SUPPORTING 6 TEST WELLS

6.1 GENERAL

In Hambantota, six test wells had been constructed during the 2nd field study (November 2001 to March 2002). During the 3rd field study (April 2002 to September 2002), six test wells have been drilled in Monaragala. In addition, two boreholes were drilled in Pahala Mattala and Sevanagala by WRB to obtain hydrogeological information in shallower part above 50 meters in which major fractured aquifer occurred.

The locations of 12 test wells are shown in *Figure 6.1*.

The main purpose of test well drilling is to gain hydrogeological information, especially below a depth of 100 meters or more. Therefore the test wells were drilled up to about 200 meters below G.L. The standard design of the well, well head block, and well emblem are shown in *Figure 6.2*, *Figure 6.3* and *Figure 6.4* respectively. The drilling procedure is summarized in *Table 6.1*.

Geophysical logging and pumping tests were conducted after completion of each borehole drilling.

This *Supporting Report* describes the results of the drilling, geophysical logging and pumping tests.

Table 6.1 Drilling Procedure

Step No.	Work Description	Items and Specification applied
1	Drill a conductor hole on the surface to the required depth	Hole size: 12-1/4" (311.2 mm)
2	Install a conductor pipe to the drilled depth.	Pipe size: 10" (OD 267.4/ ID 254.2 mm)
3	Seal the annular space between the wall of a drilled bore and the conductor pipe by cementing.	
4	Resume drilling of the borehole to the required depth.	Bit size: Bit size : 8-5/8" (219.0 mm)
5	Perform borehole geophysical logging through the drilled borehole	Resistivity(16”, 64”), SP, Natural Gamma, and Caliper log.
6	Determine the position(s) of screen pipe through the instruction of the Engineer.	
7	Install casing and screens pipe as determined.	Casing size : 6" (159 mm OD)Screen size : 6" (159 mm OD)
8	Make full hole cementing for the annular space between the hole wall and upper casing pipe by grouting pipe.	Grouting pipe 3/4”
9	Perform the development of a borehole	By air-lifting (surging or bailing from time to time may be necessary)
10	Carry out the pumping test by submersible pump.	Step drawdown test, constant discharge test and time recovery test.
11	Construct the borehole head facilities and install the water level recorder.	As described Figure 6.3

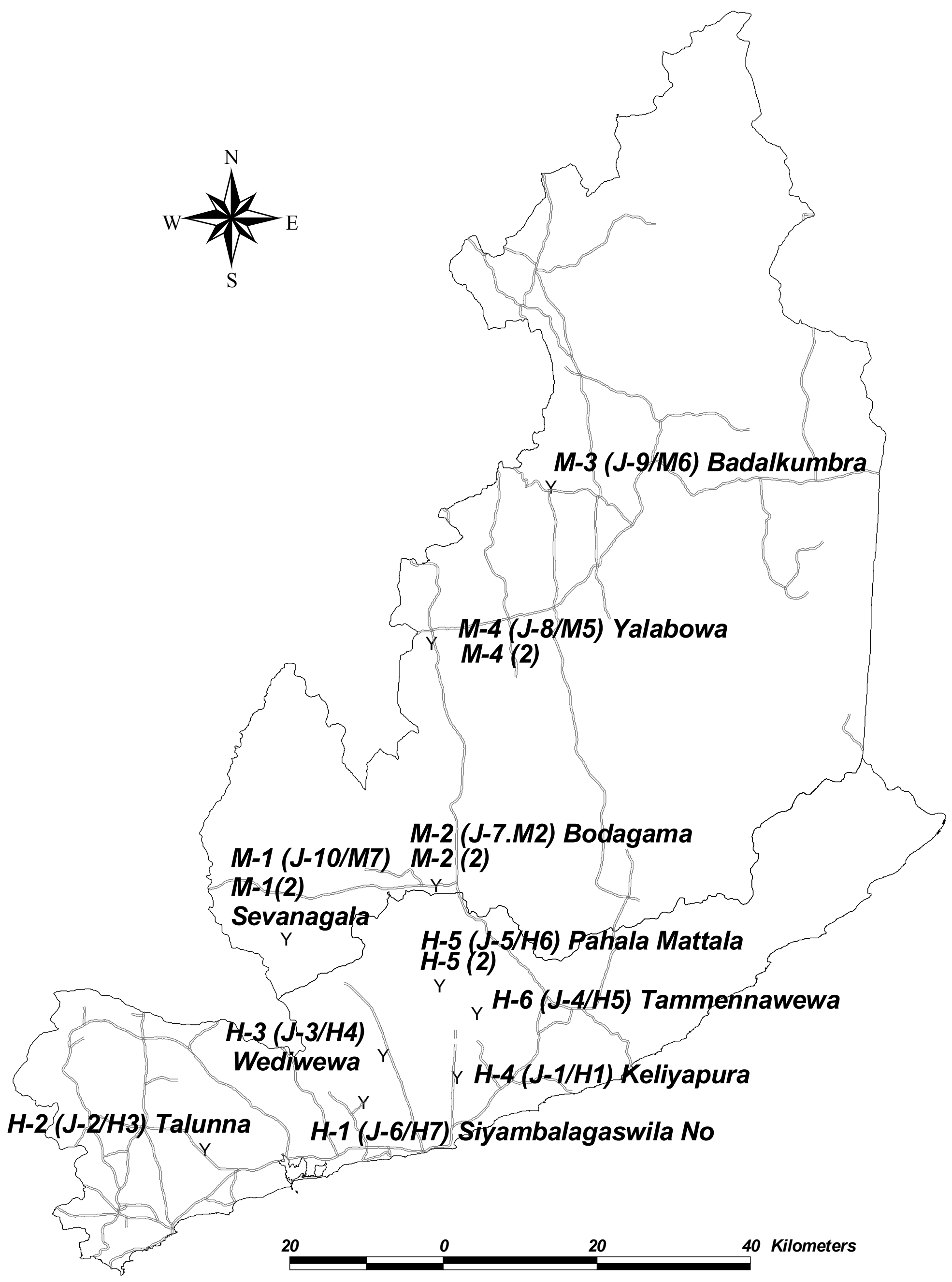

FIGURE 6.1 LOCATION OF TEST WELL

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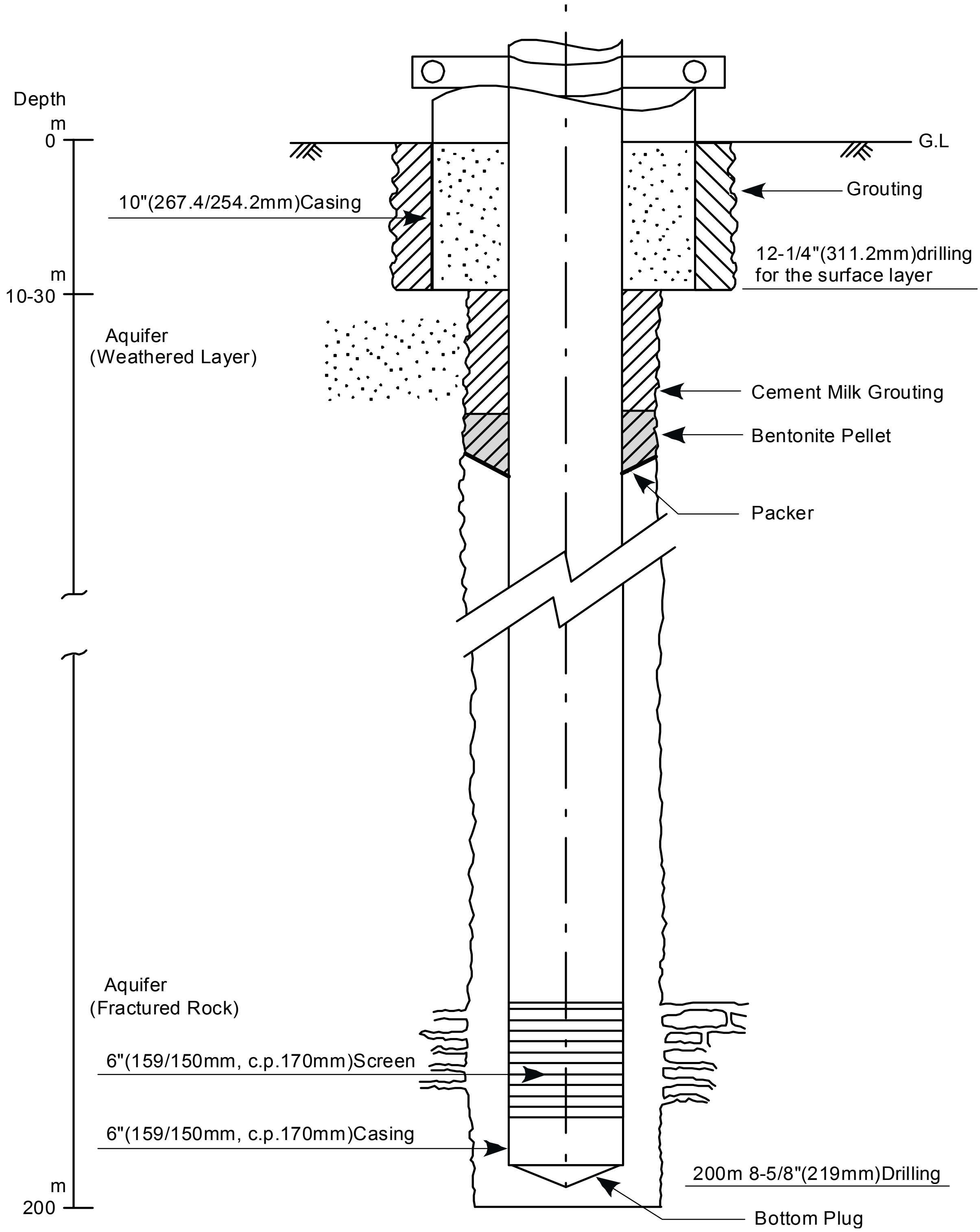

FIGURE 6.2 STRUCTURE OF TEST WELL

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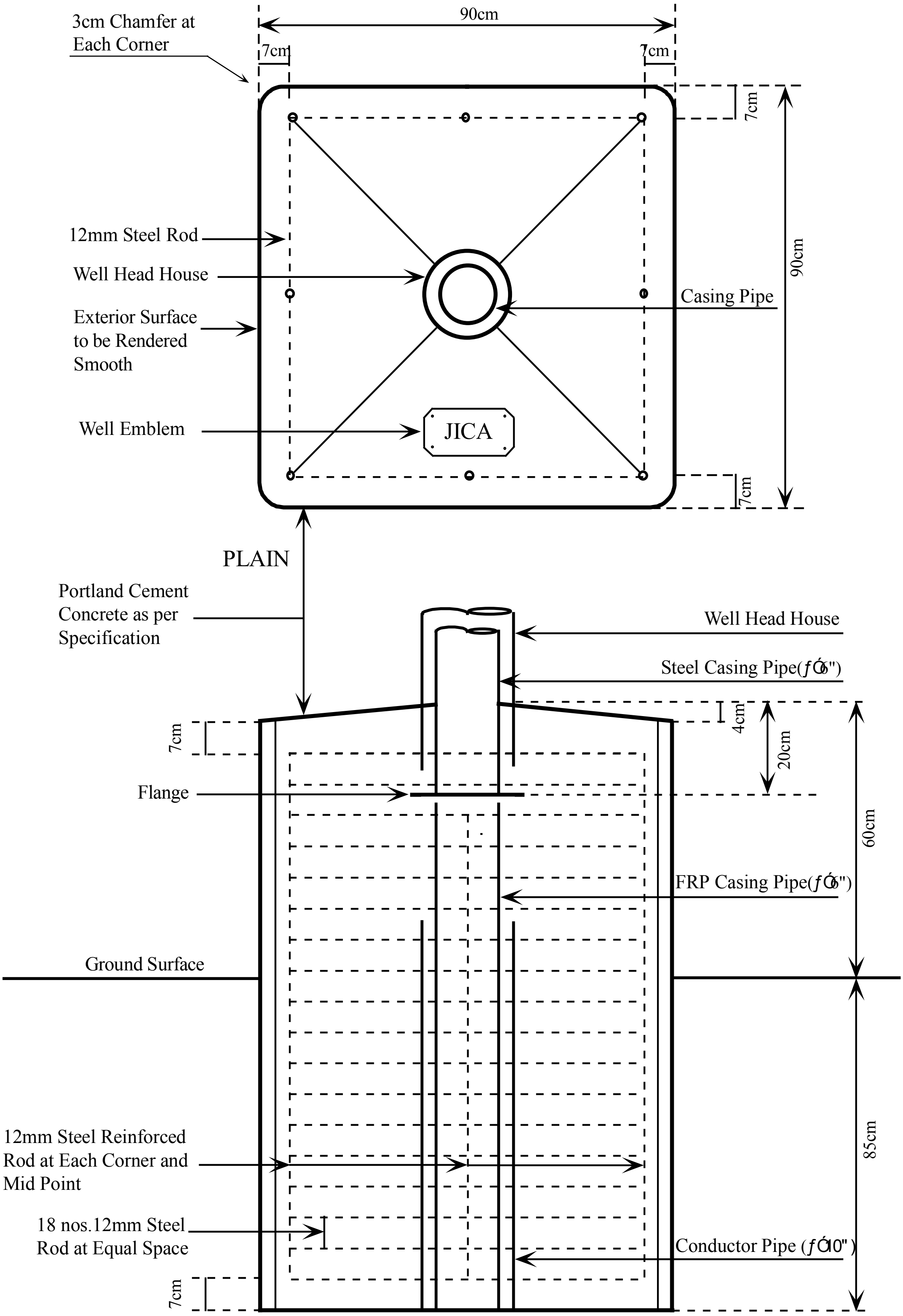

FIGURE 6.3 WELL HEAD BLOCK

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NOTE:

1) All letter to be engraved
2) 3mm aluminum plate 160 x 100mm in size
3) Letters painted with black enamel paint

FIGURE 6.4 WELL EMBLEM

6.2 TEST WELL DRILLING

The construction schedule of drilling works is summarized in *Figure 6.5* and the basic data of the test wells are tabulated in *Table 6.2*.

Table 6.2 Result of Test Well Drilling

Well No.	Location	Coordination		Altitude	Borehole Diameter	Drilled Depth	Cased Depth	Casing/Screen Diameter I.D.	Screen	Screen length	S.W.L*	Air Lifting Test**	Fractures mf: minor fractures, fy: final yield in drilling
		Lat.	Long.	m. amsl	(mm)	(m)	(m)	(mm)	from - to -	(m)	(m bgl)	(l/m, µS/cm)	
H-1 (J-6/H7)	Siyambalagaswila North	6 10'25"	81 01'10"	16.80	219	212.4	203.6	150	166.6 - 186.8	20	11.35	4.2 / 10,100 W.L 34.1 mbgl	33m: 5 l/m. 5600uS/cm mf: 17, 41, 119.5, 169, 184, 204, 207m
H-2 (J-2/H3)	Talunna	6 07'03"	80 49'57"	14.45	219	194.4	194.4	150	172.9 - 188.9	16	3.55	400 / 3510 W.L 19.5 mbgl	185m: 500 l/m. 3480 mf: 154, 155, 160, 164, 176m
H-3 (J-3/H4)	Wediwewa	6 13'42"	81 02'33"	29.57	219	200.4	200.4	150	151.0 - 171.0	20	13.00	18 / 7820 W.L 80.5 mbgl	153m: 20 l/m. 8050uS/cm mf: 16.5, 46.5, 75, 94, 96m
H-4 (J-1/H1)	Keliyapura	6 12'12"	81 07'44"	13.36	219	200.2	200.2	150	123.0 - 135.0 151.0 - 163.0 187.0 - 195.0	32	193.04	---	mf: 124, 158m
H-5 (J-5/H6)	Pahala Mattala	6 18'40"	81 06'32"	43.58	219	200.4	200.4	150	163.0 - 195.0	32	10.52	340 / 3060 W.L 70.0 mbgl	12.5, 17, 23-25, 30-31, 37-38, 44.5, 54, 78, 83, 97, 105, 113, 135, 161,166, 173-176, 176-200m
H-5 (2)	Pahala Mattala	6 18'41"	81 06'31"		150	52.5	(6.8)	(8" surface casing)	(6.8 - 52.5) open hole	(45.7) open hole	8.50	125 / 2500	28-30, 34.8m dryf; 12-12.6, 15.5-16.5, 18-18.3m wet; 20-26m
H-6 (J-4/H5)	Tammennawewa	6 16'42"	81 09'10"	34.12	219	146	102.1	150	52.5 - 60.5 72.5 - 84.5	20	9.04	360-240 / 8300 W.L. 36 mbgl	37, 53-59, 73-74, 78, 101-102, 106-115, 120-146m fy; 700-800 l/min, 4980 uS/cm
H-6 (2)	Tammennawewa	(35m east from H-6)			219 / 114	114.8	101.3	150	---	---	10.00	---	
M-1 (J-10/M7)	Sevanagala	6 21'58"	80 55'43"		219	200.4	200.4	150	127.0 - 155.0 159.0 - 163.0 171.0 - 175.0 179.0 - 191.0	48	1.73	550 / 570 W.L. 31.1m	12-13, 18, 23.5-24, 29, 130-134, 143m mf: 70, 80.5, 150-200m fy; 650 l/min, 700 uS/cm
M-1 (2)	Sevanagala	(50m east from M-1)			150	40.8	5.8	(8" surface casing)	(5.8 - 40.8) open hole	(35) open hole	2.03	---	
M-2 (J-7/M2)	Bodagama	6 25'50"	81 06'25"		219	200.2	200.2	150	131.0 - 151.0 171.0 - 183.0	32	(7.9)	510 / 2020 W.L. 19.21 mbgl	Fault zone; 35-40m mf; 18.5, 80, 88, 135-140m fy; 1000 l/min, 2050 uS/cm
M-2 (2)	Bodagama	(68m east from M-2)			219	100	100	150	27.0 - 55.0 63.0 - 95.0	60	7.60	---	
M-3 (J-9/M6)	Badalkumbra	6 53'53"	81 14'33"		219	88.32	88.3	150	63.0 - 83.0	20	12.2	850 / 420 W.L. 13.16 mbgl	44, 62, 63, 65-67, 68, 73-74, 76-78, 80-81, 83-84, 87-88m, fy; 6000 l/min. 420 microS/cm
M-4 (J-8/M5)	Yalabowa	6 42'53"	81 05'58"		219	195	195	150	146.0 - 162.0 166.0 - 174.0 178.0 - 190.0	36	12.70	550 / 770 W.L. 27.08 mbgl	55-56, 75-80, 90-91, 99m mf; 155, 188m fy; 1200 l/min, 780 uS/cm
M-4 (2)	Yalabowa	(42m east from M-4)			219	100	100	150	23.0 - 47.0 55.0 - 95.0	64	12.60	---	

*) Water level measured right after drilling completed.
**) conducted during the progress of drilling or before installation of casing/screen pipes.

Figure 6.5(1) Construction Schedule of Drilling Works (2nd Study in Sri Lanka)

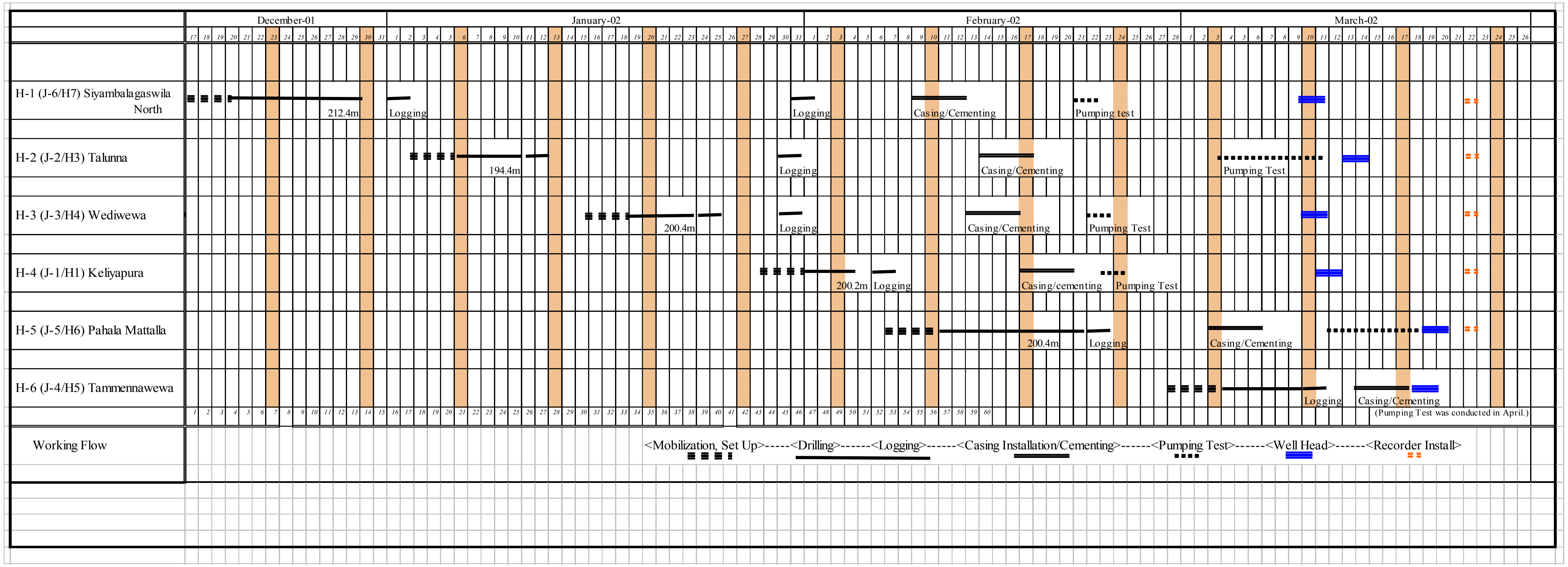
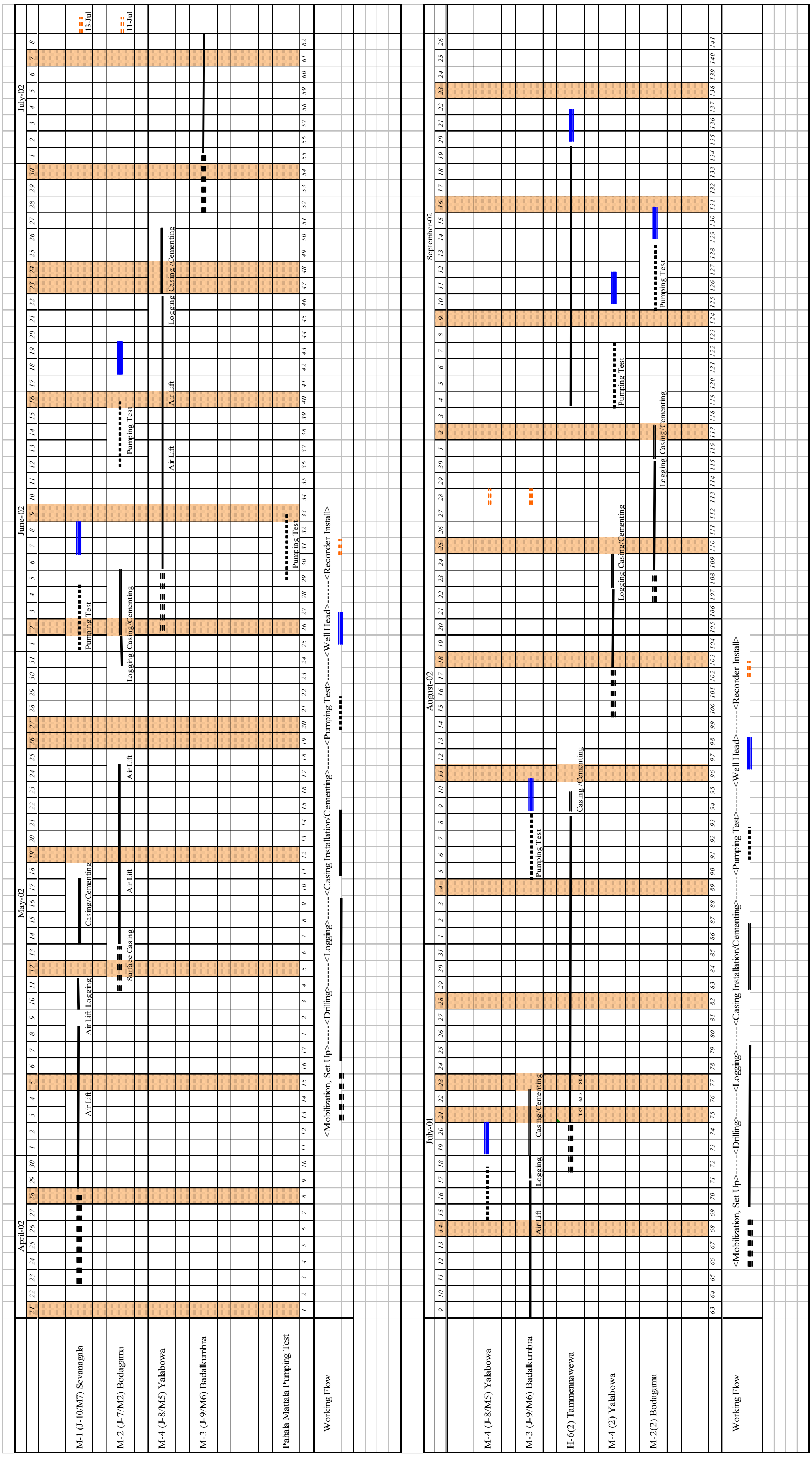


Figure 6.5(2) Construction Schedule of Drilling Works (3rd Study in Sri Lanka)



The detailed log of each test well is shown in *Appendix F*, which includes geological description, well structure and geophysical logging results.

The results of geophysical logging and the pumping test are described in the following sections, *6.3 Geophysical Logging* and *6.4 Air Lift and Pumping Test*.

The outlines of the test wells of each location are summarized as follows.

6.2.1 Siyambalgaswila North (Appendix F - LOG OF BORING H-1)

The test well was named H-1(J-6/H7). *Figure 6.6* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 17, December '01	to 19, December '01
Drilling	from 20, December '01	to 28, December '01
Logging	1, January '02 and 31, January '02	
Casing Installation	9, February '02	
Air Lifting Test	3, January '02	
Installation of Water Level Recorder	14, March '02	

(2) Construction of Well

Drilled Depth	212.4 m
Surface Casing	4.67 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	203.6 m
Screen Depth	from 166.6 m to 186.8 m (20 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

Hornblende biotite gneiss from top to bottom, highly rich in hornblende generally.

<Fractures and Water>

The yield and EC recorded below were measured when a fracture was indicated during the drilling. The fractures without any mention showed no change of yield and EC.

Prominent fracture:	33m (Yield 5 litres/min. 5600 microS/cm)
Minor fractures:	17 m(dry), 41 m(7500 microS/cm), 119.5 m, 169 m, 184 m, 204 m, 207 m
Water level measuring:	12.0 mbgl (22, December '01)
	11.6 mbgl (26, December '01)
	11.35 mbgl (28, December '01)

(4) Air Lifting Test

The air lifting test was conducted before casing installation.

S.W.L:	12.0 mbgl (3, January '02)
P.W.L:	34.1 mbgl
Drawdown:	22.1 m
Yield:	4.2 litres/min
EC:	10,100 microS/cm

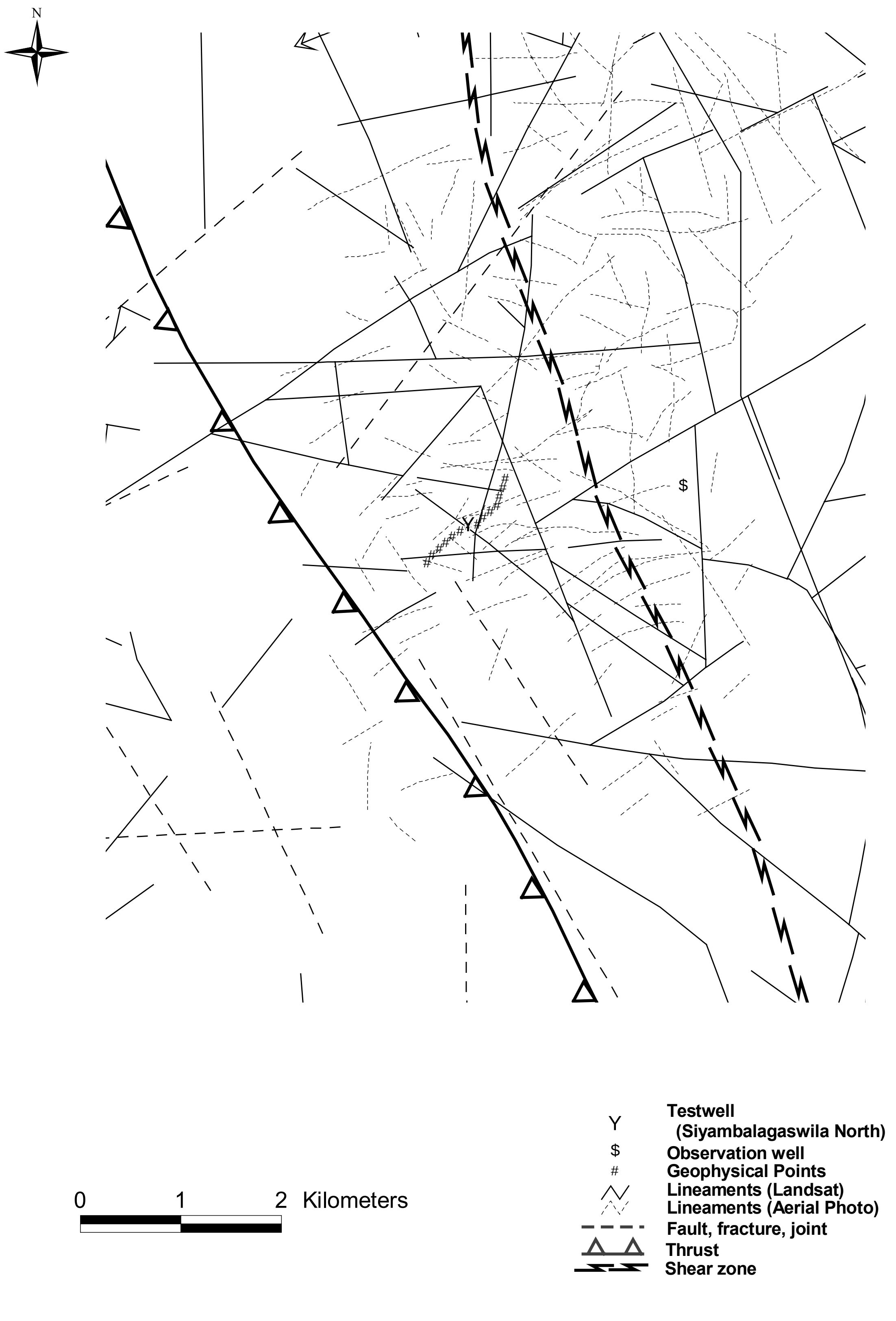


FIGURE 6.6 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (H-1 SIYAMBALAGASWILA NORTH)

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6.2.2 TALUNNA (APPENDIX F - LOG OF BORING H-2)

The test well was named H-2(J-2/H3). *Figure 6.7* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 4, January ‘02 to 5, January ‘02
Drilling	from 6, January ‘02 to 10, January ‘02
Logging	30, January ’02
Casing Installation	14, February ‘02
Air Lifting Test	15, January ‘02
Installation of Water Level Recorder	22, March ‘02

(2) Construction of Well

Drilled Depth	194.4 m
Surface Casing	5.51 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	194.4 m
Screen Depth	from 172.9 m to 188.9 m (16 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 4 to 164 m: Hornblende biotite gneiss, highly rich in hornblende.

From 164 to 186 m: Granitic gneiss, over 95% quartz and feldspar.

From 186 to 194 m: Hornblende biotite gneiss.

<Fractures and Water>

Prominent fracture:	185 m (Yield 500 litres/min. 3480 microS/cm)
Other fractures:	154 m, 155 m, 160 m (yield: unmeasurable, 2300 microS/cm), 164 m (18 litres/min, 2300 microS/cm), 176 m (20 litres/min, 2300 microS/cm)
Water level measuring:	10.5 mbgl (9, January ’02)

(4) Air Lifting Test

The air lifting test was conducted before casing installation.

S.W.L:	3.55 mbgl (15, January ’02)
P.W.L:	19.5 mbgl
Drawdown:	15.95 m
Yield:	400 litres/min
EC:	3510 microS/cm
PH:	7.4
Temperature:	29.9 C.

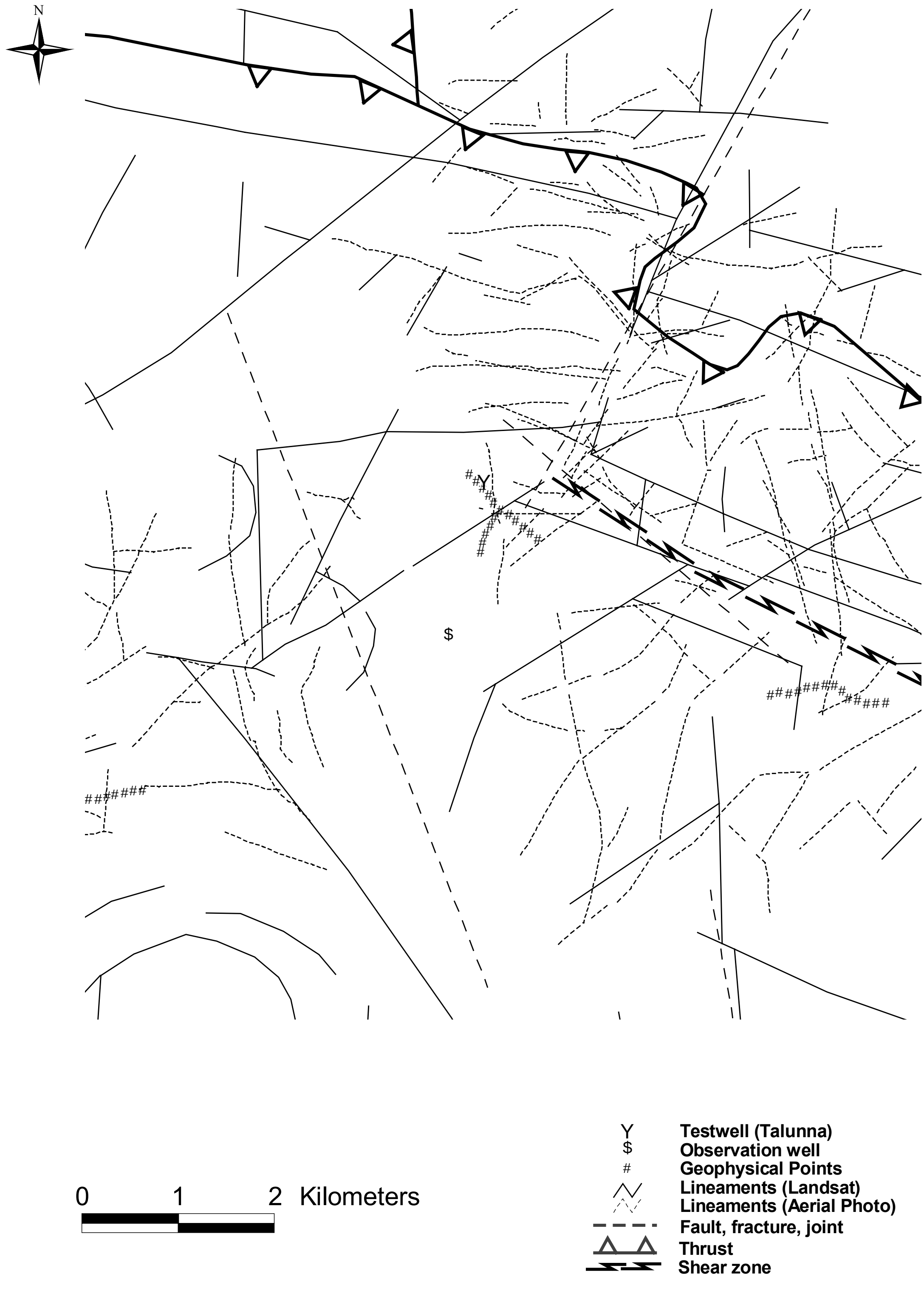

FIGURE 6.7 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (H-2 TALUNNA)	
THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT	JICA

6.2.3 WEDIWEWA (APPENDIX F - LOG OF BORING H-3)

The test well was named H-3(J-3/H4). *Figure 6.8* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 16, January '02	to 18, January '02
Drilling	from 19, January '02	to 23, January '02
Logging	30, January '02	
Casing Installation	13, February '02	
Air Lifting Test	24, January '02	
Installation of Water Level Recorder	14, March '02	

(2) Construction of Well

Drilled Depth	200.4 m
Surface Casing	9.26 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	200.4 m
Screen Depth	from 151.0 m to 171.0 m (20 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

3) Geology

<General Condition>

From 4 to 127 m: Hornblende biotite gneiss, highly rich in hornblende.

From 127 to 133 m: Granitic gneiss, hornblende and biotite as minor minerals.

From 133 to 154 m: Hornblende biotite gneiss, highly rich in hornblende.

From 154 to 170 m: Granitic gneiss, hornblende and biotite as minor minerals.

From 170 to 200 m: Hornblende biotite gneiss, highly rich in hornblende.

<Fractures and Water>

rominent fracture:	153 m (20 litres/min. 8050 microS/cm)
Other fractures:	16.5 m (dry), 46.5 m (dry), 75 m (dry), 94 m (10 litres/min. 8100 microS/cm), 96 m (8100 microS/cm)
Water level measuring;	13.0 mbgl (23, January '02), 13.0 mbgl (24, January '02)

4) Air Lifting Test

The air lifting test was conducted before casing installation.

S.W.L:	13.1 mbgl (24, January '02)
P.W.L:	80.5 mbgl
Drawdown:	67.4 m
Yield:	18 litres/min
EC:	7820 microS/cm
PH:	7.3
Temperature:	30 C.

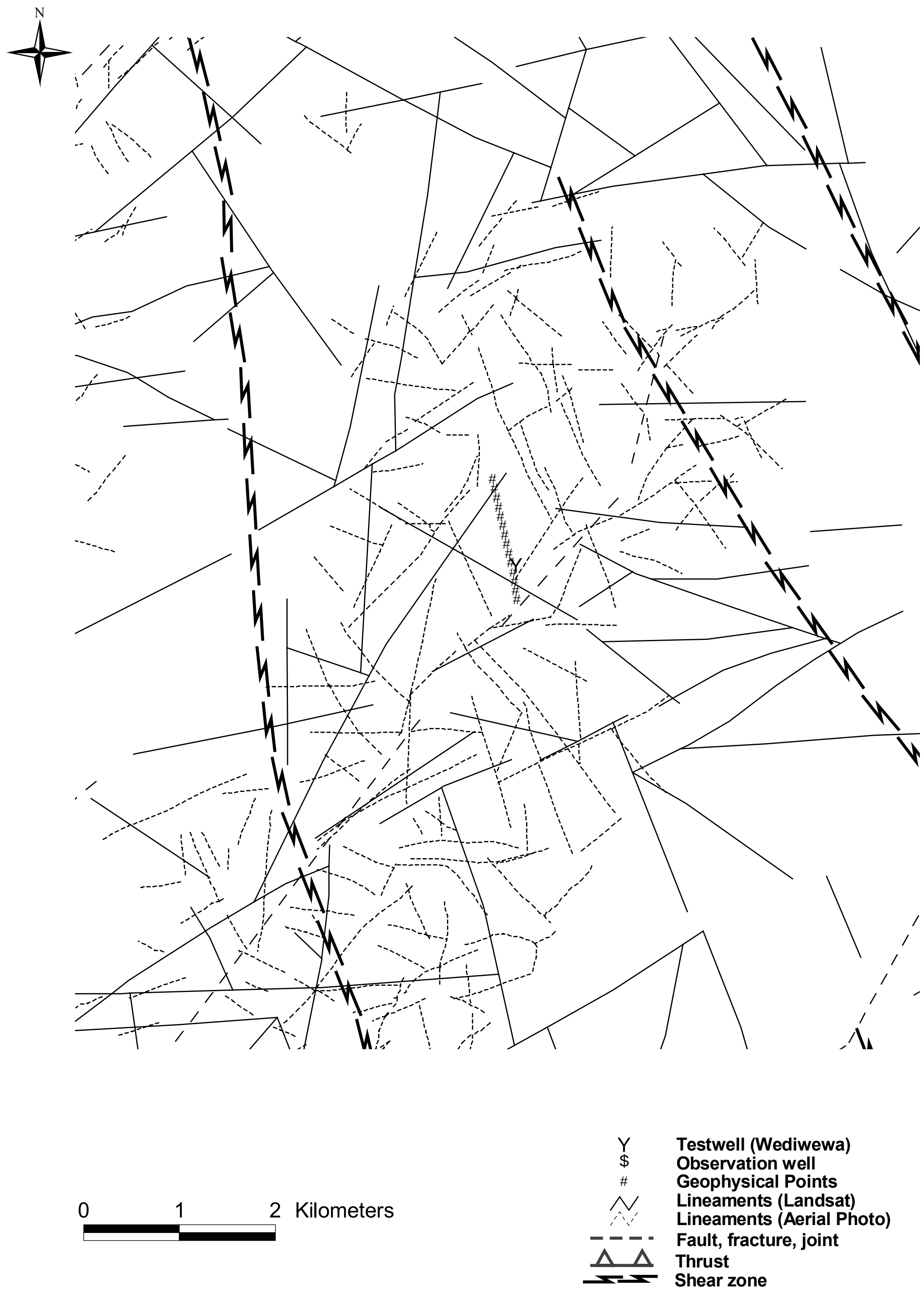

FIGURE 6.8 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (H-3 WEDIWEWA)

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6.2.4 KELIYAPURA (APPENDIX F - LOG OF BORING H-4)

The test well was named H-4(J-1/H1). *Figure 6.9* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 29, January ‘02	to 31, January ‘02
Drilling	from 1, February ‘02	to 4, February ‘02
Logging	6, February ’02	
Casing Installation	17, February ‘02	
Air Lifting Test	6, February ‘02	
Installation of Water Level Recorder	22, March ‘02	

(2) Construction of Well

Drilled Depth	200.2 m
Surface Casing	5.26 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	200.2 m
Screen Depth	from 123.0 m to 135.0 m
	from 151.0 m to 163.0 m
	from 187.0 m to 195.0 m (Total 32 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 4 to 125 m: Hornblende biotite gneiss, comparatively rich in quartz and feldspar.

