1.3.4 GEOLOGICAL CHARACTERISTICS OF THE PILOT GNDS

Geology of the 15 Pilot GNDs are described below.

(1) Hambegamuwa (M-1)

Hambegamuwa is situated on the gentle slope of 0.3 or less degree at from 80 to 140 m above sea level, which is classified into Micro Relief Planation Surface in geomorphology. It is on the upper to middle reaches of Warawe Ganga. In the western border of Vijayan Complex where this Pilot GND is located, the synclinal axes of Handagiriya-Mahagawa Synform and Hambegamuwa-Mahagala Synform and Gomawiodagala-Ambvalantota Shear Zone exist in the NW-SE direction. Gneiss and migmatite of Vijayan Complex are distributed and the beds strike N45W and dip 30-50W. The lineaments are predominant in the direction of NW-SE and its oblique direction of NEE-SWW.

(2) Bodagama (M-2)

Bodagama is in the area about 90 m in the elevation between Malala Oya and Kirindi Oya, which is a gentle slope of 0.5 degree and classified into Micro Relief Planation. Bodagama Synform, Vhragala Antiform and shear zone in NW-SE direction cross the area located in the east of Vijayan Complex. Gneiss and migmatite are distributed and the beds strike NW-SE and dip 30-50W. The lineaments are predominant in the strike direction.

(3) Hulandawa Left (M-3)

Hulandawa Left is located on the upper to middle reaches of Kunbukkan Oya at the south foot of Monaragala Range. The area is the flat land of the highest part of Micro Relief Planation from 120 to 160 m in elevation. The shear zone in NNW-SSE direction crosses the GND underlain by the Vijayan Complex. The beds strike NNW-SSE and dip 40-60W. The lineaments are predominant in the strike direction.

(4) Unawatuna (M-4)

Unawatuna is located on the upper to middle reaches of Menic Ganga at about 180 m in elevation where the hilly area close to the north. It is classified into the Micro Relief Planation Surface and is the marginal area of the Vijayan Complex distributed by gneiss and migmatite. On the east, the shear zone develops in NS direction and the alluvial deposit is partly distributed along Menic Ganga. The beds strike NS and dip 45W. The lineaments are predominant in the strike direction.

(5) Yalabowa (M-5)

Yalabowa is located on the upper reaches of Kirindi Oya at from 180 to 200 m in elevation. The elevation increases up to 300 m to the west at the border of the district. Nakkala Udumulla Shear Zone crosses the central area in NE-SW direction. The Vijayan Complex, mainly gneiss, occurs in the east and the highland complex is in the west. The beds strike NNE and dip 20-40W. The lineaments are predominant in the strike and EW direction.

(6) Badalkumbura (M-6)

It is located on the hill of the eastern edge of the Highland Complex at about 300 m in elevation between Kumbukkan Oya and Menic Ganga. Mudagahapatt Synform in NS direction and Naranwatta-Yatimulla Shear Zone in NE-SW direction cross the area where alternating beds of quartzofeldspatic and charnockitic gneiss are distributed. The beds strike NS and dip 30W. The lineaments are predominant in NS direction.

(7) Sevanagala (M-7)

It is located on the central area of the middle reaches of Walawe Ganga, which is classified to Micro Relief Planation at from 60 to 70 m in elevation in the western border of the Vijayan Complex. The alternating beds of some types of gneiss are distributed and the beds strike

NW-SE and dip 20-40W. Handagiriya-Mahagama Synform crosses the center of the area. There is a basin structure leaning towards NW near the synclinal axis. The lineaments are predominant in the strike and NW-SE direction.

(8) Keliyapira (H-1)

It is located on the lower reaches of Malala Oya, whch is classified to Micro Relief Planation at about 10 m in elevation in the south end of the Vijayan Complex. The area gently leans toward the east. The alternating beds of some types of gneiss are distributed and the beds strike NNW-SSE and dip 35-45W. Gomawiodagala-Ambalantota Shear Zone cross the eastern area in NNW-SSE direction. The lineaments are predominant in the strike and its orthogonal direction.

(9) Vitharandeniya (H-2)

It is located on the central valley of Rekawa Oya at about 10m in elevation, which is Micro Relief Planation sloping gently to the east. The area is in the Ranna rock unit. The alternating beds of gneiss of Highland Complex and Vijayan Complex are distributed and the beds strike EW and dip 20-40S along Denagama-Bedigama Antiform extending from east to west.

(10) Talunna (H-3)

It is located between Rekawa Oya and Urubokka Oya at about 40 m in elevation, which is classified to Micro Relief Planation sloping gently to the southwest. The area is in the Ranna rock unit. The alternating beds of gneiss of Highland Complex and Vijayan Complex are distributed and the beds strike NWW-SEE and dip 50-60S. The lineaments are predominant in the strike and its orthogonal direction.

(11) Wediwewa (H-4)

It is located on the gentle slope to the west in the eastern lower reaches of Walawe Ganga at from 20 to 50 m in elevation, which is classified to Micro Relief Planation in the southern Vijayan Complex. The alternating beds of some types of gneiss are distributed and the beds strike NNW-SSE and dip 20-40N. Kiribanara-Suriyawewa Antiform and Gonawiddagala -Ambalantota Shear Zone cross the region. The lineaments are predominant in the strike and its orthogonal direction.

(12) Tammennawewa (H-5)

It is located in the middle reaches of Malala Oya near the border of Embilikaya Oya Basin. The area is at about 40 m in elevation and classified into Micro Relief Planation. Gneiss of the Vijayan Complex are distributed and the beds strike NNW-SSE and dip 30W. The lineaments are predominant in ENE-WSW direction.

(13) Pahala Mattala (H-6)

It is located on the middle reaches of Malala Oya at from 40 to 80 m in elevation, which is classified into Micro Relief Planation. The alternating beds of some types of gneiss of the Vijayan Complex are distributed and the beds strike NNW-SSE and dip 20-30W. Hambegamuwa-Mahagata Synform cross the center of the area in NNW-SSE direction. The lineaments are predominant in the strike and its orthogonal direction.

(14) Siymbalagaswila North (H-7)

It is located on the central valley in the lower reaches of Walawe Ganga at 10 m or less in elevation, which is classified into River Plane in the southwestern end of the Vijayan Complex. Gneiss is distributed and the beds strike NNW-SSE and dip 40-50W. Gonawiddagala -Ambalantota Shear Zone develops and the lineaments are predominant in the strike and EW direction.

(15) Ranna West (H-8)

It is located on the gentle slope to the southwest at from 10 to 20 m in elevation in the lower central reaches of Urubokka Oya. The area is in the part of Ranna rock unit distributed by Gneiss of Vijayan Complex. The alluvial deposit is distributed about 1 km in width along Urubokka Oya. Shear zones develop in NS direction along the curving Urubokka Oya and the lineaments are predominant in the same directions.

SUPPORTING 2 METEOROLOGY AND HYDROLOGY

2.1 INTRODUCTION

2.1.1 OBJECTIVES OF METEOROLOGICAL AND HYDROLOGICAL STUDY

Meteorological and hydrological analysis was carried out by using collected existing data. Macro water balance of the area was examined to determine the potential recharge of the groundwater. Objectives of the study are;

- To analyze a potential groundwater recharge from rainwater, from the viewpoints of topography and rainfall,
- To analyze a potential groundwater recharge from surface water bodies, and, as a result,
- To provide basic information for the groundwater management plan

2.1.2 BASIS OF THE STUDY

The study was conducted on the following basis:

- Target areas of water supply are the GNDs in Monaragala and Hanbantota districts.
- Major use of groundwater is domestic use.
- Unit of hydrological and hydraulic analysis is a river basin taking the water balance into account.
- This hydrological study focuses water volume.

Meanwhile, the drought occurred in Hambantota in 2001 has a close relationship to this Study in the hydrological aspect. The details of this event is briefed in *Appendix A*.

2.1.3 RIVER SYSTEM AND HYDROLOGICAL STATIONS

There are 23 river basins in the Study area, having a total catchment area of 11,120 km^2. The rivers related to this study are listed in *Table 2.1.*

There are 34 available rainfall stations and eight river discharge gauging stations in and around the Study area. Major data and information collected from the Meteorological Department, Irrigation Department, NWSDB, the GND offices, the residents, and WRB are as follows:

- Hydrological stations (rainfall stations and runoff discharge gauging stations) and river systems related to the Study area (refer to *Figure 2.1*),
- Monthly rainfall at 34 stations and monthly river discharge at eight stations located in and around the Study area for the recent 12 years (refer to *Table 2.2*),
- Rainfall and runoff calculations of the river discharge stations in Sri Lanka, under present land use and water use conditions,
- Annual irrigation water consumption of major tanks (reservoirs) in the Study area for the recent three years,
- Water supply conditions, problems with domestic water use, population of GND, etc.

Table 2.1 Rivers in the Study Area

No	Name of River	Catchment Area (km^2)	Number of Tanks in the Catchment	Related Districts and Areas
13	Sinimodera Oya	39	9	Hambantota
14	Kirama Oya	225	206	Hambantota
15	Rekawa Oya	76	113	Hambantota
16	Urubokka Oya	352	182	Hambantota
17	Kachchigala	223	150	Hambantota
18	Walawe Ganga	2471	777	Hambantota, Monaragala
19	Karagan Oya	58	28	Hambantota
20	Malala Oya	404	378	Hambantota, Monaragala
21	Embilikala Oya	60	20	Hambantota
22	Kirindi Oya	1178	334	Hambantota, Monaragala
23	Banbawe Ara	80	27	Hambantota, Yala National Park
24	Mahasiliwa Oya	13	5	Hambantota, Yala National Park
25	Butawa Oya	39	18	Hambantota, Yala National Park
26	Menik Ganga	1287	294	Hambantota, Monaragala, Yala National Park
27	Katupila Ara	87	45	Hambantota, Yala National Park
28	Kurundu Ara	132	35	Hambantota, Yala National Park
29	Nabadagas Ara	109	9	Hambantota, Yala National Park
30	Karamba Ara	47	2	Hambantota, Yala National Park
31	Kumbukkan Oya	1233	61	Monaragala, Yala National Park
32	Bagura Oya	93	19	Monaragala, Yala National Park
35	Wila Oya	490	65	Monaragala
36	Heda Oya	611	55	Monaragala
44	Gal Oya	1813	91	Monaragala
	Total	11,120	2,923	

Source: Irrigation Department

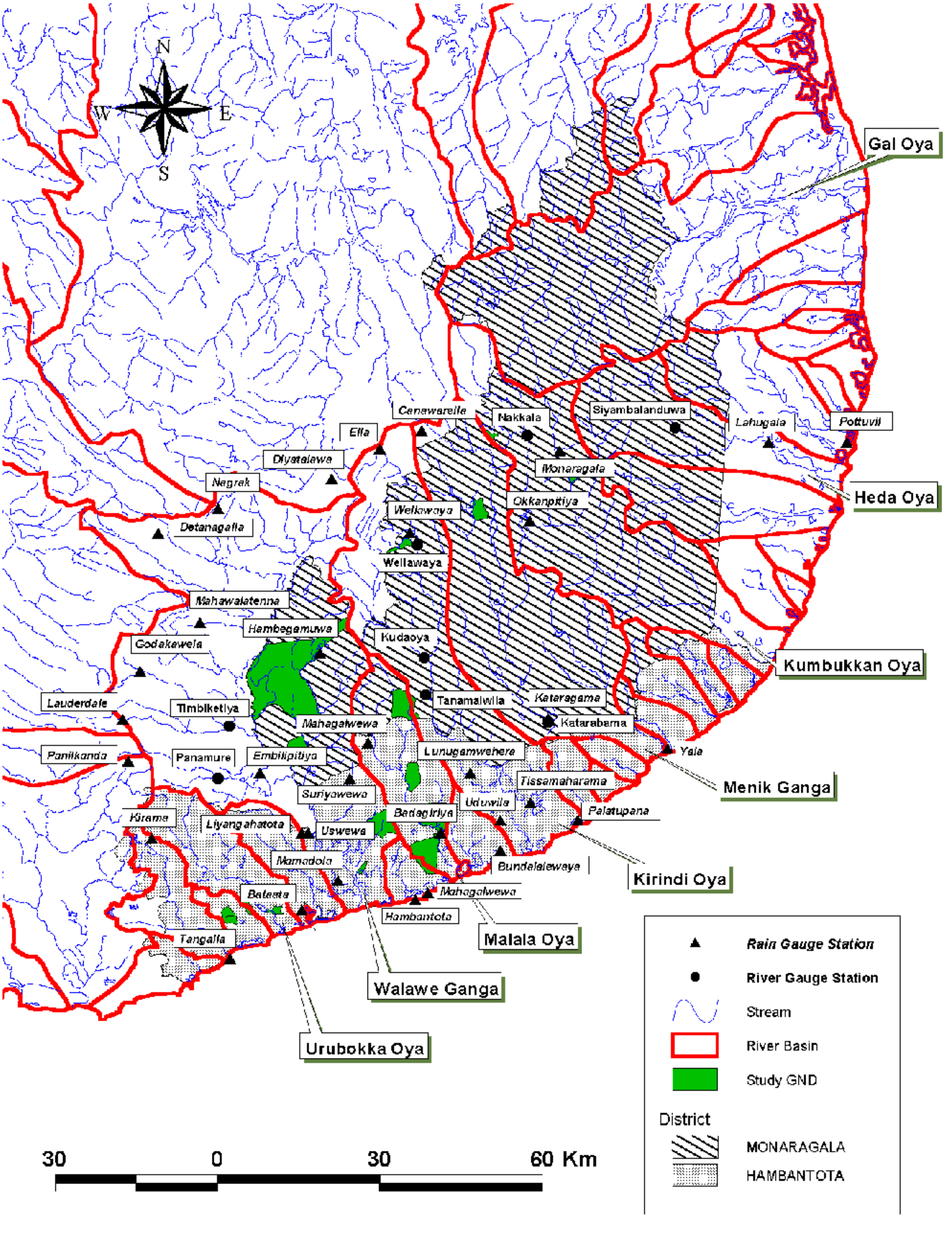


FIGURE 2.1 RIVER SYSTEMS AND HYDROLOGICAL STATIONS IN THE STUDY AREA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT	JICA

Table 2.2 Availability of Monthly River Discharge and Rainfall Data for Water Balance Analysis

(* indicates that monthly data are available through the year)

Hydrological Stations				Year 1)											
Name of River	Station	Name of Station 2)	Location	88	89	90	91	92	93	94	95	96	97	98	99
Heda Oya	River discharge	Siyambalanduwa	Upper				*	*	*	*	*	*	*	*	
	Rainfall	Lahugala	Middle					*			*				
		(Pottuvil)	Lower	*					*	*		*	*	*	*
Kumbukkan Oya	River Discharge	Nakkala	Upper	*					*						
	Rainfall	Monaragala	Middle		*	*	*	*	*	*	*	*	*	*	*
		Okkampitiya	Middle			*	*	*	*	*	*	*	*	*	*
Menik Ganga	Riverdischarge	Kataragama	Lower	*	*	*	*	*	*	*	*	*	*	*	
	Rainfall	Canawarela	Upper	*		*	*	*	*	*	*	*	*	*	
		Kataragama	Lower			*	*	*	*	*	*	*	*	*	*
		Yala	Lower	*	*	*	*	*	*	*	*				*
Kirindi Oya	River discharge	Wellawaya	Upper	*	*	*	*	*	*	*	*	*	*	*	
		KudaOya	Middle	*											
		Tanamalwaila	Middle	*	*	*	*	*	*	*	*	*	*	*	
	Rainfall	Ella	Upper	*	*	*	*	*	*	*	*	*	*	*	*
		(Diyatalawa)	Upper	*	*			*	*	*					
		Wellawaya	Upper	*	*	*									
		Lunugamwehera	Middle	*	*	*	*		*	*	*	*	*	*	
		Uduwila	Lower	*	*										
		Tissamaharama	Lower	*			*	*	*					*	*
		Palatupana	Lower		*	*	*	*	*	*	*	*	*	*	*
		(Bandalalewaya)	Lower	*	*	*	*	*	*	*	*	*	*		
Malala Oya	Rainfall	Mahaglwela	Upper				*		*	*	*				
		Badagiriya	Middle	*	*	*	*	*	*	*	*		*	*	*
Walawe Ganga	River discharge	Panamure	Middle						*				*	*	
		Timbolketiya	Middle						*				*	*	
	Rainfall	Nagrak	Upper	*	*	*	*	*				*	*	*	*
		Detanagalla	Upper	*	*	*	*		*	*	*	*	*	*	*
		Mahawalatenna	Upper												
		Hambegamuwa	Upper	*	*	*	*	*	*	*	*	*	*	*	*
		Godakawela	Upper	*	*	*	*	*		*	*				
		Lauderdale	Middle		*	*	*	*			*	*			
		Embilipitiya	Middle	*			*	*	*	*	*	*	*	*	*
		Suriyawewa	Middle	*	*	*	*	*	*	*	*	*		*	*
		Uswewa	Lower		*	*	*			*	*	*	*	*	
		Liyangatota	Lower						*	*	*	*	*	*	
		Mamadola	Lower		*		*	*	*	*	*	*	*	*	
		(Mahalewaya)	Lower	*	*	*	*	*	*	*	*	*	*		*
		(Hambantota)	Lower	*	*	*	*	*	*	*	*	*	*	*	*
Urubokka Ganga	Rainfall	Bataata	Lower			*	*	*	*	*	*	*	*	*	*
		(Tangalla)	Lower	*		*					*	*			
		(Kirama)	Upper			*	*			*	*	*	*		

Note 1): A period of the year is from October to September of the next year.

