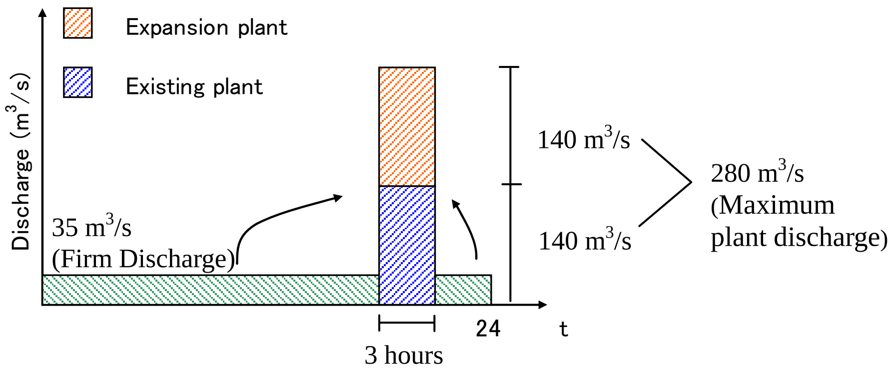


Figure 6.1.4-2
Firm Discharge and Maximum Plant Discharge for Existing and Expansion Plants

(3) Number of Expansion Units for Basic Option and Downstream Option

In this comparative study on the alternative options, it is assumed that the same unit capacity as the existing power station (70MW per unit) is used for expansion power plant. The existing power plant use 46.7 $\mathrm{m^3/s}$ (= 140 $\mathrm{m^3/s}$ ÷ 3 units) per a turbine, because the maximum discharge is 140 $\mathrm{m^3/s}$ with 3 units. Therefore, the maximum number of units is three, and it is assumed 3 units of generators are installed.

In addition, it is also studied when the two generating units are installed for the basic and downstream options. The capacity of discharge for 2 units is 93.4 $\mathrm{m^3/s}$.

Further study for examining the number of units (unit capacity) for the selected option is to be carried out in the optimization of expansion plant which is on the next step of the Study.

(4) Unit Capacity of Pumped Storage Option

The installed capacity of the pumped storage option is expected to be around 210 MW in maximum as the same size of the existing power station. Unit capacity of the option is considered as 210 MW (1 unit), 105 MW (2 units) and 70 MW (3 units), in the case of 210 MW.

The turbine of the pumped storage power station functions as pump during pumping up water. The pump has to be operated in full pumping capacity. Study Team examined affect on commencement of pumping up to the system frequency in the CEB grid.

The Load Shedding is automatically operated when the frequency deviation would be more than 1.25 Hz. Due to this criterion, 210 MW and 105 MW of unit capacity are not allowed to be installed as equipment of the pumped storage option. Hence in this comparative study, 2 units and 3 units of 70 MW class (140 MW and 210 MW in total, respectively) are examined for the pumped storage option.

(5) Study Scenarios

As described in the previous sections, Study Team conducted comparative study for 2-unit and 3-unit expansion with 3 hours as peak duration. The scenarios employed in the Study are shown in **Table 6.1.4-1**.

Table 6.1.4-1 Study Scenarios

		Basic Option		Downstream Option		Pumped Storage Option	
Number of units	(units)	3	2	3	2	3	2
Maximum plant discharge	(m^3/s)	140	93.4	140	93.4	140	93.4

6.1.5 Definition of Components of Each Option

Plan and profile of each alternative option are shown in **Figure 6.1.5-1** to **Figure 6.1.5-3**.

(1) Tunnel Alignment

1) Required Rock Cover above Headrace Tunnel

In order to confine the internal pressure of the water conveyance tunnel, it is required to have enough rock cover above the tunnel roof. For determining alignment of the headrace tunnel, the tunnel alignment is laid on where ground surface elevation is EL. 450 m or higher on the topographic maps.

2) Tunnel Length

The tunnel alignment was determined in consideration of rock coverage and elevation of sill of the outlet and location of the powerhouse which is described in the following section. The tunnel alignment is shown in **Figure 6.1.1-1**. The tunnel length of each option is estimated as shown in **Table 6.1.5-1**.

Table 6.1.5-1 Tunnel Length of Each Option

(km)

Basic Option	Downstream Option	Pumped Storage Option
5.8	9.1	10.9

It is noted that the pumped storage option has almost double length of the basic option, and the downstream option has 1.6 times as long as that of the basic option.