From 125 to 127 m: Granitic gneiss band

From 127 to 200 m: Hornblende biotite gneiss, comparatively rich in quartz and feldspar.

<Fractures and Water>

Fractures: 124 m (moisture only, 5800 microS/cm), 158 m

Water level measuring: 193.04 mbgl (6, February ’02)

(4) Air Lifting Test

The air lifting test was not conducted.

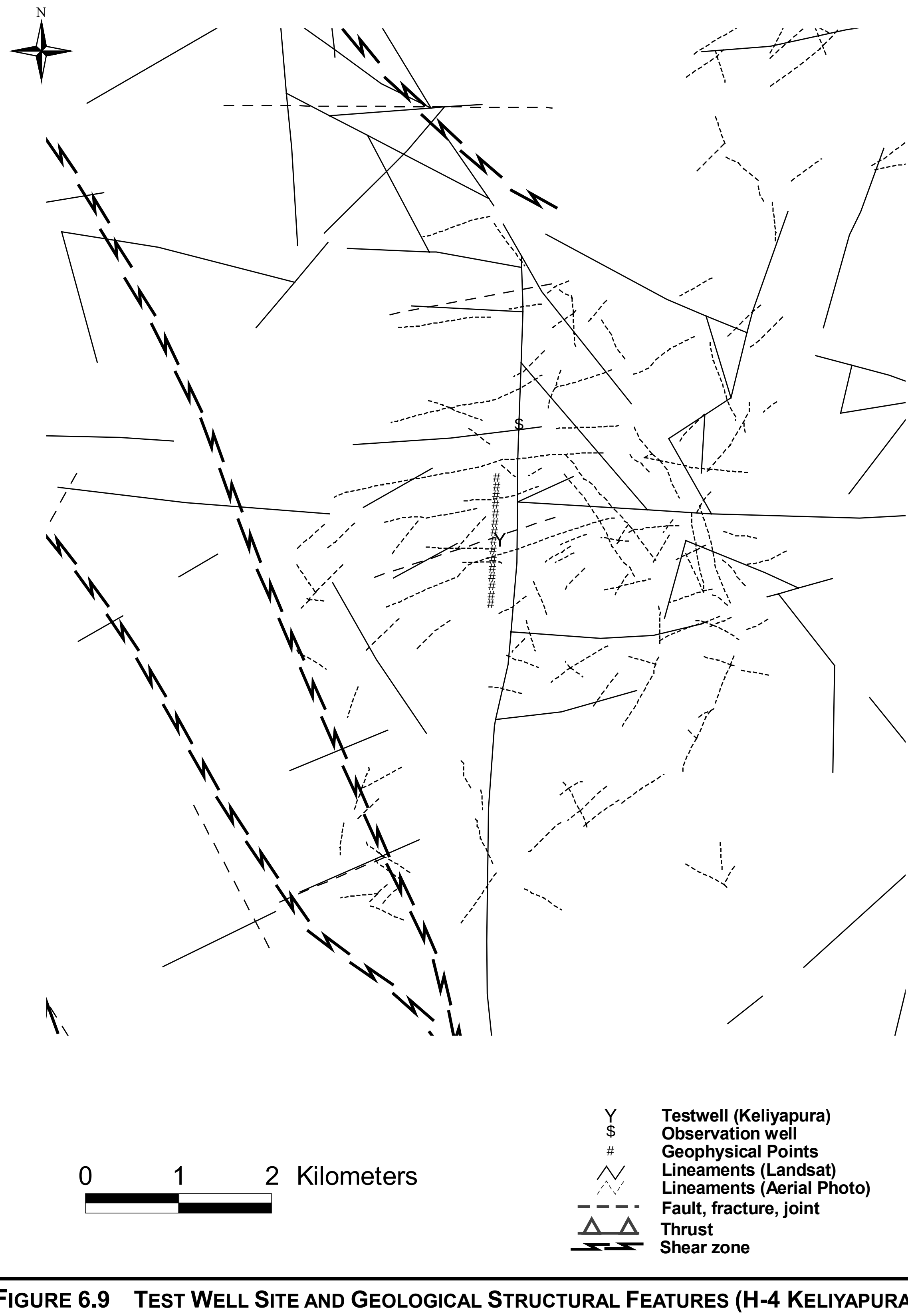

FIGURE 6.9 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (H-4 KELIYAPURA)

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6.2.5 PAHALA MATTALA (APPENDIX F - LOG OF BORING H-5)

The test well was named H-5(J-5/H6). *Figure 6.10* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 7, February '02	to 10, February '02
Drilling	from 11, February '02	to 19, February '02
Logging	22, February '02	
Casing Installation	3, March '02	
Air Lifting Test	21, February '02	
Installation of Water Level Recorder	22, March '02	

(2) Construction of Well

Drilled Depth	200.4 m
Surface Casing	8.17 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	200.4 m
Screen Depth	from 163.0 m to 195.0 m (32 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 4 to 12 m: Moderately to slightly weathered rock, granitic gneiss.

From 12 to 141 m: Hornblende biotite gneiss, rich in hornblende.

From 141 to 146 m: Granitic gneiss.

From 146 to 170 m: Hornblende biotite gneiss, rich in hornblende.

From 170 to 200 m: Calc-gneiss.

<Fractures and Water>

Fractures:	12.5 m (10 litres/mi, 3540 microS/cm)
	17 m (20 litres/min)
	23-25 m (20 litres/min, 2830 microS/cm)
	30-31 m, 37-38 m (120 litres/min, 3560 microS/cm)
	44.5 m, 54 m, 78 m (240 litres/min, 3150 microS/cm)
	83 m, 97 m, 105 m (300 litres/min, 3150 microS/cm)
	113 m, 135 m, 161 m, 166 m(300 litres/min, 3170 microS/cm)
	173-176 m (350 litres/min, 3140 microS/cm)
	176-200m; Many minor fractures (350 litres/min, 3140 microS/cm)
Water level measuring:	13.02 mbgl (Drilled depth, 92 m: 14, February '02)
	12.18 mbgl (Drilled depth, 110 m: 15, February '02)
	10.52 mbgl (Drilled depth, 200 m: 21, February '02)

(4) Air Lifting Test

The air lifting test was conducted before casing installation.

S.W.L:	10.52 mbgl (21, February '02)
P.W.L:	70.0 mbgl
Drawdown:	59.48 m
Yield:	340 litres/min
EC:	3060 microS/cm
PH:	7.9
Temperature:	30 C.

FIGURE 6.10 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (H-5 PAHALA MATTALA)

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

6.2.6 TAMMENNAWEWA (APPENDIX F - LOG OF BORING H-6)

The test well was named H-6(J-4/H5). *Figure 6.11* shows the location and the surrounding geologic structural features. Drilling of the borehole was stopped at the depth of 146 m due to underground geological condition, that is, a highly loose formation occurred from 106 m to 115 m. After drilling from 115 to 146 meters, the borehole collapsed at the depth of 106.5 m and below. Therefore the borehole was filled up with bentonite and cement up to the depth of 102 meters, and then the casing and screen pipes were installed up to the depth.

(1) Progress of Work

Mobilization and set up	from 28, February '02	to 3, March '02
Drilling	from 4, March '02	to 8, March '02
Logging	11, March '02	
Casing Installation	14, March '02	
Air Lifting Test	7, March '02 (at the drilled depth of 110.36m)	
Installation of Water Level Recorder	15, May '02	

(2) Construction of Well

Drilled Depth	146.3 m (The borehole collapsed and it was filled up with bentonite and cement up to the depth of 102 m.)
Surface Casing	5.55m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	102.0 m
Screen Depth	from 52.5 m to 60.5 m (8.0 m)
	from 72.5 m to 84.5 m (12.0 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 5.5 to 16 m: Moderately weathered rock, Hornblende-biotite gneiss.
From 16 to 65 m: Hornblende-biotite gneiss.
From 65 to 68 m: Charnocktic gneiss.
From 68 to 106 m: Hornblende-biotite gneiss.
From 106 to 115 m: Pegmatite with large mica crystals.
From 115 to 146 m: Hornblende-biotite gneiss.

<Fractures and Water>

Fractuers:	37 m (No water)
	56-59 m (75 litres/min, 8870 microS/cm)
	62-66 m; small fractures (100 litres/min, 8900 microS/cm)
	70-74 m, 75-78 m (150 litres/min, 8250 microS/cm)
	106-115 m (300 litres/min, 8400 microS/cm)
	129-134 m (600-700 litres/min, 5500 microS/cm)
	Final yield at 146 m depth (800 litres/min, 4980 microS/cm)
Water level measuring:	8.94 mbgl (Drilled depth, 110 m: 7, March '02)

(4) Air Lifting Test

The air lifting test was conducted when the borehole was drilled up to 110m.

S.W.L:	8.94 mbgl (7, March '02)
P.W.L:	35.98 mbgl
Drawdown:	27.04 m
Yield:	240 litres/min
EC:	8310 microS/cm
PH:	7.72
Temperature:	29.9 C.

6.2.7 TAMMENNAWEWA-2 (APPENDIX F - LOG OF BORING H-6(2))

The additional test well was drilled and named H-6(2). Drilling of the borehole was stopped at the depth of 114 m due to underground geological condition. The casing pipes were installed up to the depth of 101 m.

(1) Progress of Work

Mobilization and set up	from 18, July ‘02 to 20, July ‘02
Drilling	from 21, July ‘02 to 7, August ‘02
	from 4, September ‘02 to 19, September ‘02
Logging	8, August ’02
Casing Installation	9, August ‘02

(2) Construction of Well

Drilled Depth	113.3 m
Surface Casing	4.87 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	101.3 m
Casing Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 4.8 to 80.3 m: Hornblende-biotite gneiss.
From 80.3 to 82 m: Mica rich soft formation (Pegmatite)
From 82 to 97.3 m: Hornblende-biotite gneiss.
From 97.3 to 104.3 m: Mica rich soft formation (Pegmatite)
From 104.3 to 114.7 m: Hornblende-biotite gneiss.

<Fractures and Water>

Fractuers:	109.3-109.7 m (75 litres/min, 7160 microS/cm)
Water level:	10 mbgl (Drilled depth, 114.7 m: 10, September ’02)

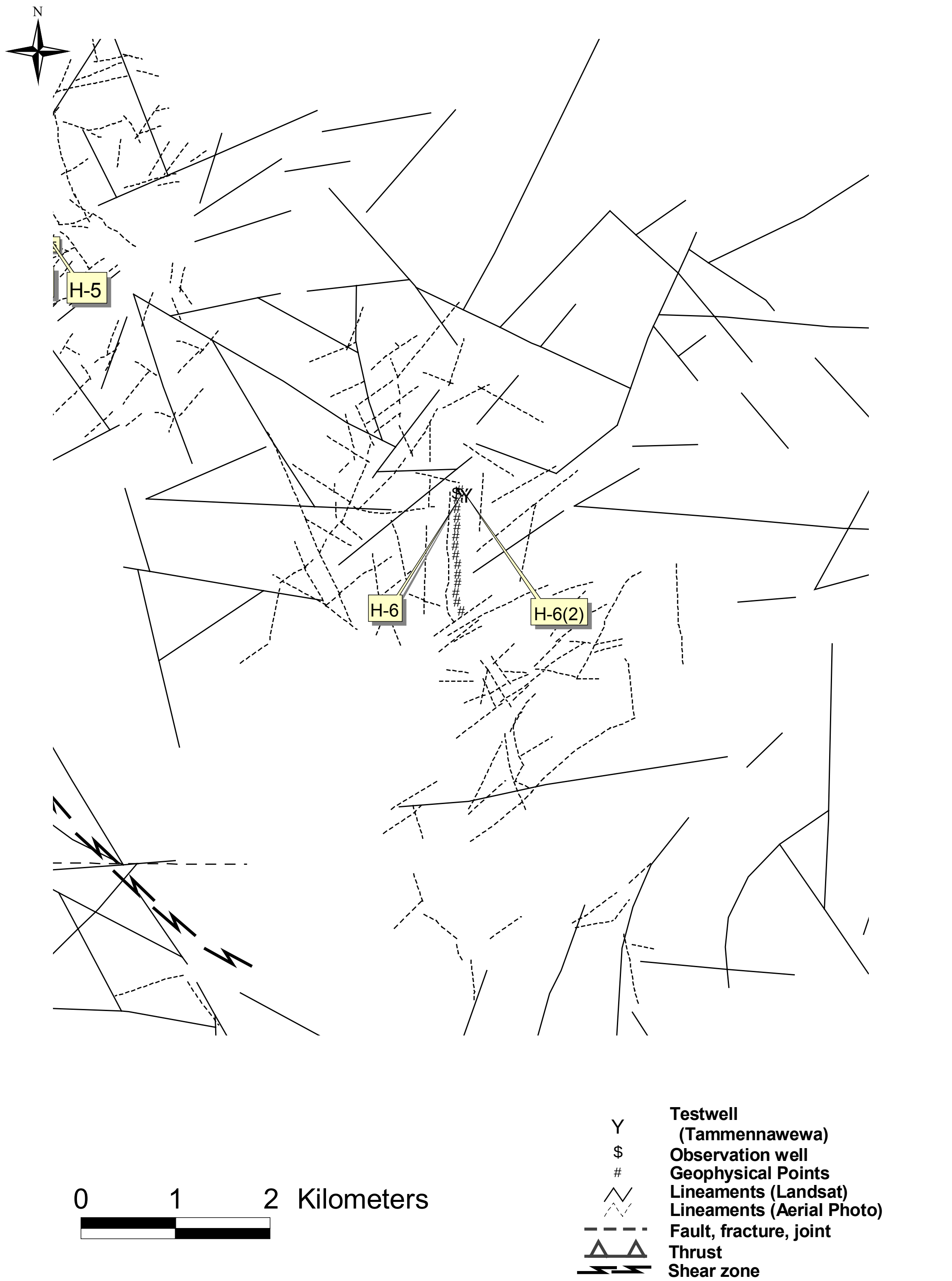

FIGURE 6.11 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (H-6 TAMMENNAWEWA)

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6.2.8 Sevanagala (Appendix F - LOG OF BORING M-1)

The test well was named M-1(J-10/M7). *Figure 6.12* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 23, April '02 to 28, April '02
Drilling	from 29, April '02 to 7, May '02
Logging	10, May '02
Casing Installation	14, May '02
Air Lifting Test	4, May '02 and 9, May '02
Installation of Water Level Recorder	13, July '02

(2) Construction of Well

Drilled Depth	200.4 m
Surface Casing	11.05 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	200.4 m
Screen Depth	from 127.0 m to 155.0 m (28 m)
	from 159.0 m to 163.0 m (4 m)
	from 171.0 m to 175.0 m (4 m)
	from 179.0 m to 191.0 m (12 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 8 to 11 m: Moderately-slightly weathered rock
From 11 to 34 m: Hornblende-biotite gneiss
From 34 to 38 m: Granitic gneiss
From 38 to 73 m: Hornblende-biotite gneiss
From 73 to 74 m: Granitic gneiss
From 74 to 85 m: Hornblende-biotite gneiss
From 85 to 86 m: Granitic gneiss
From 86 to 145 m: Hornblende-biotite gneiss
From 145 to 150 m: Granitic gneiss
From 150 to 200 m: Hornblende-biotite gneiss

<Fractures and Water>

Fractures encountered during drilling, and yield measured at the depth.

Fractures:	12-13 m; minor fracture (10 litres/min, 500 microS/cm)
	18 m (20 litres/min, 670 microS/cm)
	23.5-24 m (100 litres/min, 650 microS/cm)
	29-33 m (400 litres/min, 530 microS/cm)
	70 m; minor fracture (610 microS/cm (yield not measured))
	80.5 m; minor fracture (1100 micros/cm (yield not measured))
	130-134 m (550 litres/min, 753 microS/cm)
	142-144 m (570 litres/min, 1000 microS/cm)
Water level measuring:	1.75 mbgl (Drilled depth, 92 m: 4, May '02)
	1.73 mbgl (Drilled depth, 200.4 m: 9, May '02)

(4) Air Lifting Test

The air lifting test was conducted before casing installation.

S.W.L:	1.73 mbgl (9, May '02)
P.W.L:	31.1 mbgl
Drawdown:	29.37 m
Yield:	550 litres/min
EC:	570 microS/cm
PH:	8.1

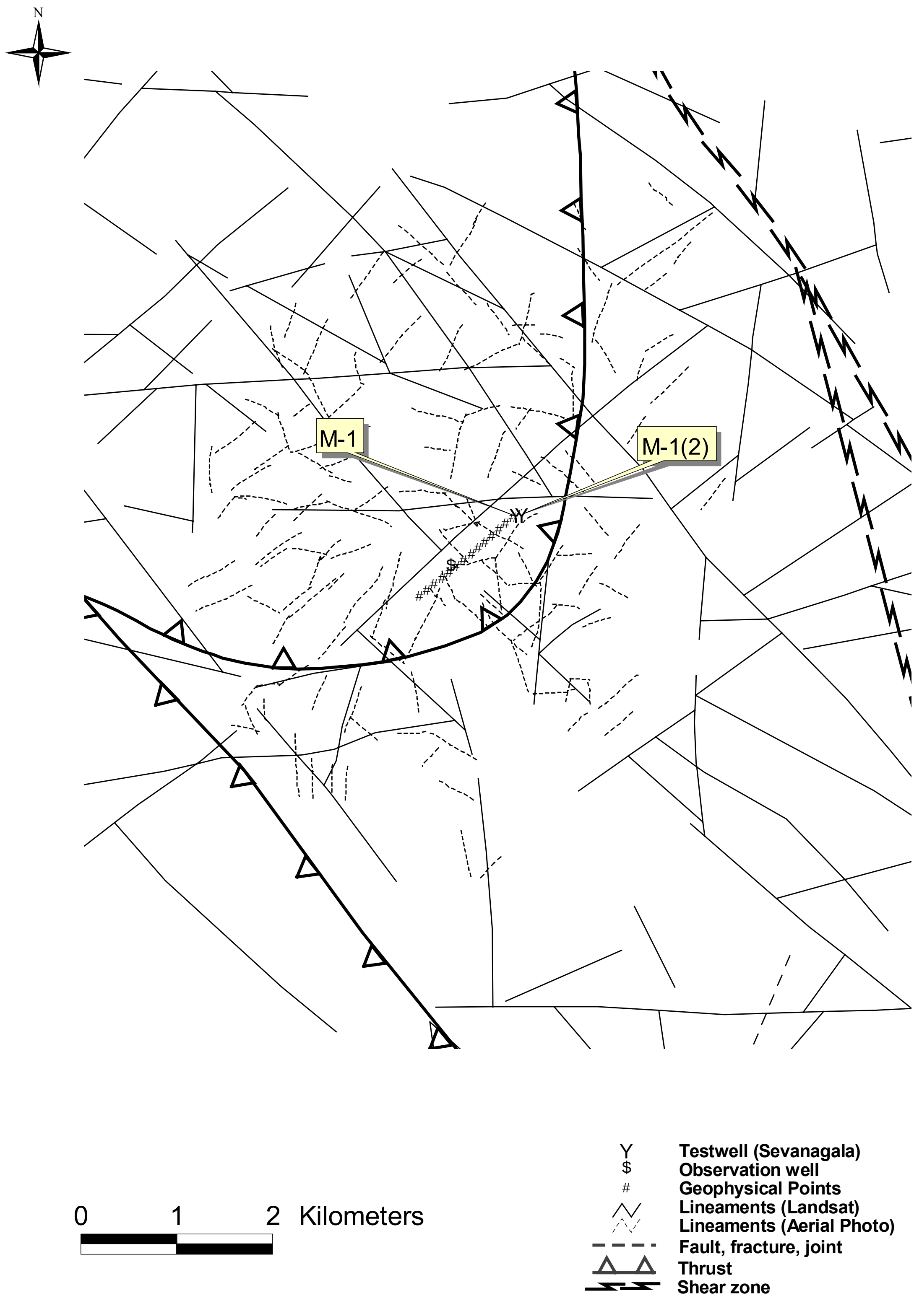

FIGURE 6.12 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (M-1 SEVANAGALA)

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6.2.9 Bodagama (Appendix F - LOG OF BORING M-2)

The test well was named M-2(J-7/M2). *Figure 6.13* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 11, May '02	to 13, May '02
Drilling	from 14, May '02	to 22, May '02
Logging	1, June '02	
Casing Installation	1-2, June '02	
Air Lifting Test	17 and 24, May '02	
Installation of Water Level Recorder	11, July '02	

(2) Construction of Well

Drilled Depth	200.2 m
Surface Casing	4.93 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	200.2 m
Screen Depth	from 131.0 m to 151.0 m (20 m)
	from 171.0 m to 183.0 m (12 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 0 to 8 m: Overburden(0-5 m), Moderately-slightly weathered rock
From 8 to 43 m: Hornblende-biotite gneiss
From 43 to 49 m: Granitic gneiss
From 49 to 60 m: Hornblende-biotite gneiss
From 60 to 61 m: Granitic gneiss band
From 61 to 200 m: Hornblende-biotite gneiss

<Fractures and Water>

Fractures encountered during drilling, and yield measured at the depth.

Fractures:	12.7 m; minor fracture (only moisture)
	18.5 m (15 litres/min, 1600 microS/cm)
	28.2 m (minor fracture)
	35-40 m; Fault zone (250 litres/min, 2200 microS/cm)
	47.5, 53-55 m; minor fractures
	80 m (900 litres/min, 2100 micros/cm)
	88 m; small fracture (1050 litres/min, 2050 microS/cm)
	(35-40 m fault zone may develop during drilling and increase yield.)
	135-140m; loose formation (2100 microS/cm)
	Final yield; (1000 litres/min, 2050 microS/cm)
Water level measuring:	7.8 mbgl (Drilled depth, 62.24 m: 17, May '02)
	7.9 mbgl (Drilled depth, 200.2 m: 24, May '02)

(4) Air Lifting Test

The first air lifting test was conducted when the bore hole was drilled up to 62.24 m.

S.W.L: 7.8 mbgl (17, May '02)
P.W.L: 18.27 mbgl (after 3 hours air lifting.)
Drawdown: 10.47 m
Yield: 360 litres/min
EC: 1950 microS/cm
PH: 8.1
Temperature: 30 C.

The second air lifting test was conducted before casing installation.

S.W.L: 7.9 mbgl (24, May '02)

P.W.L: 19.21 mbgl (after 245 minutes air lifting.)
Drawdown: 11.31 m
Yield: 510 litres/min
EC: 2020 microS/cm
PH: 8.15
Temperature: 30 C.

6.2.10 BODAGAMA-2 (APPENDIX F - LOG OF BORING M-2(2))

The additional test well was drilled to 100 m and named M-2(2).

(1) Progress of Work

Mobilization and set up	from 23, August '02	
Drilling	from 24, August '02	to 29, August '02
Logging	30, August '02	
Casing Installation	30, August '02	

(2) Construction of Well

Drilled Depth	100.0 m
Surface Casing	10.6 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	100.0 m
Screen Depth	from 27.0 m to 55.0 m (28 m)
	from 63.0 m to 95.0 m (32 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 0 to 3 m: Top soil, sand with clay
From 3 to 10.3 m: Weathered rock
From 10.3 to 16.2 m: Moderately and slightly weathered rock
From 16.2 to 100 m: Hard rock (Mainly hornblende-biotite gneiss)

<Fractures and Water>

Fractures encountered during drilling, and yield measured at the depth.

Fractures:	17.9-18.1 m (50 litres/min, 3380 microS/cm)
	21.3-21.6 m (175 litres/min, 2270 microS/cm)
	24.7-24.9 m (275 litres/min, 2350 microS/cm)
	42.7-42.8 m; minor fracture (2400 micros/cm (yield not measured))
	44.2-50.2 m (275 litres/min, 2350 microS/cm)
	64.2-64.3 m, 77.7-77.8 m (450 litres/min, 2450 microS/cm)
Water level measuring:	7.6 mbgl (Drilled depth, 100 m: 29, August '02)

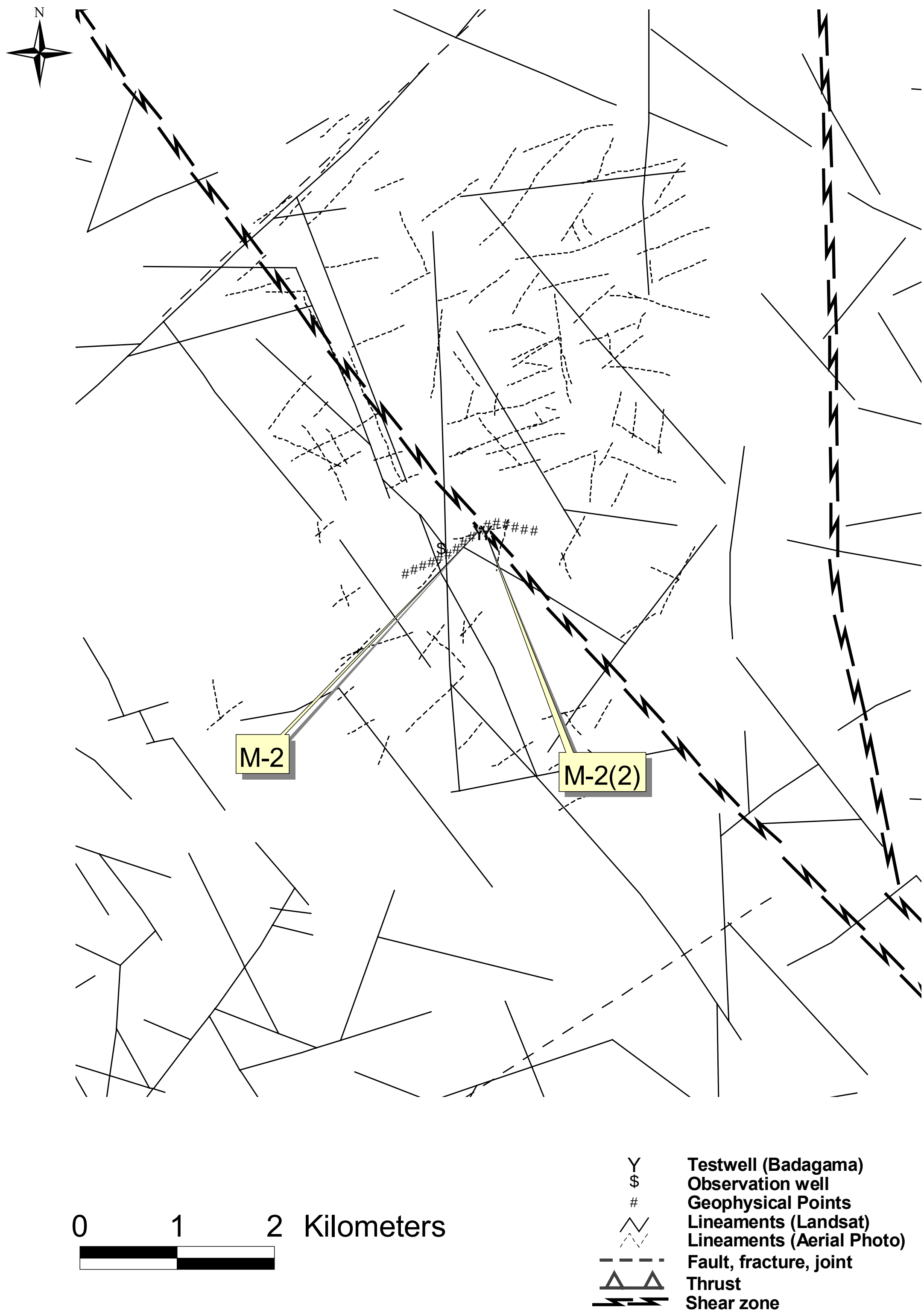

FIGURE 6.13 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (M-2 BODAGAMA)

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6.2.11 YALABOWA (APPENDIX F - LOG OF BORING M-4)

The test well was named M-4 (J-8/M5). *Figure 6.14* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 2, June '02	to 5, June '02
Drilling	from 6, June '02	to 21, June '02
Logging	22, June '02	
Casing Installation	23, June '02	
Air Lifting Test	12 and 16, June '02	
Installation of Water Level Recorder	28, August '02	

(2) Construction of Well

Drilled Depth	195.0 m
Surface Casing	17.42 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	195.0 m
Screen Depth	from 146.0 m to 162.0 m (16 m)
	from 166.0 m to 174.0 m (8 m)
	from 178.0 m to 190.0 m (12 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 4 to 13 m: Completely weathered rock
From 13 to 17 m: Highly weathered rock
From 17 to 19 m: Moderately weathered rock
From 19 to 25 m: Hornblende-biotite gneiss
From 25 to 36 m: Biotite gneiss
From 36 to 42 m: Hornblende-biotite gneiss
From 42 to 43 m: Granitic gneiss
From 43 to 74 m: Hornblende-biotite gneiss
From 74 to 77 m: Biotite gneiss
From 77 to 156 m: Hornblende-biotite gneiss
From 156 to 157 m: Granitic gneiss
From 157 to 165 m: Hornblende-biotite gneiss
From 165 to 167 m: Granitic gneiss
From 167 to 188 m: Hornblende-biotite gneiss
From 188 to 189 m: Granitic gniess
From 189 to 195 m: Hornblende-biotite gneiss

<Fractures and Water>

Fractures encountered during drilling, and yield measured at the depth.

Fractures:	22-23, 40, 48-49 m (minor fracture)
	53-56 m (500-600 litres/min, 810 microS/cm)
	75-80 m (650 litres/min, 720 microS/cm)
	90-91 m (950 litres/min, 780 micros/cm)
	99 m; small fracture (1000 litres/min, 780 microS/cm)
	155-156 m (1100-1200 litres/min, 776 microS/cm)
	188 m (1100-1200 litres/min, 776 microS/cm)
	Final yield at 195m (1200 litres/min, 780 microS/cm)
Water level measuring:	10.9 mbgl (Drilled depth, 18 m: 9, June '02)
	12.41 mbgl (Drilled depth, 62.2 m: 11, June '02)

12.55 mbgl (Drilled depth, 74.22 m: 12, June '02)
12.7 mbgl (Drilled depth, 110.2 m: 16, June '02)
13.17 mbgl (Drilled depth, 182.2 m: 21, June '02)

(4) Air Lifting Test

The first air lifting test was conducted when the borehole was drilled up to 74.22 m.

S.W.L: 12.55 mbgl (12, June '02)
P.W.L: 28.8 mbgl (after 185 minutes air lifting)
Drawdown: 16.25 m
Yield: 550 litres/min
EC: 827 microS/cm
PH: 8.2
Temperature: 27 C.

The second air lifting test was conducted when the borehole was drilled up to 110.2 m.

S.W.L: 12.7 mbgl (16, June '02)
P.W.L: 27.08 mbgl (after 150 minutes air lifting)
Drawdown: 14.38 m
Yield: 550 litres/min
EC: 770 microS/cm
PH: 8.2
Temperature: 27 C.

6.2.12 YALABOWA-2 (APPENDIX F - LOG OF BORING M-4(2))

The additional test well was drilled to 100 m and named M-4(2).

(1) Progress of Work

Mobilization and set up	from 17, August '02	
Drilling	from 18, August '02	to 21, August '02
Logging	22, August '02	
Casing Installation	22, August '02	

(2) Construction of Well

Drilled Depth	100.0 m
Surface Casing	10.7 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	100.0 m
Screen Depth	from 23.0 m to 47.0 m (24 m)
	from 55.0 m to 95.0 m (40 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 0 to 1 m: Top soil with clay
From 1 to 10.7 m: Weathered rock
From 10.7 to 100 m: Hard rock (Mainly hornblende-biotite gneiss)

<Fractures and Water>

Fractures: 14.0-14.7, 16.5-16.7 m (5-10 litres/min, 410 microS/cm)
18.1-20.1, 20.6-20.7, 25.6-25.8 m; minor fracture
30.1-30.2 m (300 litres/min, 463 microS/cm)
43.28-43.45 m (700 litres/min, 475 microS/cm)
44.2-44.4 m (900 litres/min, 490 micros/cm)

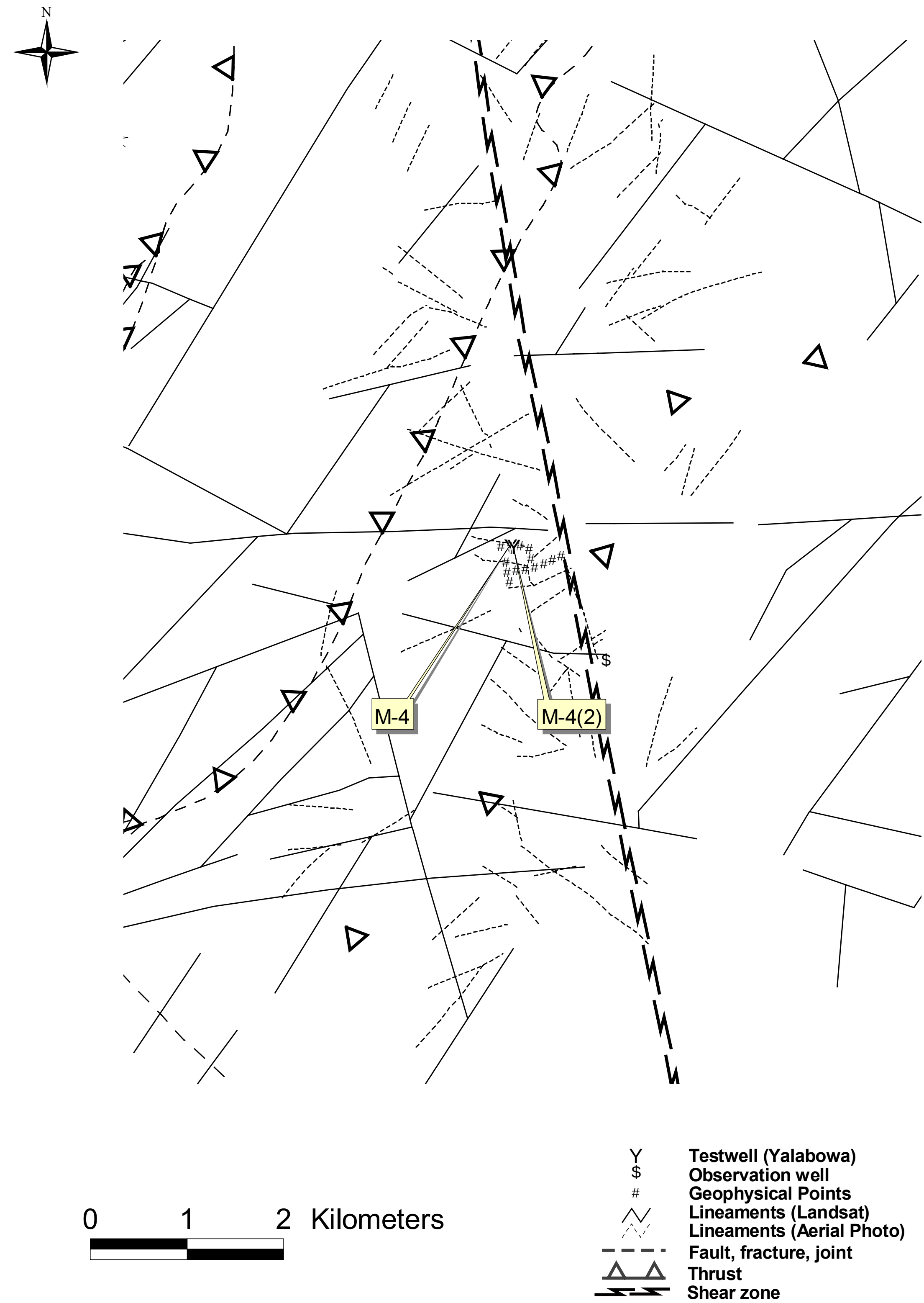

FIGURE 6.14 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (M-4 YALABOWA)

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	58.2-58.3 m (900 litres/min, 500 microS/cm)
	60.1-60.2 m, 63.6-63.7 m (900 litres/min, 500 microS/cm)
	91.7-91.9 (850 litres/min, 515 microS/cm)
Water level:	12.6 mbgl (Drilled depth, 100 m: 21, August ’02)

6.2.13 BADALKUMBRA (APPENDIX F – LOG OF BORING M-3)

The test well was drilled to 88 m and named M-3 (J-9/M6). *Figure 6.15* shows the location and the surrounding geologic structural features.

(1) Progress of Work

Mobilization and set up	from 28, June ‘02	to 1, July ‘02
Drilling	from 1, July ‘02	to 16, July ‘02
Logging	18, July’02	
Casing Installation	19, July ’02	
Air Lifting Test	14, July ’02	
Installation of Water Level Recorder	28, August ’02	

(2) Construction of Well

Drilled Depth	88.3 m
Surface Casing	11.15 m (10 in. C.P.)
Borehole Diameter	8-5/8 in. (219 mm)
Cased Depth	88.3 m
Screen Depth	from 63.0 m to 83.0 m (20 m)
Casing/Screen Diameter	I.D: 150 mm, O.D: 159 mm, 6 in. FRP pipes

(3) Geology

<General Condition>

From 5 to 11 m: Moderately - highly weathered rock
From 11 to 12 m: Hornblende gneiss
From 12 to 14 m: Granitic gneiss band
From 14 to 17 m: Hornblende gneiss
From 17 to 18 m: Granitic gneiss band
From 18 to 68 m: Hornblende gneiss
From 68 to 77 m: Granulitic gneiss
From 77 to 88 m: Garnet-biotite gneiss

<Fractures and Water>

Fractures;	44 m (120 litres/mi, 350 microS/cm)
	62 m (180 litres/mi, 370 microS/cm)
	63 m (350 litres/mi, 380 microS/cm)
	65-67 m (850 litres/mi, 400 microS/cm)
	68 m (1200 litres/mi, 400 microS/cm)
	73-74 m (1300 litres/mi, 400 microS/cm)
	76-78 m (1600 litres/mi, 420 microS/cm)
	80-81 m (2500 litres/mi, 430 microS/cm)
	83-84 m (5000 litres/mi, 430 microS/cm)
	86-87 m (6000 litres/mi, 420 microS/cm)
Water level measuring;	12.2 mbgl (Drilled depth, 86 m: 16, July ’02)
	. mbgl (Drilled depth, *** m: **, March ’02)

(4) Air Lifting Test

The air lifting test was conducted before casing installation.

S.W.L;	12.12 mbgl (14, July ’02)
P.W.L;	13.16 mbgl
Drawdown;	1.04 m
Yield;	850 litres/min
EC;	420 microS/cm
PH;	7.8
Temperature;	26 C.