2): Parenthetic stations are not located in the said river basins but regarded to represent the rainfall of the basins as they are located very close to the said basins.

2.2 METEOROLOGY

2.2.1 GENERAL CLIMATE OF SRI LANKA

The climate of Sri Lanka is classified as "Tropical monsoon" climatic zone. The monsoonal conditions are separated into two periods. From May to September is in the southwest monsoon period and from December to February is in the northeast monsoon period. The rainfall pattern is influenced by the monsoon winds. These winds bringing moisture and when these winds encounter the slopes of the mountains, they unload rains on there. At the southwest monsoon, the rainfall is exceptionally heavy. This climate condition generate dry zone in north and in southeast of Sri Lanka.

(1) Rainfall

The average annual rainfall has considerable spatial variation. The higher rainfalls are on the central highlands. The maximum values are on the western slopes recording values exceeding 5,000mm. The eastern slopes are less than 3,500mm. The minimum annual rainfall values are on the northwestern and southeastern lowlands of less than 1,000mm (See, *Figure 2.2*).

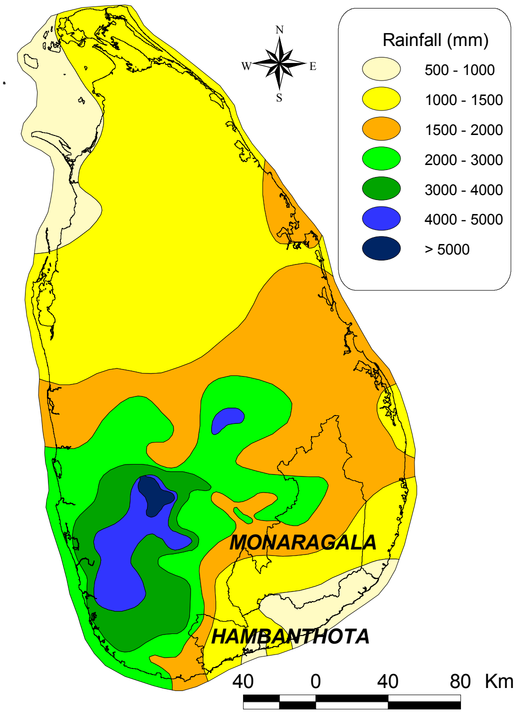


Figure 2.2 Annual Rainfall

(2) Temperature

The average annual temperature is about 28 degree in the low lands and about 16 degree in the Nuwara Eliya in central highland having an altitude of 1,800 m. At large parts of Sri Lanka, January is the lowest temperature month and May is the highest temperature month.

(3) Humidity

The humidity varies generally from 70% during the day to 90% at night. Kandy in the highlands, daytime humidity usually ranges between 70 and 79 percent, and Anuradhapura in the low land dry zone of northern part, daytime humidity falls to about 60 percent.

(4) Sunshine

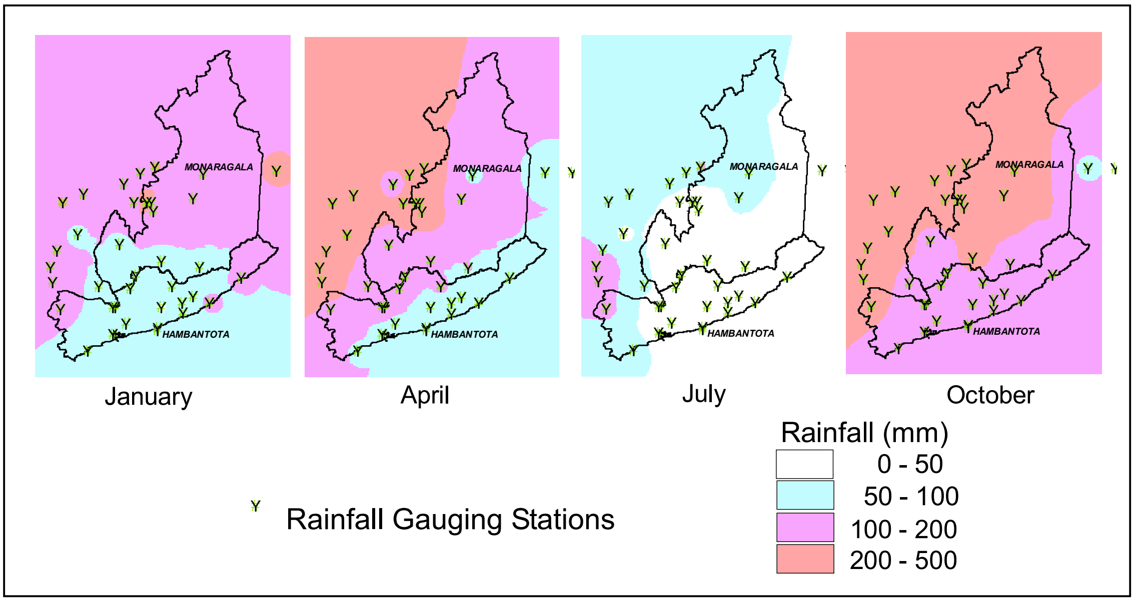
The annual average totals of sunshine hours range from 2,900 hours in the northern and eastern lowlands to 1,400 hours in the central highlands. The daily duration of sunshine hours in the western slopes during the southwest monsoon period can decrease to 2 hours while in the eastern slopes it is about 6 hours. Most of the country has 8 to 9 hours of sunshine per day during February.

2.2.2 CLIMATE OF THE STUDY AREA

The Study area (Monaragala and Hambantota district) is located in southeast quarter of Sri Lanka. Climate of the Study Area is characterized as northeast monsoon and dry area. Almost all of the Study area, except the northern part of Monaragala district, belongs to lowland or hill with an altitude less than 150 m. The rainfall by a northeast monsoon is small in this area.

(1) Rainfall

Based on the records on mean monthly rainfall from 1981 to 2001, distribution of rainfall depth is illustrated as shown in *Figure 2.3*. This figure indicates that most shallow rainfall in July of the period of southwest monsoon from May to September.



Source: Meteorological Department and Irrigation Department.

Figure 2.3 Distribution of Rainfall Depth

Monthly rainfall at Hambantota and Monaragala gauging stations are shown in *Table 2.3*. The table shows half amount of annual rainfall is concentrated in three months from October to December. In general, the rainfall depth of Monaragala is larger than Hambantota district.

Table 2.3 Monthly Rainfall

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Hambantota (1951-2000) in mm													
Average	80.3	53.1	60.0	90.2	81.0	57.0	47.4	51.1	68.8	131.7	191.7	115.4	1026.4
Max.	277.8	176.2	213.5	291.3	349.8	187.8	223.7	185.6	287.9	361.8	469.0	485.3	1825.0
Min.	0.0	0.0	0.0	12.3	0.0	0.7	0.0	0.0	0.0	0.5	32.7	5.1	590.0
Monaragala (1989-2000) in mm													
Average	166.9	98.3	42.7	78.2	66.4	25.5	61.7	95.8	131.1	233.6	338.4	248.4	1551.9
Max	335.2	236.2	127.1	188.9	214.0	60.5	178.7	247.1	167.3	342.8	944.2	498.8	2364.1
Min	9.1	0.0	0.0	1.7	0.0	0.3	2.2	27.0	35.4	90.3	121.7	83.5	1166.5

(2) Temperature

Mean monthly temperature at Hambantota gauging station from 1961 to 1990 is summarized as *Table 2.4.* The variation of the mean monthly value is small, it is only 2 degrees. The highest temperature of 31.2℃ is observed at April, meanwhile, the lowest one of 22.8℃ is observed at January. In the rainy season of October to February, the monthly temperature indicates slightly low.

Table 2.4 Monthly Temperature, Hambantota (1961-1990)

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Max	29.8	30.2	30.9	31.2	30.7	30.3	30.6	30.1	29.9	30.0	29.8	29.6	30.3
Min	22.8	23.0	23.9	25.0	25.5	25.2	24.7	24.6	24.5	24.2	23.6	23.3	24.2
Mean	26.3	26.6	27.4	28.1	28.1	27.8	27.7	27.3	27.2	27.1	26.7	26.4	27.2

(3) Pan – Evaporation

Mean monthly Pan-Evaporation at Nakkala (Monaragala district) gauging station from 1992 to 1999, exclude 1993 to 1996, is shown in *Table 2.5*. The Pan-Evaporation is rather high from February to September. In these months, the double amount of Pan-Evaporation of dry season from November to December is recorded.

Table 2.5 Monthly Pan-Evaporation, Nakkala (1992-1999) in mm

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
Average	80.0	97.0	120.0	97.8	96.3	103.0	99.3	109.8	98.5	79.8	55.5	52.5	1089.3
Max	87.0	116.0	136.0	110.0	100.0	113.0	112.0	125.0	113.0	89.0	60.0	61.0	1112.0
Min	68.0	87.0	110.0	85.0	93.0	90.0	90.0	82.0	75.0	70.0	50.0	43.0	1053.0

(4) Relative Humidity

Mean monthly relative humidity on average from 1995 to 2000 in Hambantota gauging station is shown in *Table 2.6*. The rang of monthly humidity in daytime shows 72% (March) to 79% (May), the range of its nighttime shows 85 % (February) to 88% (November). Rather high relative tendency can be observed while the period of southwest and northeast monsoon.

Table 2.6 Monthly Humidity, Hambantota (1995 – 2000)

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Mean Daytime	73	73	72	75	79	78	73	76	78	75	77	75	75
Mean Nighttime	85	85	85	86	88	88	86	87	88	87	88	87	87

Monthly variations of climates are shown in *Figure 2.4*. There is tendency to degrease the temperature and pan-evaporation as the rain increase. There is no obvious relationship between humidity and other parameter. Monaragala's rainfall is deeper than Hambantota in the period of northeast monsoon.

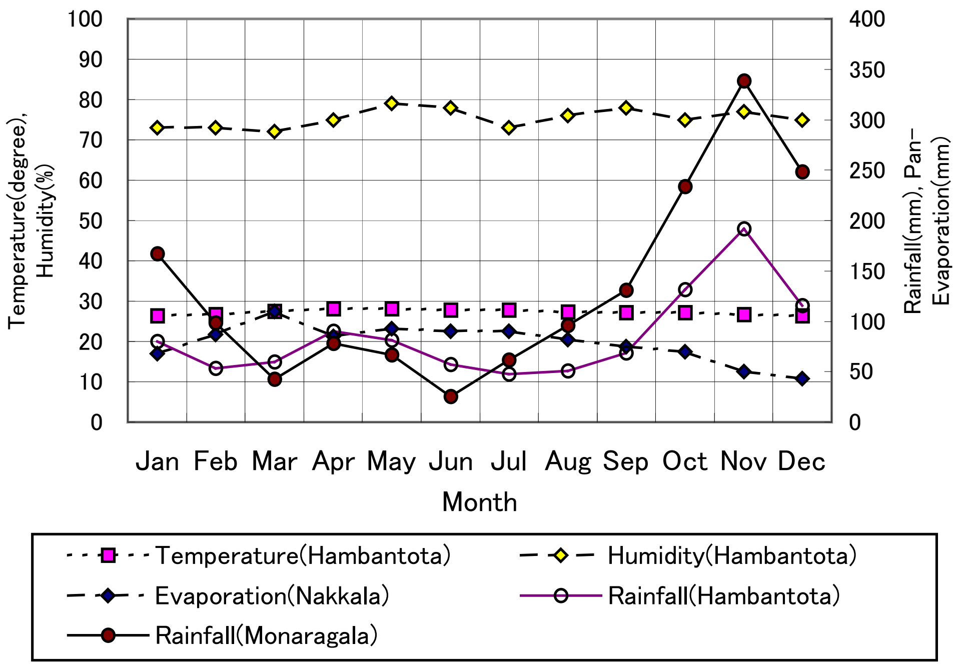


Figure 2.4 Monthly Variation of Meteorological Data

2.3 HYDROLOGICAL CHARACTERISTICS

Hydrological characteristics of the pilot GNDs such as rainfall distribution, river flow conditions, and irrigation condition were studied through topographic maps and the collected data. River flow and reservoir water conditions during the dry season were confirmed by a two-week field reconnaissance of the Study area in the dry season of 2001. Results of the field reconnaissance are summarized in *Table 2.7 (a) and (b).*

Table 2.7 (a) Result of Field Reconnaissance and Interview Survey on Hydrological Conditions of the Pilot GNDs

GND Name (JICA NO.)	Natural Conditions	Social Conditions
Hambantota District		
Badagiriya (H-5) Interviewee: Resident	Elevation: 30m Topography: Flat with gentle slope Water condition: Near the Badagiriya Tank with a little water and small tanks upstream side. Shallow wells are possible to use in normal year, but only for bathing this year because of salinity. Laterite overburden,	Population: (1089) Number of family: unknown Water supply condition: This GND is a fishery village opened this year. No water supply plan. Drinking water is supplied by bowsers.
Keliyapura (H-1) Interviewee: Resident	Elevation: 25m Topography: Flat with gentle slope Water condition: Four small tanks nearby are used for bathing Shallow wells possible to use depending on tank water level. This year supplied by bowser once a week (180 l/family/week). Laterite overburden.	Population: (553) Number of family: About 240 Water supply condition: This GND has was provided by the government and increase in population is only natural one. Rainwater tanks provided this year by a new project. Bowser of Division office do not go to some areas.
Siyambalagaswila (H-7) Interviewee: GND officer	Elevation: 25m Topography: Flat and a little higher than surrounding areas Water condition: Irrigation canal from Ridiyagama Tank (large with much water) is used for bathing and washing. Dug wells along the canal provide mainly drinking water. This year, unlike normal year, well water is not enough. The canal has no flow (no irrigation) for 3 months a year around March and August.	Population: 1328 Number of family: 272 Water supply condition: Area 8km^2. There is a water supply project with ADB loan taking water from the Walawe Ganga that will cover 20 % of population. A 400 l./fam./day (5 person) of water excluding bathing is required. Well water is not good quality. People live in high place get water from the wells and carry them to their home. Sea water goes up the Menik at least 3 km from its mouth.
(Pahala) Mattala (H-6) Interviewee: GND officer	Elevation: 40m Topography: Flat Water condition: A small tank nearby has a little water. Large tank at the Malala Oya (2km away) has water but no flow in the river downstream. One shallow well near the large tank is available now. Laterite overburden.	Population: 430 Number of family: 83 Water supply condition: Four common taps provided this year supply 2-3 times a week (2-3 hrs each) with charge 40 Rs/month. Rainwater tanks have been provided. Even bathing is difficult this year.
Wediwewa (H-4) Interviewee: GND officer	Elevation: 30m Topography: Flat with long gentle slope Water condition: No flow in the small rivers. Six tanks including one taking water from Ridiyagama Tank (large with much water) through a irrigation canal are used for bathing and washing.	Population: 1857 Number of family: 397. Consists of 4 villages Water supply condition: Bowsers supply only the areas along main roads. The shallow wells have enough water with good quality except some with salinity. A private owned bowser from Colombo was donating the water. Drinking water sources are shallow wells (non-safe 55 family and safe 137 family), common private wells 110 family. And bowser 90 family.
Ranna (West) (H-8) Interviewee: GND officer	Elevation: 25m Topography: Hilly with long slope down to Urubokka Oya. This area is located along the ridge line of the Urubokka Oya basin. Water condition: No large tanks in the vicinity. Sandy overburden.	Population: 1550 Number of family: 410 Water supply condition: Covered by a NWSDB water supply plan with treatment (private connection of 325 family), The plan will use the Katakkaduwa Tank waters covering the areas from Hunganu in the east to Kahandau in the west. Dug well water quality is not good. Problem is the adjacent Wigamuwa GND that will not covered by the plan.
Talunna (H-3) Interviewee: Resident	Elevation: 30m Topography: Hilly Water condition: Near Urubokka Oya with flow. Irrigation canal is used for bathing and washing.	Population: (981) Number of family: 280 Water supply condition: No water supply plan. No tube well. Shallow wells along the canal, with no problem both in quality and volume, are used for drinking. It is necessary to convey a long distance (some families more than 5 km).
Vitarandeniya (H-2) Interviewee: Resident	Elevation: 35m Topography: Rolling hills Water condition: Small tanks with a little water exist. Sandy overburden.	Population: (687) Number of family: unknown Water supply condition: A shallow well (3m deep) beside a tank with no water is used. Another well nearby (8m deep) contains salinity.