(2) Power Discharge

The maximum plant discharge per generator is 46.7 m^3/s as described in **6.1.4 (2)**. Therefore, 3-unit expansion plan uses 140 m^3/s, and 2-unit expansion plan uses 93.4 m^3/s.

(3) Location of the Outlets and Powerhouse

The location of the powerhouse and outlet is selected in consideration of topographical condition.

1) Basic Option

The basic option places the new powerhouse next to the existing hydropower station. Therefore, the outlet installed adjacent to the existing tailrace. The location of the planned powerhouse is shown in **Figure 6.1.5-1**.

2) Downstream Option

During the first work in Sri Lanka, Study Team visited the candidate site of CEB's planned downstream powerhouse. Later, Study Team checked the topographic map and geological condition around the candidate site, and determined to place the powerhouse adjacent to it. The location of the planned powerhouse is shown in **Figure 6.1.5-2**.

3) Pumped Storage Option

The location of the powerhouse for the pumped storage option is determined by checking topographic map of the Randenigala reservoir. Study Team obtained the topographic map which was made before the Randenigala dam was constructed. Therefore, the map shows the information of the elevation of the ground surface within the Randenigala Reservoir. Study Team used the topographic map and located the candidate site to install the outlet of the pumped storage option in the Randenigala reservoir. The location of the planned powerhouse is shown in **Figure 6.1.5-3**.

(4) Sill Elevation of Outlet

The sill elevation is the elevation of the foundation of the tailrace of powerhouse, and is determined by the elevation of tail water level. For the Victoria hydropower expansion plant, the water level of the Randenigala reservoir affects the tailrace water level of new powerhouse. The operation rule of the Randenigala reservoir is an important factor to determine the tailrace water level of the new powerhouse. The definition of water levels of the Randenigala reservoir is shown in **Table 6.1.5-2**.

Table 6.1.5-2 Randenigala Reservoir Water Level

Water level	Elevation (m)	Storage (MCM)
Maximum Flood Level	236.2	n.a.
Design Flood level	234.5	n.a.
Retention Level (FSL)	232.0	860
Drawdown Level	220.0	590
Exceptional Drawdown Level	203.3	295

Source: "Randenigala Project, Mahaweli Ganga Development, Randenigala and Rantembe Headworks and Power Stations, Part D: Design Report" Joint Venture Randenigala, Salzgitter Consult GMBH, Salzgitter, Agrar-Und Hydrotechnik GMBH, Essen, Electrowatt Engineering Serices Ltd. Zuerich, November 1981

Study Team collected information of the Randenigala reservoir water level at Randenigala Hydropower Station as follows;

- After the Rantambe reservoir was constructed, the drawdown level at EL. 220 m of the Randenigala reservoir had no role on operational aspect, and the exceptional drawdown level has been functioned as minimum operation level.
- However, generation equipment of the Randenigala Hydropower Station has an actual lower limit of the reservoir water level of EL. 209 m.
- In the usual reservoir operation, water level of the Randenigala reservoir is lowered up to EL. 207 m by using the bottom outlet.

Based on the above information, the minimum water level of the Randenigala reservoir for the downstream option is considered as EL. 209 m which is minimum operating level for the Randenigala hydropower station. For the pumped storage option, the minimum water level is the lowest recorded water level in order to enable pumping-up operation at the low water level. Therefore the minimum water level of the pumped storage option is considered as EL. 207 m. In the case of the basic option, the minimum water level of the reservoir does not affect the outlet layout, because the outlet for expansion is installed approximate same elevation as the existing outlet of the Victoria Hydropower Station.

In consideration of the information collected from the Randenigala hydropower station and the aforesaid minimum water level of the Randenigala reservoir, the sill elevation of each option is suggested as below.

1) Basic Option

Sill elevation is same as that of the existing powerhouse, i.e. EL 230 m.

2) Downstream Option

To gain the gross head, the sill elevation is set as low as possible. The lowest operation water level of the Randenigala reservoir is EL 209 m. About 4 m of draft head is required for hydropower mechanics. Therefore EL 205 m is sill elevation of the outlet.

3) Pumped Storage Option

Sill elevation should be set to below double size of outlet diameter from the lowest water level of the Randenigala reservoir, EL. 207 m. The diameter of outlet will be about 6 m. The sill elevation becomes around EL. 195 m.

(5) Hydraulic Head

1) Gross Head

Gross head is a difference of elevation between the normal intake water level and tailrace water level. The gross head of each alternative option is defined as below.

a) Basic Option

Normal water level:

(EL. 438 m – EL. 370 m) × 2/3 + 370 m ≈ EL. 415 m

Tailrace water level is EL. 232 m.