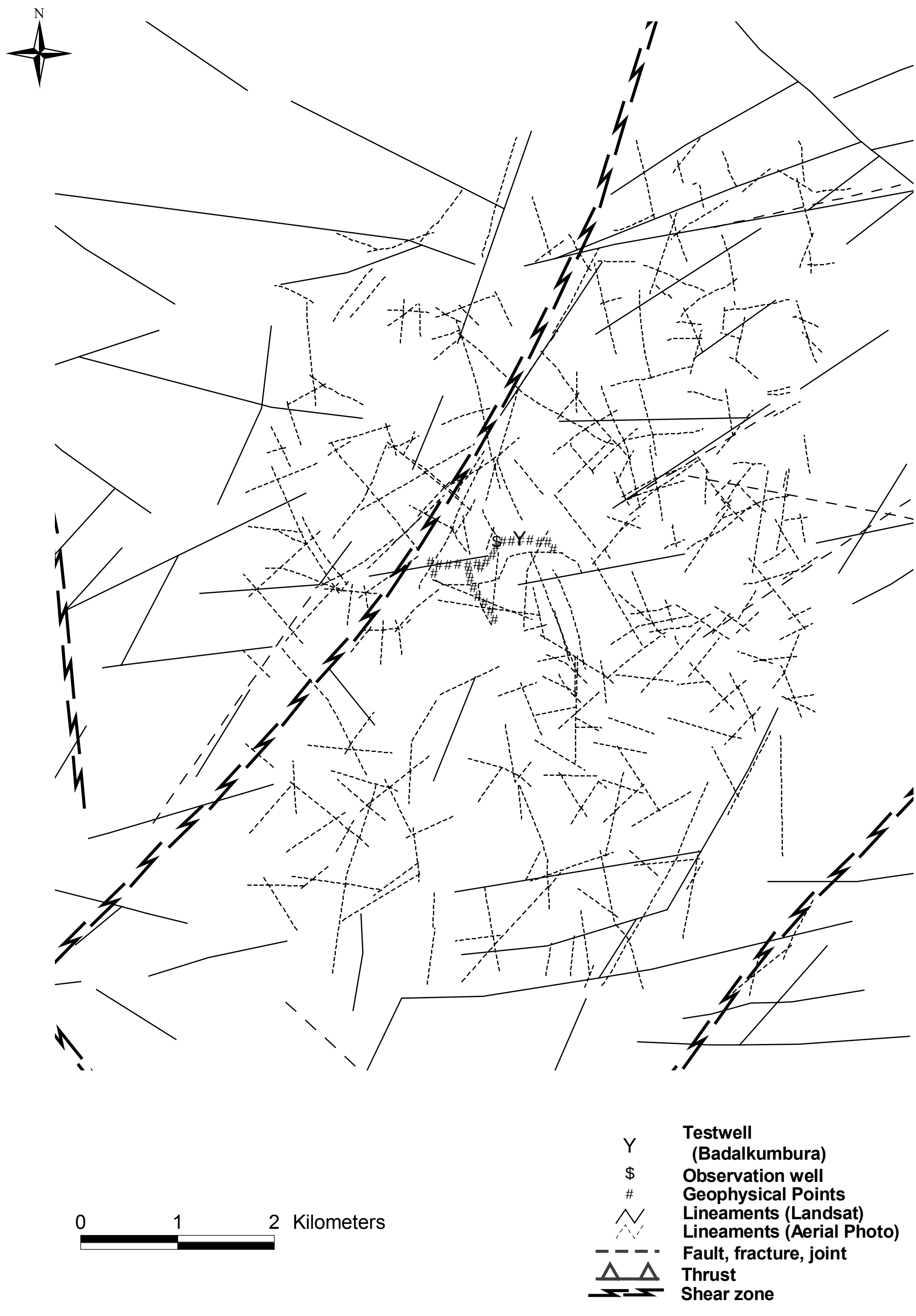

FIGURE 6.15 TEST WELL SITE AND GEOLOGICAL STRUCTURAL FEATURES (M-3 BADALKUMBURA)

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6.3 GEOPHYSICAL LOGGING

Geophysical Logging was conducted after completion of drilling. The items carried out are resistivity (16” and 64”), spontaneous potential, natural gamma and calliper log. The columnar log for each well is attached in *Appendix F*

Generally short normal (electrode spacing of 16”) resistivity logging is used for correlation of lithology and long normal (electrode spacing of 64”) is used for determining true resistivity in thick beds. Spontaneous potential helps delineate the boundaries of permeable rock units and less permeable beds. Natural gamma shows inherent radioactivity in the formations. Calliper log measures hole diameter, then indicates lithologic character of formations, and locates fractures and other cavities. Additionally it is valuable for selecting of zone to set a packer for the sealing of shallow aquifers.

Based on the result of resistivity log and gamma log, the penetrated rocks, or formations, were divided into four types as below.

4 Types of Penetrated Rocks

Type	1	2	3	4
Resistivity	low	Low	High	high
Natural Gamma	low	High	Low	high

Low/high is classified relatively.

The result of each test well logging were described considering the correlation between the above types and the presence of fracture and water that was indicated by calliper log and/or driller’s (site engineer’s) log.

6.3.1 SIYAMBALAGASWILA NORTH: WELL NO. H-1 (J-6/H7) (APPENDIX F - LOG OF BORING H-1)

Short-normal resistivity indicates the lithological condition is almost similar from top to bottom. Long-normal resistivity, however, varies from less than 1000 to about 2000 ohm-m. Some indications of fractures observed during the drilling were generally minor. The prominent one is located at 33 meters in depth that is a zone showing relatively lower resistivity. There is another low resistivity zone at around 64 meters in depth, although the engineer’s log indicates nothing. Calliper log, however, showed an unsteady curve in the part. Additionally the curve of calliper log is relatively unstable below 165 meters, where long-normal resistivity also shows rather low, less than 1000 ohm-m.

6.3.2 TALUNNA: WELL NO. H-2 (J-2/H3) (APPENDIX F - LOG OF BORING H-2)

Penetrated rocks can be divided into four parts based on Gamma log. The first part is up to around 60 meters below ground level, the second is from about 60 m to about 120 m, the third is from 120 m to around 165 m, and the forth is below that depth. Long-normal resistivity of the first and second part ranges from 3000 to 5000 ohm-m and the third part shows around 2000 to 3000. The final part below 165 meters in depth shows lower resistivity and rather higher gamma, and this part corresponds mostly to the formation of granitic gneiss described in the engineer’s log. The screen pipes were installed from 172.9 m to 188.9 m in depth and the pumping test yielded about 400 litres/min for 96 hours with a final drawdown of 27.05 m.

6.3.3 WEDIWEWA: WELL NO. H-3 (J-3/H4) (APPENDIX F - LOG OF BORING H-3)

Short-normal resistivity indicates the lithological condition is almost similar from top to bottom. Engineer’s log, however, describes granitic gneiss formations were observed from 127 to 133 and from 154 to 170 meters in depth. The highest peak of gamma corresponds to the former granitic formation and also another high gamma zone correspond to the latter. Only few fractures with water were observed during drilling, namely the fractures at around 94-96 m and the fracture of

153 m. The zone of the fractures at 94-96 m shows higher gamma and the fracture at 153 m is just above the granitic gneiss formation that is also higher gamma zone.

6.3.4 Keliyapura: Well No. H-4 (J-1/H1) (Appendix F - LOG OF BORING H-4)

During the drilling few fractures with only moisture were observed in the borehole. The water level was 193 mbgl just after the drilling was completed up to 200 m. The logging was conducted after the borehole was filled with tanked water.

As a whole, high resistivity values were recorded comparing with other boreholes. Short normal resistivity ranges from 2000 to 3000 ohm-m and long normal resistivity ranges from 4000 to 8000 ohm-m. There were some zones showing higher gamma, 32, 36, around 50, 69, some parts in from 113 to 133, 152 meters in depth. The screen pipes were installed from 123 to 135, from 151 to 163, and from 187 to 195 meters in depth.

6.3.5 Pahala Mattala: Well No. H-5 (J-5/H6) (Appendix F - LOG OF BORING H-5)

According to the result of long normal resistivity, the penetrated rocks can be classified to five zones, namely up to 55 m, 55-105 m, 105-120 m, from 120 to around 150 m, and from 150 to the bottom. Relatively low resistivity values were shown in the first zone in which some fractures were recorded by engineer's log and calliper log. The fracture at 30-31 m yielded 120 litres/min and the yield increased to 240 litres/min at 45.5 m where another fracture was indicated. The zone can be still divided into two parts based on gamma log, the upper part up to 38 m shows low gamma and the under part from 38 to about 50 m shows higher gamma. The second zone, from 55 to 105 m, shows generally high resistivity, 1000-3000 ohm-m. The curve of calliper log is stable on the whole, though the engineer's log described a water bearing fracture at 83 m, where the yield increased from 240 to 300 litres/min. The part from 59 to 82 m shows lower gamma. The zone from 103 m to 120 m shows lower resistivity and fluctuating calliper log, which suggest that formation may be somewhat soft. Fractures were recorded at 105 and 113 m in depth. From 120 to around 165 m, the curve of calliper log is generally stable. There was a granitic gneiss band with high gamma from 142 to 146 m in depth. Calliper log shows that minor fractures occur below the depth of 165 m, where relatively low resistivity and high gamma were recorded.

6.3.6 Tammennawewa: Well No. H-6 (J-4/H5) (Appendix F - LOG OF BORING H-6)

As already described in the previous *section (6.2.6)*, the drilling of the borehole was stopped at a depth of 146 m due to underground geological condition and the logging was conducted up to a depth of 105 m.

Generally long normal resistivity shows lower values, maximum of which is about 600 ohm-m, in this borehole comparing with other boreholes. Three zones in the penetrated rocks were observed from resistivity and calliper log. The first zone is up to about 20 m in depth, the second one is from 20 to 58 m in depth, and the third one is from 58 to 105 m in depth. The first zone has been recorded as mainly moderated weathered rock, showing low resistivity and fluctuated calliper log. No water was yielded in the zone. The second zone shows a hilly curve of resistivity that has two peaks, and the curve of gamma log is relatively stable. Some parts have high gamma. The rocks are most likely hard, though a minor fracture has been observed at 37 m in depth. The resistivity values decreased transiently at the boundary between the second and third zone, namely from 53 to 59 m in depth. In this place fractures with the water yield of 75 litres/min were observed, and Gamma increased and calliper changed as well. In the third zone an occurrence of different rock unit was indicated by calliper log from 73 to 83 m in depth. This part shows lower resistivity and has some fractures with the yield of 100 litres/min increasing from 75 litres/min recorded during the above drilling.

6.3.7 Tammennawewa-2: Well No. H-6(2) (Appendix F - LOG OF BORING H-6(2))

The borehole was drilled only 35 meters away from Well No.H-6 (J-4/H5). Therefore, the results of logging show generally the same aspect. The lower resistivity zones occurred from 12 to 21 m, from 75 to 81 m, and from 98 to 104 m. Driller's log described that the zones from 80.3 to 82 m and from 97.3 to 104.3 m were mica rich soft formation (Pegmatite).

6.3.8 Sevanagala: Well No. M-1 (J-10/M7) (Appendix F - LOG OF BORING M-1)

The penetrated rocks can be divided into some zones based on the curve of resistivity. The first zone is up to about 32 m, which has higher peaks of resistivity. Some fractures bearing water were observed in the zone and yield increased from 10 to 400 litres/min at 29 m in depth. A lower resistivity-curving zone with relatively higher gamma and no fractures exists below the first zone. Then, from 60 to 70 m, another high resistivity zone occurs without any fracture or water. Small fractures were observed at the depth of 70 and 80 m, where low resistivity zone. From 80 to 130 m in depth, no fractures were observed. The upper part of the zone, from 80 to 122 m, shows high resistivity and the lower part shows low resistivity. Some fractured formation occurs between 130 and 145 m. Calliper log indicates small fractures may occur at 149 m where is the boundary of granitic gneiss and hornblende-biotite gneiss. Resistivity and S.P. indicates there are boundaries or differences of rock units at the depth of about 160 and 183 m, where calliper log may suggest small fracture occurrences. Screen pipes were installed below 127 m in depth.

6.3.9 Bodagama: Well No. M-2 (J-7/M2) (Appendix F - LOG OF BORING M-2)

Generally the upper part of the penetrated rocks, which is above 100 m, shows high gamma comparing with other boreholes. The very low resistivity formation exists from 35 to 80 m in depth. The engineer's log described that the zone from 35 to 40 m was a fault zone yielding 250 litres/min. This yield had increased with the progress of the drilling. Calliper log indicates a fracture or cavity exists at 35-37 m, and small fractures occur continuously below it. Another low resistivity zone was observed from 93 to 99 m in depth. The S.P. log suggested that the zone may be permeable. Under the depth of 100 m, S.P curve was getting stable and resistivity was generally high. The engineer's log described that there was loose formation from 135 to 140 m, and calliper log indicated some fractures exist between 143 and 152 m, where was relatively low resistivity zone. The screen pipes were installed from 131 m to 151 m and from 171 to 183 m in depth.

6.3.10 Bodagama-2: Well No. M-2 (2) (Appendix F - LOG OF BORING M-2(2))

The borehole was drilled 68 meters east from Well No.M-2 (J-7/M2). The very low resistivity formation, which occurs from 35 to 80 m in No.M-2 (J-7/M2), exists from 42 to 48 m in this borehole. The engineer's log described that the zone from 44.2 to 50.2 m yielded 275 litres/min during the drilling. Another low resistivity zone was observed from 82 to 84 m. The calliper log suggests that the fractured zone occurs.

6.3.11 Yalabowa: Well No. M-4 (J-8/M5) (Appendix F - LOG OF BORING M-4)

S.P curve of the borehole shows some peaks to the left, the depth of which is identical with the point of resistivity curve changing, namely 27, 49, 125, 166, and 186 m in depth. The lower resistivity zone up to 28 m was moderately to slightly weathered rock as indicated by Calliper log. A fracture recorded no yield was observed at around the second peak of S.P of 49 m in depth. The first major fractures were observed from 53 to 56 m, showing low resistivity and yielding 500-600 litres/min. The second ones occur at 75-80 m in depth, increasing the yield to 650 litres/min. The engineer's log described that the third fractures were observed at 90-91 m in depth, where the yield increased to 950-1000 litres/min. Though the engineer's log has not mentioned any increase of water yield during the drilling, the calliper log indicates some changes of the hole diameter from 100 to 150 m in depth. The fractures at 155-156 m were located just above granitic gneiss band. Another granitic gneiss band was indicated at 166 m by S.P log and resistivity. Calliper log and resistivity show that there is a different rock unit from 174 to 179 m. From below it, some small fractures were indicated by Calliper log.

6.3.12 Yalabowa-2: Well No. M-4 (2) (Appendix F - LOG OF BORING M-4(2))

The borehole was drilled 42 meters east from Well No.M-4 (J-8/M5). The lower resistivity zone up to 29 m is considered to be moderately to slightly weathered rock as well as Well No.M-4 (J-8/M5). The first major fractures were observed from 43 to 46 m, showing low resistivity and yielding 700-900 litres/min. The calliper log indicates the zone is a large fractured zone. The second ones occur at 89-91 m in depth. The calliper log also indicates that there is a fractured zone from 86 to 93 m.

6.3.13 Badalkumbura: Well No. M-3 (J-9/M6) (Appendix F - LOG OF BORING M-3)

Penetrated rocks can be divided into five parts based on the result of the logging. The first part is up to about 20 meters below ground level, the second is from about 20 to around 43 m, the third is from 43 to around 55 m, the forth is between 55 and 61 m, and the fifth is below that depth. The first part shows higher gamma and lower resistivity and the second part show lower gamma and higher resistivity. According to the driller's log, the first major fracture occurs at 44 m that is the boundary of the second and third part. The third part has low resistivity and low gamma. The resistivity and gamma become high in the forth part. A fracture was observed at the boundary of the forth and fifth part, 62 m. The fifth part shows very low resistivity and higher gamma, and the calliper log shows that the part has many fractures. During the drilling of this part, the yield increased from 350 to 5000 litres/min or more. The site engineer described that the formation below 68 m is Highland Complex, while the upper part is Vijayan Complex.

6.4 AIR LIFT AND PUMPING TEST

After installing the casing pipes, the pumping test was carried out to estimate aquifer properties. Besides, airlift test was conducted in some cases during the drilling.

6.4.1 AIR LIFT

Airlift test was conducted for nine boreholes out of 12 wells constructed in the Study. The results of airlift test were summarized in *Table 6.3*.

Table 6.3 Results of Air Lift for Test Wells

Well No.	Location	Drilled Depth	Surface casing	Open hole length	Final Air Lifting Rate Q	Duration Time	S.W.L	P.W.L*	Drawdown s	Q/s	EC	Remarks
		(m)	m bgl	(m)	(litters/min)	(min)	(m bgl)	(m bgl)	(m)	(l/min/m)	(microS/cm)	
H-1 (J-6/H7)	Siyambalagaswila	212.4	4.67	207.7	4.2	185	12.45	34.60	22.15	0.19	10100	
H-2 (J-2/H3)	Talunna	194.4	5.51	188.9	400	195	3.95	19.90	15.95	25.08	3510	415 l/min x 5760 min. (Constant discharge test using a submersible pump)
H-3 (J-3/H4)	Wediwewa	200.4	9.26	191.1	18	185	13.31	80.76	67.45	0.27	7820	
H-4 (J-1/H1)	Keliyapura	200.2	5.26	194.9	-	-	-	-	-	-		no water encounterd during drilling
H-5 (J-5/H6)	Mattala	92.4	8.17	84.2	220	125	13.44	50	36.56	6.02	3115	50 l/min x 4320 min. (Constant discharge test using a submersible pump)
		200.4	8.17	192.2	340	185	10.52	70	59.48	5.72	3060	
H-6 (J-4/H5)	Tammennawewa	110.4	5.5	104.9	240	215	9.32	36.36	27.04	8.88	8310	432 l/min x 4320 min. (Constant discharge test using a submersible pump)
M-1 (J-10/M7)	Sevanagala	92.5	11.05	81.4	350	125	1.75	74	72.25	4.84	800	31 l/min x 360 min. (Constant discharge test using a submersible pump)
		200.5	11.05	189.4	550	240	1.73	31.30	29.57	18.60	570	
M-2 (J-7/M2)	Bodagama	62.2	4.93	57.3	360	180	8.35	18.82	10.47	34.38	1950	Finally about 1000 liters/min yielded during DTH drilling with air compressor 41 l/min x 240 min. (Constant discharge test using a submersible pump)
		200.2	4.93	195.3	510	245	8.45	19.76	11.31	45.09	2020	
M-4 (J-8/M5)	Yalabowa	74.2	17.42	56.8	550	185	12.55	28.80	16.25	33.85	827	1100-1200 litres/min yielded during DTH drilling with air compressor
		110.2	17.42	92.8	550	150	12.70	27.08	14.38	38.25	770	
M-3 (J-9/M6)	Badalkumbra	84.0	11.15	72.9	850	155	12.12	13.16	1.04	817	420	Finally about 6000 litres/min yielded during DTH drilling with air compressor. 950 l/min x 4320 min. (Constant discharge test using a submersible pump)

The points are described below.

- As tabulated in the table, seven out of 10 test wells yielded more than 200 litres/min.
- Three boreholes, H-1 Siyambalagaswila, H-3 Wediwewa and H-4 Keliyapura, were poorly productive.
- Six of seven productive boreholes, H-5 Pahala Mattala, H-6 Tammennawewa, M-1 Sevanagala, M-2 Bodagama, M-3 Badalkumbra, M-4 Yalabowa, have major fractures above the depth of 100 m.

– H-2 Talunna borehole had the major fracture at 185 m in depth, although no fracture was encountered up to 150 m in depth.

– Specific capacity of six productive boreholes ranges from 4.8 to 45 litres/min/m. And specific capacity of M-3 Badalkumbra is 817 litres/min/m.

6.4.2 METHOD OF PUMPING TEST AND ANALYSIS

The following stages were applied to the pumping test in general, if possible. The yield of some wells, however, was too low to perform the test completely. In such a case, only a short duration constant discharge test and recovery test were conducted.

Phase 1: Provisional Test

A short provisional test was normally done before the commencement of the pumping test. The purpose of the test is to measure the approximate pumping rate and to decide the number of steps for the step drawdown test, and to adjust valve-opening rate to achieve the prescribed pumping rate.

Phase 2: Step drawdown test

Four steps were performed with each step measuring 120 minutes, if possible.

Phase 3: Constant discharge test

The test was done for 72 hours or more, when the yield was enough.

Phase 4: Recovery test

The test commenced immediately on completion of the constant discharge test and continued until the water level returned to its static water level or occasionally over a shorter period.

<Measurement>

The original static water level in the well was always measured before any test pumping commenced. Throughout the duration of each test, the water level in the well was measured and recorded following the observation time schedule listed below:

Time from start of pumping or pumping rate increase (minutes)	Time interval between observations (minutes)
0 - 5	0.5
5 - 10	1
10 - 30	2
30 - 60	5
60 - 120	10
120 - 240	20
240 - 360	40
360 - 720	60
720 - 2880	120
(2880 and longer)	(240)

Electric conductivity of water from the well was recorded during the pumping test at intervals corresponding to those for water level measurements.

<Analysis>

Aquifer properties were calculated based on the results of constant discharge test and recovery test. Three fundamental analysing methods, namely Theis type curve analysis, Jacob' time darawdown method and recovery method, were applied. Additionally the following two points were considered in analysing of data.

- The types of aquifer may affect the time-drawdown curve.
- The most of the tests were single-well test without observation wells, or piezometers.

(1) Aquifer Type and Time-Drawdown Curve

The target aquifer of the drilled test wells were consolidated fractured and confined aquifers below about 100 meters. The time-drawdown curves in such type of aquifer are expected to show some variations shown in the following figures. (*Kruseman and Ridder, 1990*)

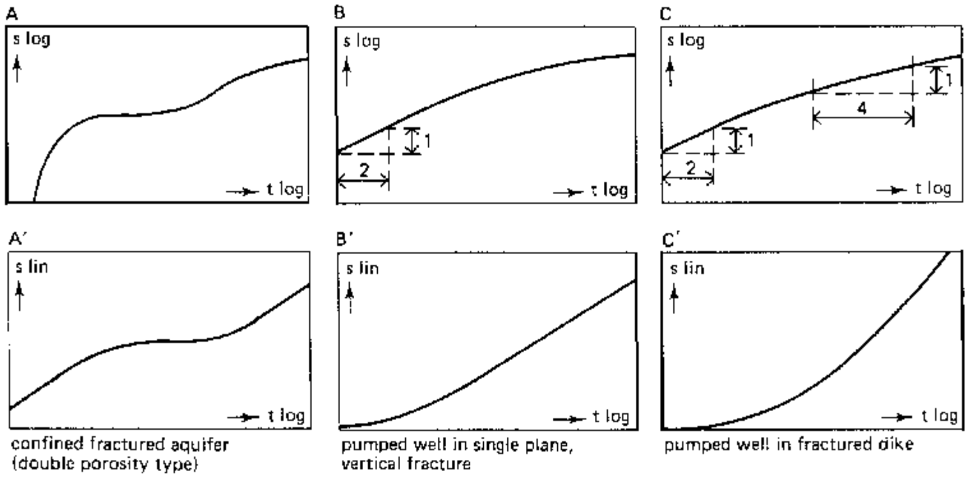

Figure Log-log and semi-log plots of the theoretical time-drawdown relationships of consolidated, fractured aquifers:
Parts A and A′: Confined fractured aquifer, double porosity type
Parts B and B′: A single plane vertical fracture
Parts C and C′: A permeable dike in an otherwise poorly permeable aquifer

According to Kruseman and Ridder (1990), these variations are described as the following.

Figure **A** shows the curve of double porosity type. Three time periods can be recognized in this type. Early pumping time, when all the flow comes from storage in the fractures. Medium pumping time is a transition period. During the time the matrix blocks feed their water at an increasing rate to the fractures, resulting in a (partly) stabilizing drawdown. Late pumping time, when the pumped water comes from storage in both the fractures and matrix blocks.

Figure **B** is a single plane vertical fracture. The fracture has a finite length and high hydraulic conductivity. A log-log plot shows a straight-line segment of slope 0.5 in the early pumping time. This segment reflects the dominant flow regime in that period; it is horizontal, parallel and perpendicular to the fracture. This flow regime gradually changes, until, at late time, it becomes pseudo-radial.

Figure **C** is a permeable dike in an otherwise poorly permeable aquifer. Characteristic of such a system are the two straight-line segments in a log-log plot of early and medium pumping time. At early time, the flow towards the well is exclusively through the dike, and this flow is parallel, which shows the first segment with a slope of 0.5 similar to Figure B. At medium time, the adjacent aquifer starts yielding water to the dike. The dominant flow regime is then near-parallel to parallel, but oblique to the dike. In a log-log plot, this flow regime is reflected by a one-forth slope straight-line segment. At late time, the dominant flow regime is pseudo-radial, which is reflected by a straight line in a semi-log plot.

(2) Single-Well Test

Ideally a pumping test should be conducted using a pumped well and some piezometers, or observation wells in which the drawdown would be measured. Actually test will be sometimes conducted without observation wells due to some reasons such as physical factors and/or financial factors. In this project, at least one well was selected as an observation well from the existing ones located in the surround of a newly drilled test well for the study. In most cases, however, water level change could not be observed in the selected well during pumping from a test well. Some of the wells may be too distant from the pumped well and/or some may be too shallow. In any case the drawdown and recovery were measured in the pumped well itself during the test and the recorded data were used for analysing, that is, single well pumping tests were conducted.

Although well-bore storage, which influences the drawdown in a pumped well, should be considered when analysing the data in a single well test, it is observed that the influence decreases with time and becomes negligible at $t > 25r_c^2/T$, where r_c is the radius of the unscreened part of the well, where the water level is changing, and T is the transmissivity. (*Kruseman and Ridder, 1990*)

When the radius of 6" casing pipe is 0.075m, $t = 25r_c^2/T$ becomes as below;

T(m^2/day)	t(day)	t(min)
0.1	1.4	2016
0.5	0.281	405
1	0.14	202
5	0.028	41
10	0.014	21

The above table shows that, if T is 1 m^2/day, the influence of well-bore storage becomes negligible after 202 minutes from the time of pump started.

6.4.3 Result

Pumping test of 14 test wells have been completed. The results were graphed in *Figure 6.16* to *Figure 6.29* and summarized in *Table 6.4*. Specific capacity, which is the discharge per unit of drawdown, was calculated and transmissivity, which is the flow in m^3/day through a section of aquifer one meter wide under a hydraulic gradient of unity, was estimated.

(1) Siyambalagaswila North: Well No. H-1 (J-6/H7)　(*Figure 6.16*)

The well was poorly productive. Consequently only the pumping could be conducted for 27 minutes with the pumping rate of 18 litres/min. When the pump stopped the drawdown was recorded to be 23.96 meters, but it was on the way of still going down, or not stable yet, at the moment. After the pump stopped, the water level recovery of 1.42 meters took 60 minutes. Although the specific capacity was calculated at 0.75 litres/min/m, it probably became poorer if the pumping continued further. Transmissivity was estimated at 0.14 m^2/day.

(2) Talunna: Well No. H-2 (J-2/H3)　(*Figure 6.17(1) and (2)*)

Step draw down test with five steps each of two hours duration and the constant discharge test with the pumping rate of 415 litres/min were conducted as summarised in the table. The duration of constant discharge test was 5760 minutes, or four days. The final draw down was 27.05 meters. The specific capacity was calculated at 15.34 litres/min/m based on the result of the constant discharge test. Transmissivity was estimated at 25.29 m^2/day.

(3) Wediwewa: Well No. H-3 (J-3/H4)　(*Figure 6.18*)

The well was poorly productive. Consequently only the pumping could be conducted for 45 minutes with the pumping rate of 30 litres/min. When the pump stopped the drawdown was recorded to be 46.43 meters, but it was not yet stable at the moment. After the pump stopped, the water level recovery of 1.21 meters took 60 minute. The specific capacity was tentatively calculated at 0.65 litres/min/m. Transmissivity was estimated at 0.18 m^2/day.

(4) Keliyapura: Well No. H-4 (J-1/H1)　(*Figure 6.19*)

The well was another poorly productive well. Actually no water encountered during the drilling. The water level was about 193 meters bgl right after the drilling finished. The borehole was filled up with tanked water in order to do geophysical logging. After that, the casing and screen pipes were installed, and then the pumping test was conducted. The pumping was continued for 145 minutes with the pumping rate of 6 litres/min. Also, the water level was not yet stable at the time of pumping stopped. The recorded drawdown was 29.43 meters at the moment. Specific capacity was tentatively calculated at 0.21 litres/min/m and transmissivity was estimated at 0.14 m^2/day. Even though the borehole was almost dry just after the drilling finished, the recovery of water level was observed after the pumping test. It was 5.11 meters in 55 minute.

(5) Pahala Mattala: Well No. H-5 (J-5/H6) (*Figure 6.20(1) and (2)*)

Step draw down test with four steps each of about two hours duration and the constant discharge test with the pumping rate of 50 litres/min were conducted. Air lifting discharge rate was, however, 340 litres/min before the installation of casing and screen pipes. The duration of constant discharge test was 4320 minutes, or three days. The final drawdown was 69.88 meters. The specific capacity was calculated at 0.72 litres/min/m. Transmissivity was estimated at 0.85 m^2/day.

During the pumping test, the water level change was observed in the existing well of JM06, selected as a piezometer. The distance between the pumped well and the observation well was about 180 m. The depth of JM06 is 38 m. Based on the recorded data in the JM06, the constant discharge test of No.H-5 was analysed. The estimated transmissivity was 6.77 m^2/day and the storativity or storage coefficient was calculated at 2.25×10^{-4}.

In the area, the additional well, No.H-5(2), was drilled up to 52 m bgl by WRB, which is about 40 m away from the H-5 test well. During drilling of this additional borehole, the water level change was recorded clearly by the water level recorder installed on the H-5 test well.

(6) Pahala Mattala-2: Well No.H-5 (2) (*Figure 6.21(1) and (2)*)

The borehole was drilled to 52.5 m by WRB. The surface casing pipes were installed to 6.8 m in depth. The part below 6.8 m is open hole. Step draw down test with five steps each of two hours duration was tried to conduct but the duration of the fifth step could be only eight minutes. The constant discharge test was conducted for 3000 minutes with the pumping rate of 106 litres/min. The final drawdown was 15.18 m and the specific capacity was calculated at 6.98 litres/min/m. Transmissivity was estimated at 9.45 m2/day.

During the pumping test, the water level change was observed in Well No.H-5. The distance between the pumped well and the observation well was about 40 m. Based on the recorded data in No. H-5, the constant discharge test of No.H-5(2) was analysed. The estimated transmissivity was 4.74 m^2/day and the storativity or storage coefficient was calculated at 5.74×10^{-4}

(7) Tammennawewa: Well No. H-6 (J-4/H5) (*Figure 6.22(1) and (2)*)

As already described, this well was not drilled up to 200 m. The depth of the completed well was 102 m and the screen pipes were installed in some parts below 52 m in depth.

Step draw down test with five steps each of two hours duration and the constant discharge test with the pumping rate of 432 litres/min were conducted. The duration of constant discharge test was 4320 minutes, or three days. The final drawdown was 30.91 meters. The specific capacity was calculated at 13.98 litres/min/m. Transmissivity was estimated at 27.67 m^2/day.

During the pumping test, the water level change was observed in the existing well of JM05. The distance between the pumped well and JM05 was about 77 m. The depth of JM05 is 35.97 m. Based on the recorded data in the JM05, the constant discharge test of No.H-6 was analysed. The estimated transmissivity was 18.83 m^2/day and the storativity or storage coefficient was calculated at 1.45×10^{-4}.

(8) Sevanagala: Well No. M-1 (J-10/M7) (*Figure 6.23*)

Step draw down test with three steps each of two hours duration and the constant discharge test with the pumping rate of 31 litres/min were conducted. Air lifting discharge rate was, however, 550 litres/min before the installation of casing and screen pipes, which were installed in some parts below the depth of 127 m. The duration of constant discharge test was only 360 minutes. The recorded drawdown was 134.45 meters, though the water level was not yet stable at the time of pumping stopped. The specific capacity was tentatively calculated at 0.23 litres/min/m. Transmissivity was estimated at 0.061 m^2/day.

(9) Sevanagala-2: Well No.M-1 (2) (*Figure 6.24(1) and (2)*)

The borehole was drilled to 40.8 m by WRB. The surface casing pipes were installed to 5.8 m in depth. The part below 5.8 m is open hole. Step draw down test with three steps each of two hours duration was conducted and the constant discharge test was conducted for 1440 minutes with the pumping rate of 85 litres/min. The final drawdown was 27.87 m and the specific capacity was calculated at 3.05 litres/min/m. Transmissivity was estimated at 1.10 m^2/day.

(10) Bodagama: Well No. M-2 (J-7/M2) (*Figure 6.25(1) and (2)*)

Step draw down test with three steps each of about two hours duration and the constant discharge test with the pumping rate of 41 litres/min were conducted. Air lifting discharge rate was, however, 510 litres/min before the installation of casing and screen pipes, which were installed in some parts below the depth of 131 m. The duration of constant discharge test was only 240 minutes. The recorded drawdown was 130.94 meters, though the water level was not yet stable at the time of pumping stopped. The specific capacity was tentatively calculated at 0.23 litres/min/m. Transmissivity was estimated at 0.061 m^2/day.

(11) Bodagama-2: Well No.M-2 (2) (*Figure 6.26(1) and (2)*)

The well is 100 m in depth. Step draw down test was conducted with five steps each of two hours duration except the fifth step with the duration of one hour. The constant discharge test was conducted for 4320 minutes with the pumping rate of 440 litres/min. The final drawdown was 28.57 meters. The specific capacity was calculated at 15.4 litres/min/m. Transmissivity was estimated at 53.2 m^2/day. However, another estimation based on the data of the latter period of the pumping test, from 1000 min after the pump started, was 9.12 m^2/day.

During the pumping test, the water level change was observed in Well No.M-2. The distance between the pumped well and No.M-2 was about 68 m. Based on the recorded data in No. M-2, the constant discharge test of No.M-2 (2) was analysed. The estimated transmissivity was 81.9 m^2/day and the storativity or storage coefficient was calculated at 3.23×10^{-4}

(12) Yalabowa: Well No. M-4 (J-8/M5) (*Figure 6.27(1) and (2)*)

Step draw down test with four steps each of two hours duration and the constant discharge test with the pumping rate of 73 litres/min were conducted. The duration of constant discharge test was 3720 minutes. The final drawdown was 99.81 meters. Transmissivity was estimated at 0.58 m^2/day and the specific capacity was calculated at only 0.73 litres/min/m.

(13) Yalabowa-2: Well No.M-4 (2) (*Figure 6.28(1) and (2)*)

The borehole was drilled to 100 m. Step draw down test was conducted with five steps each of two hours duration and the maximum pumping rate was 775 litres/min. The constant discharge test was conducted for 4320 minutes, or three days, with the pumping rate of 610 litres/min. The final drawdown was 13.0 meters. Specific capacity was calculated at 46.92 litres/min/m and transmissivity was estimated at 53.7 m^2/day.

During the pumping test, the water level change was observed in Well No.M-4. The distance between No.M-4(2) and No.M-4 was about 42 m. Based on the recorded data in No. M-4, the constant discharge test of No.M-4(2) was analysed. The estimated transmissivity was 89.4 m^2/day and the storativity or storage coefficient was calculated at 1.87×10^{-3}.

(14) Badalkumbra: Well No. M-3 (J-9/M6) (*Figure 6.29*)

The depth of the completed well was 88.3 m and the screen pipes were installed from 63 to 83 m. Step draw down test could not be conducted because the prepared submersible pump had not enough capacity. The constant discharge test was conducted for 4320 minutes, or three days, with the pumping rate of 950 litres/min. The final drawdown was 4.40 m and specific capacity was calculated at 215.9 litres/min/m. Transmissivity was estimated at 741 m^2/day.

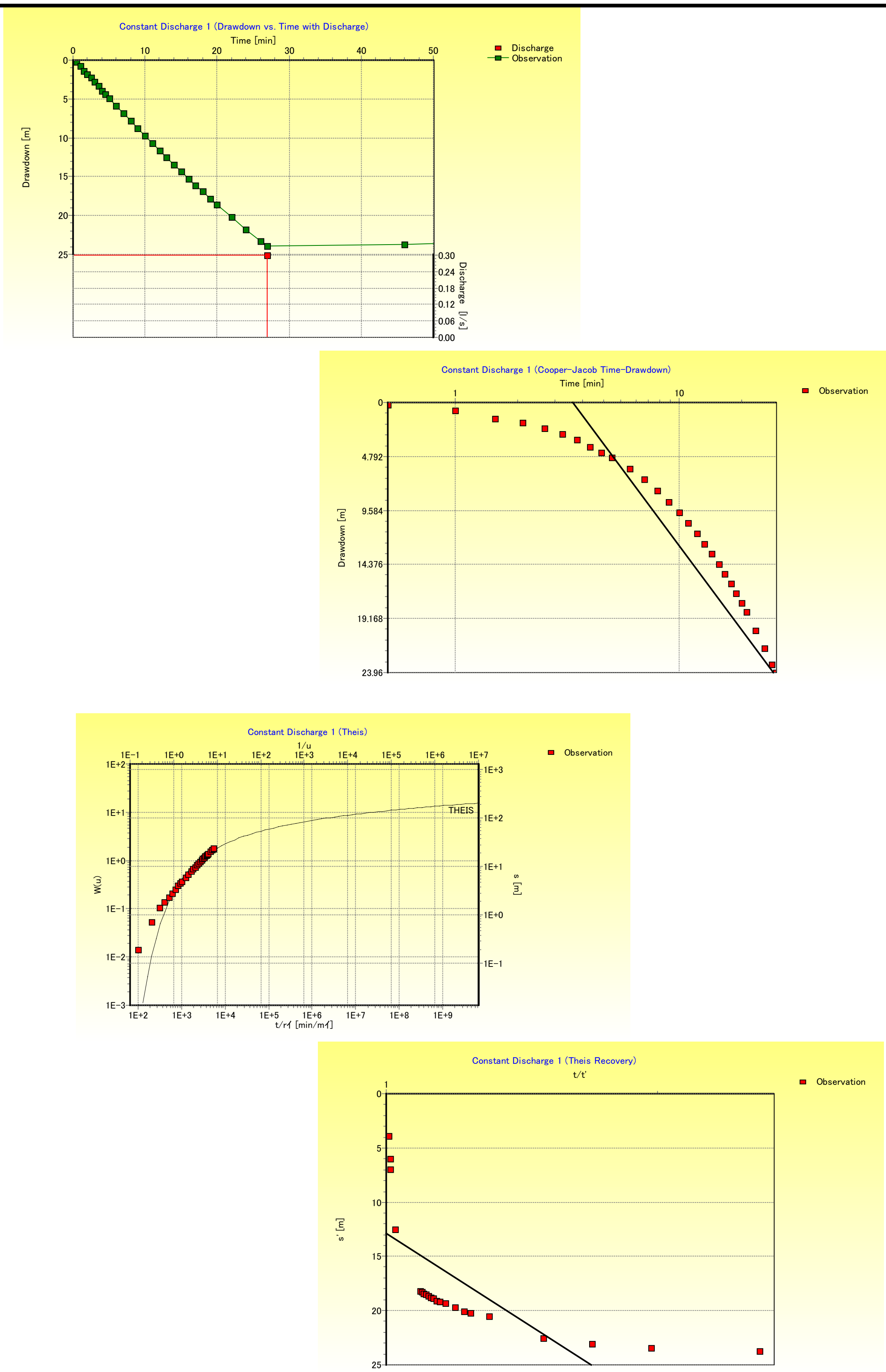

FIGURE 6.16 PUMPING TEST OF TEST WELL NO. H-1 (J-6/H7) SIYAMBALAGASWILA NORTH

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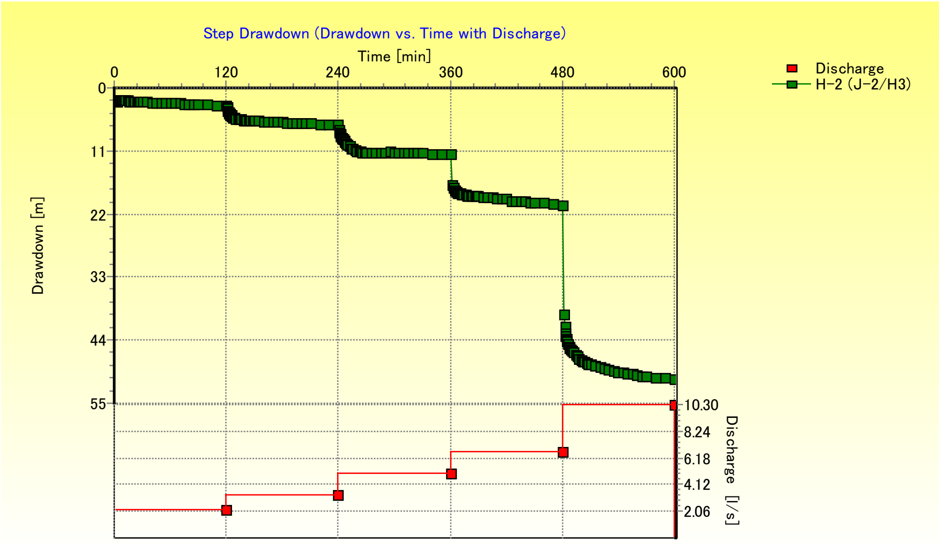