Notes: (1) Population in parenthesis indicates data from Census 2001.

(2) Field reconnaissance and interview survey were conducted on 27 August to 1 September 2001 in Hambantota District and on 7 to 10 August 2001 in Monaragala District.

Table 2.7 (b) Result of Field Reconnaissance and Interview Survey on Hydrological Conditions of the Pilot GNDs

GND Name (JICA NO.)	Natural Conditions	Social Conditions
Monaragala District		
Badalkumbura (M-6) Interviewee: GND officer	Elevation: 375m Topography: Hilly :Water condition: Located between Menik Ganga (permanent flow) and Kuda Oya (less water for 3 months a year) rivers, All water sources are groundwater, Eighteen dug wells (8 are in use now) exist and no water (even 15m deep) is available due to increase in number of wells,	Population: 1337 Number of family: 575 Water supply condition: Houses, Commercial people added on day time, A common well is polluted by human waste and prohibited to drink by the Health Dept. However still using because there is no other source, 200l/p/d, including all, is required,
Unawatuna (M-4) Interviewee: GND officer	Elevation: 170m Topography: Hilly Water condition: Located between the Kuda Oya and the Menik Ganga rivers. A tank with water is located nearby, Dug wells with ground water level of 5-8m below GL and contain fluoride a little. Sandy overburden.	Population: 2257 Number of family: 567 Water supply condition: 530 families are covered by an ADB water supply project, for 45 families (sources from Menik Ganga and groundwater). There are 150 dug wells. Four tube wells exist and additional 10 with depth of 22-38m required. A 60m deep tube well has enough water with good water quality.
Hulandawa (Left) (M-3) Interviewee: GND officer	Elevation: 120m Topography: Slope near the river and an irrigation canal Water condition: River flow for 6 months/y. Irrigation possible for 3-4 months/y. The Hulandawa River had very small flow now. No water in a dug well, Recharge from the canal to some dug wells is exist if there is a flow. Sandy overburden.	Population: 3749 Number of family: 519 Water supply condition: Water use 182 l/p/d (136 for bathing in the river etc.). Located on both sides of the road for 8 km length. Population Increase about 1 %/y. Drinking water in dry period is obtained from a low place 500 m away. Deep well is difficult due to shallow rock layers.
Bodagama (M-2) Interviewee: GND officer	Elevation: 90m Topography: Flat Water condition: Two small tanks are located nearby. Soft or hard rock layers below 9 m depth. Dug wells with 10m depth polluted in the dry season.	Population: About 1300 Number of family: 201 Water supply condition: Water of 230-340 l/family/day required. Four tube wells (presently two broken) with 30m deep exist. Three more tube well would be required.
Hambegamuwa (M-1) Interviewee: GND officer	Elevation: 30m Topography: Flat Water condition: Near the Mau Oya River and the tank with water (permanently). Irrigation canal almost no flow and polluted. Sandy overburden with soft rock layer below.	Population: 2046 Number of family: 475 Water supply condition: No water source other than groundwater. Depths of 4.5- 9m dug wells exist. Four tube wells (depth 25-30m, one broken) supply 104 family. Additional tube wells could solve the problem.
Sevanagala (M-7) Interviewee: GND officer	Elevation: 60m Topography: Flat Water condition: Surrounded by the rivers and tanks with much water. Surface waters (partially used for drinking) contain much chemicals. Clayey overburden rock layer below with less groundwater.	Population: 4661 Number of family: unknown Water supply condition: Dug wells no water and contain fluoride. Same for deep well. Remote and isolated GND in Monaragala. A sugar factory exists.
Yalabowa (M-5) Interviewee: GND officer	Elevation: 30-50m Topography: Located between Kuda Oya and Kirindi Oya rivers Water condition: Near the tributary of Kirindi Oya with flow. Sandy roam overburden. Well water level is 8 m below GL.	Population: 1280 Number of family: unknown Water supply condition: 20-30 l/p/d for drinking and cocking is required. Bathing etc are made in the river. There are 25 dug wells (water is available 1-2 wells now). Shallow groundwater contain partially urine as well as fluoride.

Notes: (1) Population in parenthesis indicates data from Census 2001.
(2) Field reconnaissance and interview survey were conducted on 27 August to 1 September 2001 in Hambantota District and on 7 to 10 August 2001 in Monaragala District.

2.3.1 DISTRIBUTION OF RAINFALL

The Study area is affected mainly by the northeast monsoon. Mountain areas where rainfall is larger than that of the flat areas are located in the west and the north. Almost all of the Study area, except the northern part of Monaragala District, is flat with an altitude less than 150 m.

(1) Rainfall Distribution in Area

Distribution of average annual rainfall in the Study area is shown in *Figure 2.5* and its major features are summarized as follows:

- The mountain slope areas facing to the northeast have a large rainfall depth with an average annual rainfall of 3,000 mm or less, while the slopes facing to the southwest have smaller rainfall depth of less than 2,000 mm.
- The southern coastal area has a small average annual rainfall of 1,100 to 800 mm.
- Average annual rainfall in the inland flat areas ranges from 1,500 to 1,000 mm.

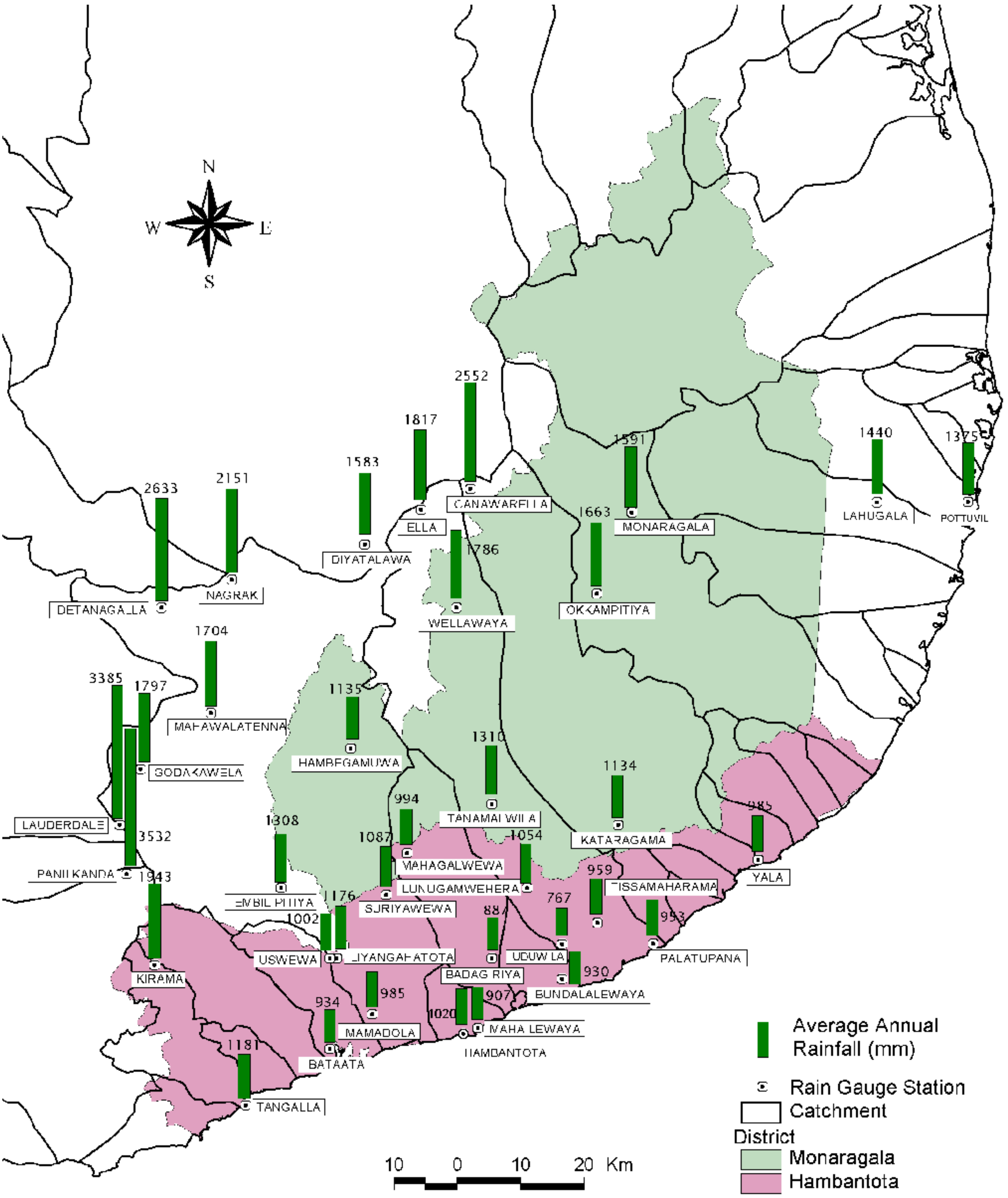


FIGURE 2.5 DISTRIBUTION OF AVERAGE ANNUAL RAINFALL

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(2) Yearly Rainfall Distribution

Annual rainfall depths from October to September were calculated using monthly rainfall records as shown in *Table 2.8(a) and (b)*. Major features are as follows:

- At Hambantota Station, in the years 1988/89 (625 mm), 89/90 (706 mm), 95/96 (737 mm) and 82/83 (800 mm) were dry (average 982 mm, maximum 1,350 mm).
- Dry years in the upper river basins were 82/83, 84/85 and 88/89 for the Menik Ganga, 86/87, 91/92 and 88/89 for the Kirindi Oya. Judging from the river discharge data, the year 88/89 was the driest.

Table 2.8 (a) Yearly Rainfall in Lower Basin (mm)

Year	Name of Rainfall Stations															
	Badagoroua	Bataata	Bundala	Kirama	Liyangaha	Lunugam	Mahagal	Mahalewaya	Mamadola	Palatupana	Suriyawewa	Tangalla	Tissamaharama	Uduwila	Uswewa	Yala
81/82	1382.1	1137.6		2110.8				1116.1						678.4		
82/83	1542.8	1062.9		1909.1				939.5	1057.2			1183.8	1060.8	939.0		
83/84		1317.1		1950.0					932.0	1289.7		1204.3		1132.4		1329.7
84/85		913.1		1928.8				899.0	680.0	861.5		1111.2	957.0	611.6		900.3
85/86		1346.1		2071.1		1076.0		1214.3		924.7		1315.6	1106.3	1097.6		1060.1
86/87	601.1			1466.6		735.4		820.8		836.9		926.6	624.8	459.0		602.7
87/88	905.3		946.6	1716.8		975.1		960.4		938.5		1378.0	921.6	670.6		1092.1
88/89			653.2			988.0		629.8			1038.3	956.8	902.0	840.7		
89/90	608.4		685.3			1069.0		591.4	528.6	529.5	960.6			470.5	558.2	640.7
90/91	1030.3	1022.0	1091.5	897.0		1303.9		1153.0		995.6	1217.5	1290.2			787.1	1154.0
91/92	459.7	498.4	993.5	1407.2		1002.2	792.6	842.0	1031.0	1023.2	758.5		662.3		623.7	1000.4
92/93	657.9	1112.1	632.4					696.3	970.4	676.0	939.1		729.2			703.6
93/94	1032.4	1224.9	1164.7		1439.3	1544.0	1361.9	909.9	1398.4	1092.5	1561.1		1156.3			1385.9
94/95	1040.6	782.7	1113.3	2251.9	1115.2	1090.1	1091.5	956.3	1085.4	1103.2	1099.9				1116.0	1042.5
95/96	729.2	702.9	982.5	2073.7	1000.6	1000.0	729.0	669.9	933.9	861.2	840.3	1195.4			945.4	875.6
96/97		1151.6	734.3	2590.0	951.2	856.8		907.1	775.1	735.3	1077.8	1245.9			1301.5	
97/98	1235.7	1341.5	1236.1	2445.7	1284.3	1337.2		1039.9	1369.7	1254.4					1380.0	
98/99	799.6	1354.5			1278.0	792.1			1218.8	1151.0	1358.2		1114.4		1086.8	
99/00	816.8	1209.3		2385.2				1100.3		979.2	1362.7		1539.8			1009.9
00/01	457.2					990.8			819.3		829.6		730.7		1217.7	987.5
Average	886.6	1078.4	930.3	1943.1	1178.1	1054.3	993.8	908.6	984.6	953.3	1087.0	1180.8	958.8	766.6	1001.8	984.6
Maximum	1542.8	1354.5	1236.1	2590.0	1439.3	1544.0	1361.9	1214.3	1398.4	1289.7	1561.1	1378.0	1539.8	1132.4	1380.0	1385.9
Minimum	457.2	498.4	632.4	897.0	951.2	735.4	729.0	591.4	528.6	529.5	758.5	926.6	624.8	459.0	558.2	602.7

Source: Meteorological Department

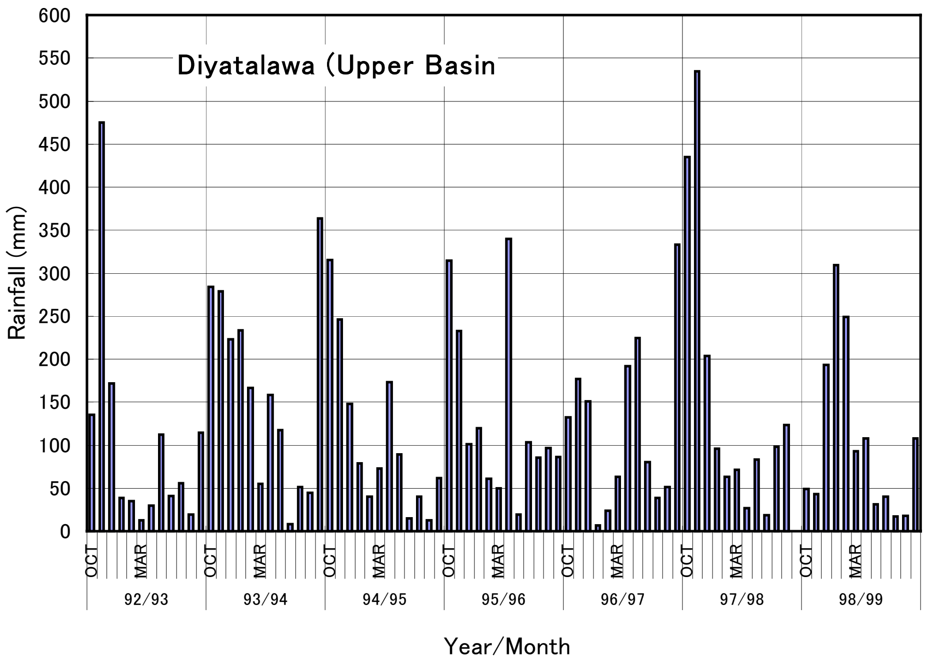
Table 2.8 (b)　　Yearly Rainfall in Upper/Middle Basin (mm)