Gross head : EL.415 m – EL. 232 m = 183 m

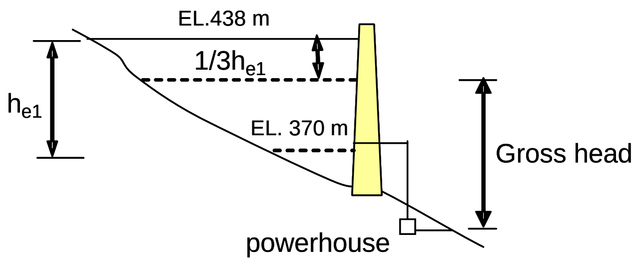


Figure 6.1.5-4 Gross Head of Basic Option

b) Downstream Option

Normal tail water level for the Randenigala reservoir:

(EL. 232 m – EL. 209 m) × 1/2 + EL. 209 m ≈ EL. 221 m

Gross head : EL.415 m – EL.221 m = 194 m

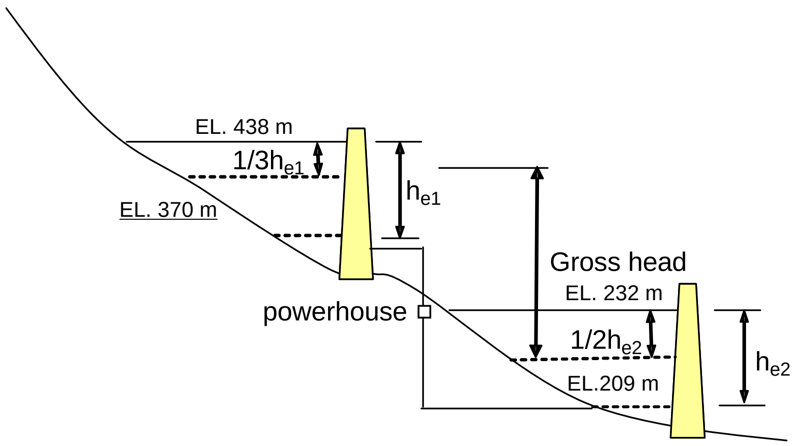


Figure 6.1.5-5 Gross Head of Downstream Option

c) Pumped Storage Option

Normal tail water level of the Randenigala reservoir:

(EL. 232 m – EL. 207 m) × 2/3 + EL. 207 m ≈ EL. 224 m

Gross head : EL. 415 m – EL. 224 m = 191 m

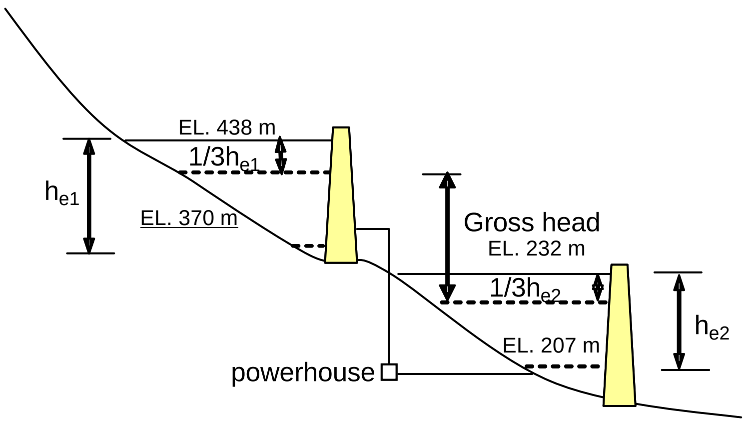


Figure 6.1.5-6 Gross Head of Pumped Storage Option

2) Effective Head

The effective head is used for obtaining the hydropower generation output, and the power output is expressed by the following equation.

P [kW] = $g \times \varepsilon \times Q \times He$

Where,

g	:	gravity acceleration [m/s^2]
ε	:	generation efficiency
Q	:	discharge [m^3/s]
He	:	effective head [m]

The effective head is obtained by deducting head loss from the gross head. Head loss indicates a head is lost while water flows down from intake to outlet and is incurred by the friction and various flow disturbances such as intake, branches of waterway, etc. Head loss, however, is mainly caused by the friction in the case of long waterway. The head loss is generally expressed by the function of discharge. The head loss of each option is estimated as shown in the **Table 6.1.5-3**.