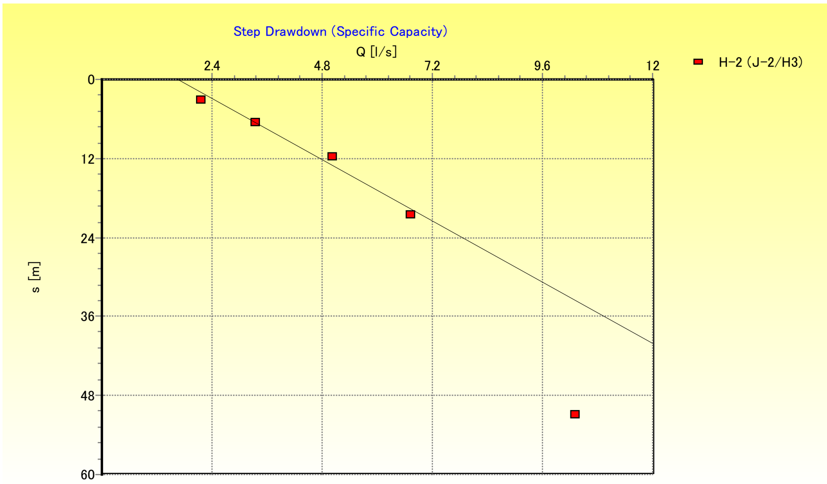

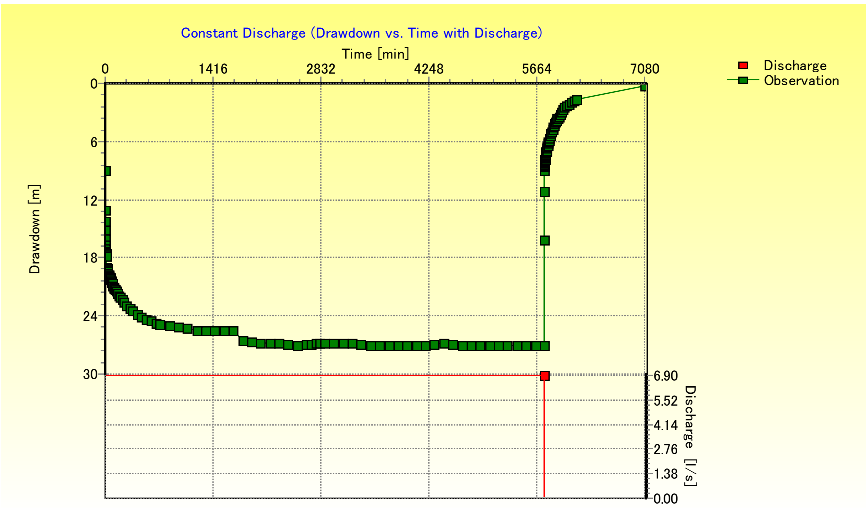

FIGURE 6.17(1) PUMPING TEST OF TEST WELL NO. H-2 (J-2/H3) TALUNNA

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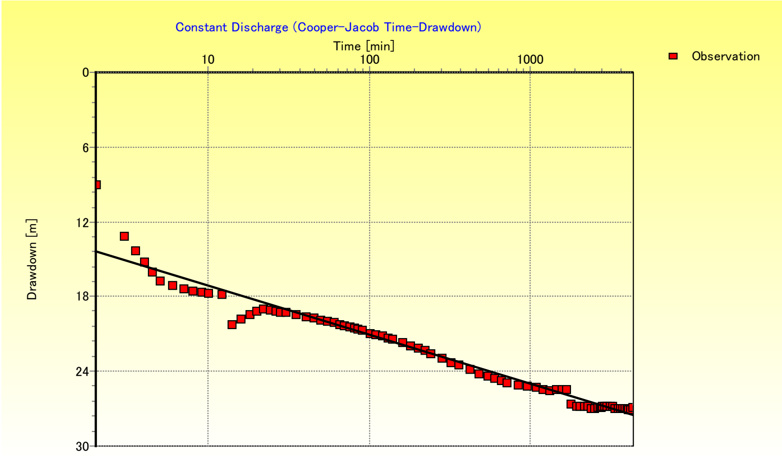

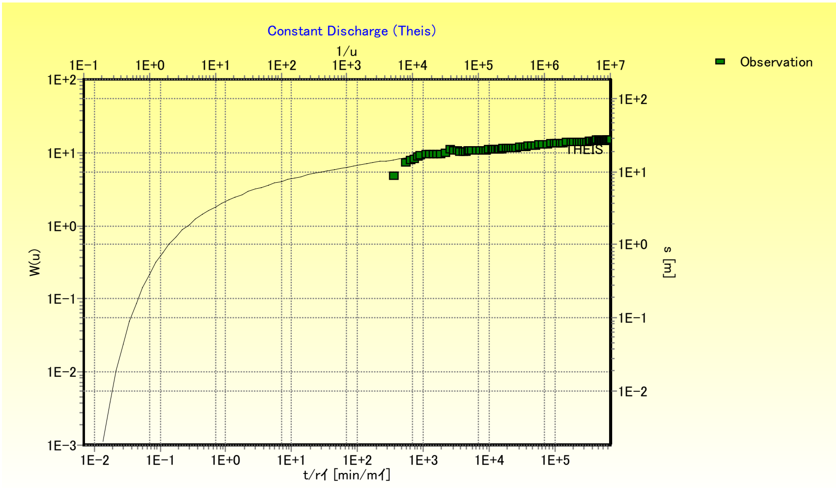

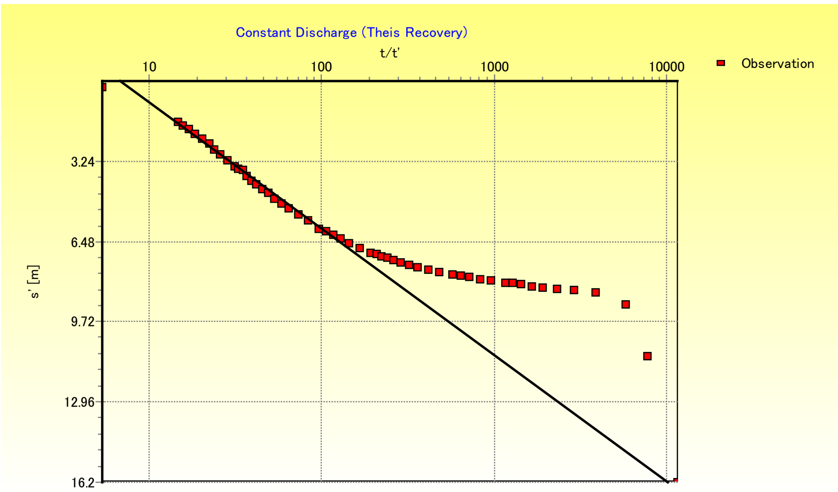

FIGURE 6.17(2) PUMPING TEST OF TEST WELL NO. H-2 (J-2/H3) TALUNNA

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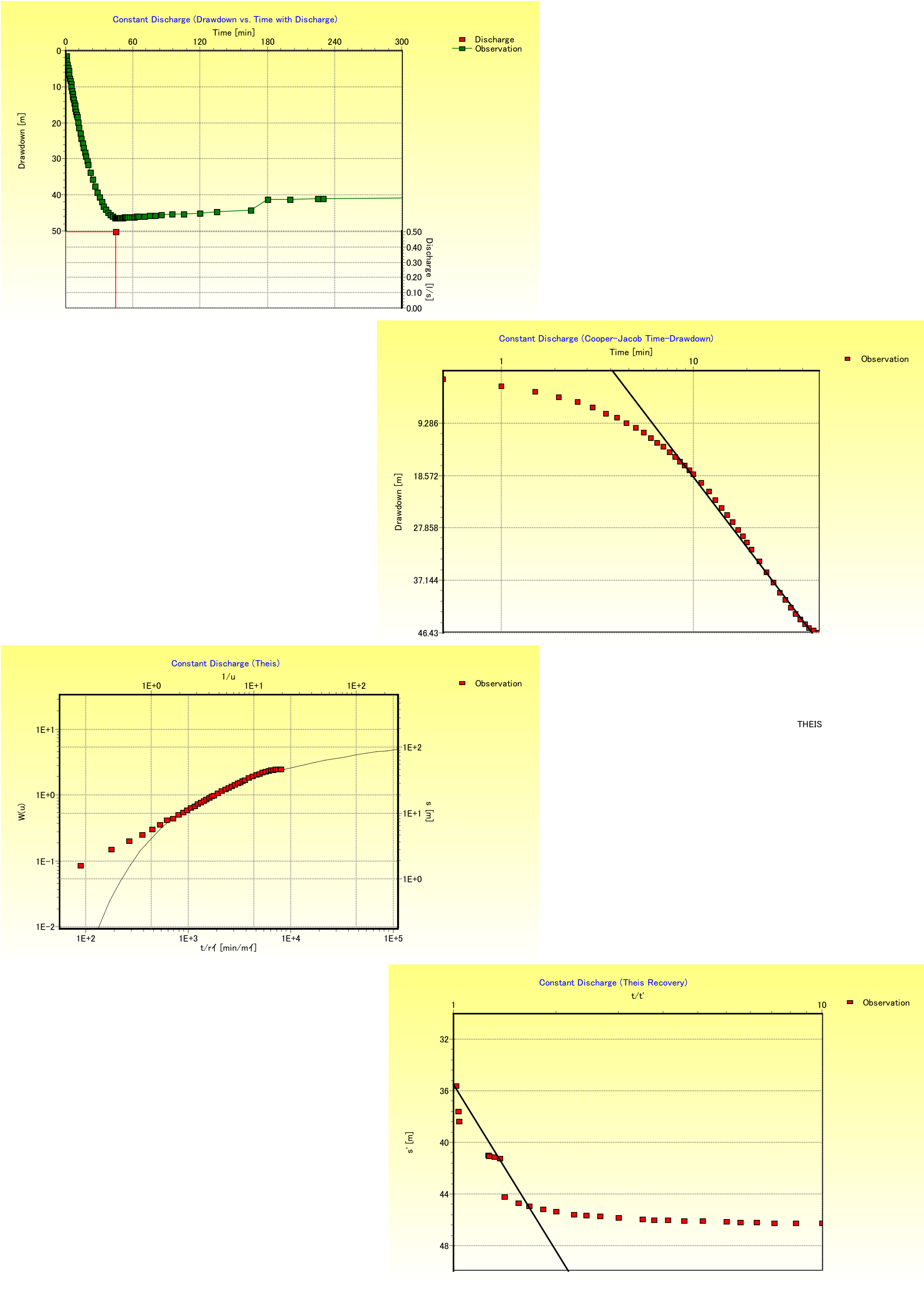

FIGURE 6.18 PUMPING TEST OF TEST WELL NO.H-3 (J-3/H4) WEDIWEWA

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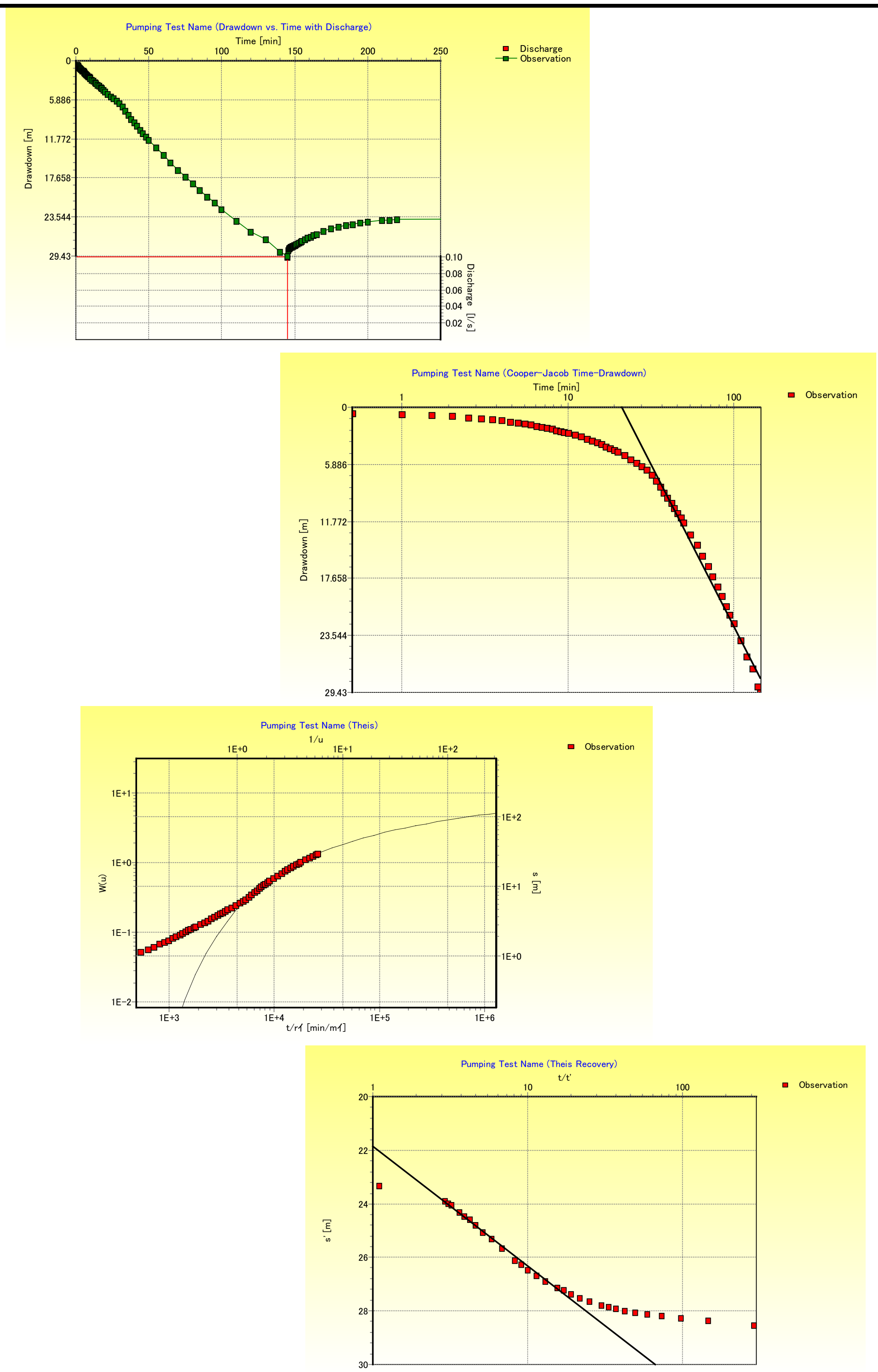

FIGURE 6.19 PUMPING TEST OF TEST WELL NO. H-4 (J-1/H1) KELIYAPIRA

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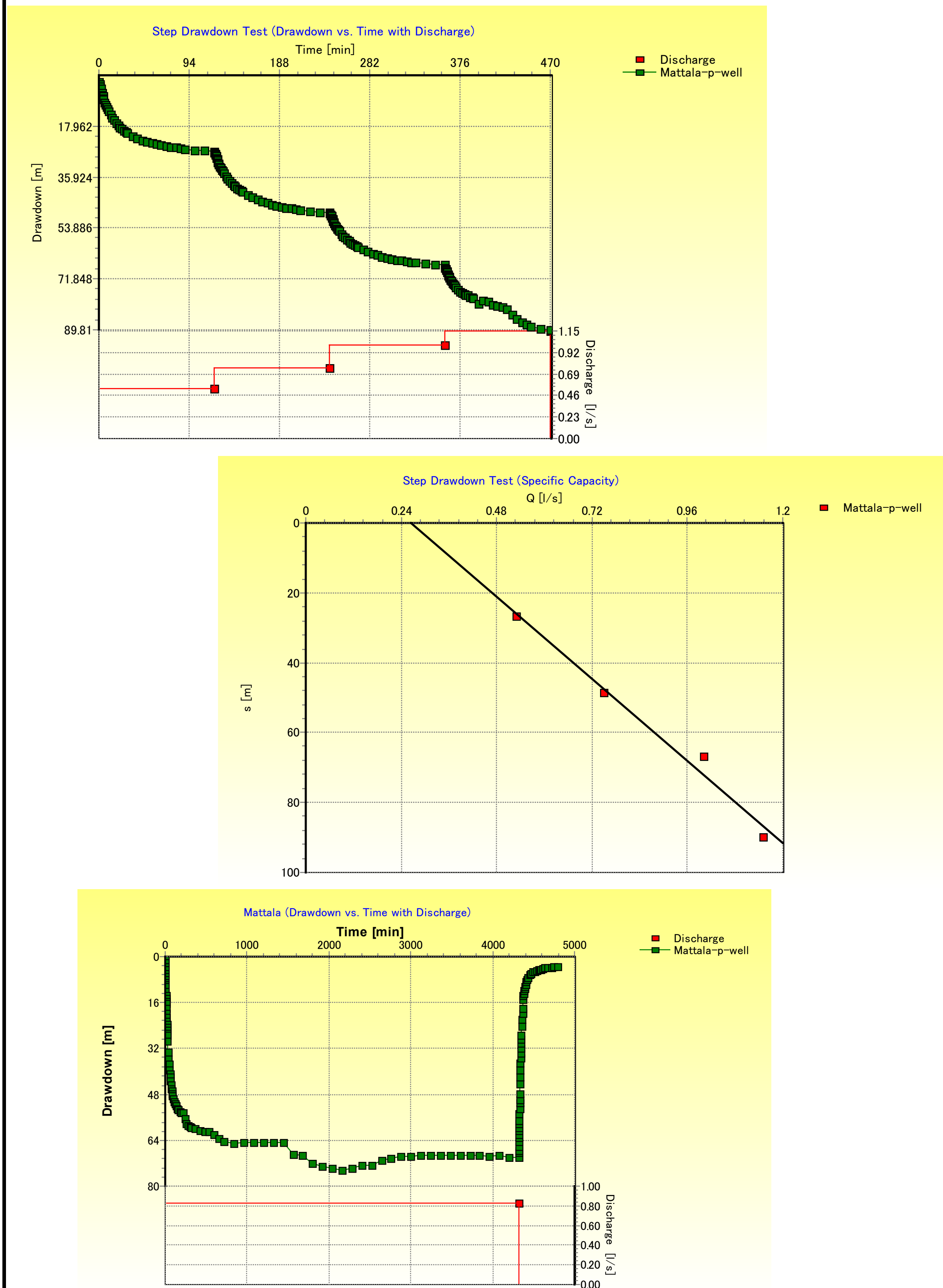

FIGURE 6.20(1) PUMPING TEST OF TEST WELL NO. H-5 (J-5/H6) PAHALA MATTALA

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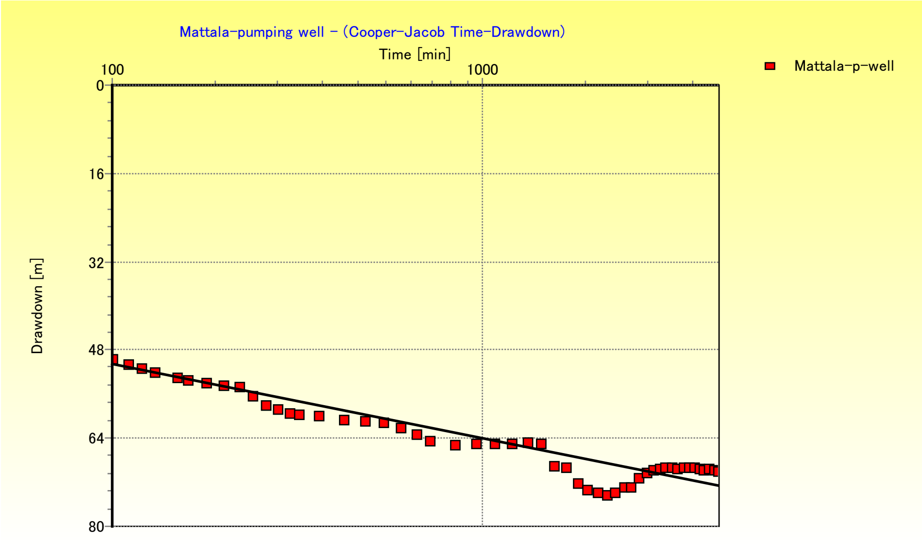
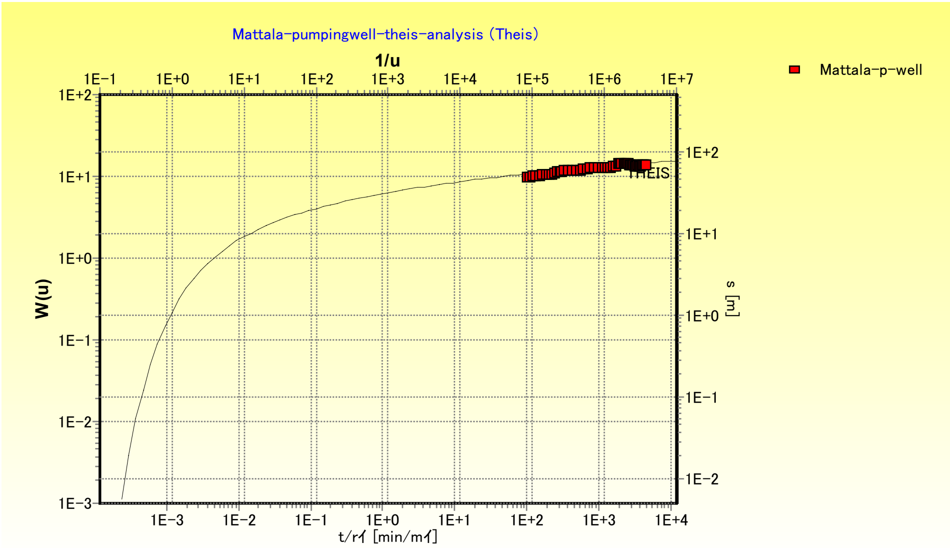




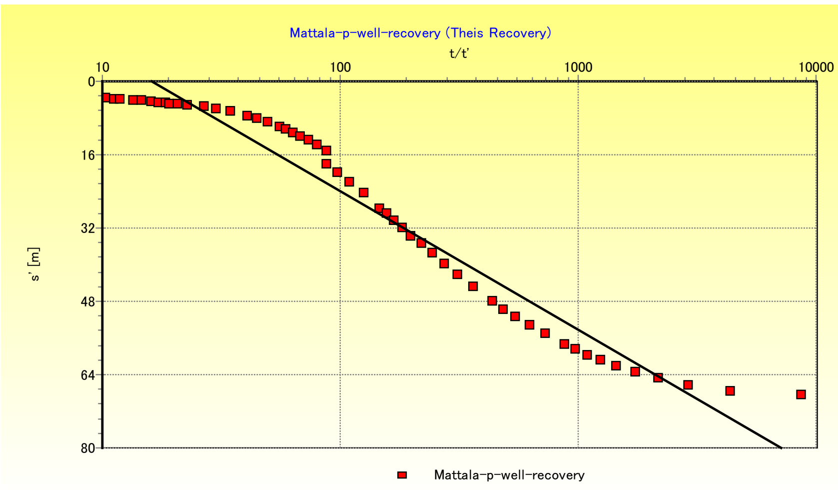
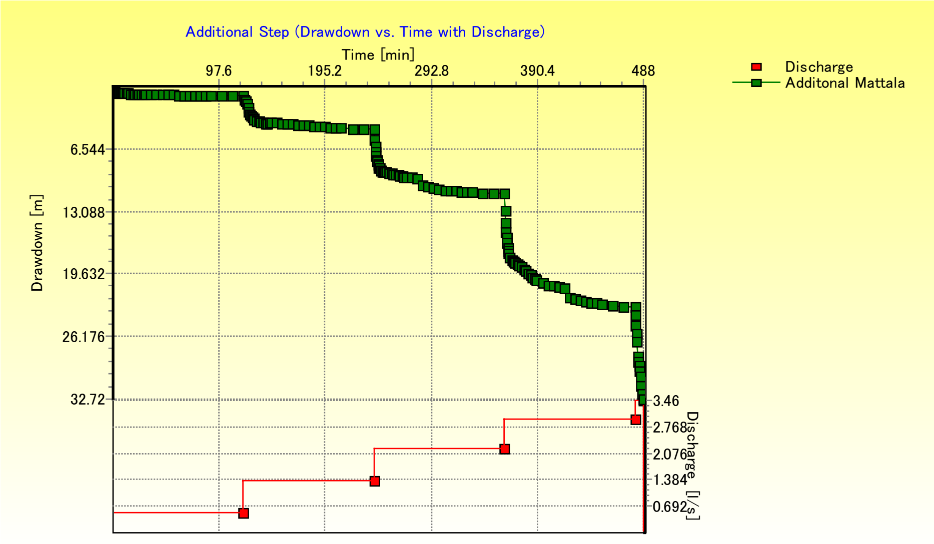
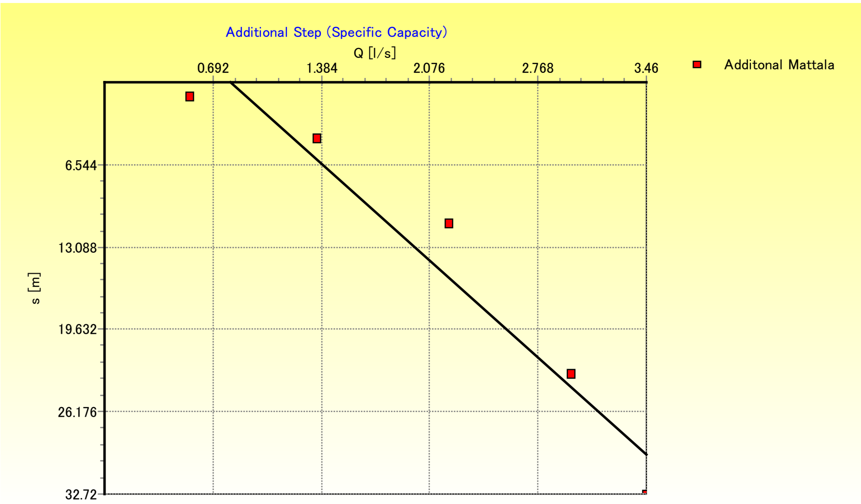


FIGURE 6.20(2) PUMPING TEST OF TEST WELL NO. H-5 (J-5/H6) PAHALA MATTALA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





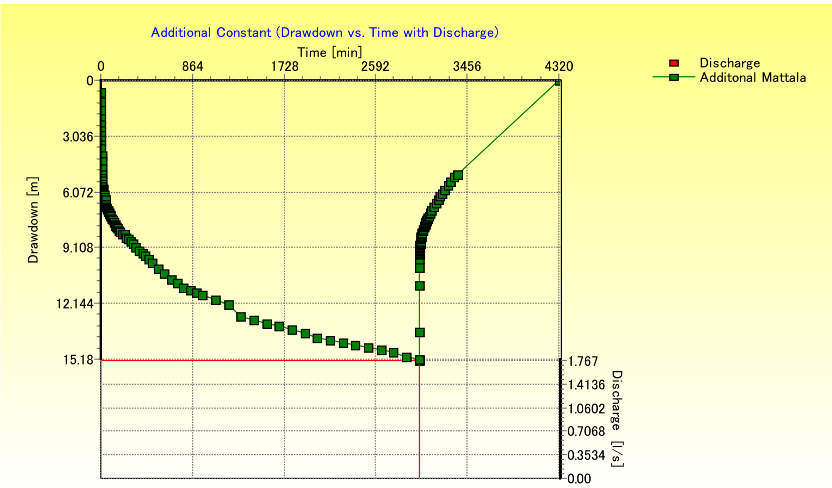
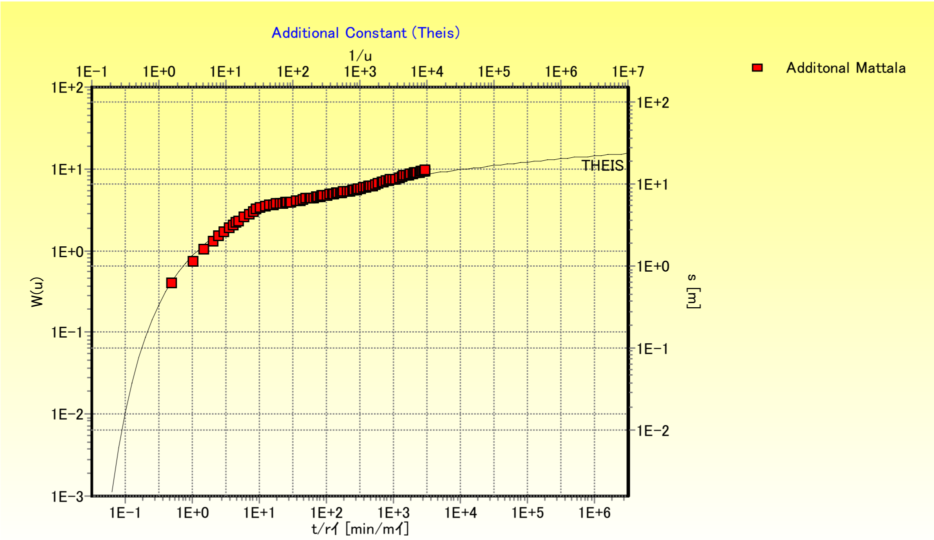


FIGURE 6.21(1) PUMPING TEST OF TEST WELL NO. H-5 (2) PAHALA MATTALA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**



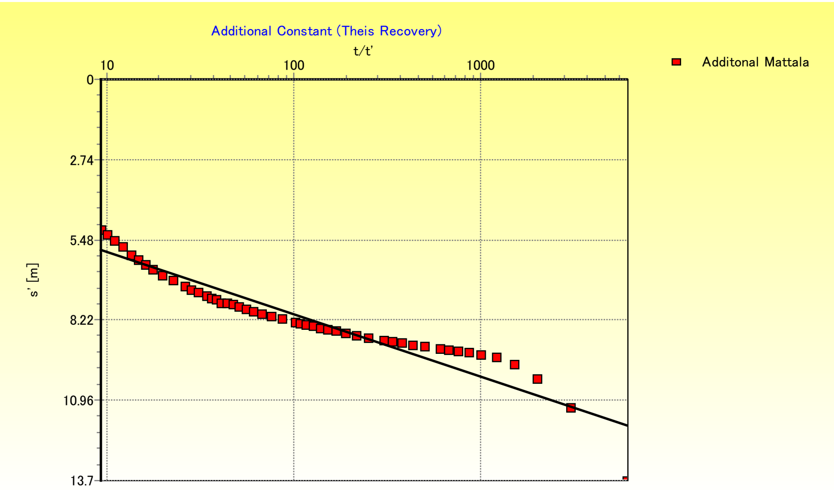
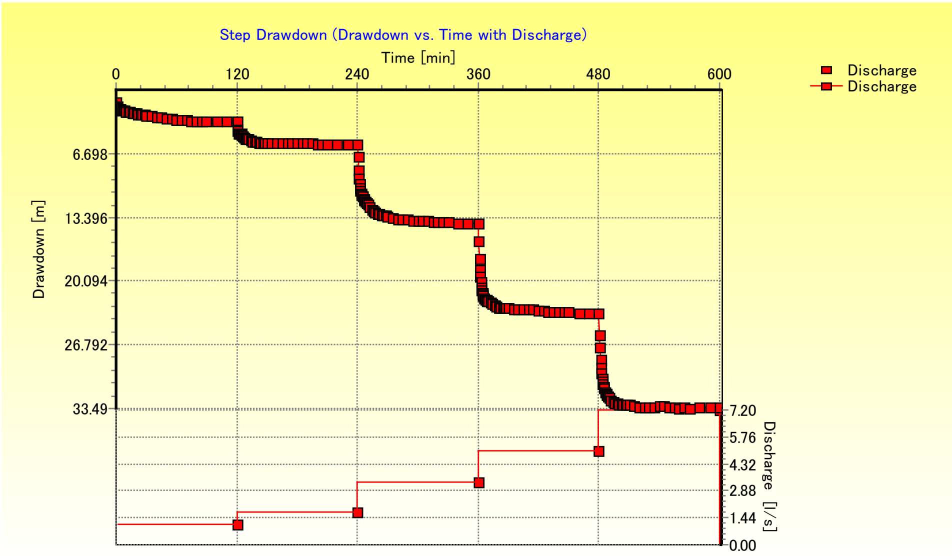


FIGURE 6.21(2) PUMPING TEST OF TEST WELL NO. H-5 (2) PAHALA MATTALA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**



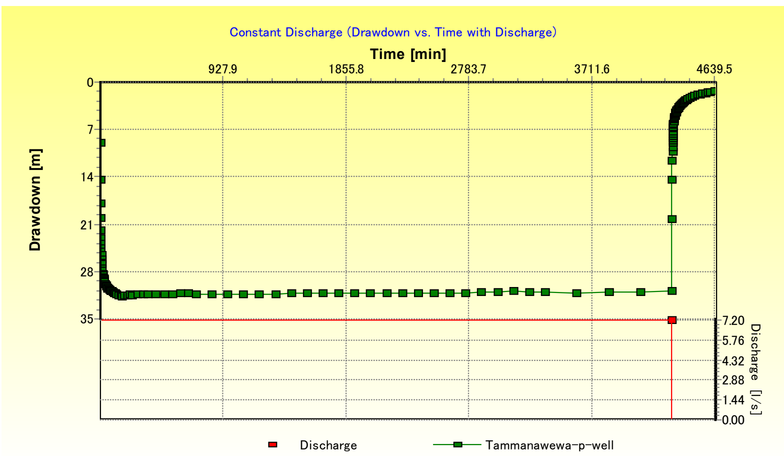
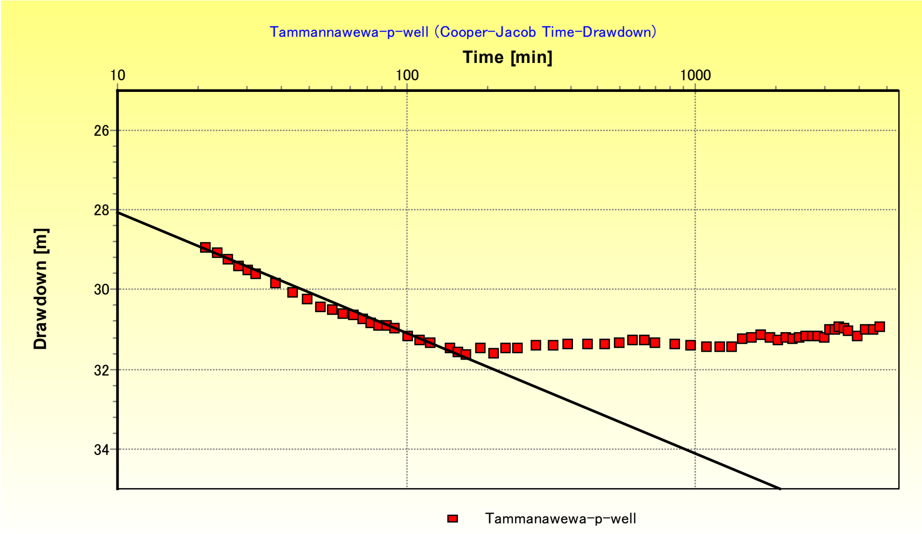
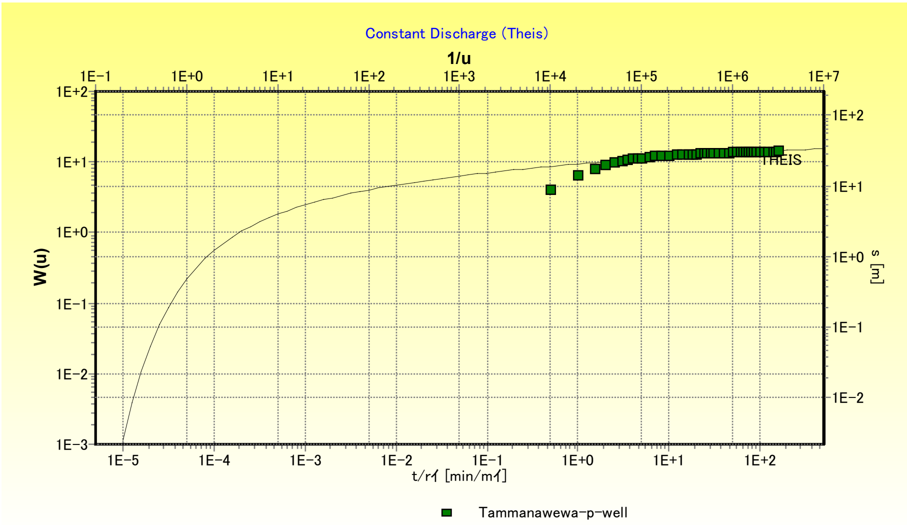


FIGURE 6.22(1) PUMPING TEST OF TEST WELL NO. H-6 (J-4/H5) TAMMENNAWEWA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





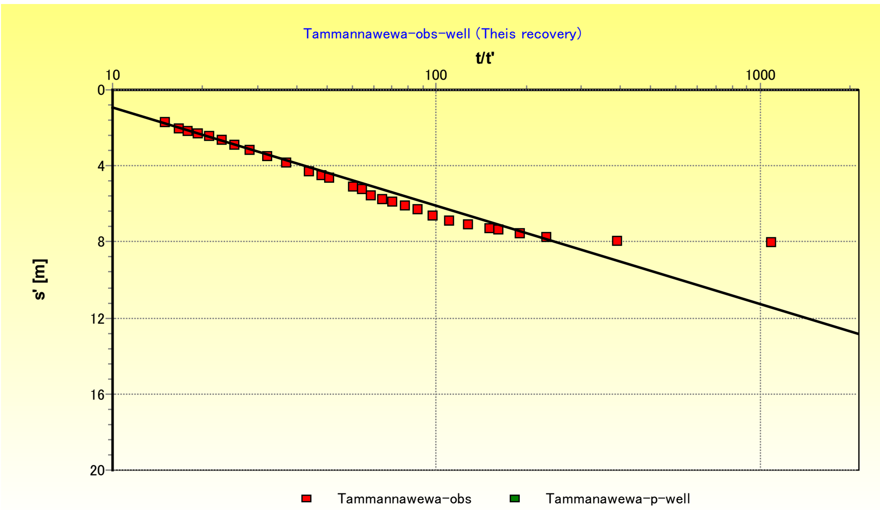


FIGURE 6.22(2) PUMPING TEST OF TEST WELL NO. H-6 (J-4/H5) TAMMENNAWEWA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

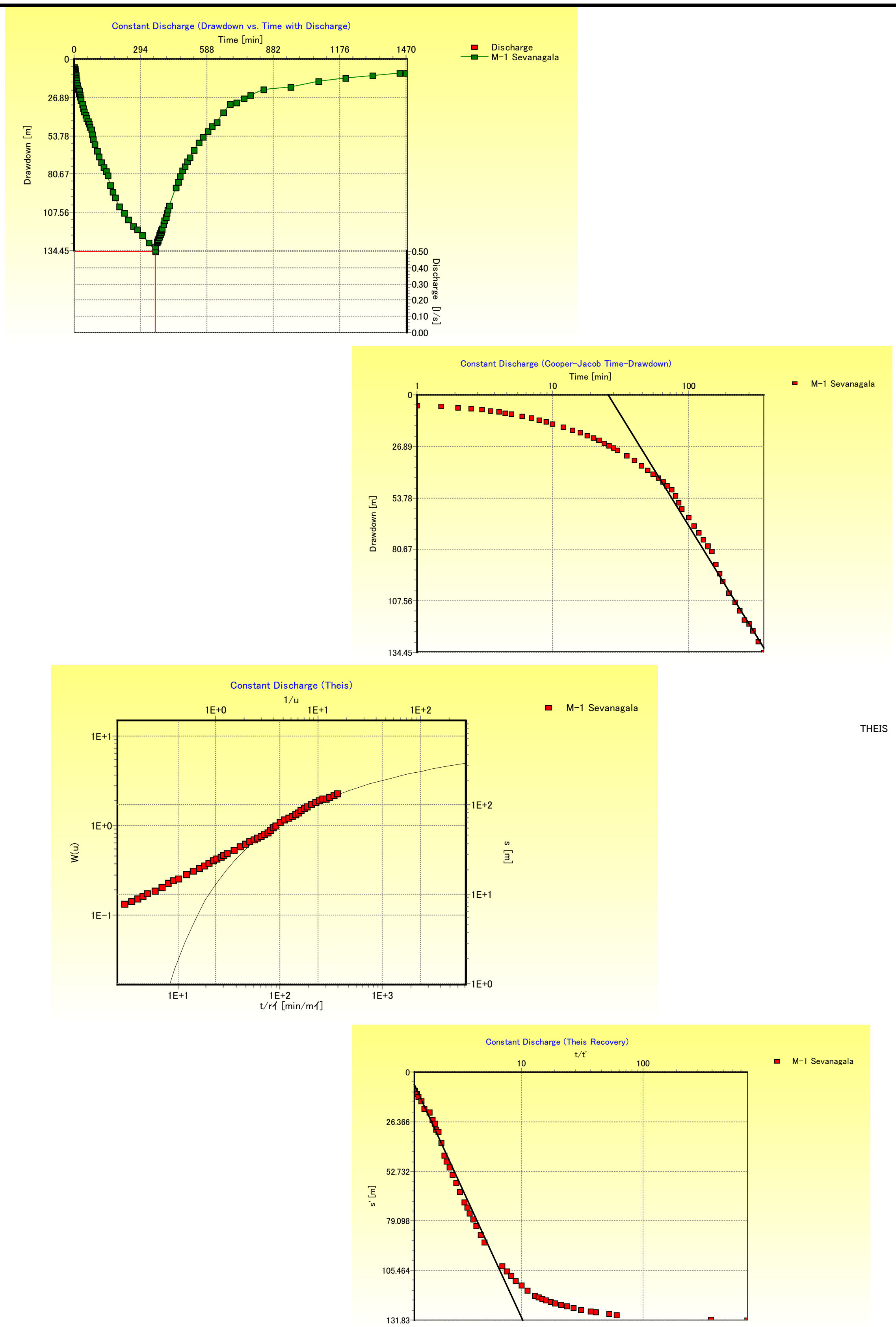
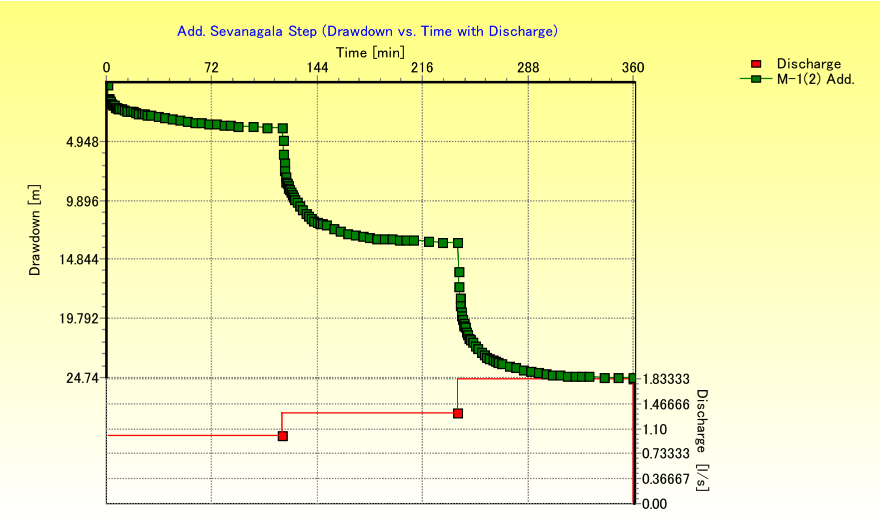
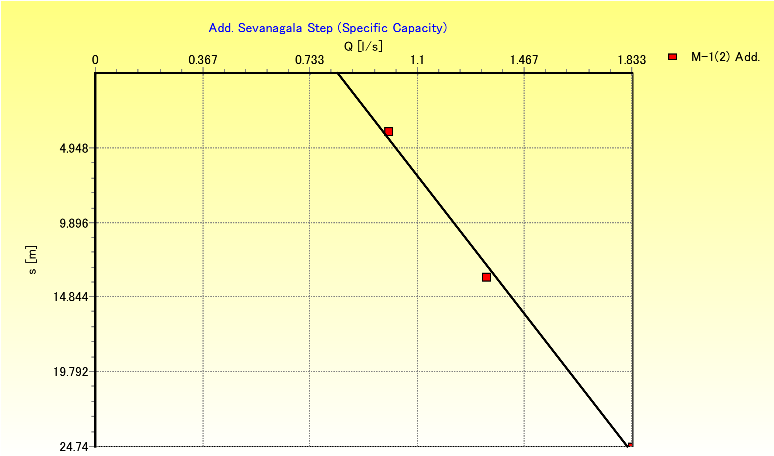