Year	Name of Rainfall Stations												
	Cannavella	Monaragala	Okampitiya	Hambegamuwa	Ella	Tanamalwila	Wellawaya	Detanagalla	Embilipitiya	Gudakawela	Lauderdale	Nagarak	Panilkanda
81/82	2181.5		1258.6		1600.3	995.6				1939.0	3638.1		3914.9
82/83	1791.4		1276.2	1299.4	1389.6	1392.4		1690.7	995.9	1394.7	2513.4		
83/84	2872.0		2184.4	1858.8	2493.7	1211.6		4460.1		2281.3			
84/85	1852.2		1321.5		1453.7		1568.2	2210.9		2143.5	3570.2		3595.1
85/86	2534.2		1454.9	1511.2	2142.3		1952.6	2005.1	1402.8	2162.6	3441.7	2037.5	3676.9
86/87	2077.3		1351.2	535.2	1467.7		961.9	1644.9	1011.9	1322.4	2183.1	2598.7	
87/88	2874.9			992.3	1967.0		1894.6	2581.4		2066.9		3199.3	
88/89	1931.6			748.6	1465.0		1386.4	2324.7	1355.2	1721.1		2185.0	
89/90		1264.5		628.4	1760.3		2090.7	2574.0		1440.0	2826.3	1943.0	
90/91	2718.4	1433.0	1654.4		1529.5		1829.1	2929.2		2483.0	3197.1	2148.8	2942.9
91/92	2130.6	1166.5	1545.3		1268.6			2332.6	1054.4	1512.3	2572.2	1663.7	
92/93	2075.8	1669.4	1285.0	1044.8	1657.5		1593.3		1045.7	1770.4	2795.9	1733.6	
93/94	2809.5	2001.3	1964.4	1524.0	2118.8		1864.7	2872.6	1333.8				
94/95	3286.9	1052.4	1861.8	1203.2	2314.0		1737.5	3388.7	1292.5	1719.8			
95/96	2572.2	1741.9	1621.3		1942.9		1516.9	2131.2	1054.5	1204.2	3385.0		
96/97	3099.2	1240.7	1285.0		1912.7		2053.9	2628.2	1100.4		2795.9		
97/98	3318.6	2364.1	2093.7		2024.5		2025.4	3137.7	1558.1			2773.4	
98/99	2868.6	1745.6	1753.4		2437.9		2596.0	3254.7	1429.1			2193.5	
99/00		1351.7	1465.1		2127.6		1726.9	2634.5	1346.1			2034.8	
00/01			1389.5		1270.0			2596.8	917.8			1301.8	
Average	2552.0	1591.4	1663.0	1134.6	1817.2	1309.6	1786.5	2633.2	1307.6	1797.2	3367.7	2151.1	3532.5
Maximum	3318.6	2364.1	2184.4	1858.8	2493.7	1392.4	2596.0	4460.1	1558.1	2483.0	3638.1	3199.3	3914.9
Minimum	1791.4	1052.4	1258.6	535.2	1268.6	995.6	961.9	1644.9	917.8	1204.2	2183.1	1301.8	2942.9

Source: Meteorological Department, except Monaragala which is from Irrigation Department)

(3) Monthly Rainfall and River Discharge Distribution

Rainfall is large from October to January in general, however, medium amount of rainfalls occur in the southwest monsoon season as shown in *Figure 2.6*, monthly rainfall distribution. Monthly river discharge also shows similar tendency as shown in *Figure 2.7.*



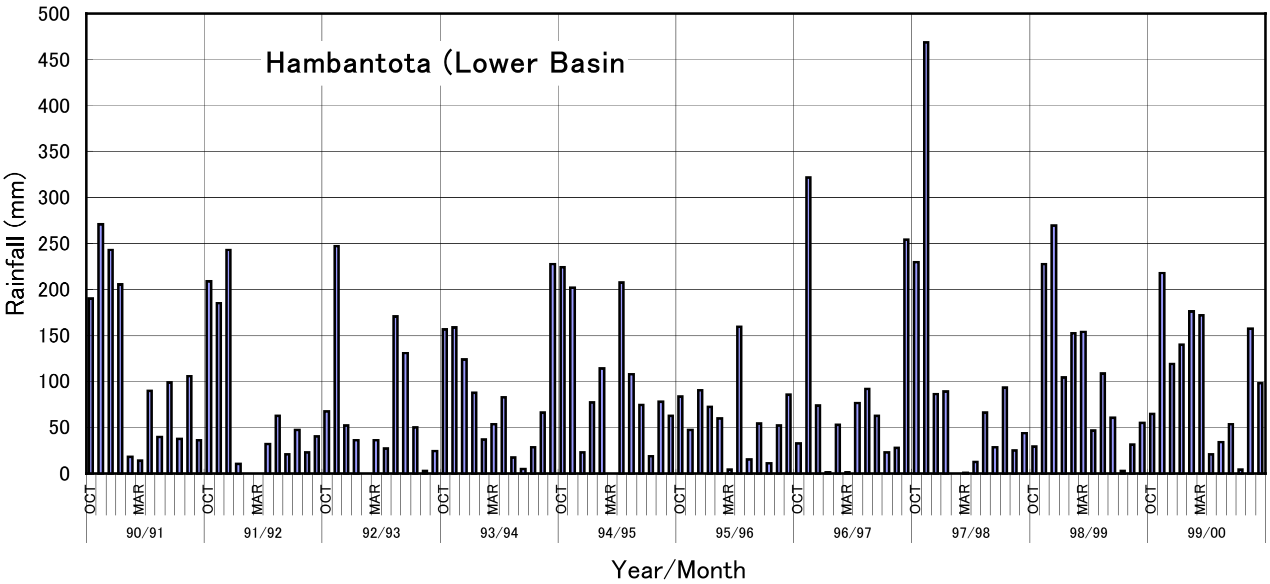


FIGURE 2.6 DISTRIBUTION OF MONTHLY RAINFALL

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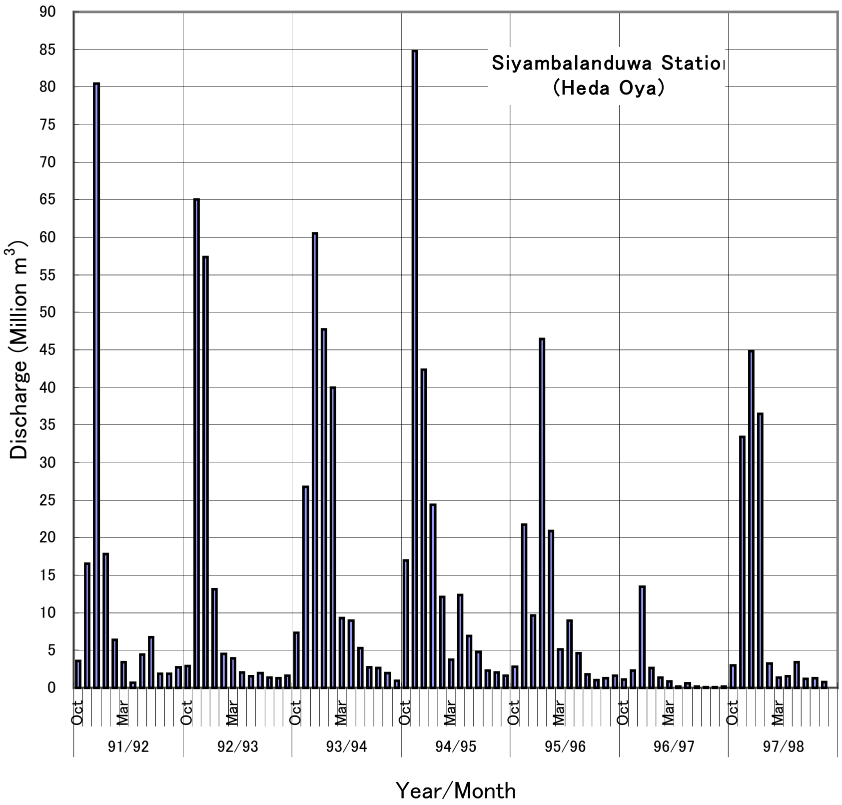

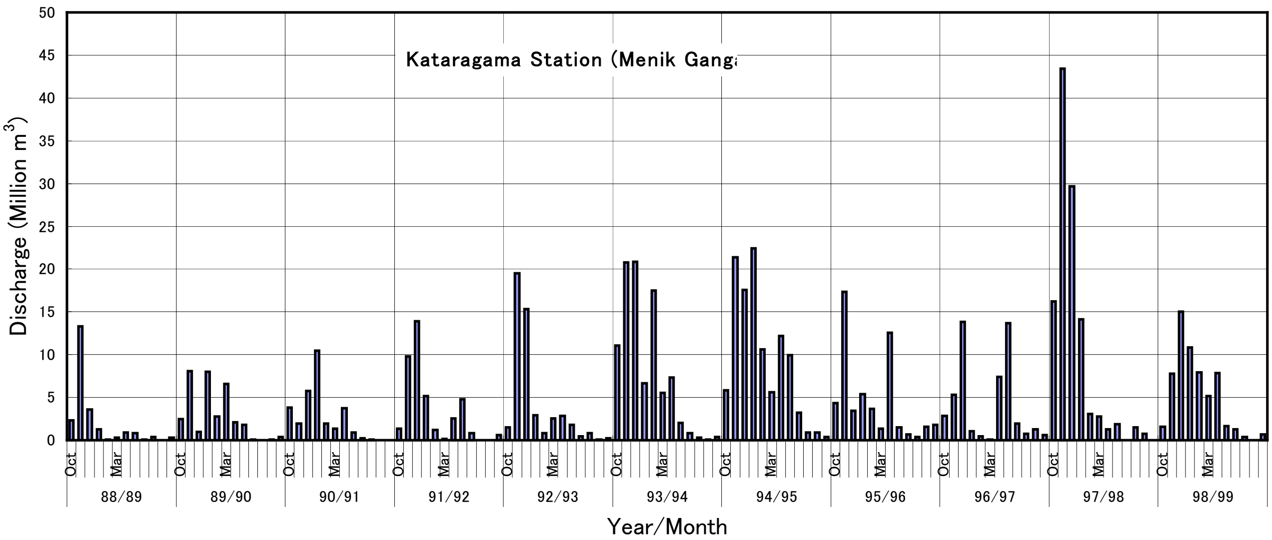

FIGURE 2.7 DISTRIBUTION OF MONTHLY RIVER DISCHARGE

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2.3.2 MAJOR HYDROLOGICAL FINDINGS

The Walawe Ganga has ample water even in the dry season because of its large catchment area and the large rainfall in its western basin. The river waters through large three reservoirs irrigate the vast area of paddy fields.

The Kirindi Oya and the Menik Ganga do not have enough water in the dry season due to small rainfall in the basin except small mountain areas in the north. Small rivers in Hambantota, except Urubokka Oya, do not have enough surface water.

There are many tanks (reservoirs) for irrigation in the Study area. Some rivers were observed to have no flow in the dry season.

Most of the 15 Pilot GNDs are located in the hilly areas with elevation of 30 to 375 m for Monaragala and 25 to 40 m for Hambantota. In these areas, dug wells usually dry up during the dry seasons.

2.3.3 PRESENT WATER USE IN THE STUDY AREA

The river waters in the Study area are used mainly for irrigation. Annual irrigation water volumes for the recent three years released from major tanks are shown in *Table 2.9(a) and (b)*. Average annual irrigation water volumes released from major tanks and anicuts in total are 135 million m^3 for Monaragala and 502 million m^3 for Hambantota.

Table 2.9 (a) Annual Irrigation Water Volume Released from Major Tanks and Anicuts (Intakes), Hambantota

Hambantota District

River Basin & Name of Tank or Anicut	Total Storage Capacity	Annual Irrigation Release (million m^3)			
	(million m^3)	1998	1999	2000	Average
KIRINDI OYA					
Lunugambehera Res.	226.0	243.55	205.20	174.02	207.59
Debara Wewa	7.93	12.66	13.94	15.34	13.98
Tissa Wewa	4.32	18.39	19.76	18.82	18.99
Yoda Wewa	9.74	23.26	21.62	20.84	21.91
Weerawila Wewa	12.95	45.17	41.86	33.85	40.29
Sub-total	260.94	343.03	302.39	262.86	302.76
Malala Oya					
Bandagiriya Tank	11.16	16.36	16.06	16.03	16.15
Mahagal Wewa (#)	2.24	5.25	5.23	5.32	5.27
Sub-total	13.40	21.61	21.29	21.35	21.42
Walawe Ganga					
Ridiyagama Tank (#)	17.64	129.40	117.23	117.81	121.48
Urubokka Oya					
Murutha Wewa	48.0	47.04	61.03	60.07	56.05
Total	339.98	541.09	501.94	462.09	501.71

Source: Irrigation Departments of Monaragala and Hambantota

Table 2.9 (b) Annual Irrigation Water Volumes Released from Major Tanks and Anicuts (Intakes), Monaragala

Monaragala District

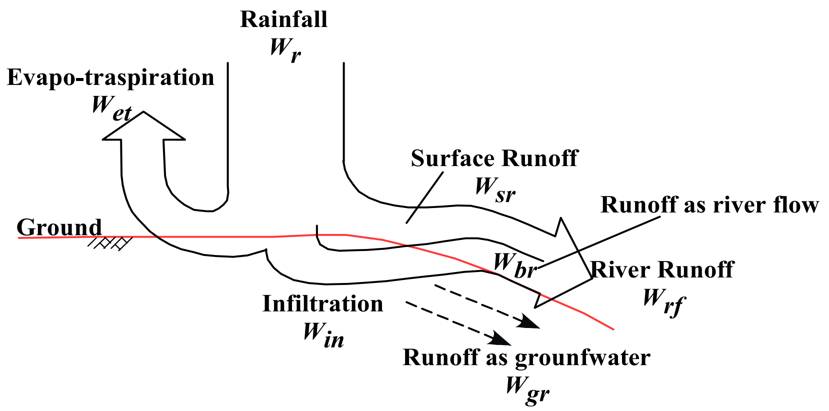
River Basin & Name of Tank or Anicut	Capacity	Annual Irrigation Release (million m^3)			
	(million m^3)	1998	1999	2000	Average
HEDA OYA					
Muthukandiya Tank	30.33	24.66	25.89	29.59	26.72
WILA OYA					
Ethimale Wewa	6.78	6.17	6.29	6.41	6.29
Kotiyagala Wewa	2.59	2.47	2.47	2.56	2.50
Sub-total	9.37	8.63	8.75	8.97	8.79
KUMBUKKAN OYA					
Kumbukkan Anicut	0.00	19.73	19.97	20.22	19.97
Hulandawa Anicut	0.00	3.08	3.17	3.21	3.15
Sub-total	0.00	22.81	23.14	23.43	23.13
MENIK GANGA					
Buttara Anicut	0.00	18.50	18.86	19.73	19.03
Yudaganawa Tank	0.97	5.55	5.80	6.17	5.84
Karawila-Maila Wewa	1.72	7.89	8.08	8.61	8.19
Kukurampola Anicut	0.00	3.95	4.32	4.44	4.23
Polwatta Anicut	0.00	3.45	3.58	3.70	3.58
Halmillapillewa Tank	1.48	2.96	3.08	3.21	3.08
Horabokka Anicut	0.00	2.96	3.08	3.21	3.08
Sub-total	4.17	45.25	46.79	49.05	47.03
KIRINDI OYA					
Handapanagala Wewa	7.15	5.67	5.80	5.92	5.80
Sudupanawela Anicut	0.00	4.93	5.06	5.18	5.06
Mallatawela-Radapola A.	0.00	2.40	2.47	2.59	2.49
Debara Ara Tank	1.20	1.97	2.03	2.07	2.03
Dambe Wewa	1.44	1.05	1.11	1.13	1.10
Balaharuwa Tank	0.78	2.00	2.03	2.07	2.03
Sub-total	10.57	18.03	18.50	18.96	18.50
WALAWE GANGA					
Hambegamuwa Tank	4.16	5.67	5.80	5.83	5.76
Kandiyapita Wewa	1.38	1.60	1.73	1.78	1.70
Kahakulullanpelessa Wewa	0.37	2.07	2.10	2.16	2.11
Maha Wewa	0.76	1.13	1.25	1.29	1.22
Sub-total	6.68	10.48	10.86	11.05	10.80
Total	61.12	129.86	133.94	141.06	134.95

Source: Irrigation Departments of Monaragala and Hambantota

2.4 ESTIMATION OF INFILTRATION OF WATER INTO THE GROUND

2.4.1 WATER BALANCE MODEL

The Study adopted a water balance model shown below. In the model, i) some portion of water volume of rain come down within a catchment is lost by evapo-transpiration, ii) some portion infiltrates into the ground and iii) some portion flows out as surface runoff. Most of the portion infiltrated into the ground leaches out downstream and flows out as parts of river runoff.