Table 6.1.5-3 Head Loss of Each Option

	# of units	Equation	Maximum head loss
Basic Option	3	$6.76 \times 10^{-4} Q^2$	13.2 m
	2	$1.81 \times 10^{-3} Q^2$	15.8 m
Downstream Option	3	$9.73 \times 10^{-4} Q^2$	19.1 m
	2	$2.61 \times 10^{-3} Q^2$	22.8 m
Pumped Storage Option	3	$1.32 \times 10^{-3} Q^2$	25.8 m
	2	$3.65 \times 10^{-3} Q^2$	31.8 m

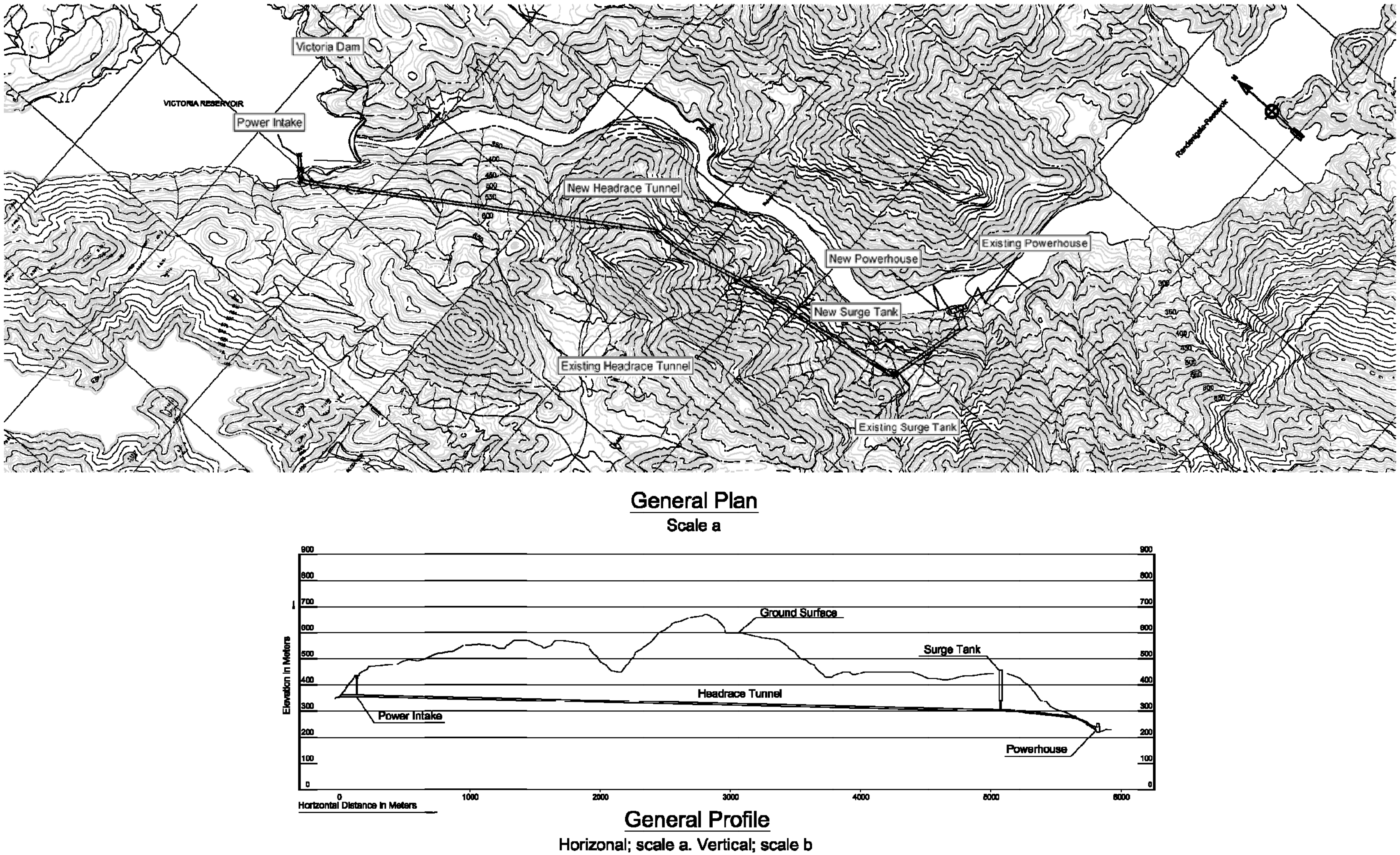
Note: Q = 140 m^3/s for 3 units and 93.7 m^3/s for 2 units

In this case, the effective head of each option is as shown in **Table 6.1.5-4**:

Table 6.1.5-4 Effective Head of Each Option

	# of units	Gross Head (m)	Head loss (m)	Effective Head (m)
Basic Option	3	183	13.2	170
	2		15.8	167
Downstream Option	3	194	19.1	175
	2		22.8	171
Pumped Storage Option	3	191	25.8	165
	2		31.8	159

Table 6.1.5-4 shows that effective heads of pumped storage option gives the lowest due to the longest tunnel, and downstream option gives the largest in value.