FIGURE 6.23　PUMPING TEST OF TEST WELL NO. M-1 (J106/M7) SEVANAGALA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





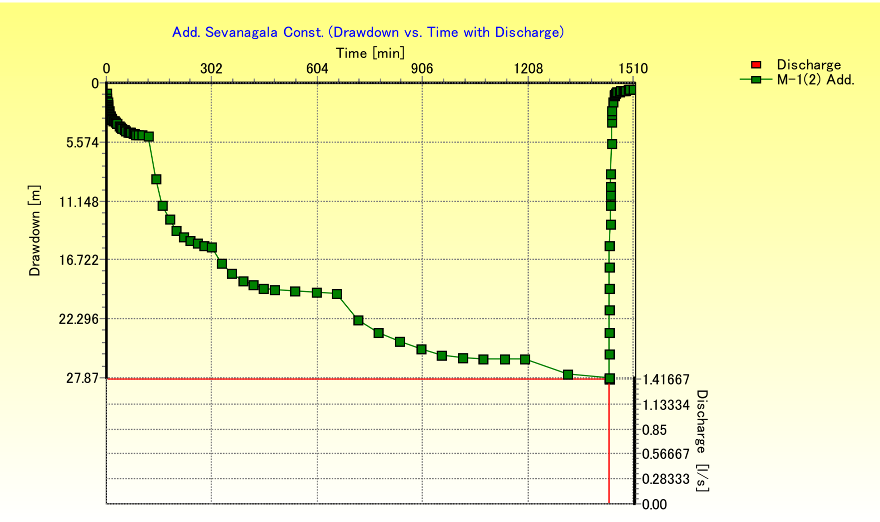


FIGURE 6.24(1) PUMPING TEST OF TEST WELL NO. M-1 (2) SEVANAGALA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

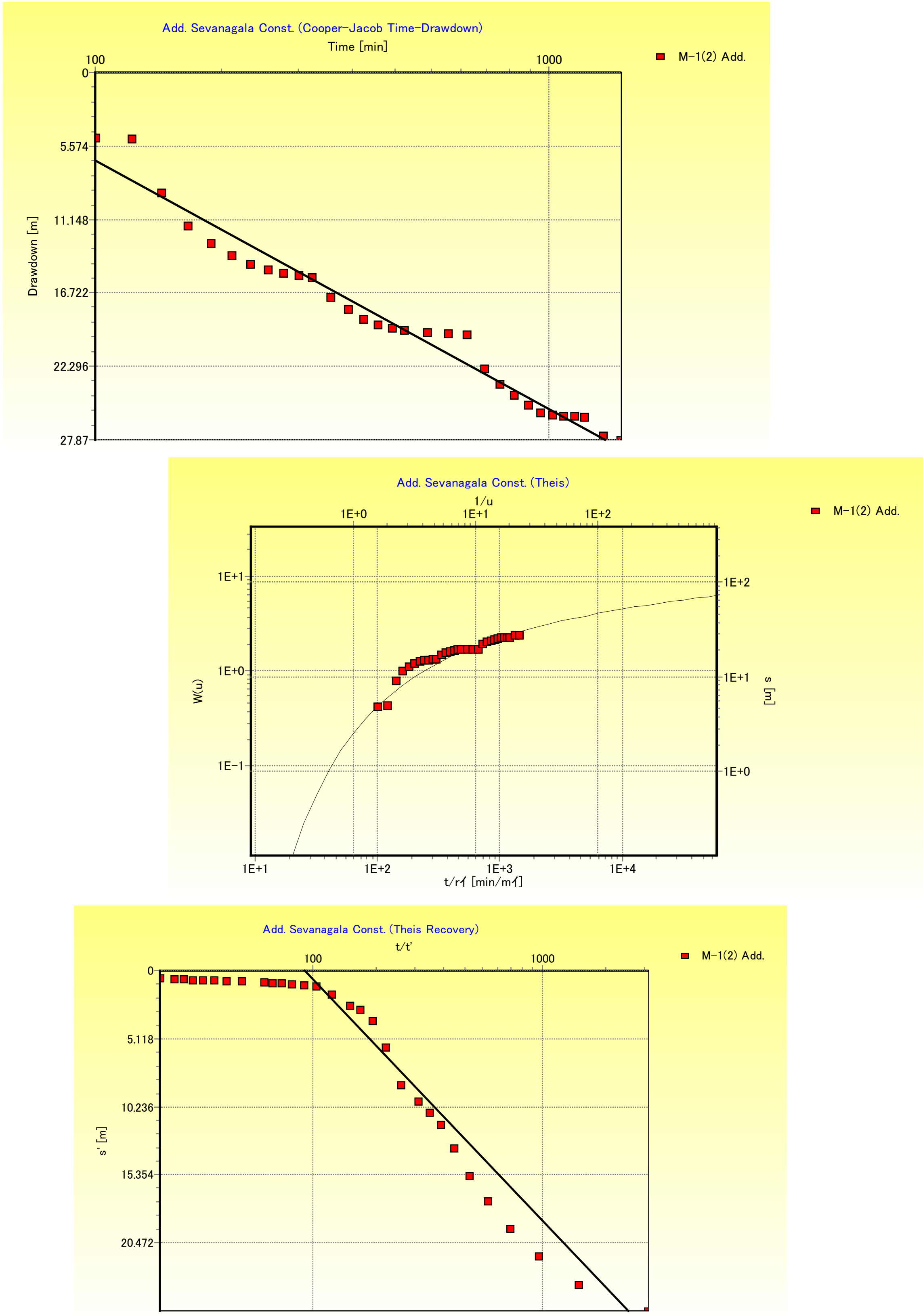
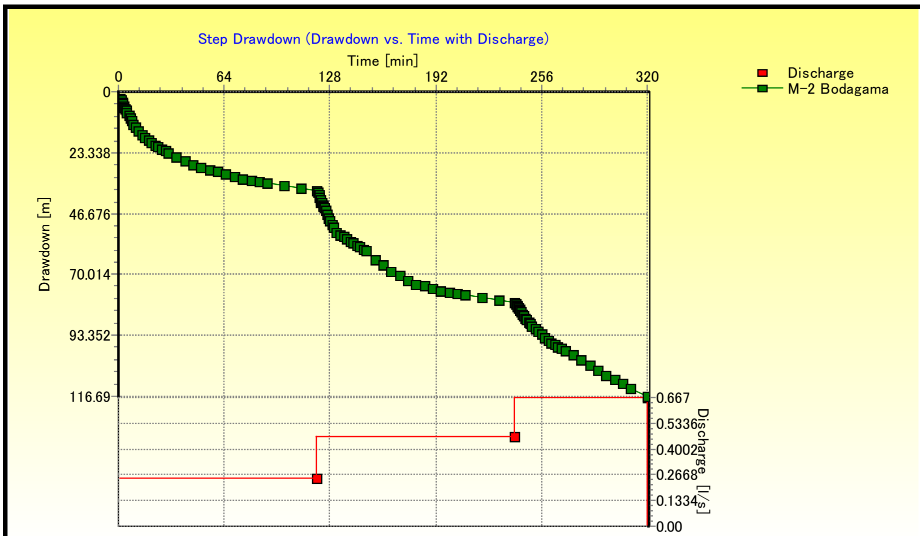


FIGURE 6.24(2) PUMPING TEST OF TEST WELL NO. M-1 (2) SEVANAGALA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**



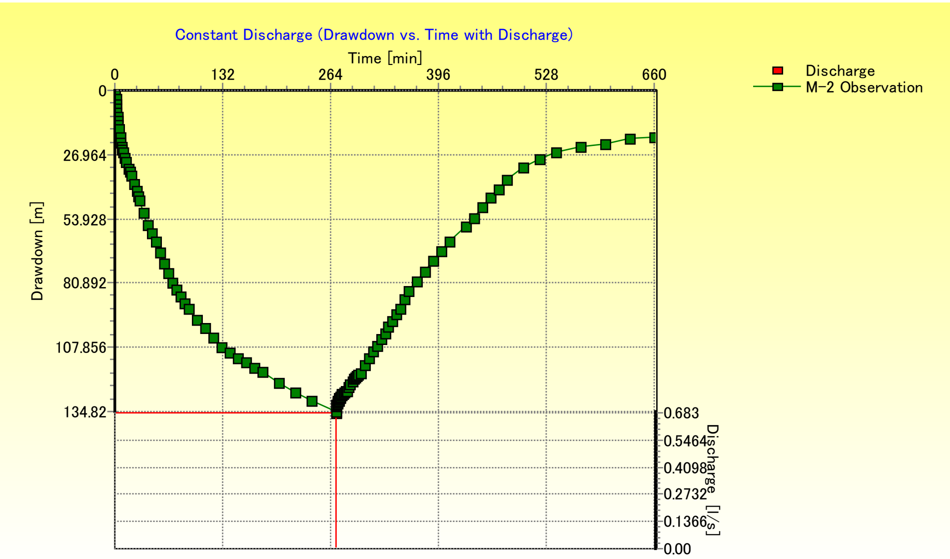
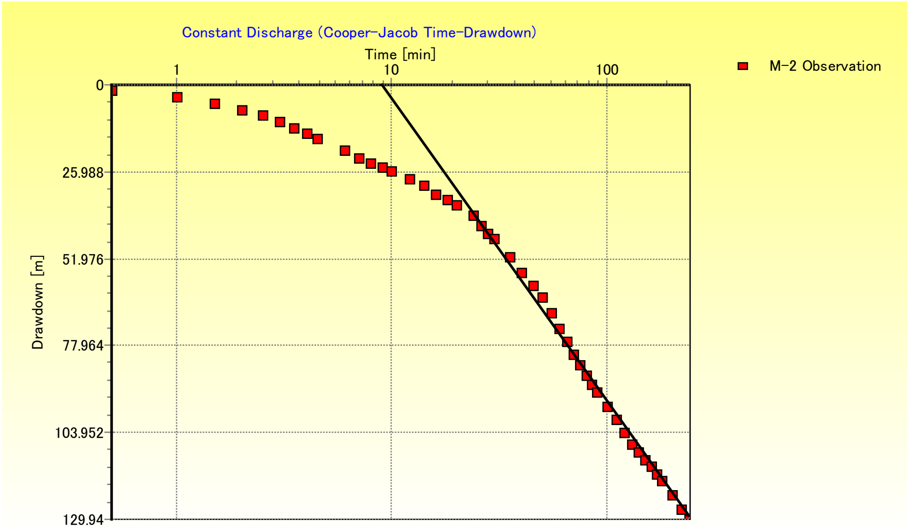
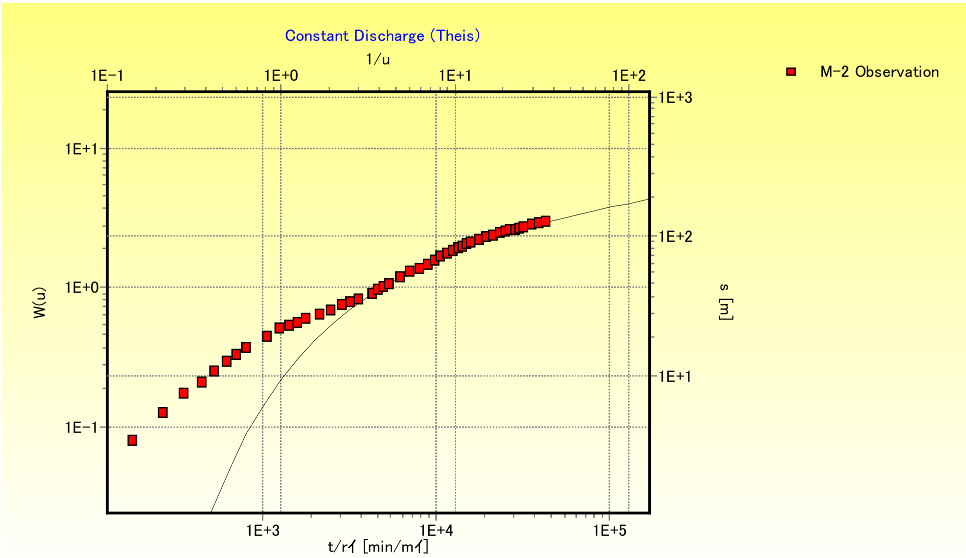


FIGURE 6.25(1) PUMPING TEST OF TEST WELL NO. M-2 (J-7/M7) BODAGAMA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





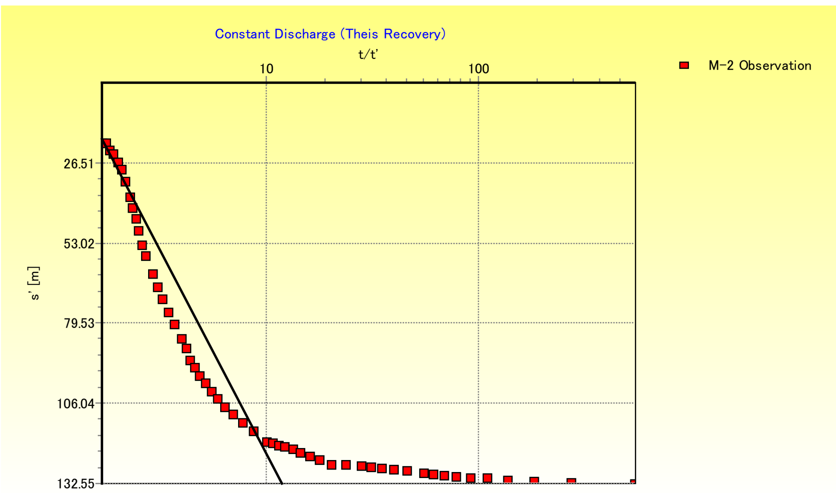
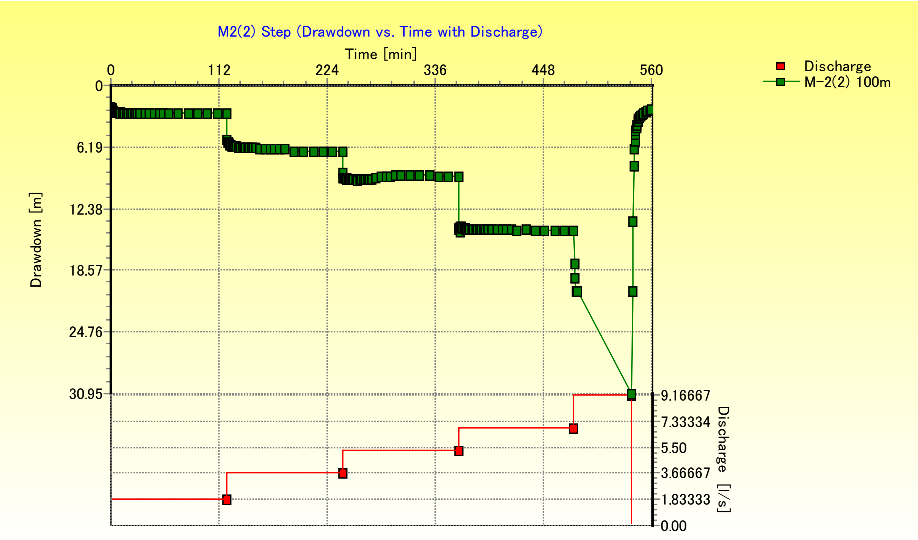
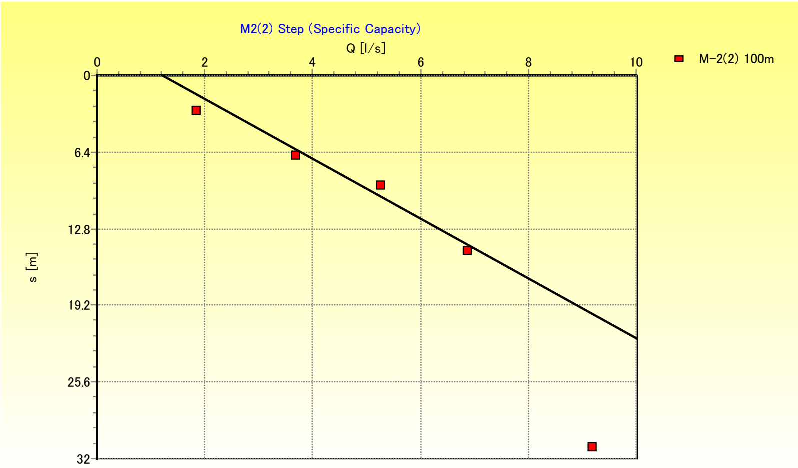


FIGURE 6.25(2) PUMPING TEST OF TEST WELL NO. M-2 (J-7/M7) BODAGAMA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





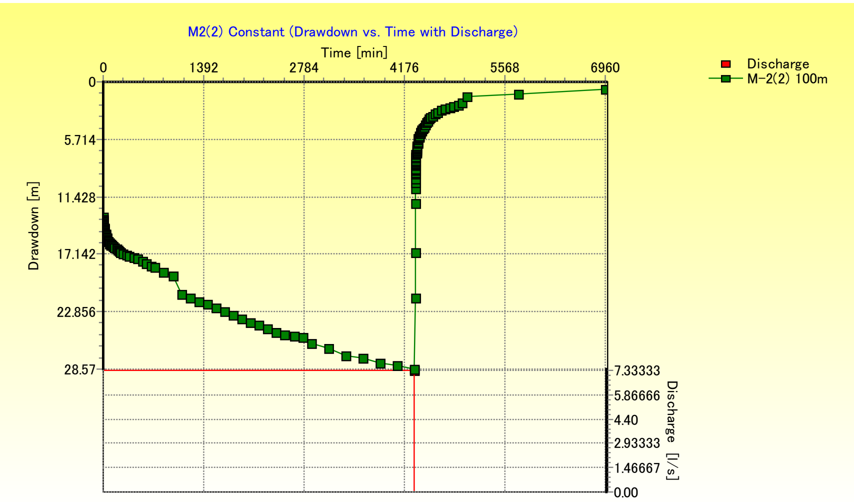
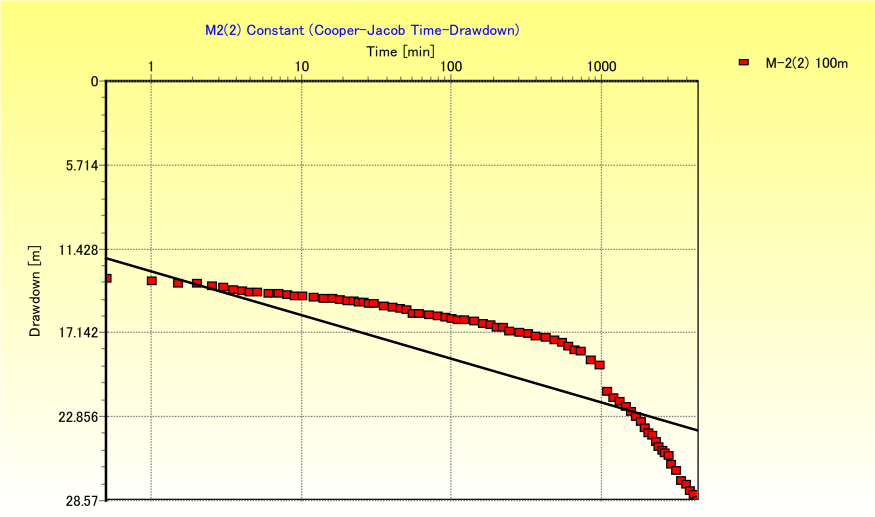
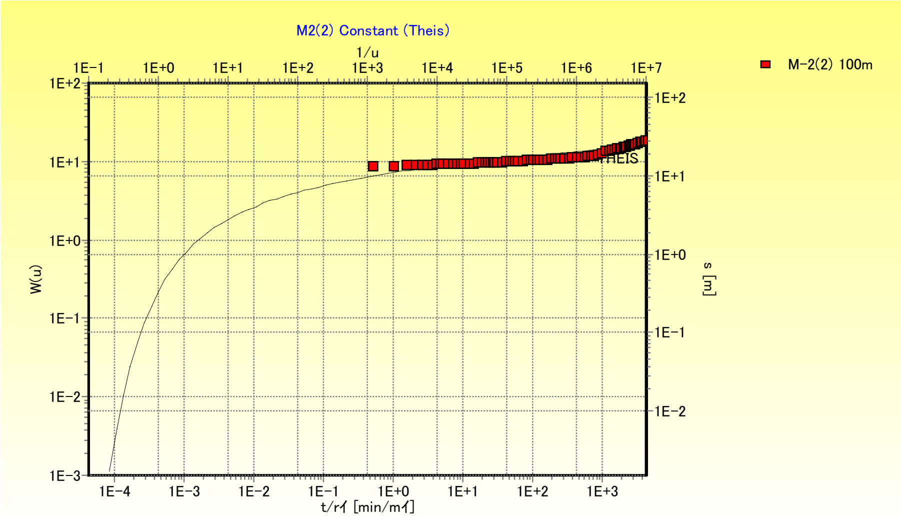


FIGURE 6.26(1) PUMPING TEST OF TEST WELL NO. M-2 (2) BODAGAMA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





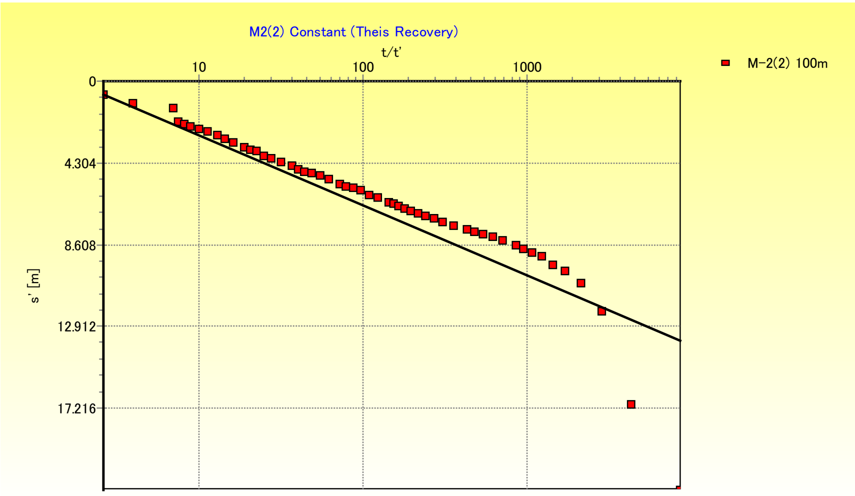
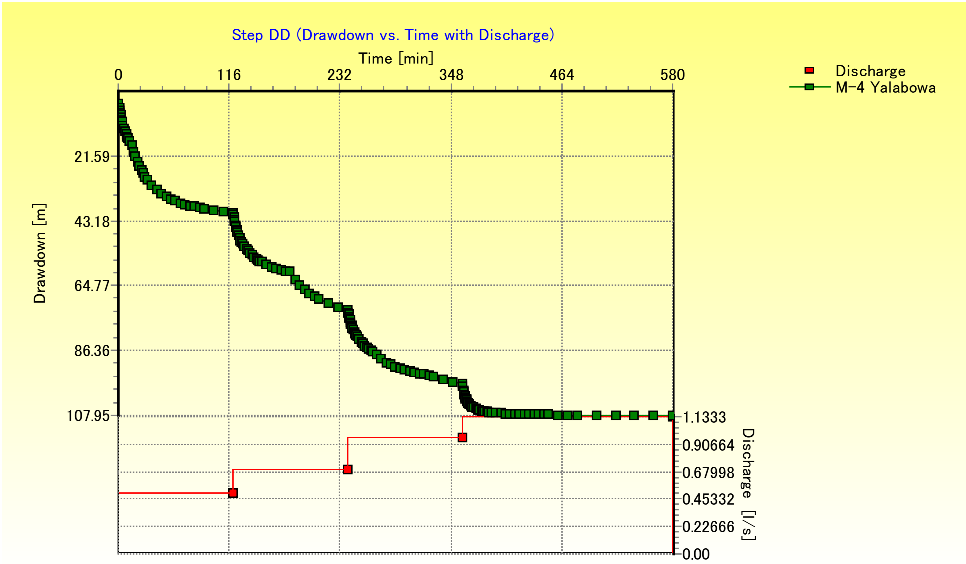
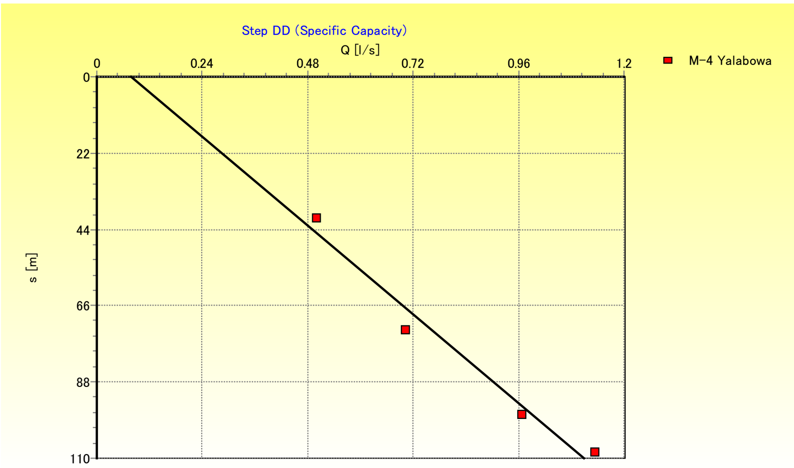


FIGURE 6.26(2) PUMPING TEST OF TEST WELL NO. M-2 (2) BODAGAMA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





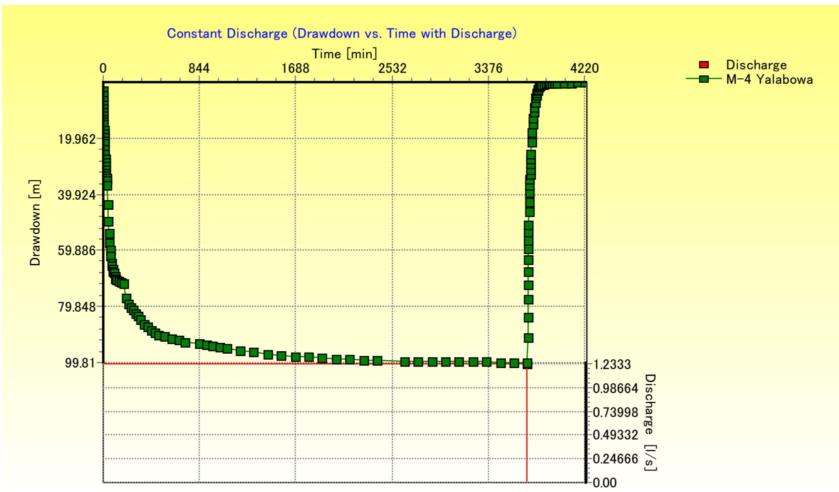
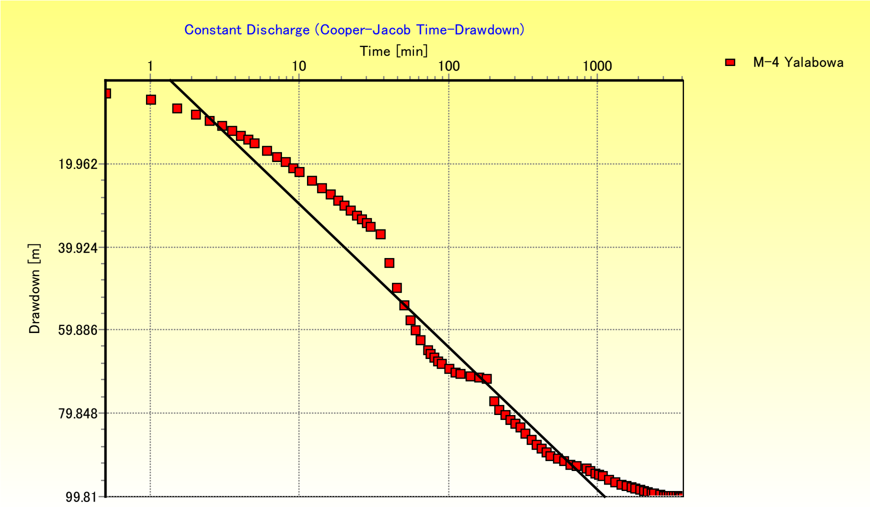
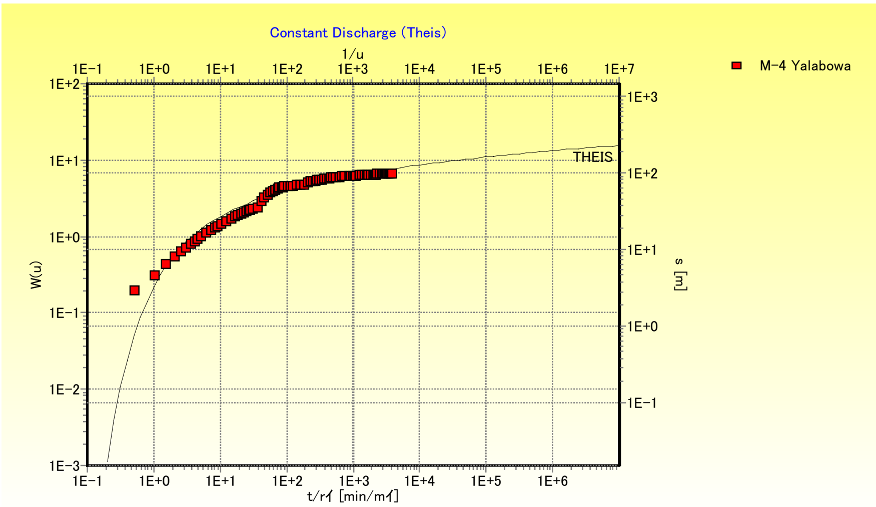


FIGURE 6.27(1) PUMPING TEST OF TEST WELL NO. M-4 (J-8/M5) YALABOWA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





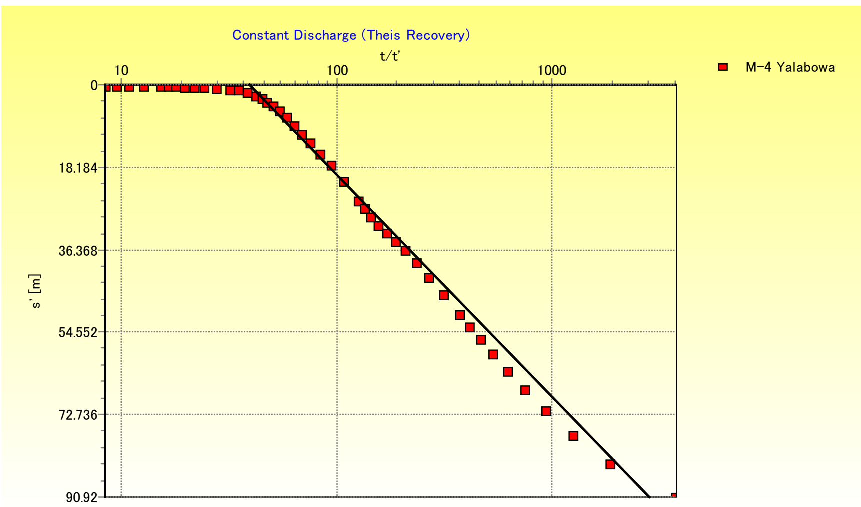
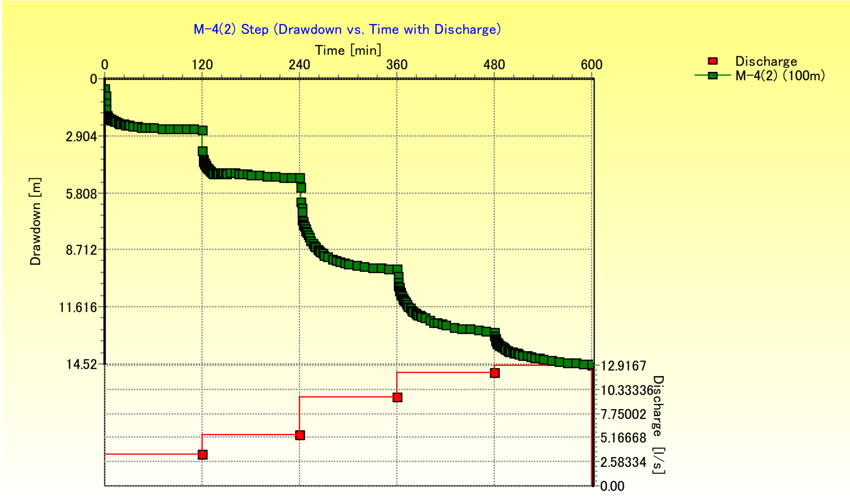
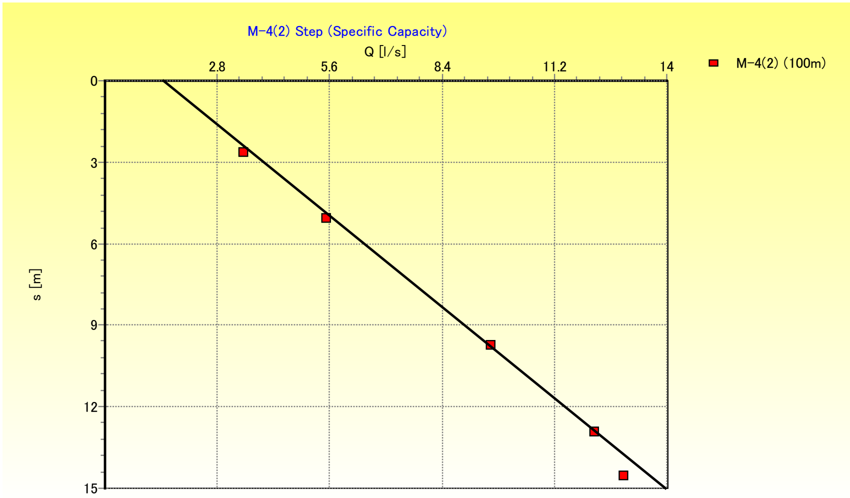


FIGURE 6.27(2) PUMPING TEST OF TEST WELL NO. M-4 (J-8/M5) YALABOWA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





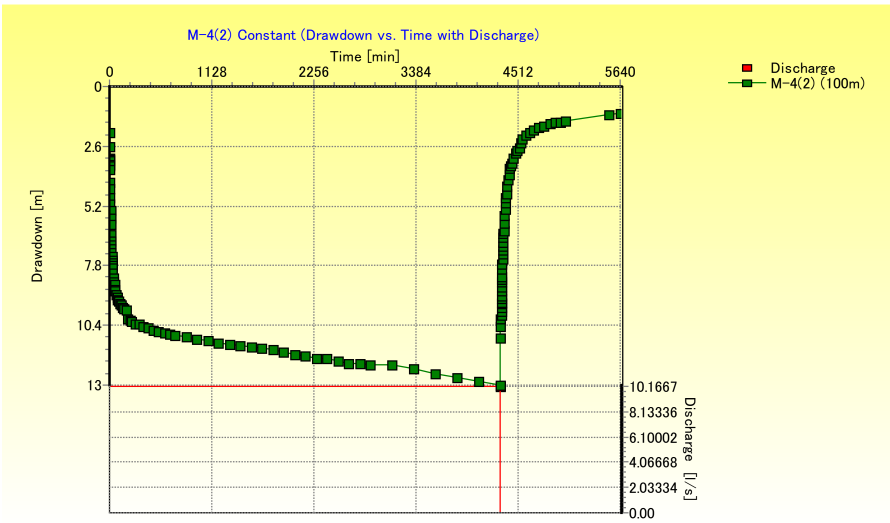
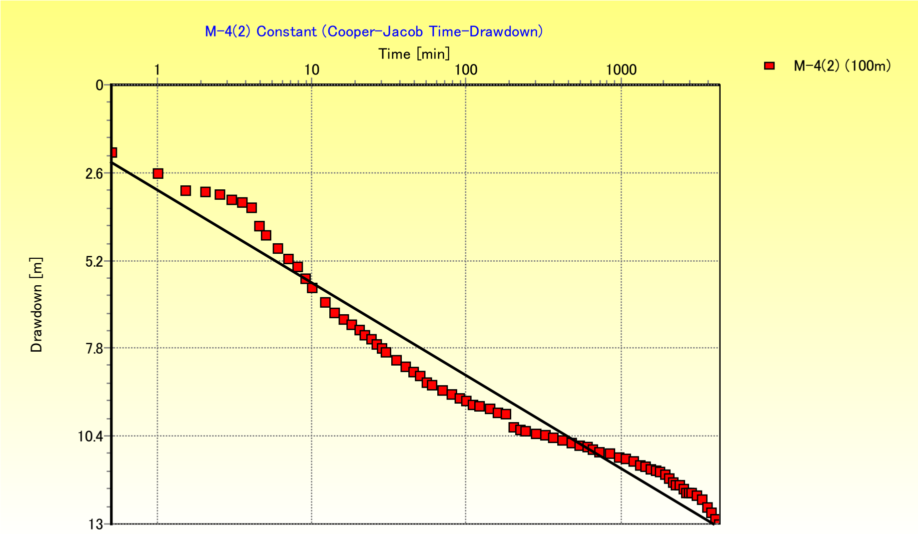
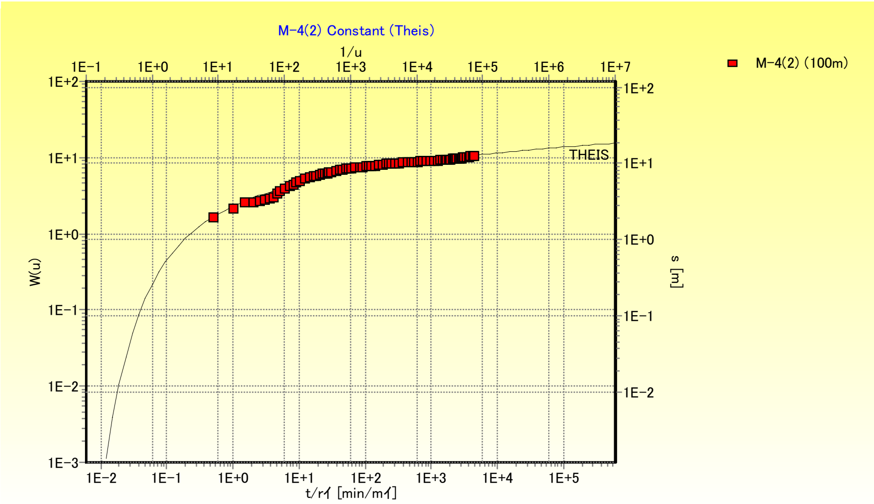


FIGURE 6.28(1) PUMPING TEST OF TEST WELL NO. M-4 (2) YALABOWA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT **JICA**





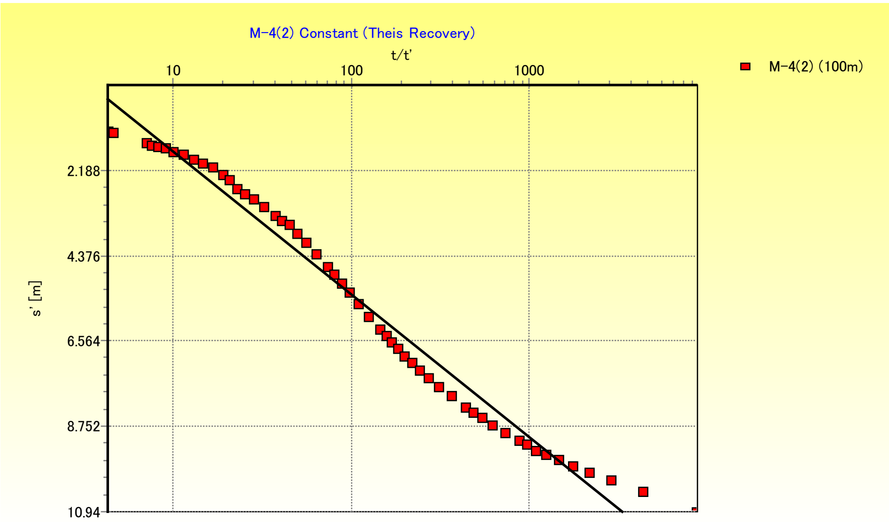
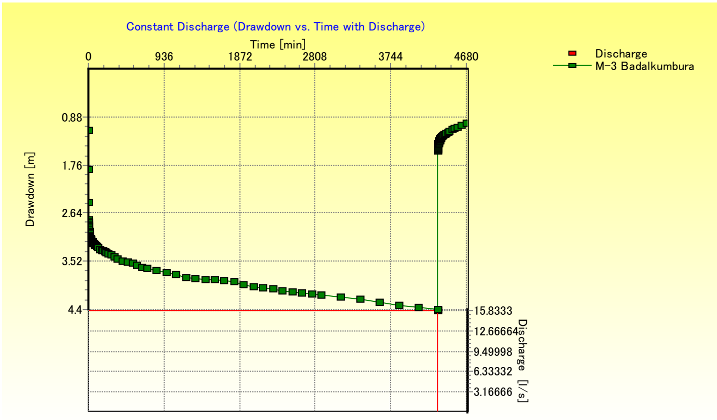
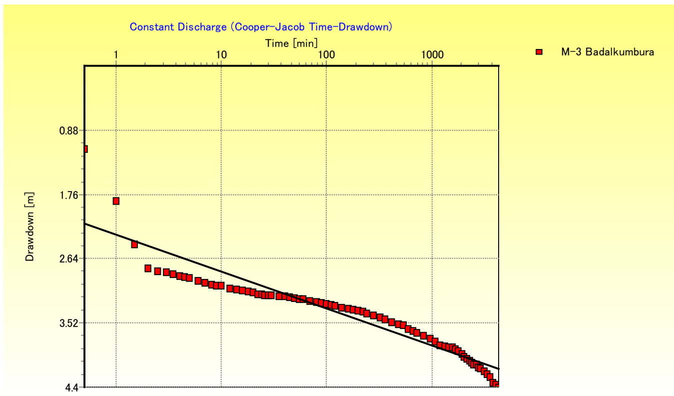