The balance is expressed by following equations:

$W_r = W_{et} + W_{in} + W_{sr}$ ***(1).***

Where,

$W_r = R \times A$:	***Rainfall (m³/year,)***
$W_{et} = ET \times A$:	***Evapo-transpiration (m³/year),***
W_{in} :	***Infiltration (m³/year),***
W_{sr} :	***Surface Runoff (m³/year),***
R :	***Basin average rainfall (mm/year),***
ET :	***Basin average evapo-transpiration (mm/year), and***
A :	***Catchment area at a discharge measuring point (km²).***

Most of the infiltrated water flows out as parts of river runoff while small portion flows out as groundwater, thus;

$W_{in} = W_{gr} + W_{br}$ ***(2),***

where,

W_{gr}:	***Runoff as groundwater (m³/year),***
W_{br} :	***Runoff as river flow (m³/year).***

And,

$W_{rf} = W_{sr} + W_{br}$ ***(3),***

where,

W_{rf}: ***River flow (m³/year).***

By assuming that the runoff as groundwater is negligible compare to the runoff as river flow considering a difference in magnitudes of the flow rate of the two runoff, (2) comes as below;

$W_{in} = W_{br}$ ***(4)***

Moreover, by assuming draught conditions where rainfall that causes surface runoff hardly occurs, (3) comes;

$W_{rf} = W_{br} = W_{in}$ ***(5)***

2.4.2 Estimation of Potential Recharge by River Flow

(1) Drought Year

Based on the data from the Irrigation Department, yearly runoffs (in mm) of the rivers (expressed as river flow in the water balance model) in the Study area have been obtained as shown in *Table 2.10*. Runoff depth ranges from 78 mm (in 96/97 at Siyabalanduwa of Heda Oya) to 1397 mm (in 97/98 at Wellawaya of Kirindi Oya) depending on rainfall amount. Among these rivers, the basins of the Kirindi Oya (Tanamalwila station) and the Menik Ganga

(Kataragama station) spread over the Study area and suitable to represent runoff phenomenon, therefore, subsequent analysis were carried out based on the data from these two rivers.

Table 2.10 Yearly Runoff of Rivers in the Study Area

Name Of Station	Catchment Area (km^2)	Runoff Depth (mm)											
		88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	Average
Tanamalwila	749.1	211	314	347	183	246	468	548	221	335	755		363
Wellawaya	172.4	268	666	561	370	406	867	831	521	629	1393		651
Siyabalanduwa	295.3					515	718	678	429	78	442	515	482
Katalagama	787.4	113	160	146	195	236	450	536	261	237	554	291	289
Panamure	81.3						248				472	218	313
Timbolketiya	268.7						205				657	317	393

Source: Irrigation Department

It is a common practice to adopt a 10 years drought as a design drought for the surface water source development of water supply. The minimum runoffs Kirindi Oya at Tanamalwila and Menik Ganga at Katalagama during the past 10 years are 183 mm in 91/92 and 113 mm in 88/89 respectively. In Kirindi Oya, the second smallest runoff at Tanamalwila occurred in 88/89 and the smallest runoff at Wellawaya occurred in 88/89. Therefore, the year 88/89 was assumed as a 10 years drought year.

The rainfall data shown in *Table 2.11* gives broad agreement to the above assumption, too. The table shows that the yearly rainfalls in 88/89 at Hambantota and Ella recorded the 5th smallest in 49 and 20 years respectively. These are comparable to the rainfall once in 5 to 10 years.

Table 2.11 Yearly Rainfall and Order from the Smallest

Year	Hambantota		Year	Hambantota		Ella	
	Rainfall (mm)	Order		Rainfall(mm)	Order	Rainfall(mm)	Order
51/52	901	17	77/78	878	14	-	-
52/53	798	9	78/79	954	23	-	-
53/54	1322	43	79/80	1014	28	-	-
54/55	1220	38	80/81	1028	30	-	-
55/56	568	2	81/82	1059	33	1600	8
56/57	619	4	82/83	800	10	1390	3
57/58	1410	46	83/84	975	26	2494	20
58/59	899	15	84/85	876	13	1454	4
59/60	936	21	85/86	1013	27	2142	17
60/61	1471	48	86/87	928	19	1468	6
61/62	1243	40	87/88	969	25	1967	13
62/63	1249	41	88/89	625	5	1465	5
63/64	1513	50	89/90	706	6	1760	10
64/65	604	3	90/91	1350	44	1530	7
65/66	1385	45	91/92	873	12	1269	1
66/67	1130	35	92/93	846	11	1658	9
67/68	938	22	93/94	1046	32	2119	15
68/69	911	18	94/95	1190	37	2314	18
69/70	1459	47	95/96	737	8	1943	12
70/71	1036	31	96/97	1021	29	1913	11
71/72	928	20	97/98	1144	36	2025	14
72/73	1093	34	98/99	1243	39	2438	19
73/74	967	24	99/00	1259	42	2128	16
74/75	1476	49	00/01	712	7	1270	2
75/76	479	1	-	-	-	-	-
76/77	901	16	Average	1020	-	1817	-

(2) Balance between Rainfall and Infiltration

The infiltration rate in the Study area, where the agriculture land and forest areas prevail, are supposed to have an order of more than 100 mm per hour. Therefore, yearly rainfalls, 625 mm at Hambantota and 1465 mm at Ella in 88/89, are far less than the estimated infiltration rate. Of course, rain never fall evenly through the year. However, the biggest monthly rainfall at Ella in 88/89 recorded in November as shown in *Table 2.12* is 268.9 mm, which is still far small compared to the infiltration rate.

Table 2.12 Monthly Rainfall in 88/89 at Ella, Lungam and Hambantota Stations

Station	Oct	N0v	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Yearly Total
Ella	147.4	268.9	131.6	96	11.5	49.7	135.9	144.1	62.9	182	84	151	1465
Lungam	75.3	255.8	67.1	61.5	23.4	67.6	103.3	108.6	6.6	154.6	7	57.2	988
Hambantota	10.6		5.1	135.7	48	40.8	28.9	63.4	24	146.8	96.5	25	624.8

There may be impermeable areas, such as roads and rock surface, these areas, however, are very limited. Therefore, almost all the rainfall in such a drought year could be infiltrated into the ground without surface runoff and river runoff in the drought year is considered to consist of the infiltrated water.

(3) Results

In conclusion, the study regarded the runoff in the drought year as a potential groundwater recharge. The annual recharge potential for the dry areas in Hambantota and Monaragala are estimated to be 100 mm (a round value of the minimum yearly river runoff at Katalagama in *Table 2.10*) to 200 mm (a round value of an average of the minimum and second minimum yearly runoffs at Tanamalwila in *Table 2.10*) in a drought year. These will give a potential or the maximum value of recharge in a drought year with about 10 % probable drought (once every 10 years on average).

2.5 POTENTIAL RECHARGE TO GROUNDWATER IN EACH GND

2.5.1 METHODOLOGY

Potential groundwater recharge to the test well site in each of the 15 Pilot GNDs is estimated by the following method.

(1) Assumptions for Recharge from Rainwater

- Target of recharge is groundwater up to 200 m deep.
- Rainwater infiltrated into the topographic catchment area of the geophysical survey area in a GND is a potential for groundwater recharge.
- Effective rainfall (Rainfall - ET) is the rainwater infiltrate into the ground.
- Geology under overburden shown in the geological maps is taken into account.
- The minimum runoff depths of the rivers are expected to infiltrate into the ground in drought years.

(2) Assumptions for Recharge from the Surface Water Bodies

- Recharge potential from the rivers and the tanks are considered qualitatively according to the conditions in dry season.
- Deep geology is not taken into account.
- Monthly river discharge and hydraulic condition in the dry season in 2001 are the basis of this study.

2.5.2 RESULTS

Results of the study on groundwater recharge from rainwater and surface water bodies are shown in *Table 2.13*. In the table, a value of the minimum runoff was given by the following manners:

- In Hambantota, a lower value (100 mm) was given to all the Pilot GNDs by considering that it is a dry area.
- In Monaragala, a higher value was given to the Pilot GNDs located at high elevation where annual rainfall is comparatively high, whereas a lower value was given to the Pilot GNDs located at lower elevation.

In addition, a recharge potential was evaluated by considering the minimum runoff above in its size of the catchment.

2.6 HYDROLOGICAL RECOMMENDATIONS

Groundwater recharge potential seems low especially in Hambantota because of small rainfall, large seasonal and yearly variation, etc. The river waters are presently used for irrigation a little in Monaragala and a large volume in Hambantota. Under such condition, domestic water supply in the rural areas is an urgent issue. As sources of the domestic water supply, groundwater with good quality and the surface water from upper river basins will be considered. Since the volume of domestic water is small, groundwater could be used for some rural areas, however, it will be difficult to cover all problem areas.

As described, in the "National Water Resources Policy and Institutional Arrangements", surface water and groundwater are connected with each other especially in the dry zone like the Study area. In order to manage the water resources in terms of their volume and quality, present conditions and prediction of water resources should be studied.

The following recommendations are made from the viewpoint of groundwater management:

- To conduct water balance study based on the additional measurements of river discharges and rainfalls in the upstream basin of discharge measurement point. The measurements should be made in small catchments with land uses of forest and agriculture for several years.
- Water supply for the flat areas in the Study area should be planned in combination with the surface water and groundwater. The areas where groundwater use is difficult, the river waters of the Walawe Ganga for the southern part and the Menik Ganga for eastern part of the Study area would have potential resources, though it will require some reservoirs.

Table 2.13 Groundwater Recharge Potential to Geophysical Exploration Areas in the 15 Pilot GNDs

District	GND Name (JICA NO.)	Recharge from Rainwater	Recharge from Rivers and Tanks	Overall Evaluation
Monaragala	Badalkumbura (M-6)	A = 5.80 km^2, R_{ave} = 1700 mm, Min. runoff = 200 mm, RE potential: Medium - Low	Rivers: Menik Ganga, Kuda Oya (Kumbukkan Oya system) Tanks: None RE potential: Medium	Medium
	Unawatuna (M-4)	A = 26.56 km^2, R_{ave} = 1700 mm, Min. runoff = 200 mm, RE potential: High	Rivers: Kuda Oya, Menik Ganga Tanks: Yudagonawe RE potential: High	High
	Hulandawa Left (M-3)	A = 18.82 km^2, R_{ave} = 1600 mm, Min. runoff = 200 mm, RE potential: High	Rivers: Hulandawa Oya with almost no water, Irrigation canal with no water. Tanks: None RE potential: Low	Medium-Low
	Bodagama (M-2)	A = 20.08 km^2, R_{ave} = 1300 mm, Min. runoff = 100 mm, RE potential: High	Rivers: Small streams Tanks: Small tanks RE potential: Low	Medium
	Hambegamuwa (M-1)	A = 257.75 km^2, R_{ave} = 1150 mm, Min. runoff = 100 mm, RE potential: High	Rivers: Mau Ara Tanks: Hanbegamuwa with a little water RE potential: Low	Medium
	Sevanagala (M-7)	A = 15.00 km^2, R_{ave} = 1250 mm, Min. runoff = 100 mm, RE potential: High	Rivers: Mau Ara, Walawe Ganga Tanks: Habaralu (A=25.6 km^2) and Mohagama RE potential: High	High
	Yalabowa (M-5)	A = 14.18 km^2, R_{ave} = 1750 mm, Min. runoff = 200 mm, RE potential: High	Rivers: Close to Kirindi Oya and its tributary Galamela Ara with much water. Tanks: close to small 2 tanks RE potential: High	High
Hambantota	Tammennawewa (H-5)	A = 25.60 km^2, R_{ave} = 900 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: One small river with no water. Tanks: Badagiriya with water, Small tanks with less water RE potential: Medium	Low
	Keliyapura (H-1)	A = 15.59 km^2, R_{ave} = 900 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: None Tanks: Keligama and small tanks RE potential: Low	Low
	Siyambalagaswila North (H-7)	A = 4.92 km^2, R_{ave} = 1000 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: Walawe Ganga Tanks: Ridiyagama through irrigation canal RE potential: Medium	Medium
	Pahala Mattala (H-6)	A = 61.83 km^2, R_{ave} = 1050 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: Malala Oya with no water, Two small rivers Tanks: Many small tanks RE potential: Medium	Medium-Low
	Wediwewa (H-4)	A = 44.37 km^2, R_{ave} = 1000 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: Two small rivers Tanks: Many small tanks RE potential: Low	Low
	Ranna West (H-8)	A = 2.78 km^2, R_{ave} = 1000 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: Urubokka Oya with much water Tanks: None RE potential: Medium	Medium-Low
	Talunna (H-3)	A = 6.14 km^2, R_{ave} = 1000 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: Urubokka Oya and its small tributary, Tanks: None RE potential: Medium	Medium-Low
	Vitarandeniya (H-2)	A = 7.37 km^2, R_{ave} = 1000 mm, Min. runoff = 100 mm, RE potential: Low	Rivers: Urubokka Oya, Small river Tanks: Tanks with a little water RE potential: Low	Low

Notes: **A:** catchment area (km^2),
R_{ave}: Approximate average annual rainfall (mm)
Min. runoff: An order of the minimum rainfall depth expected to infiltrate into the ground at the maximum in drought year (mm),
RE: Groundwater Recharge Potential in the 15 Pilot GNDs

SUPPORTING 3 GEOPHYSICAL EXPLORATION

3.1 OUTLINE OF EXPLORATION

3.1.1 OBJECTIVES AND METHODS

The objectives of geophysical exploration are 1) to assist in the evaluation of the potential of water resources by delineating promising areas for drilling, and 2) to transfer the technology of geophysical exploration to the counterpart personnel during the course of the study.

Two types of geophysical exploration methods were adopted in the study. One is an electromagnetic method called Controlled Source Audio-frequency Magnetotelluric (CSAMT), and the other is a DC electric resistivity method called Schlumberger. The CSAMT method is useful to delineate fractured zones, which are related to aquifer boundaries at relatively deep depths. The Schlumberger method, on the other hand, is useful to investigate the hydrogeological structure of the subsurface at the shallower depths. Therefore, the combined technique of CSAMT and Schlumberger gives good results from the shallow depth to the depth of 200 m.

3.1.2 LOCATION OF GEOPHYSICAL EXPLORATION

A total of 18 areas, consisting of eight areas in Monaragala district and 10 areas in Hambantota district were selected for geophysical exploration. These includes 15 Pilot GNDs and other areas selected by the hydrogeological reasons. In each area, both CSAMT and Schlumberger methods were adopted to carry out the surveys along lines of 1.3 to 1.5 Km long on the road. The measurements were made at 10 to 16 stations along the line, each separated by 100 m of intervals. The areas surveyed and survey lines are shown in *Figure 3.1*. The locations of each survey line are shown in *Appendix B*.

3.1.3 SURVEY STATIONS

The line length and number of stations are listed in *Table 3.1*. Both CSAMT and Schlumberger methods were adopted at each station.

The measurements were made at a total of 254 CSAMT and 278 Schlumberger stations in 18 areas.

3.1.4 SURVEY METHODOLOGY

Prior to the geophysical exploration, the Study team visited all the survey areas along with WRB counterpart team, to define the survey location on the basis of the geological and geographical features of the area. The survey stations were located by using a pocket compass and a measuring tape placed at every 100 meters. The station numbers were marked on the road or nearby trees with white paint.

The base stations for each line were set at landmarks such as road junctions or milestones, and its latitude and longitude were recorded by a GPS.