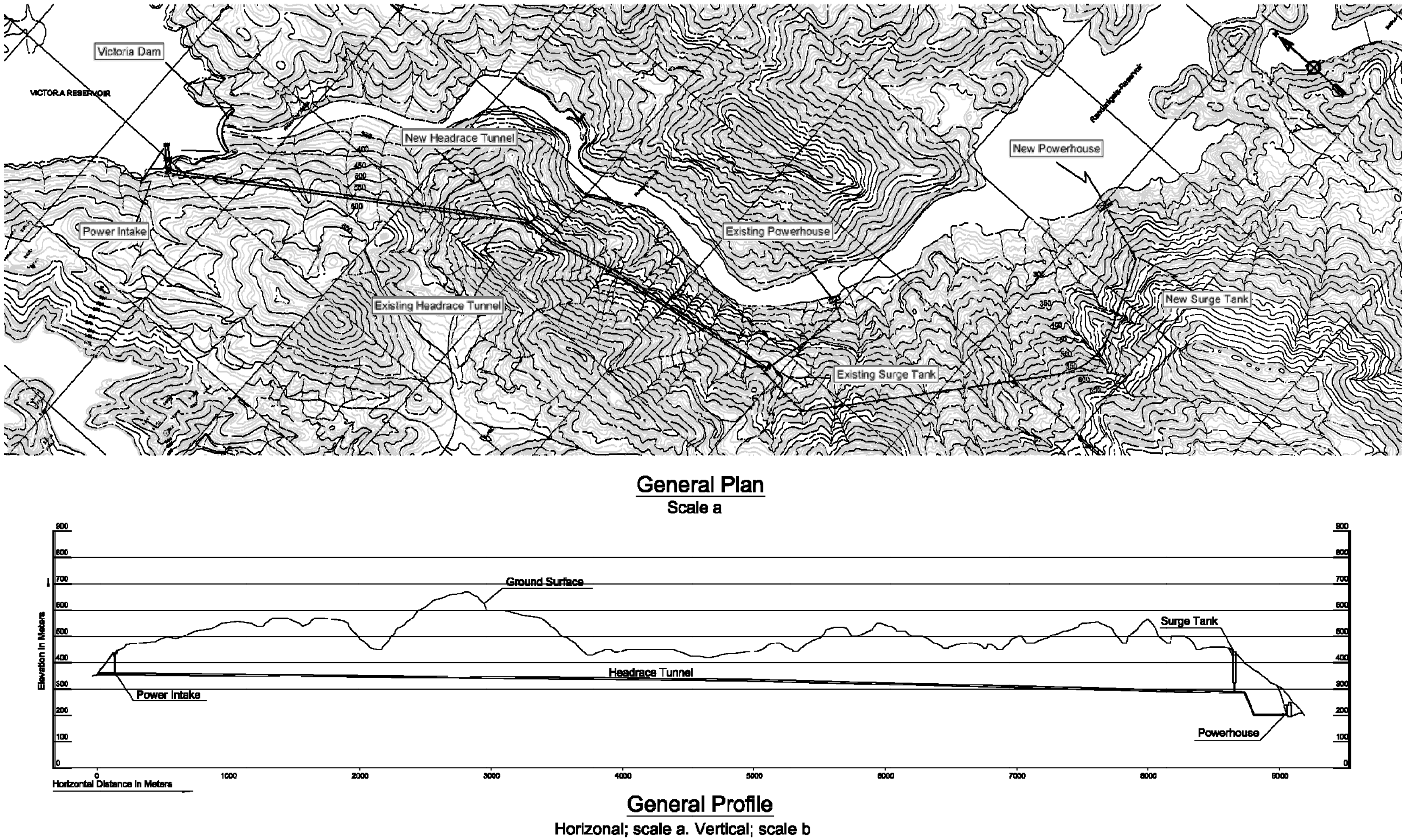
SCALE a 0 2 km

SCALE b 0 1 km

Figure 6.1.5-1 Basic Option: General Plan and Profile

Fesibility Study for Expansion of Victoria Hydropower Station

Basic Option, General Plan and Profile



SCALE a 0 — 2 km

SCALE b 0 — 1 km

Figure 6.1.5-2 Downstream Option: General Plan and Profile

Fesibility Study for Expansion of Victoria Hydropower Station
Dowsntream Option, General Plan and Profile