FIGURE 6.28(2) PUMPING TEST OF TEST WELL NO. M-4 (2) YALABOWA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**





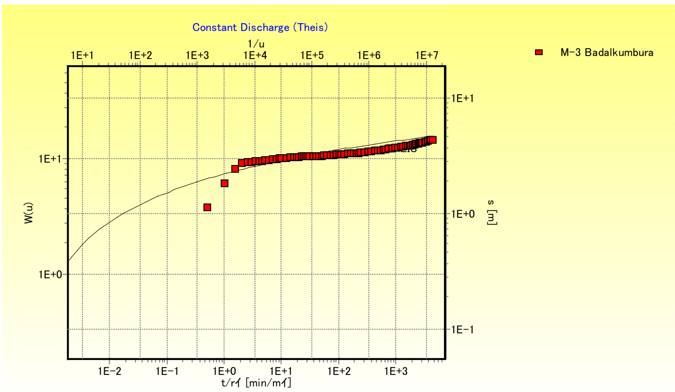


FIGURE 6.29 PUMPING TEST OF TEST WELL NO. M-3 (J-9/M6) BADALKUMBRA

THE STUDY ON COMPREHENSIVE GROUNDWATER RESOURCES DEVELOPMENT | **JICA**

Table 6.4 Results of Test Well Pumping Test

Well	Location	Well Depth (m)	Screen Length (m)	Step No. / Constant	Pumping rate Q (l/min.)	Duration (min)	Drawdown s (m)	Specific Capacity Q/s (l/min/m)	Jacob time-drawdown T (m3/day/m)	Theis type curve T (m3/day/m)	Recovery T (m3/day/m)
H-1	Siyambalagaswila	200.4	20	Constant*	(18)	(27)	(23.96)	(0.75)	0.18	0.16	0.08
									Average = 0.14		
		212	(207.7)	Air Lift	4.2	185	22.15	0.19	0.43	0.33	0.73
H-2	Talunna	194	16	1st	129	120	2.99	43.1	27.80	26.04	22.04
				2nd	200	120	6.39	31.3			
				3rd	300	120	11.60	25.9			
				4th	404	120	20.53	19.7			
				5th	616	120	50.79	12.1			
				Constant	415	5760	27.05	15.34	Average = 25.29		
			(188.9)	Air Lift	400	195	15.95	25.08	30.60	26.60	44.20
H-3	Wediwewa	200	20	Constant*	(30)	(45)	(46.43)	(0.65)	0.18	0.18	0.17
									Average = 0.18		
			(191.1)	Air Lift	18	185	67.45	0.27	-	-	-
H-4	Keliyapura	200	32	Constant*	(6)	(145)	(29.43)	(0.21)	0.05	0.03	0.35
									Average = 0.14		
H-5	Mattala	200	32	1st	31	120	26.76	1.2	1.14	0.98	0.44
				2nd	45	120	48.51	0.9			
				3rd	60	120	66.83	0.9			
				4th	69	110	89.81	0.8			
				Constant	50	4320	69.88	0.72	Average = 0.85		
		92.4	(84.2)	Air Lift	220	125	36 ?	6.0 ?	-	-	3.08
		200	(192.2)	Air Lift	340	185	59 ?	5.7 ?	4.01	3.24	5.78
H-5(2)		52.5	(45.7)	1st	32	120	1.04	31.2	7.38	7.87	13.10
				2nd	81	120	4.43	18.4			
				3rd	132	120	11.20	11.8			
				4th	179	120	23.09	7.8			
				5th*	208	8	32.32	6.4			
				Constant	106	3000	15.18	6.98	Average = 9.45		
H-6	Tammennawewa	102	20	1st	65	120	3.36	19.3	37.60	23.40	34.80
				2nd	103	120	5.72	18.0			
				3rd	200	120	14.04	14.2			
				4th	300	120	23.50	12.8			
				5th	434	120	33.38	13.0			
				Constant	432	4320	30.91	13.98	Average = 31.93		
		110	(104.9)	Air Lift	240	215	27.04	8.88	123	42	179
M-1	Sevanagala	200	48	1st	15	120	29.75	0.5	0.069	0.058	0.056
				2nd	25	120	72.73	0.3			
				3rd	36	120	119.83	0.3			
				Constant*	31	360	134.45	0.23	Average = 0.061		
		92.5	(81.4)	Air Lift	350	125	75 ?	4.6 ?	-	-	3.01
		201	(189.4)	Air Lift	550	240	29.57	18.60	17.80	8.94	8.38
M-1(2)		40.8	(35.0)	1st	60	120	3.84	15.6	1.19	0.85	1.25
				2nd	80	120	13.45	5.9			
				3rd	110	120	24.74	4.4			
				Constant	85	1440	27.87	3.05	Average = 1.10		
M-2	Bodagama	200	32	1st	15	120	38.13	0.4	0.12	0.11	0.08
				2nd	28	120	80.68	0.3			
				3rd	40	80	116.69	0.3	Average = 0.10		
				Constant*	41	240	130.94	0.31			
		62.2	(57.3)	Air Lift	360	180	10.47	34.38	21.0	11.1	27.9
		200	(195.3)	Air Lift	510	245	11.31	45.09	42.6	29.2	33.1
M-2(2)		100		1st	110	120	2.84	38.7	67.4	57.6	34.6
				2nd	220	120	6.64	33.2			
				3rd	315	120	9.10	34.6	Average = 53.2		
				4th	412	120	14.56	28.3	(8.98)	(9.85)	(8.54)
				5th	550	60	30.95	17.8			
				Constant	440	4320	28.57	15.40	Average = (9.12)**		
M-3	Badalkumbura	88.3	20	Constant	950	4320	4.40	215.91	495	369	1360
									Average = 741		
		84	(72.9)	Air Lift	850	155	13.71	62.0	797	697	2160
M-4	Yalabowa	195	36	1st	30	120	40.77	0.7	0.61	0.72	0.40
				2nd	42	120	72.92	0.6			
				3rd	58	120	97.27	0.6			
				4th	68	220	107.95	0.6			
				Constant	73	3720	99.81	0.73	Average = 0.58		
		74.2	(56.8)	Air Lift	550	185	16.25	33.85	56.0	53.1	44.8
		110	(92.8)	Air Lift	550	150	14.38	38.25	34.6	65.0	17.1
M-4(2)		100		1st	205	120	2.59	79.2	58.7	58.5	43.9
				2nd	330	120	5.05	65.3			
				3rd	575	120	9.71	59.2			
				4th	730	120	12.89	56.6			
				5th	775	120	14.52	53.4			
				Constant	610	4320	13.00	46.92	Average = 53.7		

*); Yield was not enough to continue long duration pumping. **); After the pumping duration time of 1000min.

(figures in blankets); Open hole length

6.4.4 Groundwater Quality Measurement

At the pumping test, groundwater quality measurement for the 12 test wells was carried out. On site measurements of water quality and the laboratory chemical analysis were carried out. Measured and analyzed items are given in the following tables.

Measured and Analysis Items

	Item
On-Site Measurement	Appearance, Water level, Temperature, Electric Conductivity (EC), pH, TDS, Dissolved Oxygen, Coliform Bacteria, Other Bacteria
Laboratory Analysis	Appearance, Temperature, Color, Odor, Taste, pH value, Electric Conductivity(EC), Chloride(Cl^-), TDS, Total Alkalinity(as $CaCO_3$), Total Hardness(as $CaCO_3$), Nitrate(as N), Total Iron(as T-Fe), Sodium(as Na^+), Potassium(as K^+), Calcium(as Ca^{2+}), Magnesium(Mg^{2+}), Sulphate(as SO_4^{2-}), Fluoride(F^-), Bicarbonate(as HCO_3^-), Arsenic (As), Lead (Pb), Cadmium (Cd), Chromium (Cr)

The results of the analysis are shown in *Table 6.5*. Based on the above results of groundwater analysis, the characteristics of the test wells will be described in *Supporting 7*.

Table 6.5 Results of Groundwater Quality Measurement of Test Wells

Place Collected	Siyambalagas -wila North	Talunna	Wediwewa	Keliyapura	Pahala Mattala	Tammennawewa (about 100 m)	Sevanagala	Bodagama	Badalkumbra	Yalabowa	Bodagama (about 100 m) Additional well	Yalabowa (about 100 m) Additional well
Location No.	H-1(J-6/H7)	H-2(J-2/H3)	H-3(J-3/H4)	H-4(J-1/H1)	H-5(J-5/H6)	H-6(J-4/H5)	M-1(J-10/M7)	M-2(J-7/M2)	M-3(J-9/M6)	M-4(J-8/M5)	M-2(J-7/M2)	M-4(J-8/M5)
Laboratory Analysis												
Date of Collection	16-Mar-02	10-Mar-02	22-Feb-02	23-Feb-02	14-Mar-02	06-Feb-02	02-Jul-02	02-Jul-02	10-Aug-02	19-Jul-02	21-Oct-02	26-Sep-02
Appearance	turbid	turbid	Clear	turbid	turbid	turbid	turbid	turbid	Clear	Clear	Clear	Clear
Temperature (^oC)	33.5	32.7	33.2	32.0	33.9	32.6	30.1	31.0	-	31.0	26.5	28.2
Colour (Hazen Units)	5	5	10	10	5	5	5	5	20	5	Colourless	Colourless
Odour	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Unobjectionable	None	None	-	-
Taste	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	None	Salty	Good	Normal	-	-
pH Value	7.9	6.8	12.1	12.1	8.7	7.8	10.4	7.9	7.4	7.6	6.8	6.9
Electrical Conductivity (mS/cm)	9.1	2.8	9.4	5.9	1.2	4.4	2.1	6.0	0.4	0.7	2.43	0.73
Chlorides (Cl^- mg/l)	2,800	780	520	100	430	1,200	96	860	7	30	244	25
Total Dissolved Solids (mg/l)	4,970	1,380	5,130	3,150	1,060	2,270	1,060	3,140	194	835	1,603	515
Total Alkalinity as CaCO3 (mg/l)	150	50	1,900	1,400	325	200	230	355	255	324	995	476
Total Hardness as CaCO3 (mg/l)	4,060	1,200	980	1,200	500	1,700	14	1,220	310	360	361	314
Nitrates as N (mg/l)	<0.01	0.40	0.07	0.50	<0.01	0.02	<0.05	<0.05	0.30	ND	-	-
Total Iron as Fe (mg/l)	0.6	0.1	0.1	1.4	0.6	0.4	0.6	0.4	1.2	0.5	0.3	0.3
Sodium as Na^+ (mg/l)	750	208	900	130	450	500	290	590	12	31	-	-
Potassium as K^+ (mg/l)	130	70	600	90	50	60	36	60	5	8	-	-
Calcium as $Ca2^+$ (mg/l)	724	328	164	400	96	360	4.8	115	56	90	51.4	57.1
Magnesium as $Mg2^+$ (mg/l)	1,082	92	138	48	63	194	0.5	270	40	33	56.6	41.6
Sulphate as SO_4^{2-} (mg/l)	880	292	660	350	300	735	232	430	4	56	78.3	95.2
Fluoride as F (mg/l)	0.7	0.3	0.6	0.6	0.9	0.6	1.3	0.9	0.6	0.6	1.7	0.5
Bicarbonate (HCO_3^- mg/l)	150	50	160	120	325	200	10	354	255	248	-	-
Lead as Pb (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.062	0.027	<0.01	<0.01	<0.01	<0.01
Cadmium as Cd (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Arsenic as As (mg/l)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.001	<0.001	<0.001	<0.001	-	-
Chromium as Cr (mg/l)	<0.005	<0.005	0.100	0.080	<0.005	<0.005	0.027	0.010	<0.005	<0.005	<0.005	<0.005

ND: not detected
- : not analysis

6.5 WATER LEVEL RECORDER

6.5.1 THE RECORDERS, INSTALLED

The float type water level recorders were installed in 10 test wells. Locations of these wells are shown in *Figure 6.1*. The water level recorder mainly consists of plug, cable, clamp, data logger, ball chain, floater, and weight. The data logger connects to plug by clamp and cable (See, *Figure 6.30*).

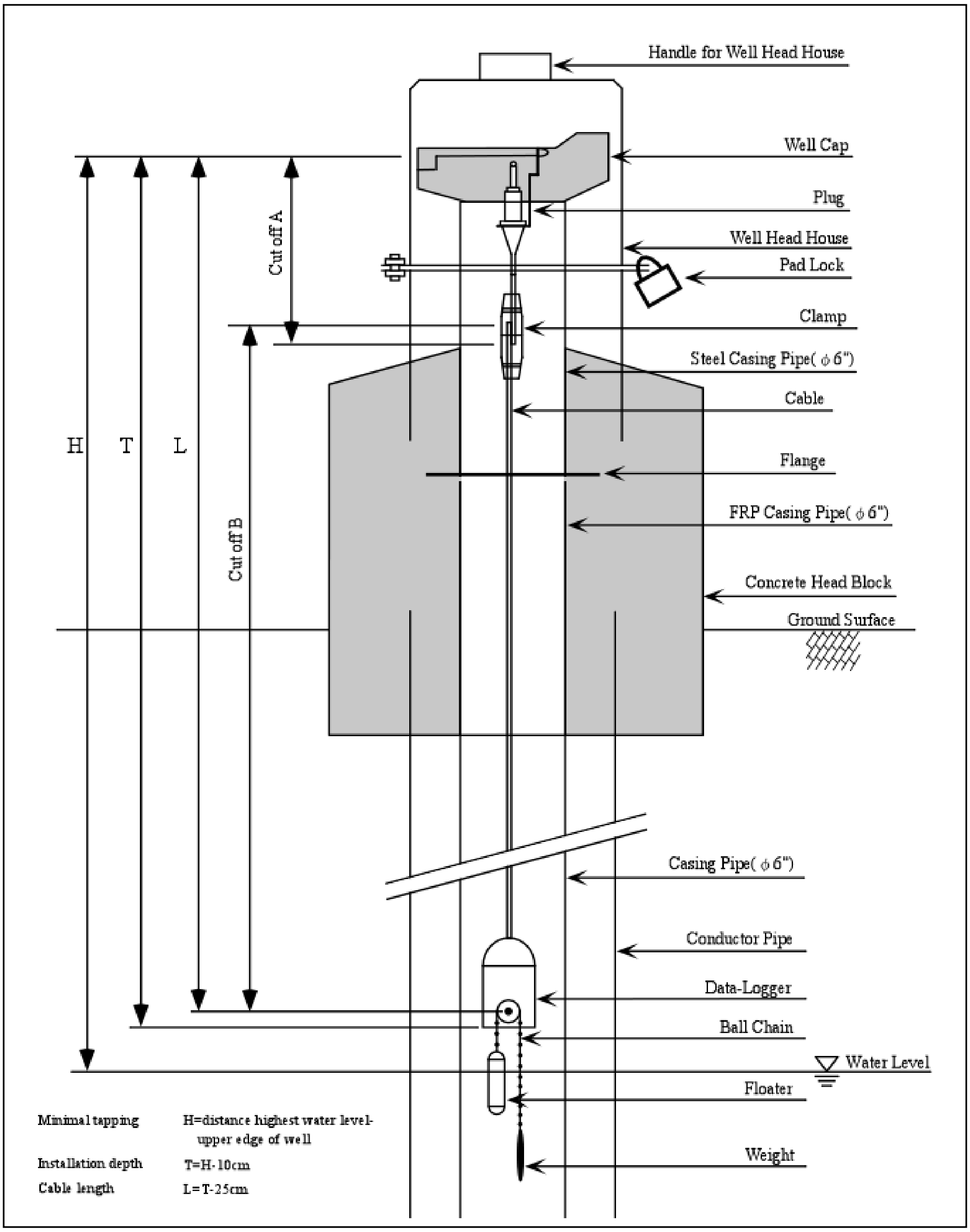


Figure 6.30 Well Head Facilities and Water Level Recorder

All the information in connection with water level of the installed wells is summarized in *Table 6.6*. In the columns of “Water Level Recorder”, the information of water level recorder installed is described. “Serial Number” shows the identification of each water level recorder. “Date Installed” corresponds to the beginning date of water level monitoring. “Cut-off A” and “Cut-off B” shows the length of cable from plug to clamp, and from clamp to data logger, respectively.

Table 6.6 Data Related to Water Level Recorder for Test Wells

Locality Information						Water Level Information					Water Level Recorder			
Location		Well Number	Coordination											
No.	GND Name	JICA Ref. No.	Latitude (d:m:s)	Longitude (d:m:s)	Elevation (masl)	Rest Water Level (mbsu)	Stick up (m)	Rest Water Level (mbgl)	Rest Water Level (masl)	Distance logger to RWL (m)	Serial Number	Date installed	*Cut-off A (m)	*Cut-off B (m)
1	Siyambalagaswila North	H-1 (J-6/H7)	06º10’25”	81º01’10”	16.8	11.93	0.660	11.27	5.53	7.73	6869	14-Mar-02	0.11	4.11
2	Talunna	H-2 (J-2/H3)	06º07’03”	80º49’57”	14.45	5.31	0.960	4.35	10.10	4.31	6826	22-Mar-02	0.91	0.83
3	Wediwewa	H-3 (J-3/H4)	06º13’42”	81º02’33”	29.57	16.18	0.720	15.46	14.11	5.18	6633	14-Mar-02	0.21	10.81
4	Keliyapura	H-4 (J-1/H1)	06º12’12”	81º07’44”	13.36	5.90	0.740	5.16	8.20	5.00	6621	22-Mar-02	0.21	0.71
5	Pahala Mattala	H-5 (J-5/H6)	06º18’40”	81º06’32”	43.58	10.43	0.700	9.73	33.85	7.43	6634	22-Mar-02	0.21	2.81
6	Tammennawewa	H-6 (J-4/H5)	06º16’42”	81º09’10”	34.12	9.40	0.710	8.69	25.43	6.40	6873	15-May-02	0.19	2.83
7	Sevanagala	M-1 (J-10/M7)	06º21’58”	80º55’43”	62.95	8.18	0.930	7.25	55.70	5.18	905	13-Jul-02	0.21	2.81
8	Bodagama	M-2 (J-7/M2)	06º25’50”	81º06’25”	84.66	8.61	0.930	7.68	76.98	5.61	680	11-Jul-02	0.21	2.81
9	Badalkumbura	M-3 (J-9/M6)	06º53’53”	81º14’33”	357.65	12.20	0.930	11.27	346.38	in progress	in progress	28-Aug-02	in progress	in progress
10	Yalabowa	M-4 (J-8/M5)	06º42’53”	81º05’58”	184.35	12.70	0.930	11.77	172.58	in progress	in progress	28-Aug-02	in progress	in progress

Note; “Cut off A” means length from top plug to connection clamp
“Cut off B” means length from connection clamp to data Logger

6.5.2 Specification of Water Level Recorder

The main features of specification are summarized as follows;

- memory : 32KByte for at least 32x484 = 15,488 measuring values (without time marks)
- communication : via M-Bus with communication interface at RS232 with 2400Baud
  : increase by read data up to 4800 Baud values
- clock : real time clock ±15ppm
- operating temperature : -20 to +70℃ (exception: glaciation)
- power supply conditions : average temperature <25℃
  : max. pluses 500/day
  : measuring cycle times >=15min
  : interface operation max. 5min/month
- operating life : 15 years
- expected runtime : 20 years

As described above, manufacturer guarantees 15 years for battery life, accordingly, data-logger must be sent to the manufacturer to change the battery 15 years after.

The memory capacity of the data logger is only 15,488. Time interval for data recording was set every 1 hour for monitoring purpose. If data capturing is carried out once a year, number of data becomes 8,760. The data logger can be left about 1.5 years.

6.5.3 TECHNICAL TRANSFER ON OPERATION AND MAINTENANCE OF THE RECORDER

Technical transfer related to the operation and maintenance of the recorder was carried out in July 2002, to the WRB counterpart team. The items transferred and confirmed are summarized as follows.

i) Reading the actual value of the water level and total memorized number in the data logger

ii) Checking the function of the data logger by laptop computer

iii) Data capturing by the laptop computer

6.5.4 RECOMMENDATION ON OPERATION AND MAINTENANCE

As mentioned above, maximum number of the data can be memorized is only 15,488. If the number of data exceeds the capacity, new data will be overwritten automatically. In order to avoid such data missing, it is recommended that data capturing should be executed at least once a year. The well head facility consists of not only the data-logger, but also a lot of device was installed to maintain proper function of the data-logger. Inspection of these devices also required. From this point of view, it is considered that visit to the wells for data capturing at least once a year is appropriate.

The washer was fixed between nut and fixing device in the cap, to prevent fall the recorder down. It must be handled with care, however, on the occasion of water sampling or pumping, the recorder must be kept hold properly.

When the settings of data-logger are going to be changed, such as interval time, memory of the data-logger will be initialised automatically. To avoid such data missing in the data-logger, memorized data must be saved before change the settings.

SUPPORTING 7 HYDROGEOLOGY

7.1 GENERAL

7.1.1 REVIEW OF PREVIOUS STUDY

There are large numbers of the tube wells exist in the study area. Most of them are drilled as rural water supply with hand pump by WRB and NWSDB. Consequently, nowadays, hydrogeology attracts a great deal of attention. Its importance has been increased since the beginning of well drilling on a large scale in 1978 (Karunaratne, 1994).

Many studies related to the groundwater resources have been carried out in the two districts, mainly by WRB and NWSDB. In the course of 1st study in Sri Lanka, such study reports have been collected and reviewed by the Study Team. The followings are the studies reviewed and examined in the course of the Study. The result and findings of this review will be compiled to the further analysis and evaluation of the Study.

(1) Monaragala

The major previous studies related to the groundwater in Monaragala are as follows.

1) HYDROGEOLOGICAL Study on Groundwater Condition in Monaragala District (1982), U. G. M. Ariyaratne et. al. (NWSDB) and K. V. Raghava (WHO)

Hydeogeological Investigation, by drilling of 94 wells in Madulla, 110 wells in Siyambalanduwa, 123 wells in Thanamalwila.

Summary of the hydrogeological analysis such as groundwater quality in relation to rock types and depth versus yield are presented.

2) ORIGIN AND RECHARGE OF GROUNDWATER THROUGH ISOTOPE STUDIES MADULLA DIVISION, MONARAGALA DISTRICT (1984), J.K. DHARAMASIRI (UNIVERSITY OF COLOMBO) AND U.G.M. ARIYARATNE (NWSDB) AND K. V. RAGHAVA (WHO)

Geo-chemical investigation was carried out by stable and tritium isotope analysis to understand the recharge mechanism of the groundwater in Madulla. Groundwater recharge of the area is estimated at 18% of the precipitation.

3) GROUNDWATER RESOURCES OF A METAMORPHIC TERRAIN MONARAGALA DISTRICT SRI LANKA, 9TH INTERNATIONAL ADVANCED COURSE ON WATER RESOURCES MANAGEMENT CASE STUDY, WATER RESOURCES RESEARCH DOCUMENTATION CENTRE (WARREDOC) (1992) WIJERATNA E.M.B., ITALIAN UNIVERSITY FOR FOREIGNERS PERUGIA, ITALY

The objectives of the case study were to understand the groundwater flow and environmental impacts of groundwater pollution by the groundwater chemistry evaluation using available existing data.

The distribution of electrical conductivity, chlorine, fluoride, total hardness, TDS and sulphate are given. The fluctuation of groundwater level of 36 tube wells in Kotawaheramankada and Hambegamuwa areas (south-western part of the district) was monitored in every month for one year. As a result, it was confirmed that the fluctuation of groundwater level corresponds the rainfall.

4) MONARAGALA IRRIGATION AND COMMUNITY DEVELOPMENT PROJECT (MICDP) DRINKING WATER SURVEY (1997), EUROPEAN COMMISSION AND GOVERNMENT OF SRI LANKA, MINISTRY OF PLAN IMPLEMENTATION & PARLIAMENTARY AFFAIRES, CONSULTANTS WATER RESOURCES BOARD.

The hydrogeological study, to identify the areas with high groundwater potential for drinking and domestic purposes, and to confirm a potentiality of groundwater as drinking water, in the six areas of Kumbukkana, Yundaganawa, Handapanagala, Dambewewa, Dehiattawela, and Ethimole.

Two different aquifer systems, i.e., a shallow overburden and a deep fractured hard rock were identified by the study. The shallow overburden aquifer system is defined as a subsurface water bearing formations that are capable to provide enough quantity of water to shallow dug wells. This system exists within the uppermost surface soil cover and lower highly weathered rock formation. This aquifer system consists of silty sand, sandy clay, insitu soil and alluvium. Most of dug wells are generally excavated through the soil zone, up to the weathered rock formation underneath. Among the shallow overburden aquifer system, high potential aquifer is identified as alluvium deposit, while low potential aquifer is identified as high relief area. Most of the low potential aquifers in high relief area appear to dry up during long droughts. The deep fractured aquifer system is defined as well fractured and fissured Granites and Gneisses underlined by the Precambrian Metamorphic hard rock. Aero photo shows well-developed lineaments and well developed joint patterns. These evidences suggest that sub surface geological formation well fractured and fissured. Transmissivity and storability of this formation could be high. This aquifer is suitable for the deep-drilled tube well. More than 250 of water samples were collected from existing wells in the project area, and analysed at the laboratory of WRB. The area of high concentrated of fluoride is identified. These are Ethimole, Kotiyagala, Handapanagala and Dambewewa.

5) ADB Assisted Third Water Supply and Sanitation (Sector) Project Moneragala, Yudaganawa Area - Well Level Survey. (2000) Buttala DS Division

Small-scale study report showing the results of the monitoring of the water levels of a river (Kuda Oya), irrigation channels and wells. Observation was carried out from February to May. As the result, no fluctuation of the water level of the wells and a possibility of the groundwater recharge from irrigation channels was reported.

6) Groundwater Potential in Moneragala District, ADB assisted Third Water Supply and Sanitation, ADB Loan No.1575 SRI(SF), Draft Report Part1 Deep Ground Water. (2000) A.S.P Manamoeri Direct Water Supply & Sanitation (Sector) Project, NWSDB, Monaragala

The study focused on top of a basement rock aquifer. There are 652 tube wells in the district. Among these wells 535 wells are in use. Using the data of the existing wells in district, evaluation on both water quality and quantity has been made.

High concentration of fluorides at the south west of district (Wellawaya and Thanamalwila) and the east of district (Siayamblalanduwa and Katharagama) has been clearly identified. These areas belong to Vijayan complex and associated with mica and appetite containing rocks (i.e., biotitic hornblende gneiss, migmatitic gneiss and pegmatite). The fluoride contamination was considered as natural pollution. A total of 102 wells have been distinguished as a high yield (more than 100 l/min) well. Such well abounds in Thanamalwila (58 wells) and Buttala (38 wells). Macro water balance was estimated by Kiring Oya catchments, as 1647 million m3 of rainfall volume, 329 million m3 of runoff volume, 1,294 million m3 of evapotranspiration volume and 23.4 million m3 of groundwater recharge.

Besides the groundwater studies, related to water resources, the following previous studies have been reviewed.

7) Surface Water Potential for Drinking Water in Monaragala District, Preliminary Assessment (1999), District Office, RWS Monaragala

Summary of the water resources, existing water supply schemes, demand forecast, water budged in the Monaragala are described.

8) Wellawaya Water Supply Scheme Pre-Feasibility Report Third Water Supply and Sanitation, ADB Loan No.1575 SRI (SF) (2001) NWSDB

The study objective is to investigate a preliminary feasibility of sustainable water supply to

Wellawaya town and it's suburban (17 GNDs).

(2) Hambantota

The major previous studies related to the groundwater in Hambantota are as follows.

1) Hydrogeological Investigation for the Groundwater in Walawe, Malala and Kiridioya Drainage Basins (19??), WRB

Hydrogeological investigation carried out by WRB. The investigation includes geological and geophysical survey and water quality analysis.

2) Hambantota Integrated Rural Development Project Groundwater Investigation Programme, Progress Report (1980), WRB

Comprehensive groundwater investigation, including geological and geophysical survey, well inventory survey and test well drilling and pumping test. Only the Progress Report was obtained.

3) Groundwater Development for Rural Community Water Supplies in Hambantota and Anuradhapura District, Summary Result of Pilot Groundwater Project 1979 – 81 (1984), A.P. Chandraratne et.al. (NWSDB & WHO) 25pp

Hydeogeological Investigation by drilling of 113 wells in Hambantota and Monaragala and 87 wells in Anuradhapura and Puttalam districts.

Summary of the hydrogeological information such as yield, groundwater quality, rock type and depth drilled are described.

4) Groundwater Conditions Along Tissamaharama – Kataragama Section, Hambantota District with Special Reference to Community Water Supply (1984), A.P. Chandraratne et.al.

Hydeogeological Investigation by geophysical soundings (vertical electrical soundings), test well drilling, chemical analysis of the groundwater quality and pumping test. Hydrogeological condition of Tissamaharama – Kataragama are presented.

5) Ground Water Exploration in Hambantota District (1984), K. P. L. Silva (WRB)

The study is a first large scale groundwater investigation program carried out in a hard rock area in Sri Lanka by WRB, as a part of the Hambantota Integrated Rural Development Project financed by Norwegian Agency for International Development (NORAD). The study consists of geological investigation including aero photo analysis, geophysical investigation and evaluation of the information obtained from test wells drilled (153 wells) such as lithology, water quality and yield. It was concluded that the groundwater potential in the district is low; moreover, more than 69% of the whole district is covered by saline groundwater source.

6) A Hydrogeological Assessment of a Coastal Hard Rock Terrain in Sri Lanka (1994), G.R.R. Karunaratne M.Sc Thesis Study, School of Environmental University of East Anglia Norwich

Hydrogeological investigation including groundwater resistivity soundings and hydrochemistry of the groundwater in Weeraketiya, western part of Hambantota.

A productive aquifer unit of the area was defined as "the weathered and fractured zone", which is laid between an uppermost soil zone and a lower fresh hard rock. The aquifer is extremely anisotoropic and heterogeneous. It is consisted with a dual porosity system, i.e., low matrix porosity and high fracture porosity. Transmissivity of the aquifer is very low, ranging from 3 to 30 m3/day/m. The main source for groundwater recharge is limited only to rainfall in period from October to December. Evapotranspiration could not be affected considerably to saturated fracture due to its confining conditions. Regional groundwater flow was observed in north-south direction towards the sea. The results of groundwater chemistry analysis show the recharge area above the elevation of 60m. High concentrations of HCO_3^- and Ca^{2+} are result of solution of aquifer matrix of Marble.

7) Water Resource Planning Preliminary Study, Hambantota District (2000) Project Implementation Unit, ADB assisted Third Water Supply and Sanitation Hambantota District

Overall review of the surface and groundwater resources demand forecast (2025) and water demand.

Outlines of water source river system, reservoirs and existing water supply schemes are described. There are 8,557 tube wells and 20,374 dug wells. Evaluation of groundwater, mainly tube wells are described. The study reported that the major problem in groundwater is unsatisfactory quality of water in 60% of the area where people live, e.g., high iron concentration in the southern coastal belt, high fluoride concentration in the Lunuganwehera and Suriyawewa, and high EC (more than 2,500 mhos/cm) in 60% of the district. Evaluation of surface run off and an annual water balance in the major river basins of Kirama Oya, Urubokka Oya, Kachigala Ara, Walawa Ganga, Karagen Oya, Malala Oya and Kirindi Oya are presented.

7.1.2 Outline of the Study

The Study Team carried out the following work concerning hydrogeological study during the Study in cooperation with WRB counterpart team.

- Collection and analysis of the existing data.
- Hydrogeological field survey.
- Geophysical survey.
- Test well drilling. (including geophysical logging and pumping test)
- Measurement of groundwater levels (periodic measurement of the selected existing wells and continuous recording by the water level recorders installed on the newly drilled test wells).
- Analysis of the pumping test data of the selected existing wells and the test wells.
- Water quality analysis of the test wells and the selected wells.

Based on the result of the above survey, the attached hydrogeological map, was prepared for evaluation of groundwater potential in the area. This *Supporting Report* describes the hydrogeological condition in the Study area.

7.2 Aquifer Categories and Yield

7.2.1 Category of Aquifer

According to Silva (Silva, 1984), the water bearing zone was classified into three types in Hambantota, namely the coastal sand deposits, the weathered zone and the fractured zone. The report on Moneragala Irrigation and Community Development Project (WRB and EC, 1997) classified the aquifer into two types, namely, shallow overburden and fractured hard rock. Since a weathered zone and a fractured zone mentioned in the former cannot be divided clearly and have not been clarified in the database, here the aquifer is described as two types. One is the shallow aquifer occurring in the subsurface deposits overlying the basement rock in the area. Another one is the aquifer occurring in the fractured or weathered zone in the basement rock. In addition, the aquifer in the basement rock was categorized into three categories as described later. The shallow aquifer is extracted mainly by dug wells constructed in the subsurface deposits. The fractured/weathered aquifer has been exploited by tube wells penetrating the basement rocks.

(1) Shallow Aquifer in the Subsurface Deposits

In the inland area, the aquifer has been generally exploited with dug wells for domestic use although no organization has the overall information or data of them. Almost all houses seem to have their own well in some districts. Additionally there are some communal dug wells for village people. The depth varies from a few meters to about 10 m. The yield or extracting volume has not been recorded. According to the local users of a dug well, the water level fluctuates widely from season to season. During the field reconnaissance in the dry season, some dug wells had only little water at their bottom while the water level reached almost ground level in the wet season. Naturally, usable water amount changes seasonally on a large scale.

In the coastal area where alluvium deposits are thickly distributed, some tube wells have been constructed with a submersible pump to extract water from the aquifer for water supply schemes by NWSDB. Several tube wells about 15 m deep have extracted by 300 to 700 liters/minute from a sand layer along the Kirama Oya in Tangalla. The Kirama Oya was almost dry in August ‘02 when the Study Team visited. These wells also are affected by seasonal condition.

(2) Aquifer in the Basement Rocks

The aquifer has been exploited mainly by tube wells installed a hand pump. *Figure 7.1* shows the correlation between the depth of tube well and the yield from well. Almost 90% of the tube wells were drilled up to 20 to 70 m in depth. A line graph indicates the number of tube wells for every 5 meters in depth. Bar charts indicate average yield and median yield from tube wells classified by depths.

The figure indicates the average yield decreases clearly below the depth of 70 m. It increases between the depth of 80 m and 90 m and decreases again below the depth of 90 m. The bar charts of the median yield also show the same tendency. The graph suggests that a main exploited zone of groundwater is usually the fractured and/or weathered zone occurring above the depth of 70 m in hard rocks. In addition, the graph indicates that a relatively large scale water bearing zone may occur around the depth between 80 m and 90.

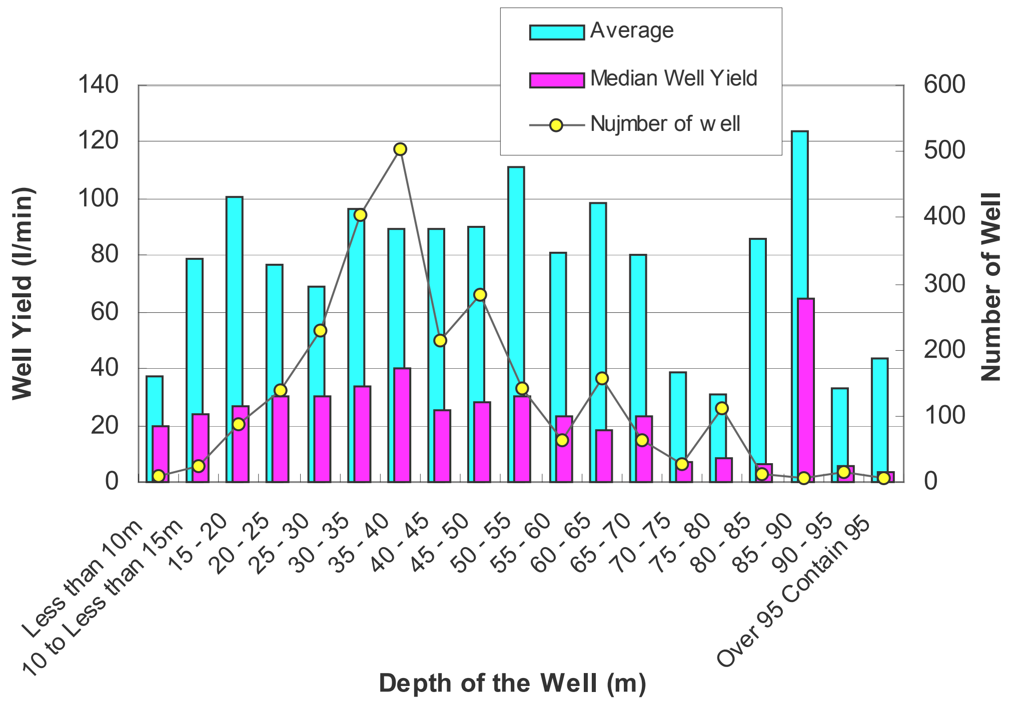


Figure 7.1 Relationship between Average of Well Yield and Well Depth

Figure 7.2 shows the locations of fractures recorded during the drilling of test wells. The figure indicates that the many fractures are developed above the depth of about 50 m in the wells of No.H-5 (Pahala Mattala), M-1 (Sevanagala), M-2 (Bodagama), and some fractures in No.H-1 (Siyambalagaswila North) and M-4 (Yalabowa). Then, a non-fracture zone with a thickness of 20 to 40 meters occurs in the wells below around the depth of 50 m. The results of calliper log conducted in these wells show that this was the zone of hard rocks. And again some fractures followed by other hard rocks were observed between the depth of around 70 and 100 m in the wells of No.H-5, No.H-6, M-2, and M-4. Some wells had further fractures below the depth of 100 m. The well of No.H-2 (Tanmennawewa) was peculiar. The penetrated rock was continuously hard and no fracture up to the depth of 154 m in the well. Below the depth, some fractures occurred intermittently and a major fracture yielding 500 litres/min existed at the depth of 185 m.

The above results show the aquifers can be practically classified into three categories to consider a future groundwater development in the area, though a network of fractures in the basement rock, or a fractured aquifer system, is not clear yet. These categories are;

- Upper fractured aquifer; A fractured aquifer already exploited mainly in the depth to about 70 meters.
- Lower fractured aquifer, A deep fractured aquifer in the depth from 70 to 100 m.
- Deeper fractured aquifer; A deeper aquifer in the depth from 100 to 200 m.

According to the database, more than 90 % of the existing wells were drilled up to 70 meters or less in depth. And the number of the remaining wells with the depth of more than 70 m was 251 including 5 wells with the depth of more than 100 m, in which only one well was productive. And as described already ten test wells were constructed to investigate the deeper fractured aquifer. The following sections describe the aquifers categorized above.