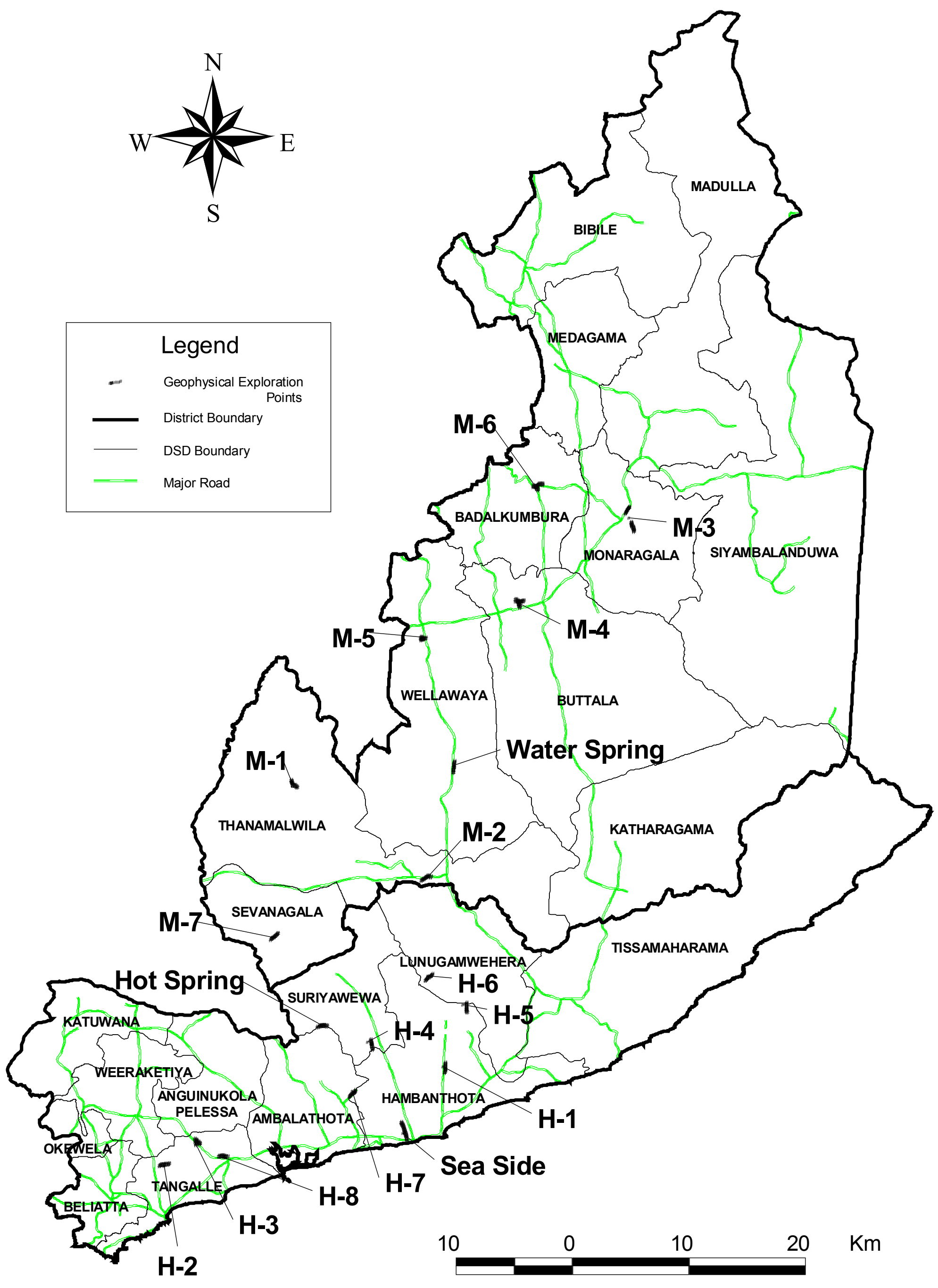


Figure 3.1 Location Map of Geophysical Exploration

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Table 3.1 Quantities of Geophysical Works

District	Area Code	Area Name	Line Length (km)	CSAMT Stations	Schlumberger Stations
Monatagala	M1	Hambegamuwa	1.4	14	14
	M2	Bodagama	1.5	15	15
	M3a	Hulandawa	1.4	15	12
	M3b	Hulandawa Additional	1.3	0	10
	M4a	Unawatuna	2.5	15	25
	M4b	Unawatuna Additional	0.7	0	8
	M5	Yalabowa	1.4	12	15
	M6	Bodalkumbra	2.4	14	11
	M7	Sevanagala	1.3	14	14
	M8	Water Spring (Tellula)	1.4	16	16
	Sub Total		15.3	115	140
Hambantota	H1	Keliyapura	1.3	14	14
	H2	Vitarandenya	1.3	15	14
	H3	Talunna	1.5	16	16
	H4	Wediwewa	1.3	14	14
	H5	Tammennawewa	1.3	14	14
	H6	Mattala	1.3	14	14
	H7	Siyambalagaswila	1.3	14	14
	H7	Ranna	1.3	14	14
	H8	Hot Spring (Mahapelessa)	1.3	14	14
	H9	Sea Side (Mirijjavila)	2.5	10	10
	Sub Total		14.4	139	138
Ground Total			29.7	254	278

3.2 BASIC PRINCIPLES AND METHODOLOGY

3.2.1 CSAMT METHOD

CSAMT is a frequency-domain electromagnetic sounding technique that uses a fixed grounded dipole as an artificial signal source. CSAMT is similar to the natural-source magnetotellurics (MT) and audio-frequency magnetotellurics (AMT) techniques, with the main difference being the use of the artificial signal sources for CSAMT which provides a stable signal, resulting in higher precision and faster measurements than are usually obtainable with natural-source measurement in the same spectral band. The method has been proven particularly effective in mapping the ground resistivity to the depth of 20 m to 2,000 m. Therefore, the application of CSAMT method should provide reliable results at the target depth of 200 meters in this project.

CSAMT was initially introduced in the mid-1970s as an EM method for the detection of conductive ore bodies. More recently, the method has been widely adopted for mineral, groundwater, geothermal, and engineering applications.

A CSAMT source usually consists of a grounded electric dipole of 1 to 2 km in length, located at 4 to 10 km away from the area where the measurement are to be made. In this investigation study, a dipole of about 1 km long was set up at about 5 km from the survey area. The frequency range for the receiver (GDP-32NJ) is from 0.125 to 8,192 Hz in binary steps, but the actual measurements were made in the 16 to 8,192 Hz range. Magnitude and phase are measured for one electric (Ex) and one magnetic (Hy) field component with Ex parallel to the transmitter dipole and Hy perpendicular. Schematic drawing of CSAMT configuration is shown *Figure 3.2*.

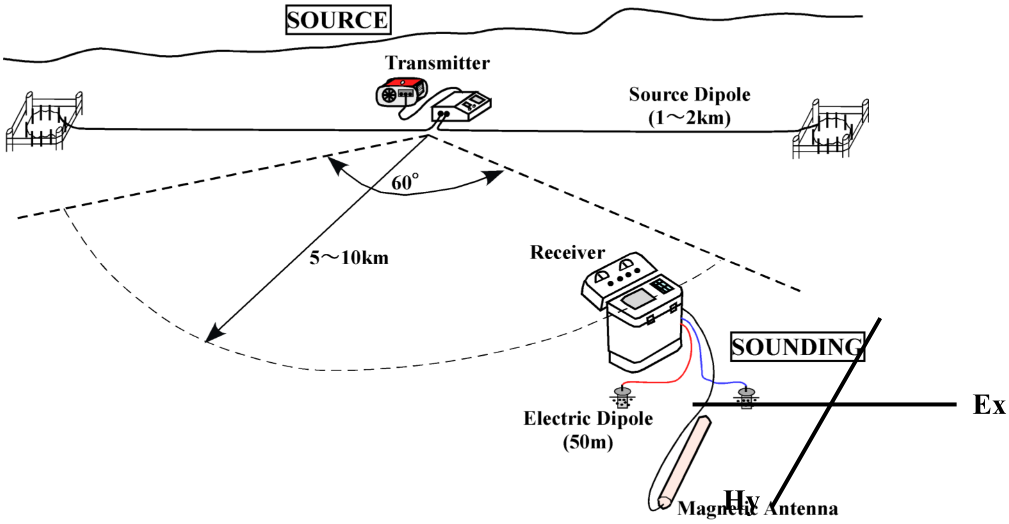


Figure 3.2 Schematic Drawing of CSAMT Configuration

In the field, the soundings were made by using a grounded dipole of 50 m to detect electric field, and a coil antenna to detect magnetic field at the receiver station. The measurement of orthogonal, horizontal electric and magnetic field magnitudes (Ex and Hy) yields the apparent resistivity, ρ a, according to the following equation:

$$\rho_a = \frac{1}{5f}\left|\frac{E}{H}\right|^2$$

Where : ρ_a = apparent resistivity in ohm-meters

E = electric field in mV/km

H magnetic field in gammas or nanoteslas

A parameter used extensively in CSAMT is skin depth, which is defined as the depth where the amplitude of a plane wave signal drops to 37% (1/e) of its original value.

Skin depth is equal to;

$$\delta = \sqrt{\frac{2}{\mu\sigma\omega}} = 503\sqrt{\frac{\rho_a}{f}}$$

Where : δ = skin depth in meters

μ = magnetic permeability of air = $4\pi \times 10^{-7}$

σ = conductivity in siemen/meters = $1/\rho$

ω = $2\pi f$ (f = frequency in hertz)

In an area with generally high resistivity as in the survey area of this Study, the skin depth calculated in the above equation becomes a considerable value, however, in actual practice the maximum depth does not exceed 3 km.

Phase difference, ψ in milliradians is defined as follows,

$$\psi = \psi_E - \psi_H$$

These data are calculated and stored in the memory of GDP for each frequency.

2-D inversion Analysis

For each CSAMT cross section, the underground structure was analysed by dividing the section into many blocks as shown in *Figure 3.3*. By giving a certain resistivity to every block, 2-D inversion analyses were repeatedly made by changing their values until it reaches an acceptable error.

2-D inversion analysis was carried out by using software developed by the Geological Survey of Japan in 1979.

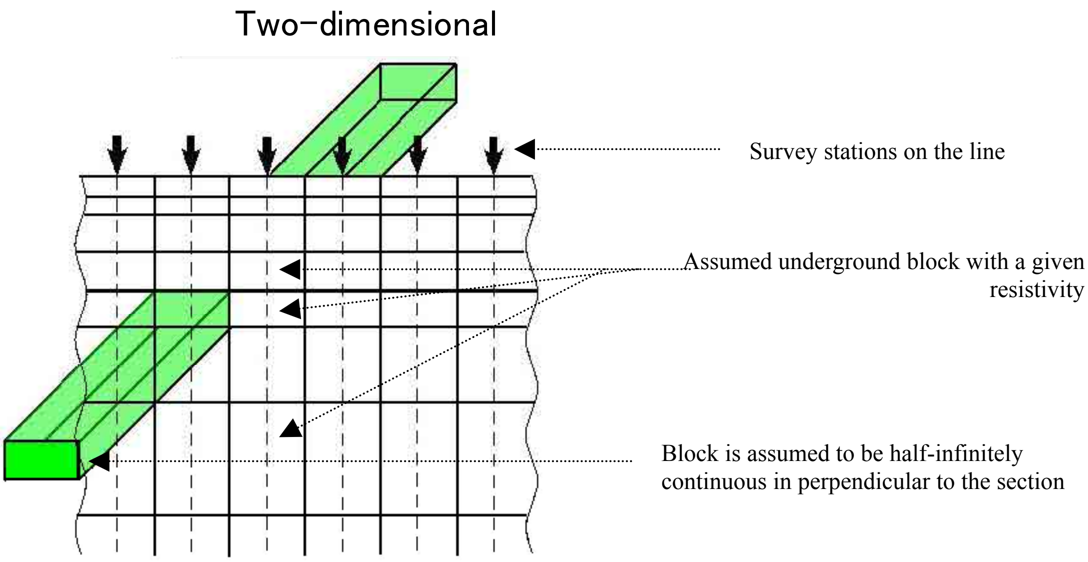


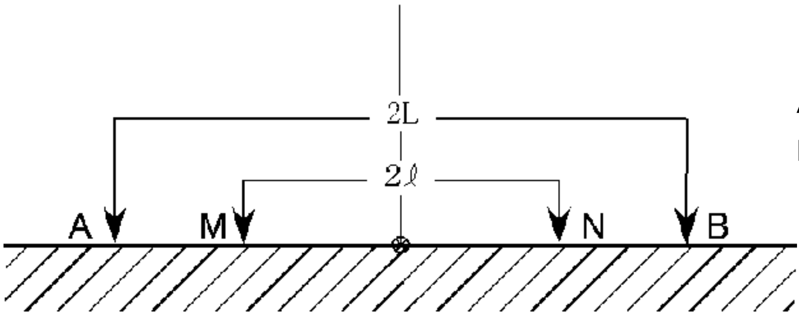
Figure 3.3 2-D Inversion Analysis

3.2.2 SCHLUMBERGER METHOD

In the Schlumberger method, the electrode array consists of a pair of current electrodes (2L or AB) with large separation as compared with the interval between the potential electrodes (2l or MN). Both current and potential electrodes are symmetrically placed as shown in *Figure 3.4*, and the apparent resistivity is simply given by;

$$\rho a = \frac{\pi}{2l}(L^2 - l^2)\frac{V}{I}$$

where, $L = AB/2$ and $l = MN/2$ $(AB/2 > 5MN/2)$



A, B: Current electrodes
M,N: Potential electrodes

Figure 3.4 Schlumberger Electrode Configuration

In this Schlumberger survey, the electrodes were configured at each station as shown in *Table 3.2*.

No.12 and 13 indicated in *Table 3.2* were used only for the deeper investigation at the seaside line in Mirijjavila, Hambantota.

By expanding AB/2 to 300 m, the analyzed depth would be around 100 m from the ground surface.

Table 3.2 Schlumberger Electrode Configurations

No.	L or AB/2 (m)	l or MN/2 (m)
1	10	2
2	20	2
3	30	2
4	40	2
5	50	5
6	75	5
7	100	5
8	150	10
9	200	10
10	250	10 or 20
11	300	10 or 20
12	(350)	20
13	(400)	20

Data Analysis

For the interpretation of the Schlumberger Vertical Sounding Curves (VES), software called RESIX developed by Interpex Ltd. (USA) was used.

In general, the resistivity increases in proportion to the incrased electrode separation from the conductive overburden to the resistive bedrock. The difference of resistivity sometimes exceeds three digits in recorded values, such as 10 to 10,000 .

3.3 Results of Geophysical Exploration

Measured at several wells by a conductivity meter, the groundwater resistivity was found to range from 1 to 15 Ohm-m. On the other hand, the resistivity of overburden was in the range of 50 to 200 Ohm-m, while the basic rocks over 1,000 Ohm-m. For this reason, the groundwater was assumed as a good target for the resistivity methods in this survey. From the survey results, three kinds of sections were obtained: Schlumberger resistivity, CSAMT 2-D Inversion and Interpreted Sections, each at a scale of 1:10,000 (See, *Figures 3.5 to 3.40* for the resistivity cross sections and survey line).

3.3.1 HAMBEGAMUWA AREA (M1) --- *SURVEY LINE, FIGURE 3.5, RESISTIVITY CROSS SECTION, FIGURE 3.6*

Overburden detected by Schlumberger method is generally thin in the central to the southeastern part of the line, and thicker towards northwest. High resistivity distributions over 1,000 Ohm-m are dominantly observed at depths indicating the existence of hard basement rocks. At the centre of the line, the surface of basement rock shows a basin structure but a shallow well drilled by Australian International Development Bureau at station 7 did not yield enough water.

A sheared zone or a fault might be passing through the northern end of this line.