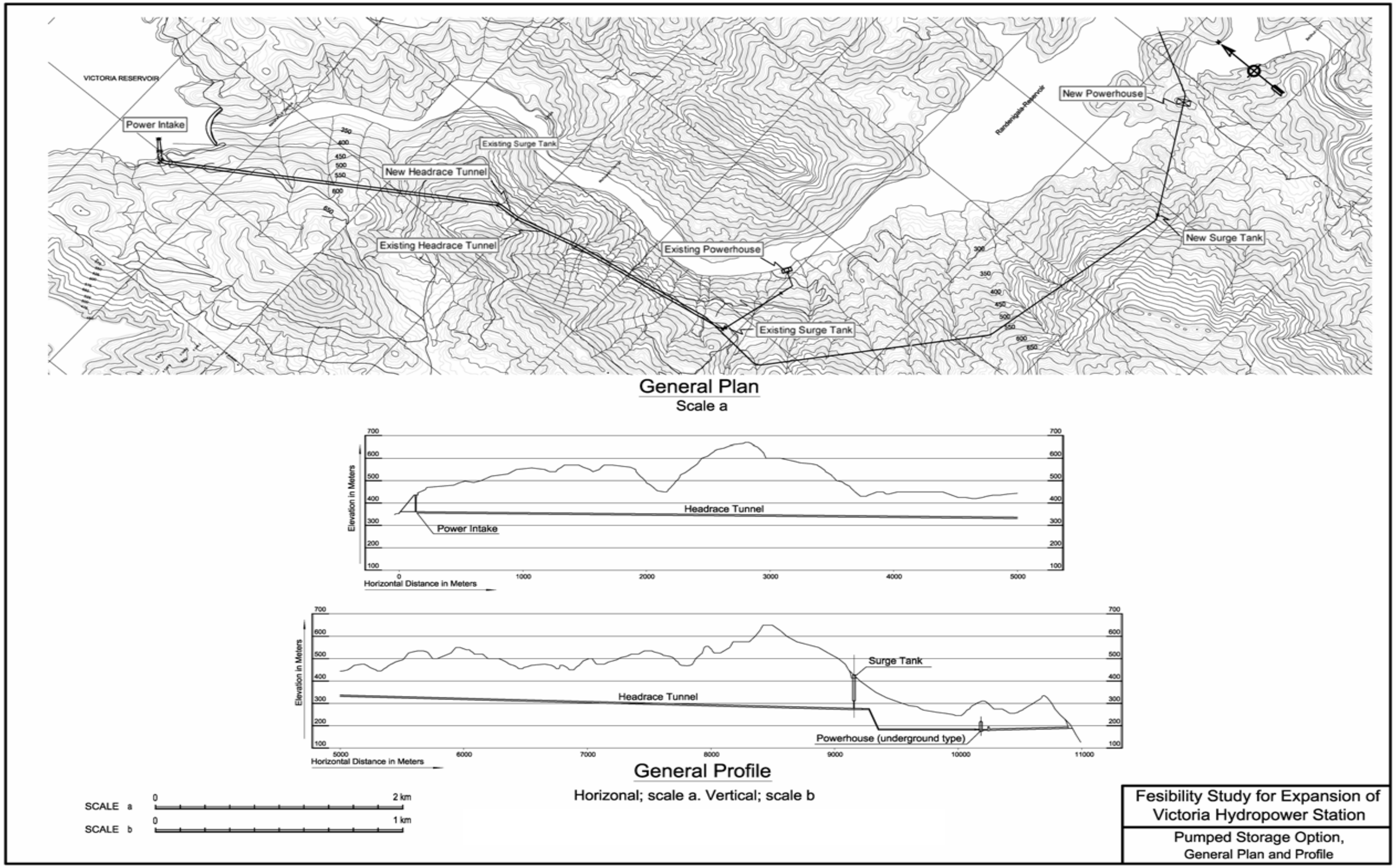


Figure 6.1.5-3 Pumped Storage Option: General Plan and Profile