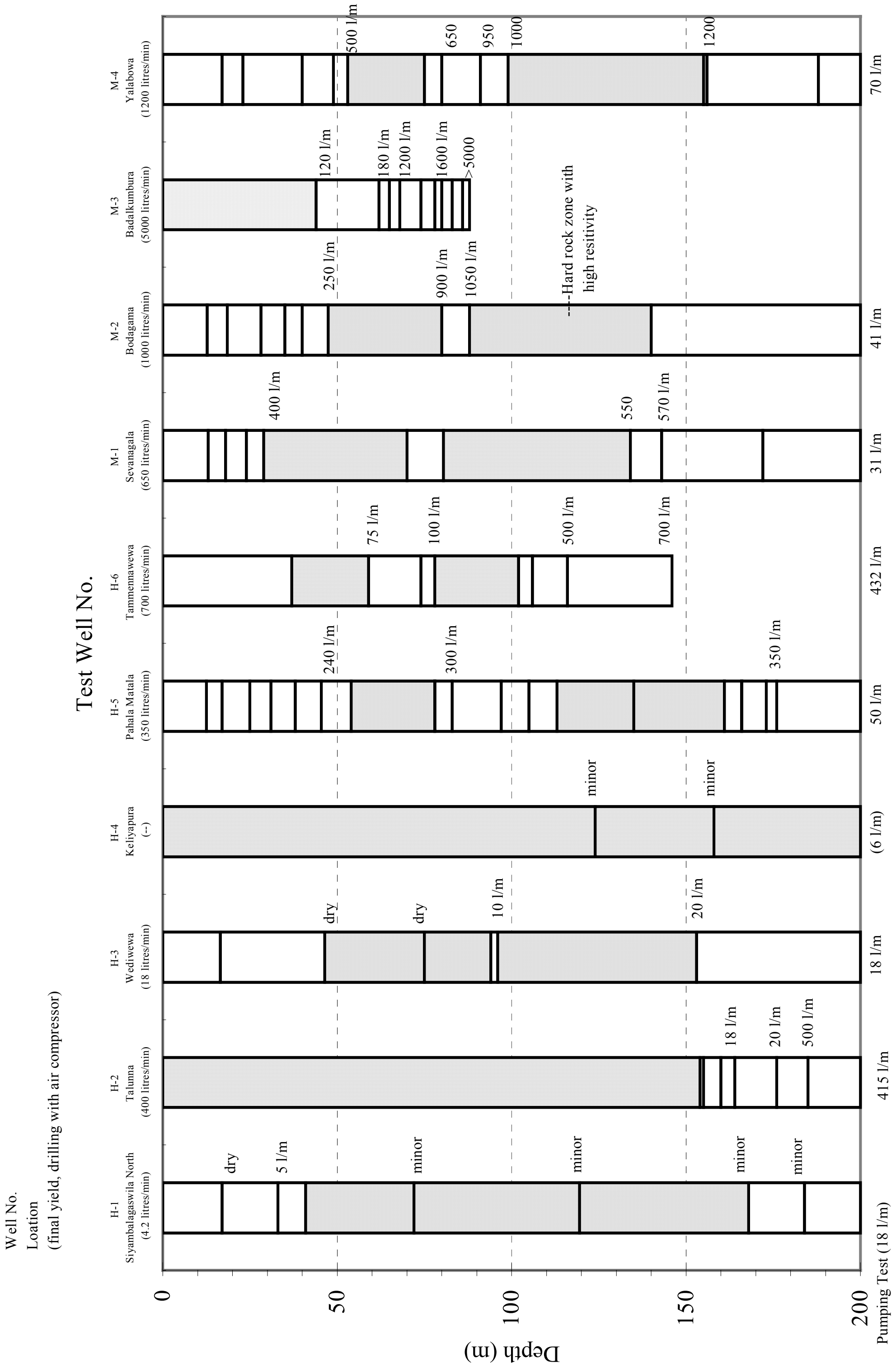
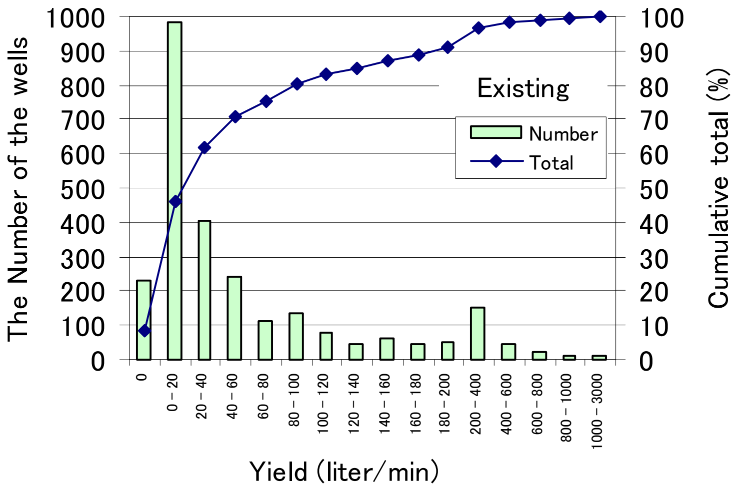


Figure 7.2 Fractures Recorded in Test Wells

7.2.2 UPPER FRACTURED AQUIFER (LESS THAN 70 M. IN DEPTH)

Most of the existing wells installed a hand pump extract water from this zone, though the yield varies widely. According to the database, 2625 wells, which is 92.3 % of the total number of existing wells, are 70 meters or less in depth. *Figure 7.3* shows the number of wells classified by yield. Though the yield ranges widely from 0.25 to 3000 litres/min in Hambantota and from 0.5 to 1200 litres/min in Monaragala, 981 wells (37.4 %) yielded 20 litres/min or less and 239 wells (9.1 %) yielded between 20 to 40 litres/min. Consequently 61.6 % of existing wells yielded 40 litres/min or less including no yielded wells. Only a hand pump can extract this range of yield. On the other hand, there are 519 wells (19.8 %) yielding more than 100 litres/min, which can be extracted by a submersible pump if necessary. There are productive fractures with a certain scale in the area.



Yield (liter/min)	Number of Wells	Accumulating Total	
		No.	%
0	228	228	8.7
0 - 20	981	1209	46.1
20 - 40	407	1616	61.6
40 - 60	239	1855	70.7
60 - 80	115	1970	75.0
80 - 100	136	2106	80.2
100 - 120	79	2185	83.2
120 - 140	47	2232	85.0
140 - 160	60	2292	87.3
160 - 180	43	2335	89.0
180 - 200	51	2386	90.9
200 - 400	151	2537	96.6
400 - 600	45	2582	98.4
600 - 800	20	2602	99.1
800 - 1000	9	2611	99.5
1000 - 3000	14	2625	100.0

Figure 7.3 Number of Wells Classified by Yield (0 to 70m in Depth)

The yield map, *Figure 7.4 (1), (2) and (3)*, was also provided based on the database. The figure shows the areas where wells are expected to yield more than 100 litres/min are located in the western end of Hambantota and the south end, the middle, and the eastern area of Monaragala. The western Hambantota is the low level plain with the altitude of about 140 m where the Highland Complex is distributed and the most of the Monaragala productive areas are located on the micro relief planation surface with the altitude from 100 to 200 m lying at the foot of the hills with inselberg in the northeast part of Monaragala. In geology, biotite gneiss of Vijayan Complex is distributed mainly in the area.

The test wells of the No.H-5 (Pahala Mattala), M-1 (Sevanagala), M-2 (Bodagama) encountered productive fractures above the depth of 50 m. The fractures yielded from 240 to 400 litres/min during drilling. The No.M-4 test well (Yalabowa) encountered fractures at the depth of 56 m, which yielded 500 lites/min. Small fractures yielding 5 litres/m were observed in the No.H-1 (Siyambalagaswila North). The fractures in the above three wells, No.H-5, M-1, and M-2, occur relatively densely.

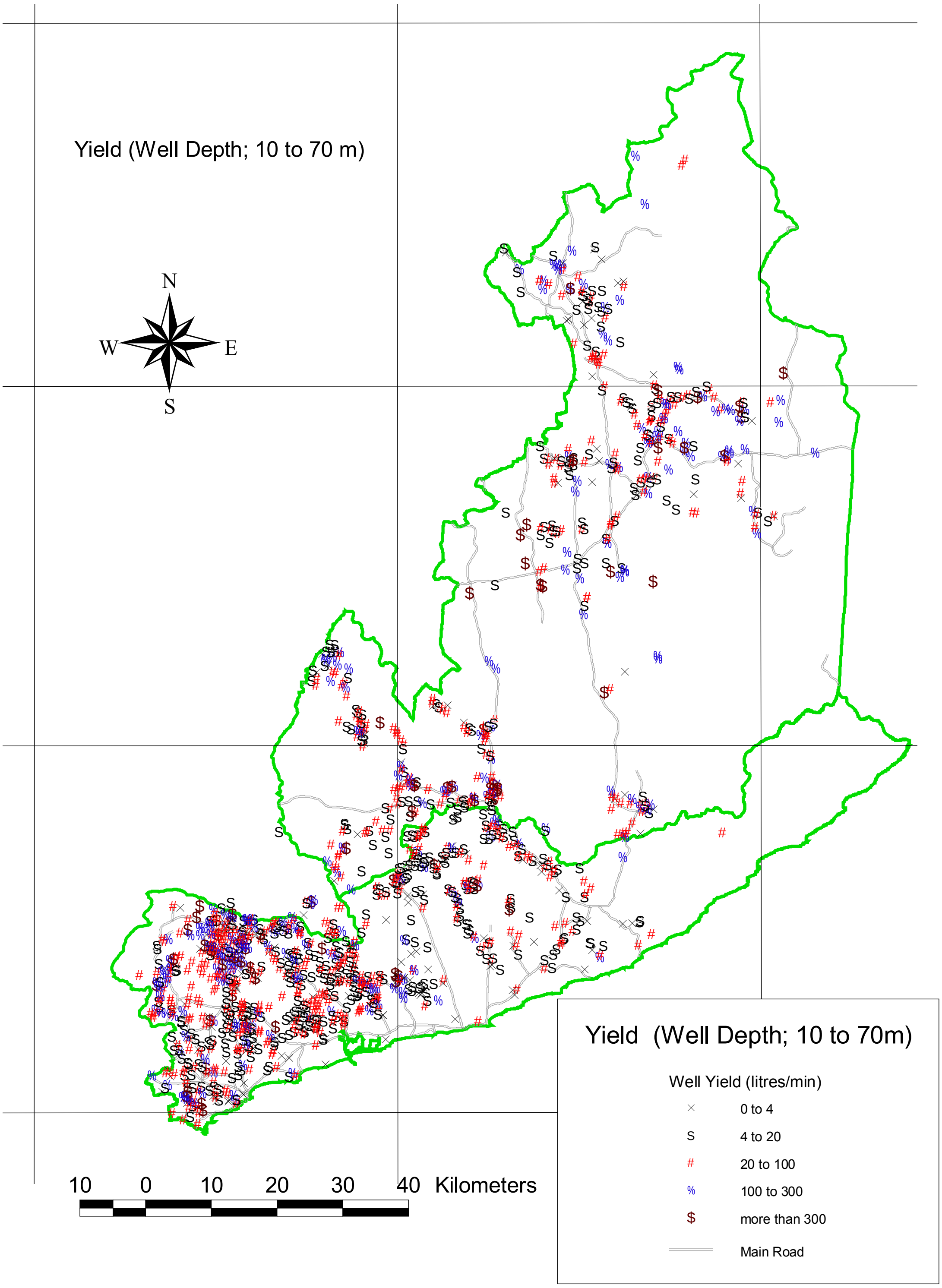


FIGURE 7.4(1) WELL YIELD (WELL DEPTH; 10 TO 70 M)

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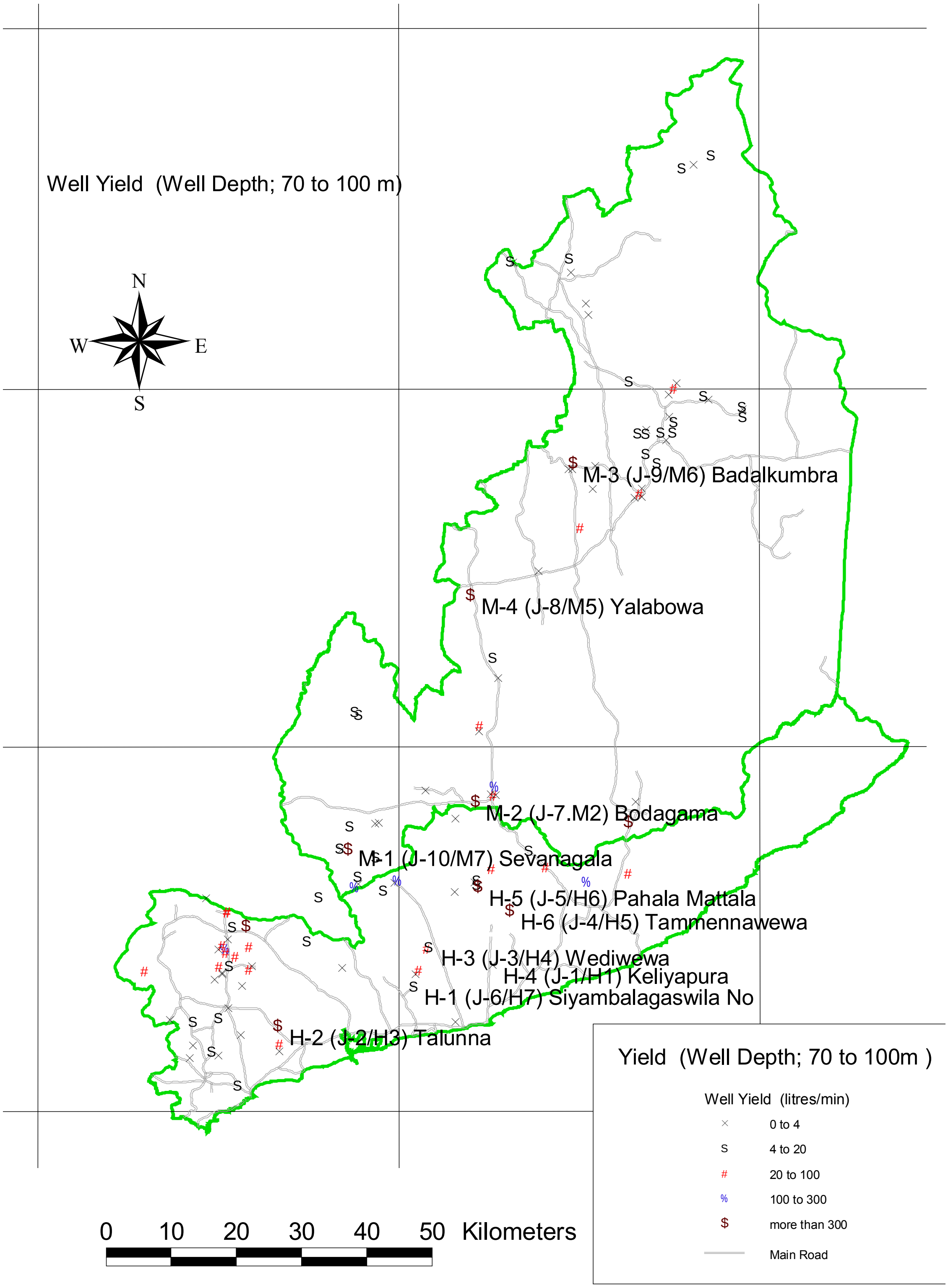

FIGURE 7.4(2) WELL YIELD (WELL DEPTH; 70 TO 100 M)

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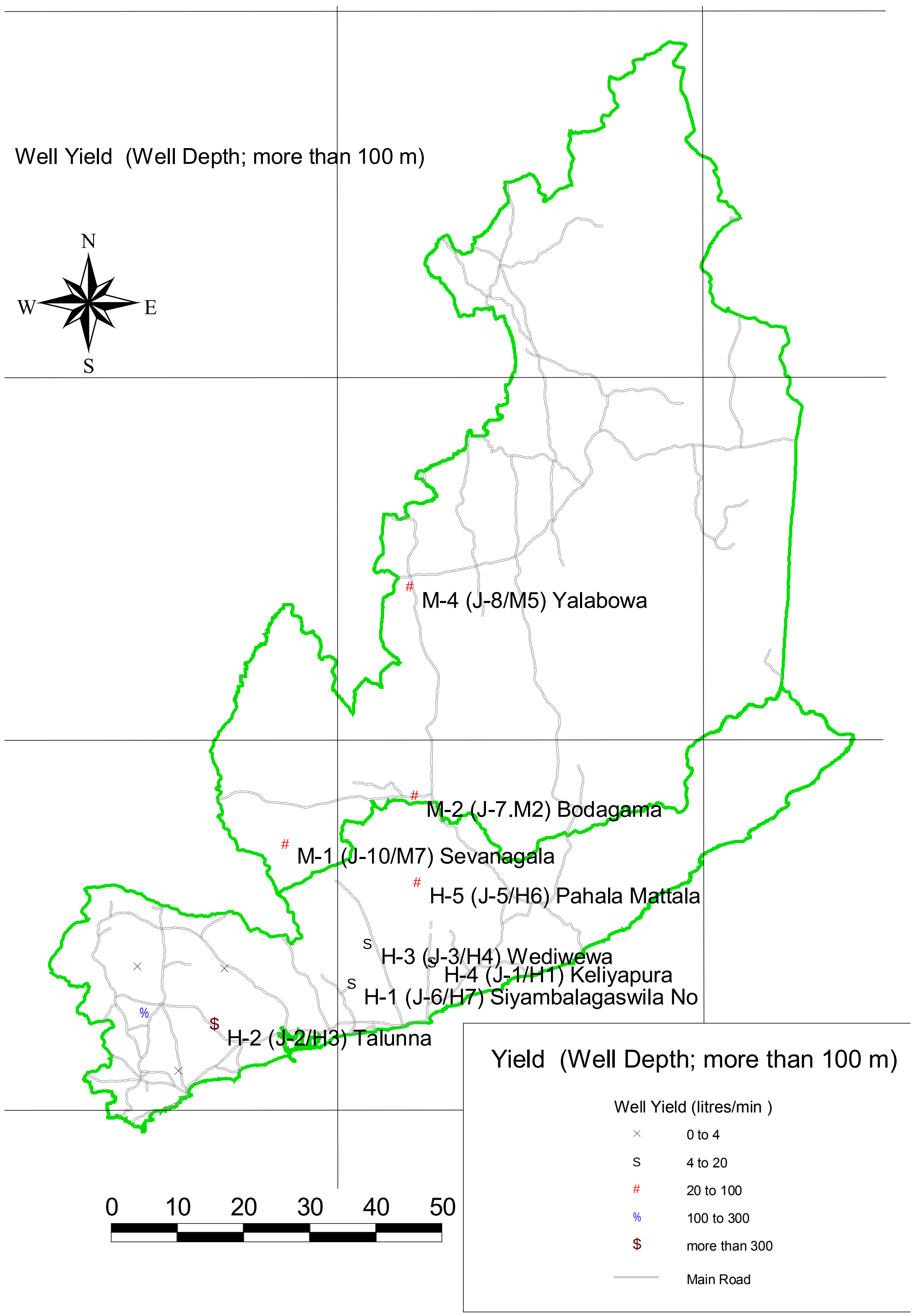

FIGURE 7.4(3) WELL YIELD (WELL DEPTH; MORE THAN 100 M)

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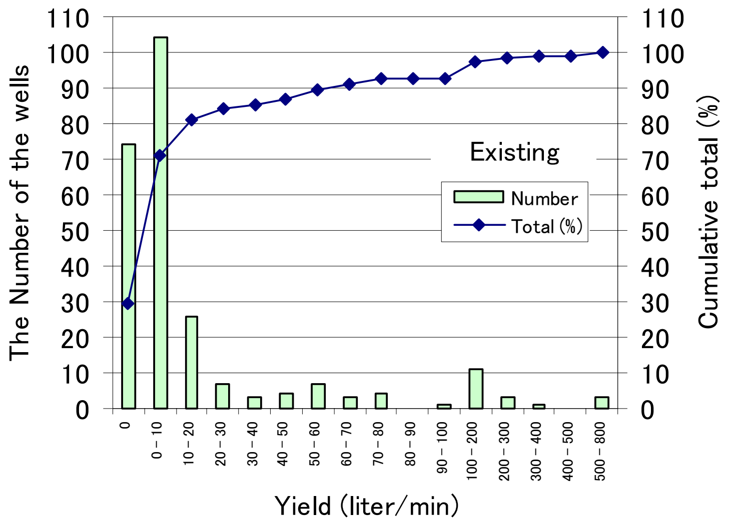
7.2.3 LOWER FRACTURED AQUIFER (70 TO 100 M. IN DEPTH)

Figure 7.4(2) shows the distribution of yield from the wells with a depth between 70 and 100m. *Figure 7.5* shows the number of wells classified by yield. Actually almost 30 % of the wells drilled to the depth of more than 70 m were not productive and the 130 wells (51.8 %) yielded 20 litres/min or less. The 18 wells (7.2 %) yielded more than 100 litres/min. The bar chart shows the range of the yield from 100 to 200 litres/min was prominent. It may be expectable yield when a well encounters a productive fracture zone.



Yield (liter/min)	Number	Accumulating Total	
		No.	%
0	74	74	29.5
0 - 10	104	178	70.9
10 - 20	26	204	81.3
20 - 30	7	211	84.1
30 - 40	3	214	85.3
40 - 50	4	218	86.9
50 - 60	7	225	89.6
60 - 70	3	228	90.8
70 - 80	4	232	92.4
80 - 90	0	232	92.4
90 - 100	1	233	92.8
100 - 200	11	244	97.2
200 - 300	3	247	98.4
300 - 400	1	248	98.8
400 - 500	0	248	98.8
500 - 800	3	251	100.0

Figure 7.5 Number of Wells Classified by Yield (70 to 100m in Depth)

The test wells of No.M-2 (Bodagama) and No.M-4 (Yalabowa) hit productive fractures in this zone of from 70 to 100 m in depth. No.M-2 and No.M-4 were probably expected to yield hundreds of litres per minute of water, even it was not clear because the fractures were sealed up with cement after the casing pipes were installed. Therefore, additional test wells with the drilled depth of 100 m, namely No.M-2(2) (Additional Bodagama) and No.M-4(2) (Additional Yalabowa), were constructed to confirm the productivity of this large fractured zone. As a result, the constant discharge pumping tests of No.M-2(2) and No.M-4(2) were conducted for 72 hours with the pumping rate of 440 and 610 litres/min respectively. No.M-3 (Badalkumbura) also encountered a large productive zone from 63 m to 84 m in depth. The well yielded more than 5000 litres/min during the drilling from 83 m to 88 m in depth. Consequently the drilling was stopped at the depth of 88 m because the yielding volume was too large to continue the drilling safely. In the wells of No.H-5 (Pahala Mattala), No.H-6 (Tammennawewa), and No.M-1 (Sevanagara), less productive fractures were recorded during the drilling. Fractures in these wells may yield dozens of litres per minute of water.

The above results of the test well drilling seem to indicate that the productive lower fractured aquifer exists in the interior part of the Study area.

7.2.4 DEEPER FRACTURED AQUIFER (100 TO 200 M IN DEPTH)

According to the database, only one well had been recorded to yield 240 litres/min while a total of four wells had been drilled up to 100 m or over in the area. Three other wells yielded only 0-3.5 litres/min. The test wells construction for the Study was the first drilling to 200 m in the area. The results are as follows.

The productive fractures located below 100 m occurred in the test wells except No.H-1 and No.H-4. Particularly the fracture that occurred in the well of No.H-2, Talunna, was most productive. The yield from the well had increased from 20 to 500 litres/min after the drilling reached up to 185 m, though any fractures had not been observed up to the depth of 154 m. Screen pipes were installed from 172.9 to 188.9 m in the well of No.H-2. The pumping test had been conducted for 4 days with the pumping rate of 415 lites/min. The major fractures in No.H-2 developed in a granitic gneiss formation indicated by the geophysical logging. Other fractures were observed just upper part of the granitic gneiss formation.

There was a large fractured zone from the depth of 105 m to the depth of 116 m in the well of No.H-6. The yield from the well had increased from 250 to 500 litres/min during drilling the zone. During the further drilling up to the depth of 146 m, the yield improved to 700 litres/min. Additionally EC of water also improved during the drilling. While it might mean other productive fractured zone occurred below the depth of 116 m, the zone had been filled by the collapse of the upper zone. The well was cased up to the depth of 102 m. Though the construction of the additional test well was planned just near No.H-6, the drilling could not be completed up to 200 m. The formation was too loose to penetrate. Probably it is very difficult to make a well into the loose formation.

The fractures observed in No.H-3, H-5, M-1, M-2, and M-4 yielded from 20 to 50 litres/min. Even this amount of yield, on the average, these test wells were more productive than the existing tube wells drilled up to 70 m or more. The geophysical logs show that some fractures occur in and around the boundary between granitic gneiss and hornblende-biotite gneiss.

7.2.5 INTERCONNECTION OF AQUIFERS

Each fractured aquifer described in the previous section is separated by the hard rock as shown in the result of geophysical logging. In this study, the only targeted aquifer has been installed screen pipes to extract groundwater. In certain areas, however, the pumping from a test well had influenced the water level in a shallow well located near the pumped well, that is, Well No.H-5 Pahala Mattala and Well No.H-6 Tammennawewa as shown in *Figure 7.6*.

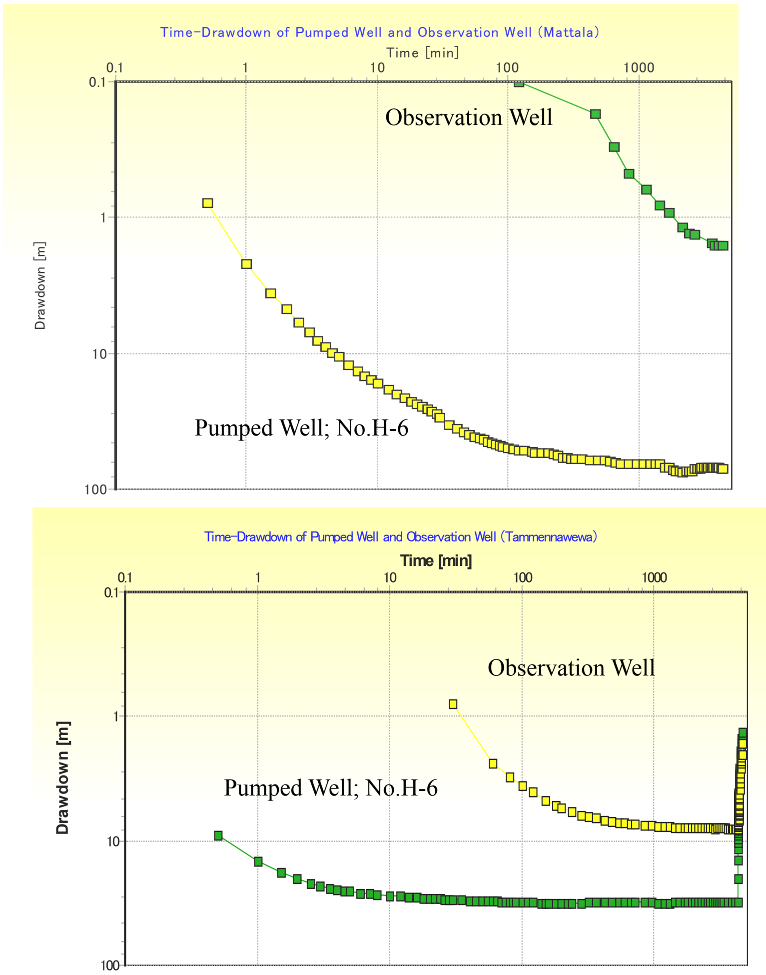


Figure 7.6 Influence of Pumping Well

The screen pipes of No.H-5 have been installed from 163 to 195 m. The upper part of annular space between the casing pipes and drilled hole was grouted up to the packer just above the screen. The observation well was located about 180 m away from the No.H-5 and its depth was 38 meters. The geophysical log shows that the hard rock formation occurs between the depth of 55 m to the depth of 85 m, which is a zone with high resistivity and low gamma. This zone is most likely an impermeable zone. Even so, the fact that the water level of the observation well had been affected by the pumping from the test well indicates that there is an interconnected fracture network between the upper fractured aquifer and the deeper fractured aquifer.

The test well of No.H-6 has been cased up to 102 m and the positions of screen pipes is 52.5-60.5 m and 72.5-84.5 m in depth. The upper part of annular space was grouted up to the packer just above the screen as well as other test wells. A well located 77 meters away from the test well was influenced by the pumping from the test well. The observation well was 35 m in depth. The geophysical log shows that the hard rock formation occurs between the depth of 37 m to 53 m in the well of No.H-6. The influence of the pumping, however, suggests also that the deeper fracture is connected with the upper fracture in the area.

As described in the following section, the seasonal water level fluctuation also seems to reveal the existence of the interconnection of fractures in the basement rock.

The changes of water level in other observation wells were not observed during the pumping tests. However, please note that some wells were located more than 1 km away from the pumped well, and the duration time and the pumping rate of some pumping tests were very short and little.

7.3 GEOLOGICAL STRUCTURE AND GROUNDWATER

7.3.1 GENERAL

The forming of water bearing fractured zone in hard rock is considered to be highly dependent on the geological structure in the area. Therefore, some analyses were conducted to confirm the relation between geological structure and groundwater occurrence using GIS database.

The results of the analysis were tabulated as below.

No.	Analysis Item	Relation
1	Relation between Well yield [a)] and Fault and thrust/shear zone [b)]	A well with the nearer distance to fault or thrust/shear zone yields a little more than a distant well.
2	Relation between Well yield [a)] and Lineament [c)]	A well located near the lineament with the direction of NNW-SSE yields more than other wells on average.
3	Relation between Well yield [a)] and Geology [b)]	Not clear
4	Relation between Well yield [a)] and Surface water (river) [d)]	A well with the nearer distance to a river yields a little more than a distant well.
5	Relation between Well yield [a)] and Lineament density [c)]	Not clear
6	Relation between Electric conductivity [a)] and Geology [b)]	Not clear
7	Relation between Fluoride [a)] and Geology [b)]	Not clear
8	Relation between Total iron [a)] and Geology [b)]	Not clear

Sources; a) Well database (WRB, NWSDB, JICA test well)
b) Geological Map with a scale of 1:100,000 by GSMB
c) Landsat imagery analysis in Chapter 3
d) Digital Map with a scale of 1:250,000 by Survey Department

7.3.2 ANALYSIS

(1) Yield and Geological Structure

The selected items to see the relation between yield and geological structure are as follows.

<Fault and thrust/shear zone>

– The distance between an existing well and the nearby fault or thrust/shear zone shown in the 1: 100,000 geological map issued by GSMB was calculated with GIS. *Figure 7.7* was made to show the relation between yield and the distance from a fault or thrust/shear zone, after the existing wells were divided into some groups based on the obtained distance. The figures seem to indicate that a well with the nearer distance to fault or thrust/shear zone yields a little more than a distant well.

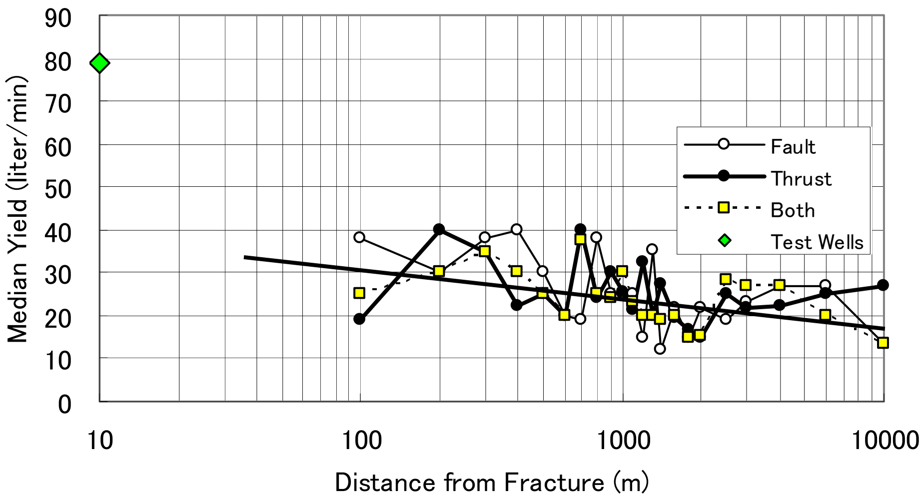


Figure 7.7 Relation between Yield and Distance from Fracture

<Lineament>

- First we had tried to see the relation between yield and the distance from lineaments extracted from the Landsat imagery as well as the above. The relation, however, was not clear. Second the relation between yield and the direction of lineament was examined with GIS. *Figure 7.8* shows the result. The figure indicates that a well located near the lineament with the direction of NNW-SSE yields more than other wells on average.

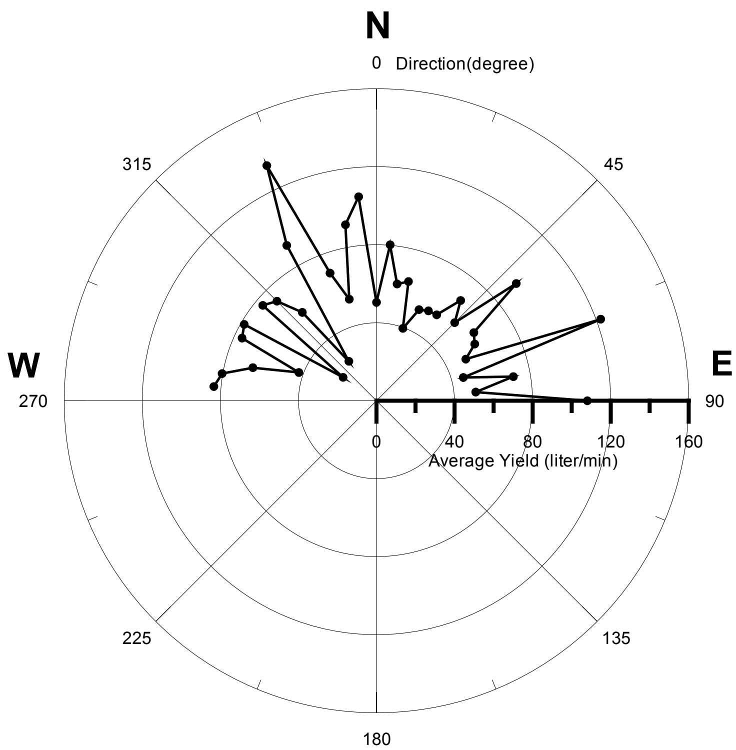


Figure 7.8 Relation between Yield and Direction of Liniament

<River, geology, lineament density>

- The distance between an existing well and the nearby river was calculated with GIS. A well with the nearer distance to a river yields a little more than a distant well.
- The relation between yield and geology classified in the 1:100,000 geological map was not confirmed.
- Also the relation between yield and lineament density was not confirmed.

(2) Groundwater Quality and Geology

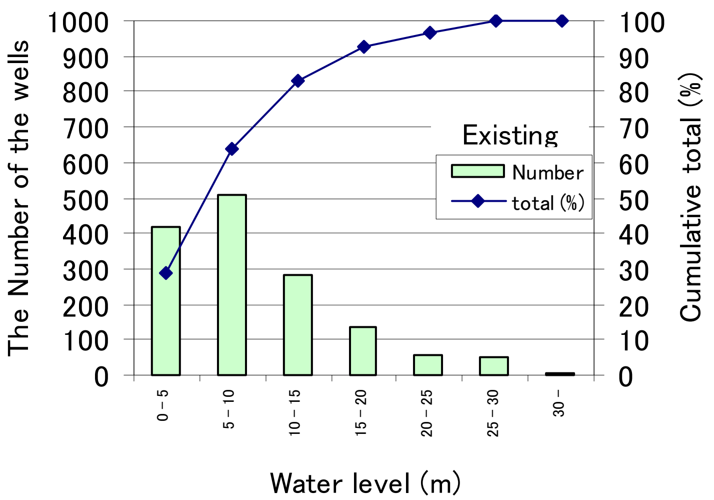
Although the relation between groundwater quality, namely EC, Fluoride, and Total Iron, and geology was analysed with GIS, the considerable relation was not found.

7.4 GROUNDWATER LEVEL

7.4.1 GENERAL FEATURE OF THE STUDY AREA

(1) Upper Fractured Aquifer (GL - 70m)

The number of wells and the depth to water surface of the upper fractured aquifer are graphed as shown in *Figure 7.9*. 63.8 % of the water levels are 10 m or above in depth and 28.8 % ranges between 10 and 20 m in depth. Consequently 92.6 % of the water level are 20 m or above in depth.



SWL (mBGL)	Number	Accumulating Total	
		No.	(%)
0 – 5	416	416	28.6
5 – 10	511	927	63.8
10 – 15	281	1208	83.1
15 – 20	137	1345	92.6
20 – 25	55	1400	96.4
25 – 30	49	1449	99.7
30 –	4	1453	100.0

Figure 7.9 Number of wells and water level; Upper fractured aquifer

Figure 7.10 shows the depth to groundwater surface in a well. The wells with relatively deeper water level are mostly located in the western Hambantota where the low level planation surface with the altitude of 100 m or more is distributed. And also the central western part in Monaragala is the relatively deeper water level area that is a southern part of the hills with inselberg.

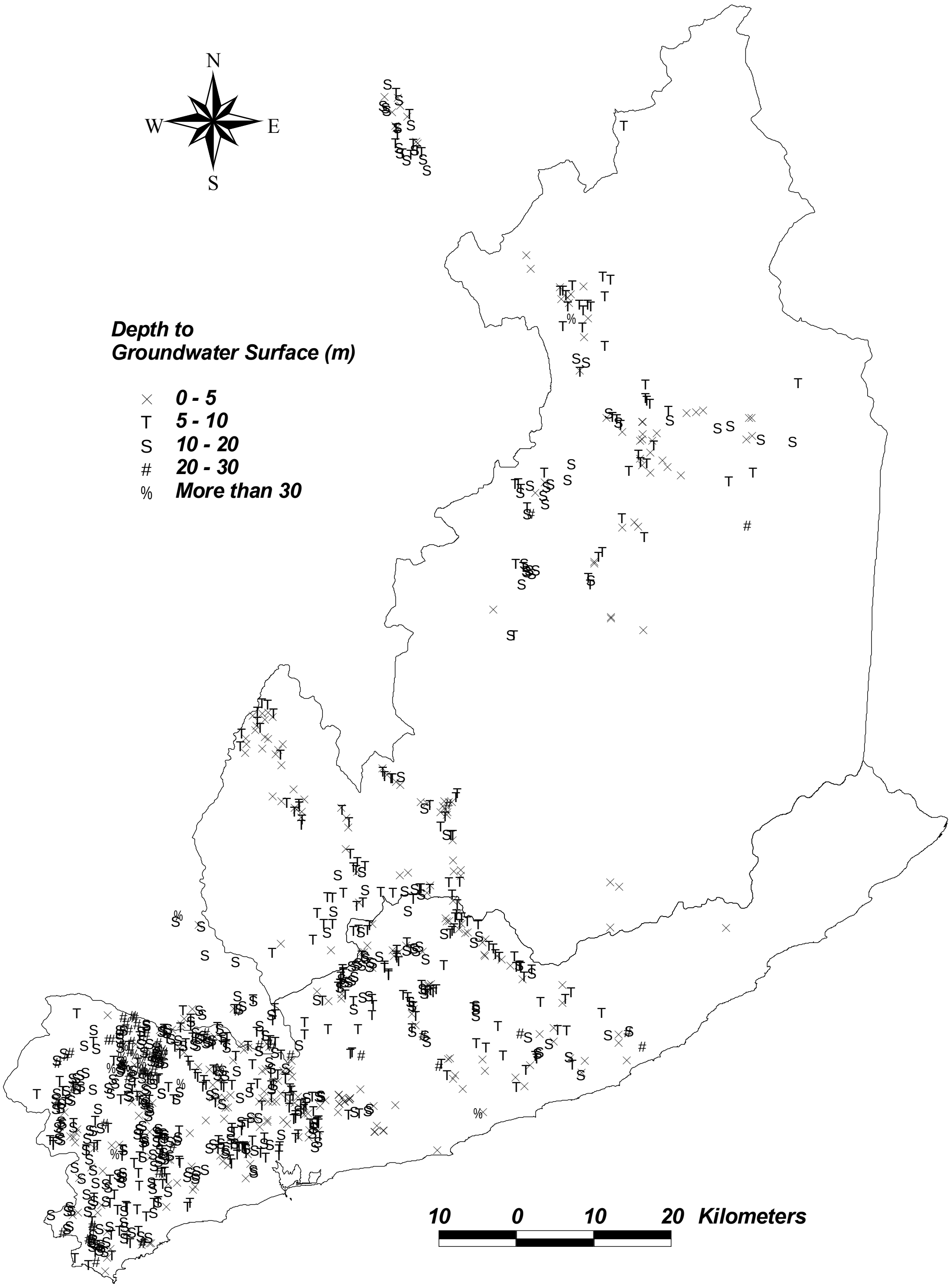


FIGURE 7.10 DEPTH TO WATER SURFACE (WELL DEPTH; 10 TO 70 M)

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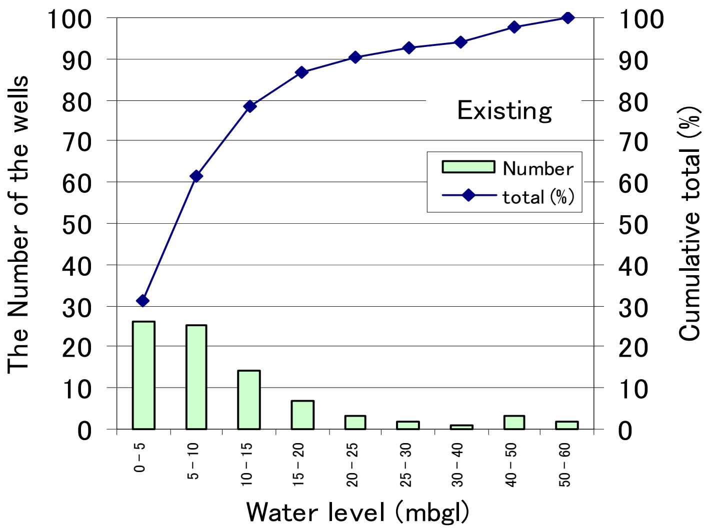
(2) Lower Fractured Aquifer (70 - 100)

The number of wells and the depth to water surface of the lower fractured aquifer are graphed as shown in *Figure 7.11*. 61.4 % of the water levels are 10 m or above in depth and 25.3 % ranges between 10 and 20 m in depth. Consequently 86.7 % of the water level are 20 m or above in depth. The number of wells with the water level of 40 m or below is 6.0 %. The depth of 40 m is the almost marginal pumping capacity of a usual hand pump such as India Mark II.