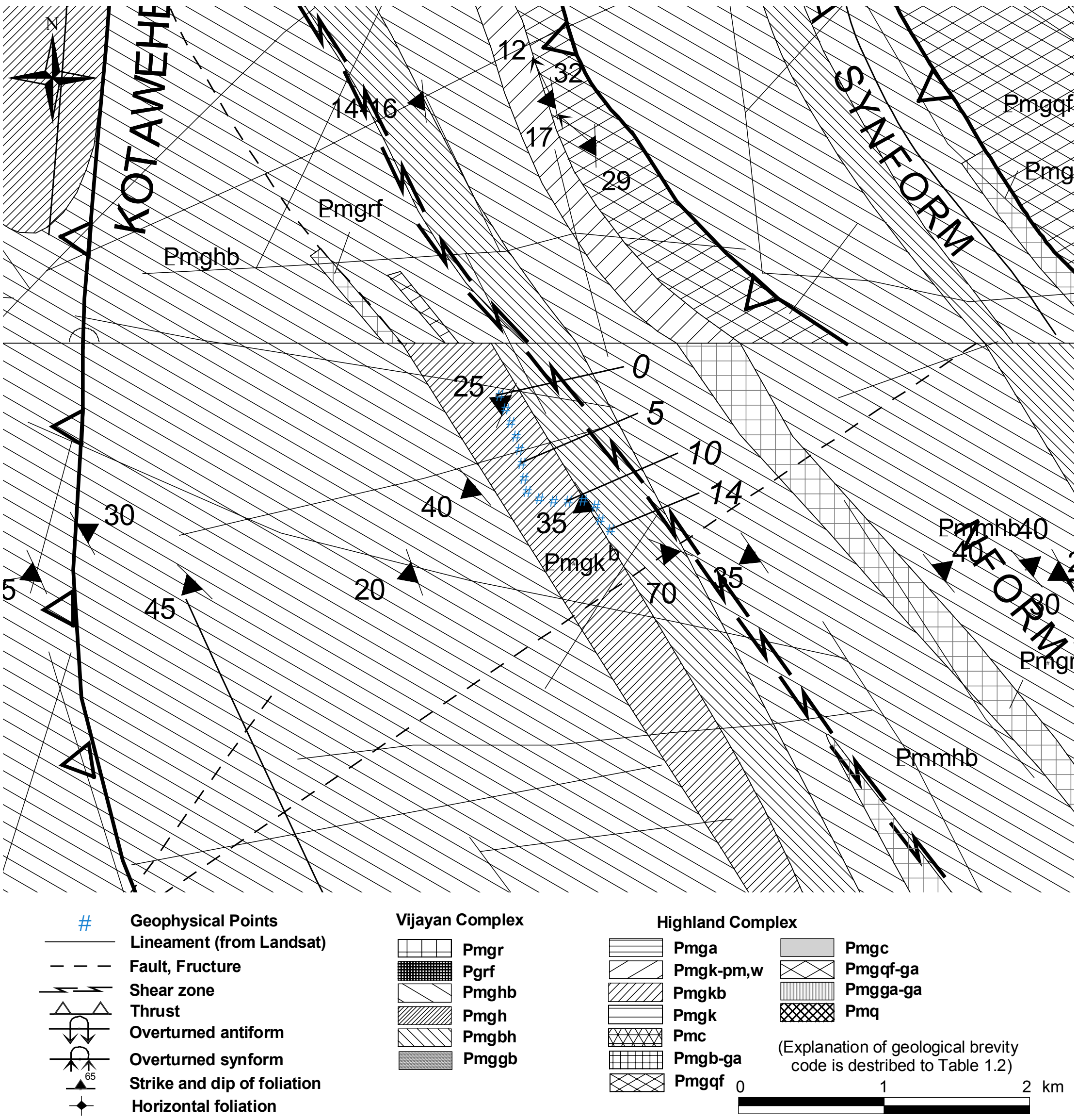


FIGURE 3.5 SURVEY LINE - HAMBEGAMUWA (M1)

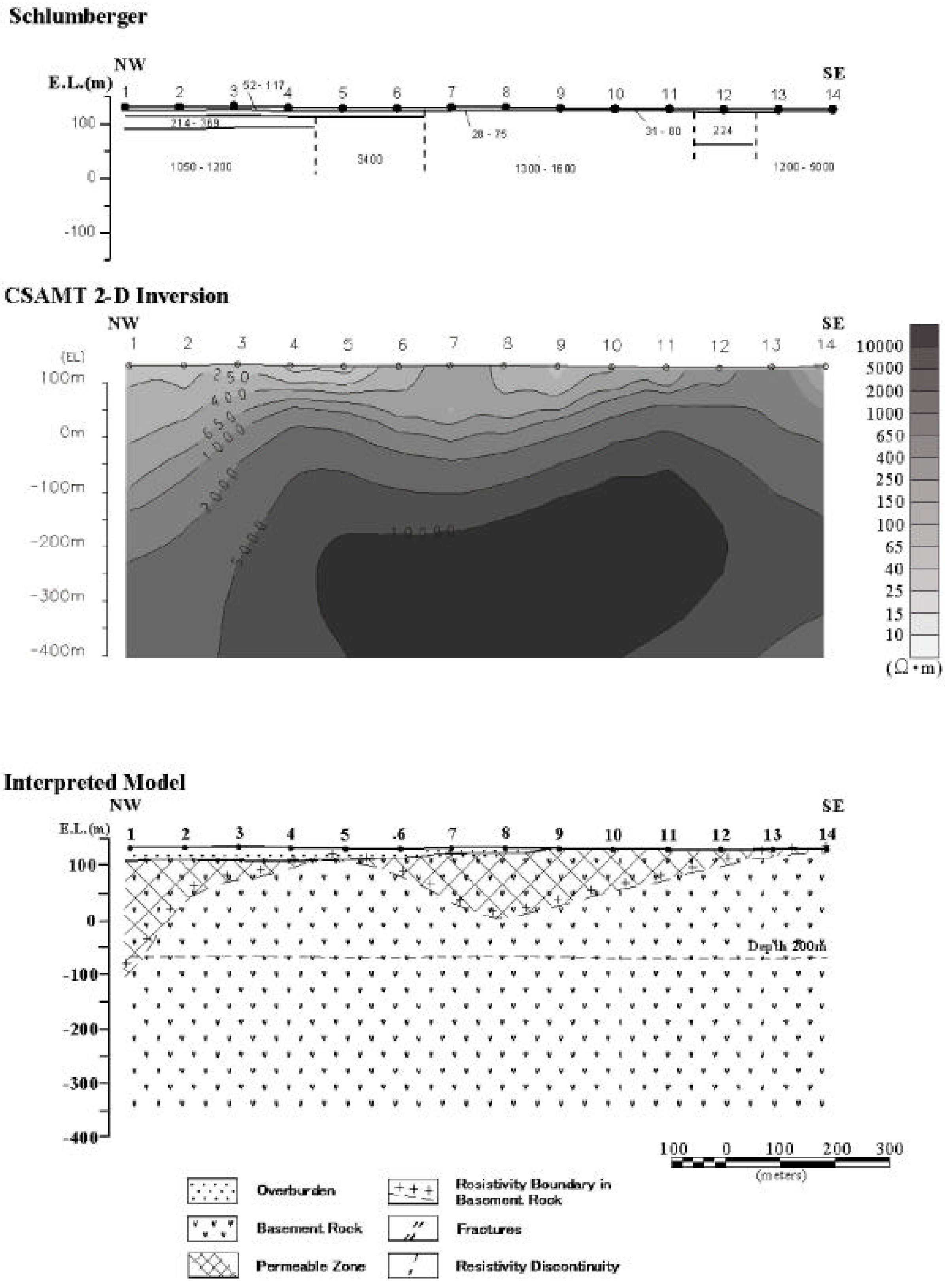


FIGURE 3.6 RESISTIVITY CROSS SECTION - HAMBEGAMUWA (M1)

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3.3.2 BODAGAMA AREA (M2) --- *SURVEY L INE, FIGURE 3.7, RESISTIVITY CROSS SECTION, FIGURE 3.8*

A major anomaly was detected at the centre of the line, showing a strong anomaly contrast around stations 7 to 8. Low resistivity less than 20 Ohm-m is distributed in depths at stations 5-6, due to the conductive water in the fractured zone. This result suggests that geological boundary or a fault runs through this anomaly dipping westward from stations 7 and 8. This is indicative of the sheared zone in Vijayan group that cuts this line at the centre. Accordingly, the most promising point for drilling would be around station 6. The test well location was decided as station 7, based on the availability of the land.

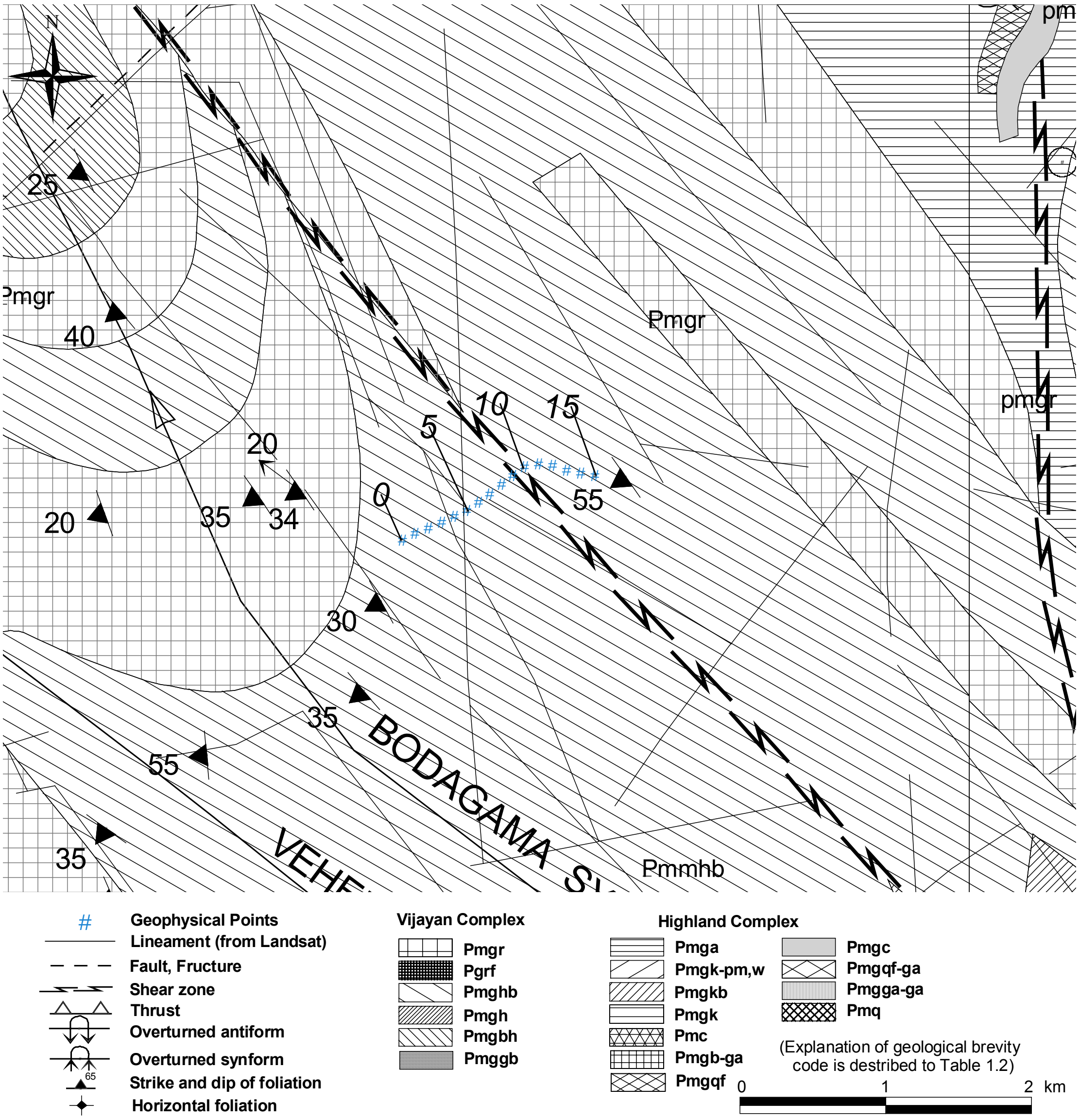

FIGURE 3.7 SURVEY LINE - BODAGAMA (M2)

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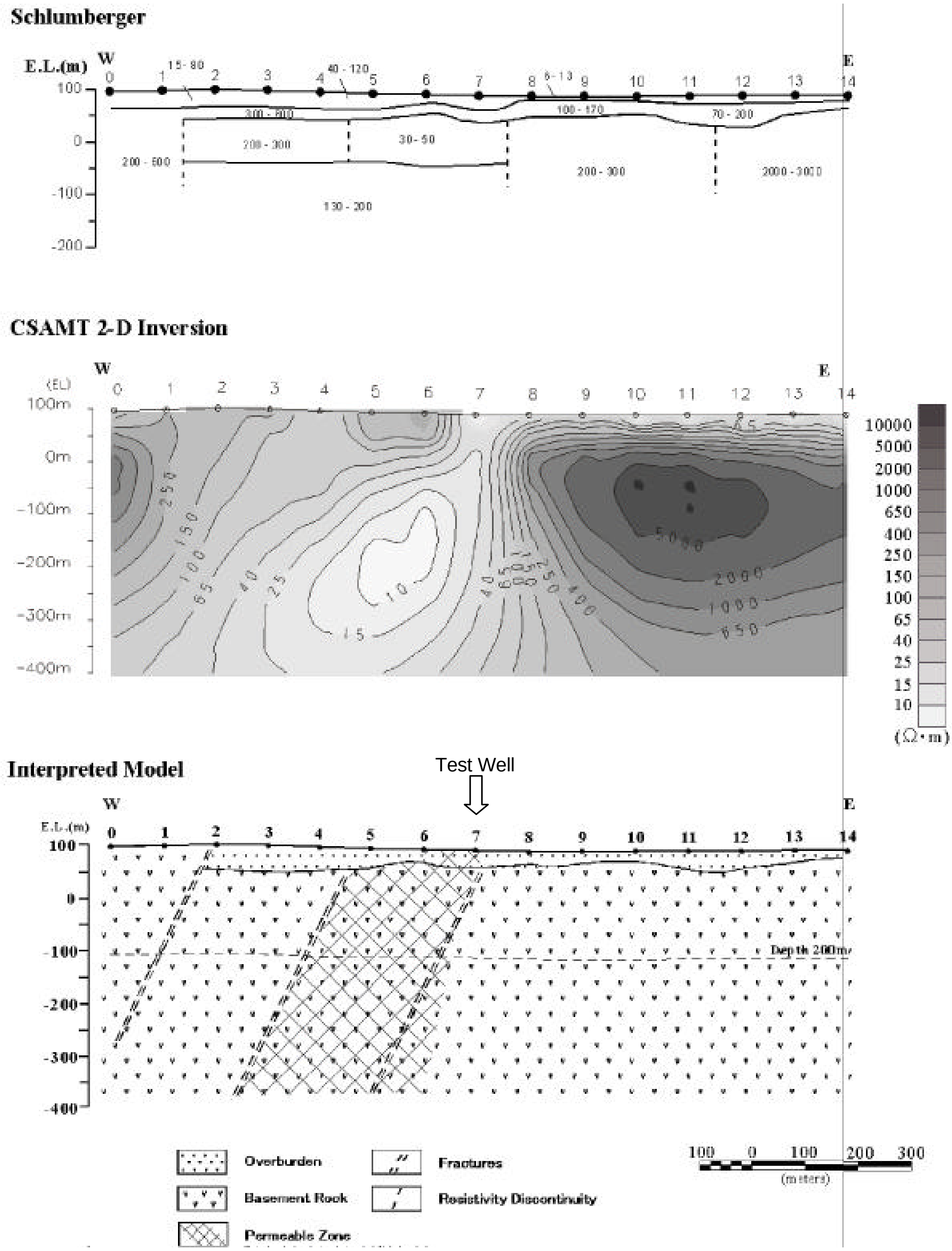

FIGURE 3.8 RESISTIVITY CROSS SECTION - BODAGAMA (M2)

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3.3.3 HULANDAWA AREA (M3) --- *SURVEY LINE, FIGURE 3.9, RESISTIVITY CROSS SECTION, FIGURE 3.10(A) AND FIGURE 3.10(B)*

In general the survey line indicates high resistivity of more than 1,000 Ohm-m, except for overburdens at both sides of the line. Basement rocks are distributed near the surface on most of the line, but a water spring is observed at station 0, which indicates a lower resistivity around 50 Ohm-m. No promising point was detected for a drilling to find groundwater resources in deeper formation on this line. In order to detect an assumed N-S trending structure, an additional survey line of 1.3 km was set up for Schlumberger method from the bridge of Hulandawa Oya to the centre of Monaragala town (See, *Figure 3.10(b)*). Despite of noisy circumstances, a contact between Stations 3 and 4 was detected, showing a distinct boundary separating a conductive zone in the east and a resistive zone in the west.

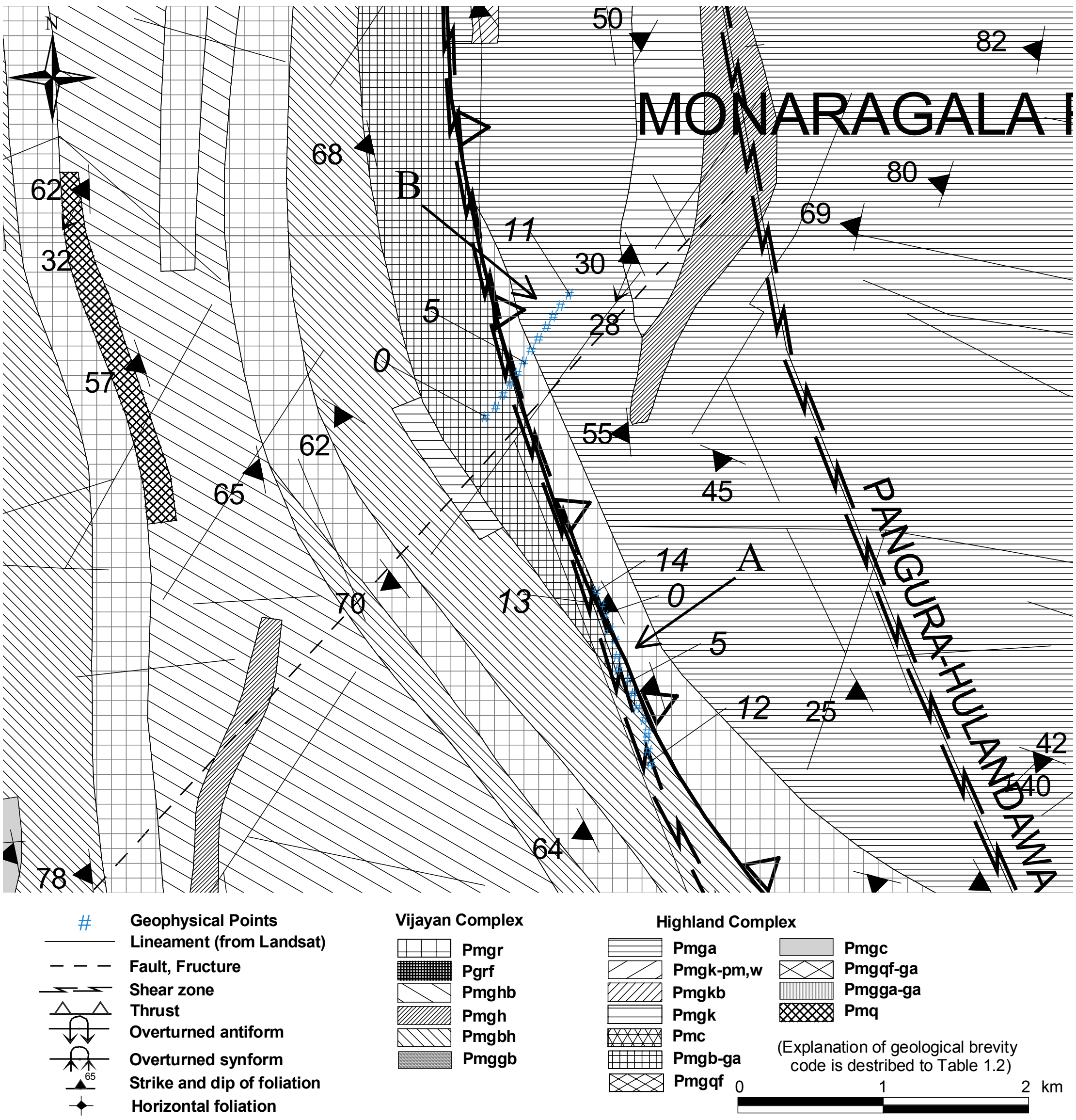

FIGURE 3.9 SURVEY LINE - HULANDAWA (M3A,M3B)

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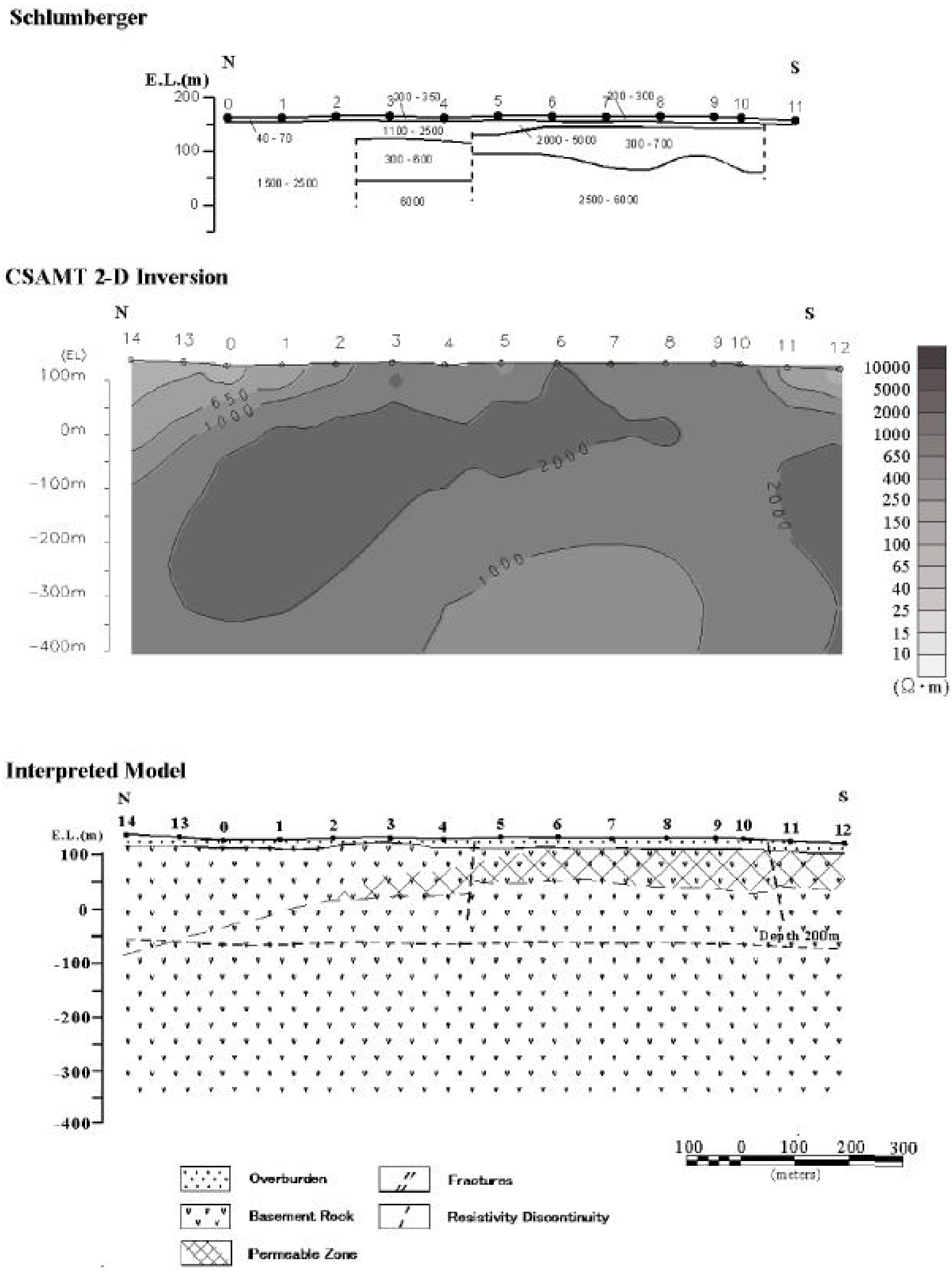

FIGURE 3.10(A) RESISTIVITY CROSS SECTION - HULANDAWA (M3A)

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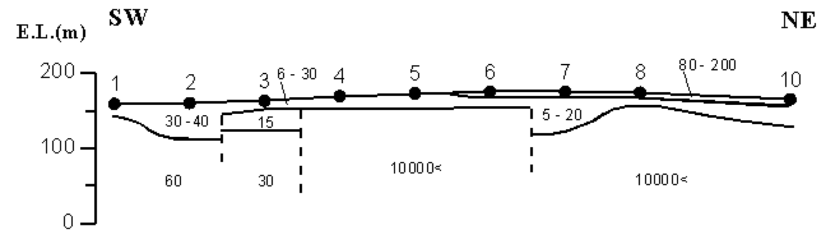
Schlumberger



Interpreted Model

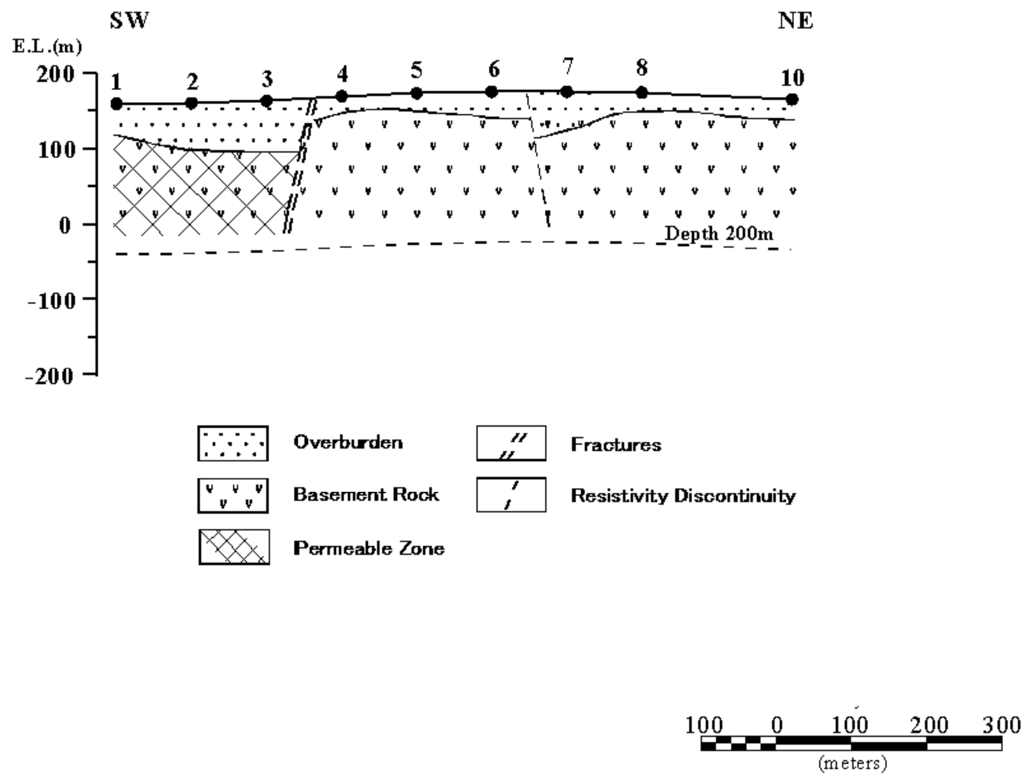


FIGURE 3.10(B) RESISTIVITY CROSS SECTION - HULANDAWA (M3B)

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3.3.4 UNAWATUNA AREA (M4) --- *SURVEY LINE, FIGURE 3.11, RESISTIVITY CROSS SECTION, FIGURE 3.12(A) AND FIGURE 3.12(B)*

A contour line of 650 Ohm-m of CSAMT section seems to delimit the weathered zone and the hard bedrock, confirming the existence of a large basin structure around stations 5-9. On the interpreted section, a graben structure is presumed at around stations 6-7 and which may extend to the depth of 200 meters from the surface.

Again, in order to detect an assumed N-S trending structure, an additional survey line of 0.7 km was established for Schlumberger method from station 7 (See, *Figure 3.12(b)*). This additional Schlumberger line that runs towards east to the Yudaganawe Wewa, indicates a boundary between stations 19 and 20 with the western side of the boundary being slightly lower than the eastern side.

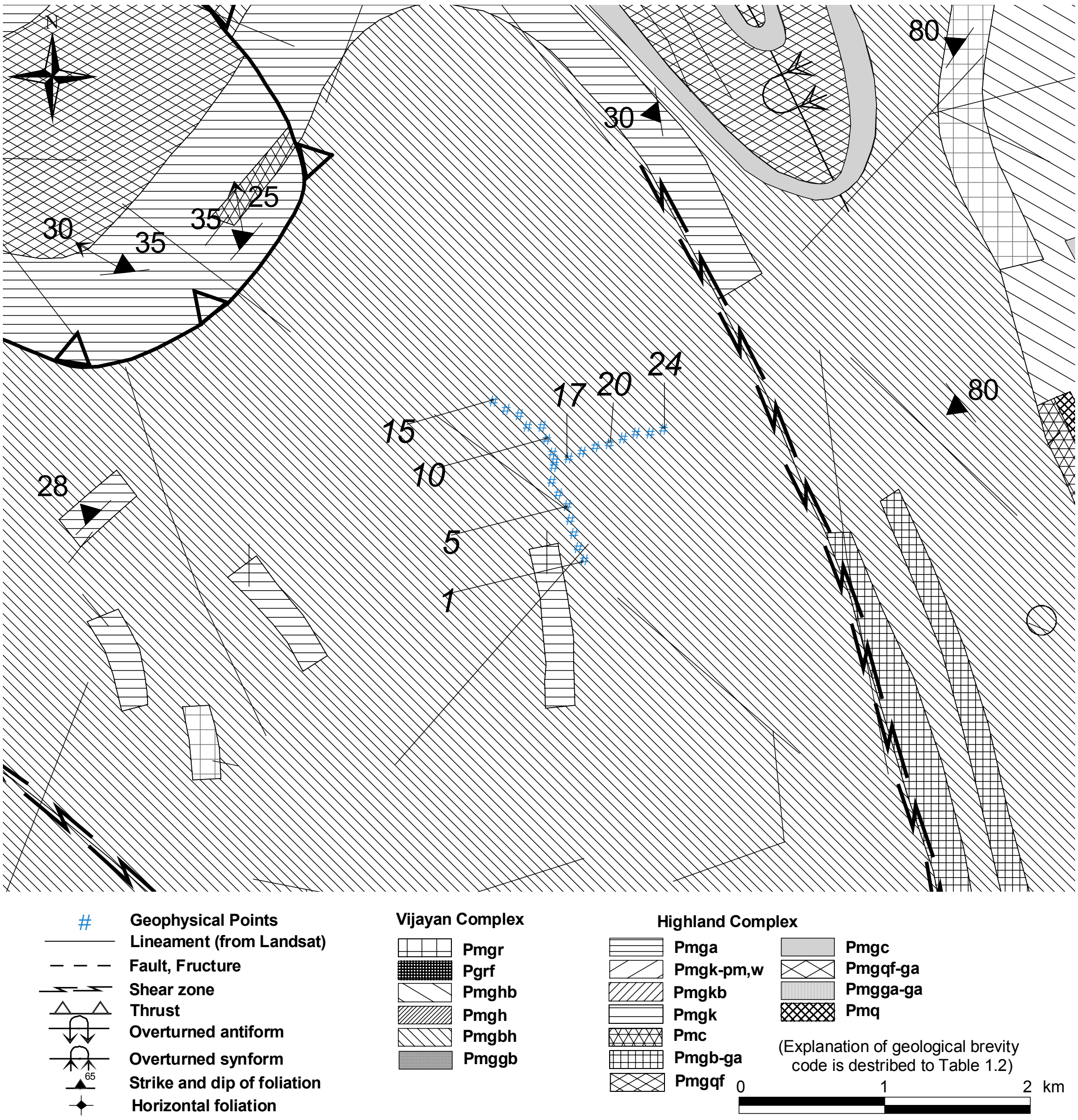

FIGURE 3.11 SURVEY LINE - UNAWATUNA (M4)

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