SWL (mbgl)	Number	Accumulating Total	
		Total	total (%)
0 – 5	26	26	31.3
5 – 10	25	51	61.4
10 – 15	14	65	78.3
15 – 20	7	72	86.7
20 – 25	3	75	90.4
25 – 30	2	77	92.8
30 – 40	1	78	94.0
40 – 50	3	81	97.6
50 – 60	2	83	100.0

Figure 7.11 Number of wells and water level; Lower fractured aquifer

Figure 7.12 shows the depth to groundwater surface in a well with the depth from 70 to 100 m. Similarly to the upper fractured aquifer, the western area of Hambantota seems to be the relatively deeper water level area. In general, the water level becomes deeper to the coastal side of the Study area.

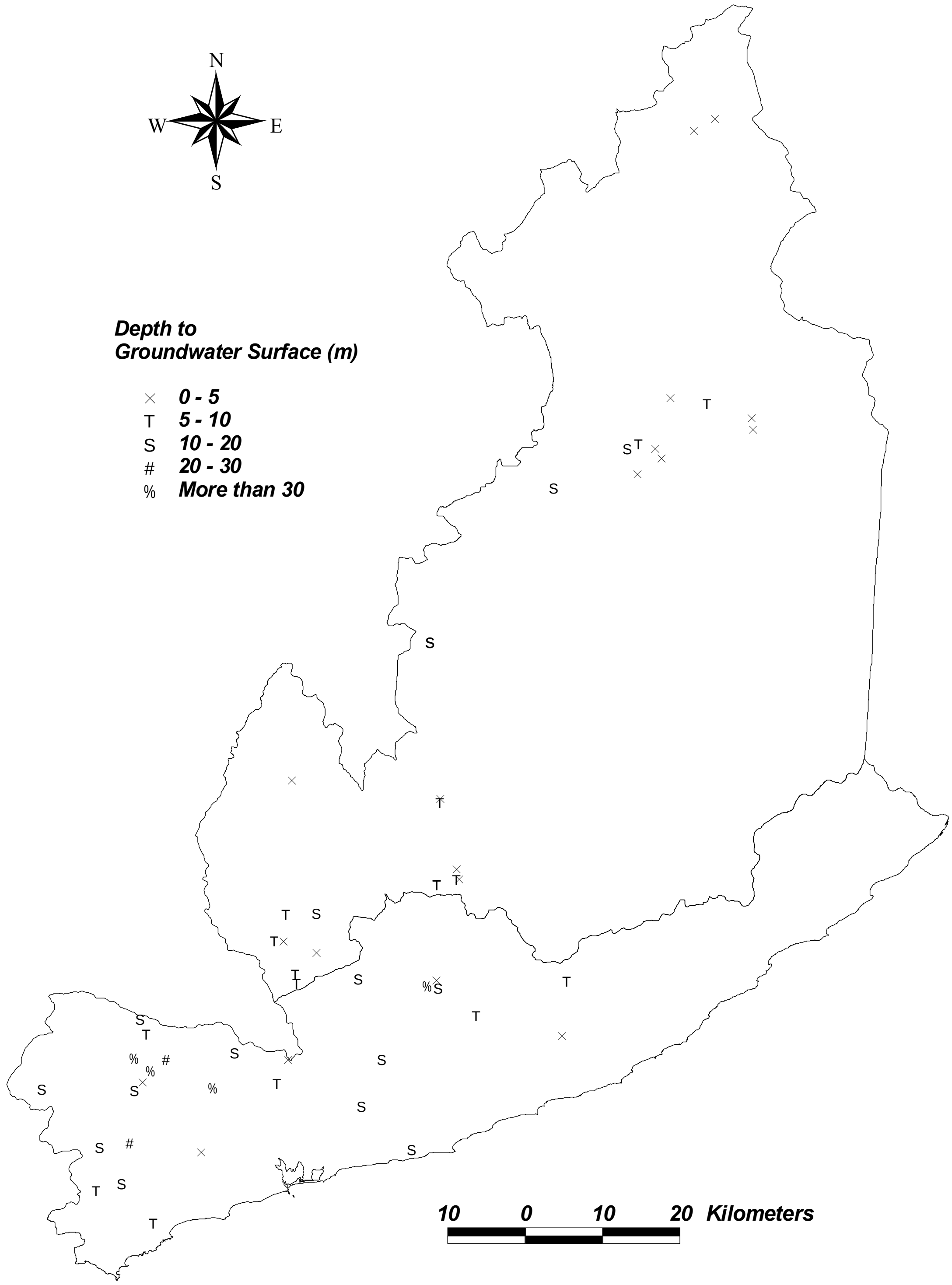


FIGURE 7.12 DEPTH TO WATER SURFACE (WELL DEPTH; 70 TO 100 M)

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(3) Deeper Fractured Aquifer (100 – 200 m)

The water level records of the test wells constructed in the Study are all of the data of the deeper fractured aquifer.

In Hambantota, the water level ranges from 8.5 mbgl to 13 mbgl with two exceptions. One exception is the water level of 3.55 mbgl in the No.H-2 (Talunna) and the other exception is the No.H-4 (Keliyapura) that is actually dry. In Monaragala, the water levels were 1.73 mbgl in Sevanagala, 7.9 mbgl in Bodagama, and 12.7 mbgl in Yalabowa. Even the aquifer occurring below 100 m or more in depth, its pizometric head is about 10 mbgl or above.

7.4.2 WATER LEVEL FLUCTUATION

Groundwater level fluctuates depending on natural and artificial conditions. Generally the natural conditions are seasonal and daily change in as precipitation, evaporation, level of surface water, and atmospheric pressure. The artificial conditions are pumping rate from wells, construction work and others. A drastic drawdown in groundwater level is often an indication of future management problems. Therefore, continuous measurement of groundwater level is indispensable for groundwater development and management. Groundwater levels of most tube wells in the Study Area have not been monitored since early 1980's, when groundwater explorations were conducted in Hambantota by WRB (*Silva, 1984*).

The Study Team conducted periodical measuring of water levels of the 30 selected existing wells and installed the automatic water level recorders provided by JICA on the 10 test wells constructed for the Study to observe continuous water level fluctuations.

(1) Results of Periodical Measurement of Existing Wells

The periodical water level measurements of the 30 selected existing wells were conducted as already explained in *Supporting 5*. They were carried out from September 2001 to July 2002. The depths of the observed existing wells ranged from 24 to 79 m. The summarized result is as follows.

In general, the groundwater level had decreased from September to November 2001, and then had increased in December. The level slightly fell in January 2002 and had risen from March to May. Although the rainfall had increased from September to November, the groundwater level had not been affected yet in November. The effect of rainfall seemed to appear in December. Rainfall decreased in December and the water level had fallen a little in January. As rainfall increased over from January to April, the groundwater level had risen slightly from March to May. The correlation between water level fluctuations and monthly rainfall variation suggests that the rainy season from September to January and also the rain in April have recharged the upper fractured aquifer.

(2) Results of Continuous Water Level Record

A water level recorder provided by JICA was installed after the test well was constructed. In Hambantota, the water levels of the completed test wells except No.H-6 have been recorded since the late of March, and the level of No.H-6 has been recorded since the middle of April. The records of water levels in the test wells in Monaragala have started from September '02.

The data obtained during the Study were graphed in *Figure 7.13*. Some points were found out as follows.

1) Artificial Effects

<Influences of water extraction from a nearby well>

- The momentary drop and recovery of water level was recorded at 8 and 9 April in Well No.H-5. During these two days, an additional well had been drilled at the location about 40 meters away from Well No.H-5 (Pahala Mattala). According to the driller's log, a fracture zone from 28.8 to 31.1 m in depth had been penetrated with a yield of about 20 litres/min from 2:30 p.m. to 3:00 p.m. on 8 April. After that, another fracture yielding 120 litres/min was encountered at about 4:30 p.m. The drilling work stopped at 5:30 p.m.

on 8 April. The drilling of the next day started at 10:00 a.m. and stopped at 2:30 p.m. after drilled up to 52 m bgl. The recorded water level change in Well No.H-5 was in agreement with the above drilling situation of the additional well.

- The same kind of water level drop was recorded from 5 June. This time, a pumping test of the above additional Mattala well had been carried out from 5 June. After that, in the middle of the water level recovery, it is suspected that the float of the recorder might have been stuck in the well.

<Influences of its own water extraction>

- Well No.H-3 was a poor productive well. The pumping test was conducted on 22 February and caused a drawdown of 46 m. The curve of the water level change seems to show that the water level has been recovered recently.
- Well No.H-1 was also poorly productive. The water level had been stable till the middle of April and had slowly increased till the middle of May. Three time sharp drops and recovery curve had happened at the date when a bottle of water was sampled
- The water level of Well No.H-4 has strangely moved. Actually the well was dry just after drilled up to 200 m. In order to do a geophysical logging, the well was filled with tanked water up to the depth of 12.5 m. The pumping test caused the drawdown of about 29 m. The water level had been recovered up to the depth of about 6 m when a water level recorder was installed. Since then the water level have decreased.

2) Natural Effects

<Daily changes>

- Daily fluctuations have been recorded in Well No.H-2, Talunna, Well No.H-5, Pahala Mattala, and Well No.H-6, Tammennawewa. The width of daily fluctuations has varied with a half-month cycle. The largest daily fluctuation occurs in the day of a new moon and a full moon. This daily fluctuation is the effect of an earth tide.

<Seasonal variation and rainfall>

- For a long-term variation, the water level in Well No.H-5 had been rather stable from the middle of March to the middle of April, and then the level had slowly risen to the early June.
- The water level in Well No.H-6 began to increase gently after the record started and had reached the highest level around 7 May. And then the level continues to fall so far.
- Although the screen pipes of Well No.H-2 had been installed below 160 m as well as Well No.H-1 and Well No.H-5, the water level in Well No.H-2 had another tendency. The penetrated rocks in No.H-2 were no fractured formation at all up to about 150 m bgl. On the other hand some fractures occurred in the upper part of the penetrated rocks in the other wells. The fracturing conditions in a basement rock probably have an effect on the above difference of the water level fluctuation in these wells.
- The bar chart in *Figure 7.13* shows the mean daily rainfall of 23 stations in the Study area. It had rained relatively a little from February to around 20 March. The daily rainfall had generally increased from 22 March to around 4 May. The water level of Well No.H-1 and No.H-5 had been rather stable till about 20 April. Thereafter the level had risen to the middle of May. The recharge by rainfall during the above term, from March to May, had caused probably the rising of the water level from the late April.
- The rising of the water level in Well No.H-6 had started earlier than other two wells, No.H-1 and H-5, and the level had become stable a few days after daily rainfall turn out to be little. The observed aquifer is a fractured zone from 52 to 84 m in Well No.H-6, the cased depth of which was 102 m. The screen pipes of the other two wells have been installed below the depth of 160 m. The upper part of the fractured zone has been affected

earlier by rainfall than the deeper fractured zone.

– Generally, the recorded water level fluctuation correlates with rainfall in the area, even the aquifer occurs below the depth of 150 m. Seasonal rain recharges a deeper fractured aquifer as well.

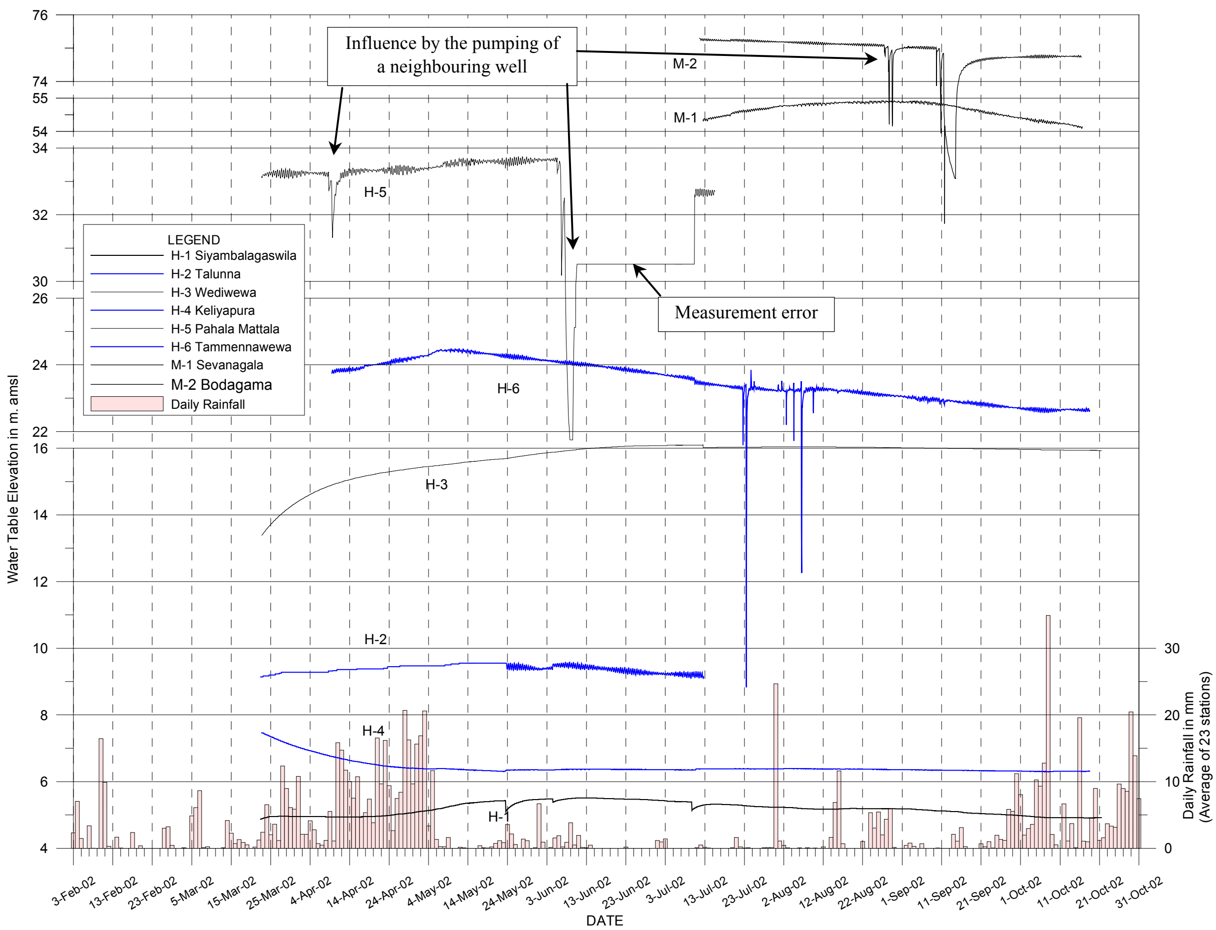


Figure 7.13 Hydrograph of Test Wells

7.5 WATER QUALITY

Based on the following water quality data, this section describes the groundwater quality characteristics of the existing tube wells and the test wells in the Study area.

- The groundwater quality data of the existing tube wells from the database
- The periodical measurements of the 30 existing tube wells (refer to *Supporting 5*)
- The groundwater quality analysis of test wells (refer to *Supporting 6*)

7.5.1 WATER QUALITY OF THE EXISTING TUBE WELLS (UPPER FRACTURED AQUIFER)

(1) Satisfaction of the Criteria for Drinking Water

The water quality standards for drinking water in Sri Lanka was introduced in 1983, and two required criteria were provided as maximum desirable level and maximum permissible level (See, *Table 7.1*)

Table 7.1 Water Quality Standards for Drinking Water in Sri Lanka

Substance or Characteristics	Maximum Desirable Level	Maximum Permissible Level
Colour	5 units	30 units
Odour	Unobjectionable	Unobjectionable
Taste	Unobjectionable	Unobjectionable
Turbidity	38 NTU	152 NTU
pH	7.0 to 8.5	6.5 to 9.0
Electrical Conductivity	750 micro-S/cm	3,500 micro-S/cm
Chloride (as Cl)	200 mg/l	1,200 mg/l
Free residual chlorine (as Cl_2)	-	0.2 mg/l
Total Alkalinity (as $CaCO_3$)	200 mg/l	400 mg/l
Free ammonia	-	0.06 mg/l
Albuminoid ammonia	-	0.15 mg/l
Nitrate (as N)	-	10 mg/l
Nitrite (as N)	-	0.01 mg/l
Total Hardness (as $CaCO_3$)	250 mg/l	600 mg/l
Fluoride (as F)	0.6 mg/l	1.5 mg/l
Total phosphates (as PO_4)	-	2.0 mg/l
Total residue*	500 mg/l	2,000 mg/l
Total Hardness (as CaCO3)	250 mg/l	600 mg/l
Total Iron (as Fe)	0.3 mg/l	1.0 mg/l
Sulphate (as SO_4)	200 mg/l	400 mg/l
Anionic detergents	0.2 mg/l	1 mg/l
Phenolic compounds (as phenolic OH)	0.001 mg/l	0.002 mg/l
Grease and oil	-	1.0 mg/l
Calcium (as Ca)	100 mg/l	240 mg/l
Magnesium (as Mg)	30 mg/l if SO4 >=250mg/l 150 mg/l if SO4 <250mg/l	140 mg/l
Copper (as Cu)	0.05 mg/l	1.5 mg/l
Manganess (as Mn)	0.05 mg/l	0.5 mg/l
Zinc (as Zn)	5.0 mg/l	15 mg/l
Aluminum (as Al)	-	0.2 mg/l
Pesticide residue	-	As per WHO/FAO requirements
Chemical oxygen demand (COD)	-	10 mg/l
Arsenic (as As)	-	0.05 mg/l**
Cadmium (as Cd)	-	0.005 mg/l**
Cyanide (as CN)	-	0.05 mg/l**
Lead (as Pb)	-	0.05 mg/l**
Mercury (total as Hg)	-	0.001 mg/l**
Selenium (as Se)	-	0.01 mg/l**
Chromium (as Cr)	-	0.05 mg/l**

Note; * Total Dissolved Solids
** Upperlimit of concentration

For the evaluation of the groundwater quality conditions, the groundwater quality data of the existing tube wells in Hambantota and Monaragala are classified into three categories according to the water quality standards for drinking water in Sri Lanka.

- I: Satisfy the criteria (maximum desirable level) for drinking water.
- II: Meet the criteria (maximum permissible level) for drinking water.
- III: Not satisfactory, the required criteria for drinking water.

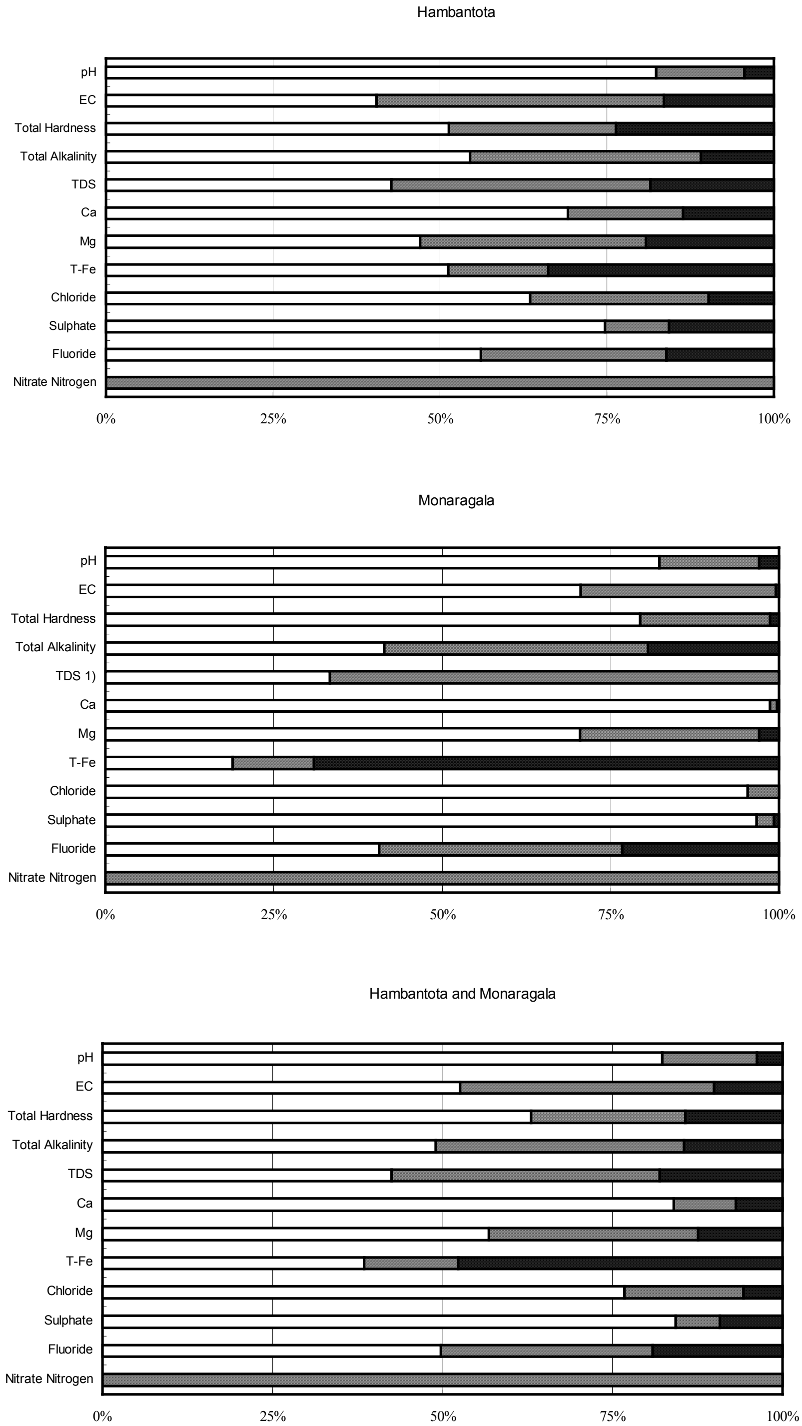
According to the results of the above classifications, outline of present groundwater quality conditions is summarized as follows (See, *Table 7.2* and *Figure 7.14*).

Table 7.2 Existing Condition of Groundwater Quality

District	Items	Satisfaction of Water Quality Standards for drinking water in Sri Lanka (Number of Wells)						
		Total	Category I		Category II		Category III	
			No.	(%)	No.	(%)	No.	(%)
Hambantota district	pH	523	431	(82.4)	69	(13.2)	23	(4.40)
	EC	565	229	(40.5)	243	(43.0)	93	(16.50)
	Total Hardness	519	266	(51.3)	130	(25.0)	123	(23.70)
	Total Alkalinity	515	281	(54.6)	178	(34.6)	56	(10.90)
	TDS	443	189	(42.7)	172	(38.8))	82	(18.50)
	Calcium	383	265	(69.2)	66	(17.2)	52	(13.60)
	Magnesium	527	248	(47.1)	178	(33.8)	101	(19.2)
	Total iron	408	209	(51.2)	61	(15.0)	138	(33.80)
	Chloride	529	336	(63.5)	141	(26.7)	52	(9.80)
	Sulphate	477	356	(74.6)	46	(9.6)	75	(15.709
	Fluoride	545	306	(56.1)	151	(27.7)	88	(16.10)
	Nitrate Nitrogen	63	-	(-)	63	(100.0)	0	(0.00)
Monaragala district	pH	382	314	(82.2)	57	(14.9)	11	(2.9)
	EC	380	268	(70.5)	110	(28.9)	2	(0.5)
	Total Hardness	373	296	(79.4)	72	(19.3)	5	(1.3)
	Total Alkalinity	379	157	(41.4)	148	(39.1)	74	(19.5)
	TDS	9	3	(33.3)	6	(66.7)	0	(0.0)
	Calcium	383	378	(98.7)	4	(1.0)	1	(0.39
	Magnesium	379	267	(70.4)	101	(26.6)	11	(2.99
	Total iron	265	50	(18.9)	32	(12.1)	183	(69.1)
	Chloride	380	362	(95.3)	18	(4.7)	0	(0.0)
	Sulphate	367	355	(96.7)	9	(2.5)	3	(0.8)
	Fluoride	377	153	(40.6)	136	(36.1)	88	(23.3)
	Nitrate Nitrogen	3	-	(-)	3	(100.0)	0	(0.0)
Hambantota and Monaragala district	pH	905	745	(82.3)	126	(13.9)	34	(3.8)
	EC	945	497	(52.6)	353	(37.4)	95	(10.1)
	Total Hardness	892	562	(63.0)	202	(22.6)	128	(14.3)
	Total Alkalinity	894	438	(49.0)	326	(36.5)	130	(14.5)
	TDS	452	192	(42.5)	178	(39.4)	82	(18.1)
	Calcium	766	643	(83.9)	70	(9.1)	53	(6.9)
	Magnesium	906	515	(56.8)	279	(30.8)	112	(12.4)
	Total iron	673	259	(38.5)	93	(13.8)	321	(47.7)
	Chloride	909	698	(76.8)	159	(17.5)	52	(5.7)
	Sulphate	844	711	(84.2)	55	(6.5)	78	(9.2)
	Fluoride	922	459	(49.8)	287	(31.1)	176	(19.1)
	Nitrate Nitrogen	66	-	(-)	66	(100.0)	0	(0.0)

Category I : satisfy the criteria (maximum desirable level) for drinking water
Category II : meet the criteria (maximum permissible level) for drinking water
Category III : not satisfy the required criteria for drinking water

Source: Database of Hambantota and Monaragala district



: Satisfy the criteria (maximum desirable level) for drinking water

: Meet the criteria (maximum permissible level) for drinking water

: not satisfy the criteria (maximum permissible level) for drinking water

1): the available data of TDS in Monaragala is shortage.

FIGURE 7.14 UPPER FRACTURED AQUIFER CONDITION OF GROUNDWATER QUALITY (Existing Wells)

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- In general, parameters representing inorganic substances namely, electrical conductivity (EC), total hardness, total alkalinity, magnesium, total iron and fluoride, are at a high level.
- Approximately from 10 % to 20 % of tube wells in the Study area do not satisfy the criteria of EC, total hardness, total alkalinity, total dissolved solids (TDS), magnesium and fluoride for drinking water.
- Especially, total iron as high as approximately 50 % of tube wells exceed the criteria of total iron for drinking water.
- In comparison of Hambantota and Monaragala, concentrations of major inorganic substances of groundwater in Hambantota tend to be higher than in Monaragala, while concentration of total iron and fluoride in Monaragala are higher than in Hambantota.

The trace element in groundwater in Sri Lanka has been studied in Hydrogeochemical Atlas of Sri Lanka (C.B.Dissanayake et al., 1995). Based on this report, the concentration of trace element of groundwater in Hambantota is reported in the report as below.

Parameter	Max.	Min	No. of samples	Average	Standards in Sri Lanka	
					MDL	MPL
Vanadium	320 ppb	2 ppb	28	101 ppb	-	-
Cobalt	22 ppb	1 ppb	37	6 ppb	-	-
Chromium	19 ppb	1 ppb	37	8 ppb	-	0.05 mg/l *
Copper	72 ppb	2 ppb	27	18 ppb	0.05 mg/l	1.5 mg/l
Zinc	232 ppb	12 ppb	24	54 ppb	5.0 mg/l	15 mg/l

Note * : This criteria is required as upperlimit of concentration.

MDL : Maximum Desirable Level, MPL: Maximum Permissible Level

Unit : 1 mg/l = 1,000 ppb

According to the existing available data, trace elements in Hambantota satisfy the criteria for drinking water in Sri Lanka. Accumulation of heavy metal data by further groundwater monitoring would be required for the confirmation.

(2) Regional Distribution of Groundwater Quality

Regional distributions of groundwater quality of the existing tube wells in the Study area are shown in *Figure 7.15 to 7.17 and Appendix G*. Based on this figure, the regional distributions of groundwater quality can be classified as two patterns. One is high concentration values centralise in the central to the western part of Hambantota (Pattern I). The other is high concentration values distributed in the western part of Monaragala to the western part of Hambantota (Pattern II).

The Characteristics of two regional distribution patterns are described as following.

1) Regional Distribution Pattern I

The distribution of EC is distinctive feature for this pattern, high concentration of EC is observed from central to the western part of Hambantota (See, *Figure 7.15*). Water quality items of TDS, total hardness, calcium, magnesium, chloride and sulphate also shows similar trend.

As the reasons, it seems that EC depends on the total concentration of dissolved inorganic substances. Similarly, TDS is a term used to describe the inorganic salts, which are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogencarbonate, chloride, sulphate, and nitrate anions. And hardness is caused by predominantly calcium and magnesium cations.

It seems that the regional distribution pattern I concerning EC, TDS, total hardness, maybe affected by the geological factors. In addition, the above groundwater quality items are accelerated to rise by the strongly influence of climatic factors in this area.

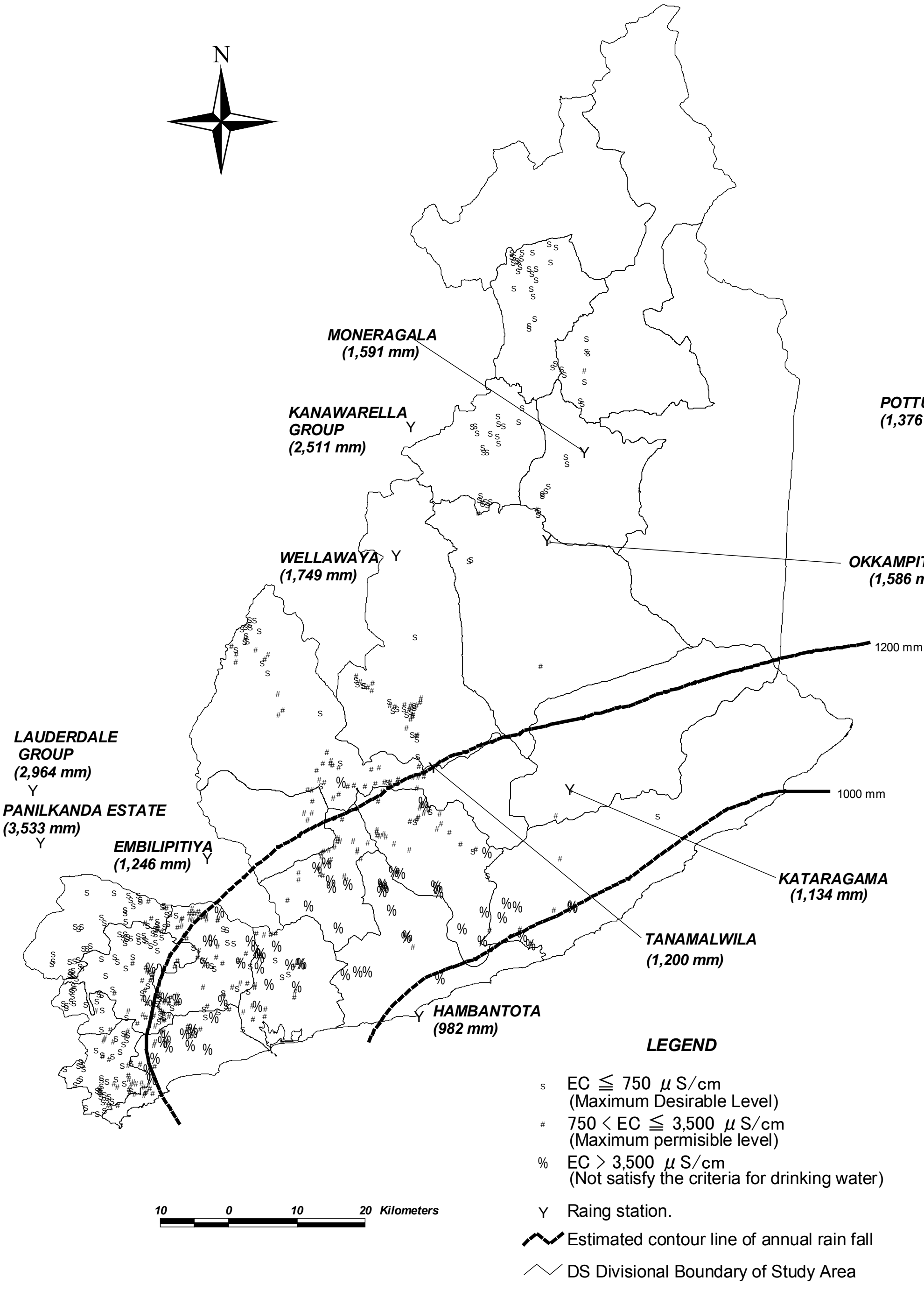

FIGURE 7.15 REGIONAL DISTRIBUTION OF GROUNDWATER QUALITY (EC)

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2) Regional Distribution Pattern II

High concentration of total iron was generally observed in the whole Study area. However, the high concentration areas of total iron are observed in the northern part of Monaragala, and the western part of Hambantota and Monaragala. The regional distribution of fluoride shows similar distribution to the one of total iron (See, *Figure 7.16* and *Figure 7.17)*.

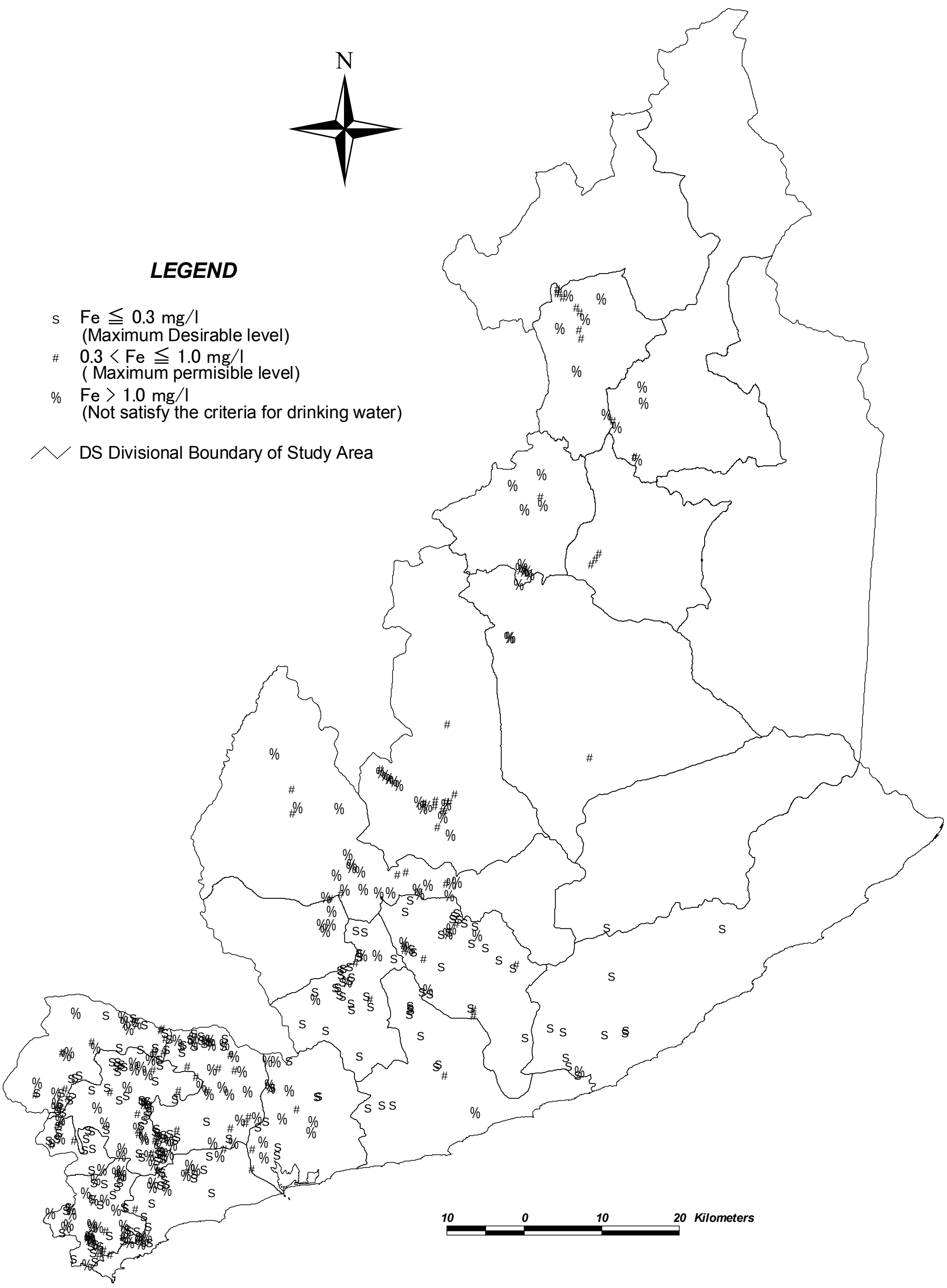

FIGURE 7.16 REGIONAL DISTRIBUTION OF GROUNDWATER QUALITY (TOTAL IRON)

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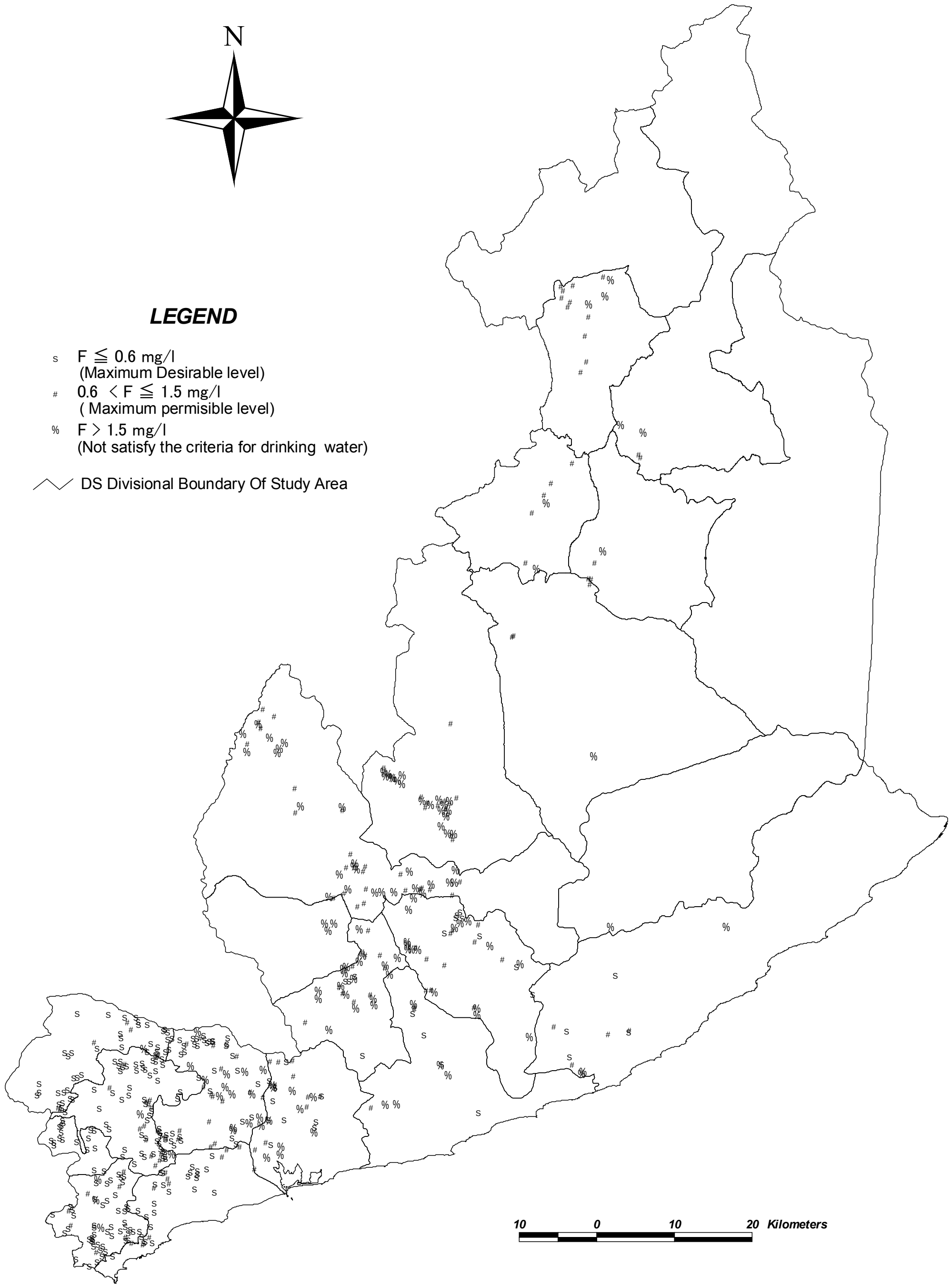

FIGURE 7.17 REGIONAL DISTRIBUTION OF GROUNDWATER QUALITY (FLUORIDE)

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(3) Stiff Diagrams and its Distribution

Based on the database and the results of periodical measurement of existing well survey, stiff diagrams of groundwater are illustrated by composition of main ionized substances to understand groundwater quality characteristics.

The investigation time and season of database are irregular, while the periodical measurement was carried out from September 2001 to May 2002. According to the results of periodical measurement, however, similar stiff diagrams throughout the term of investigation are obtained (See, *Appendix H*). Therefore, the examination of roughly regional distribution of water quality in the Study area was made by the database and the results of the first measurement.

The stiff diagrams are classified into five patterns by its shape. The classified stiff diagrams and its regional distribution are shown in *Figure 7.18(1), (2) and (3).*

The figure shows that three patterns of A, B and E are roughly distributed in northern part and western part of Monaragala, and the central part of Hambantota, respectively. In the western most of Hambantota, the other minor patterns are concentrated.

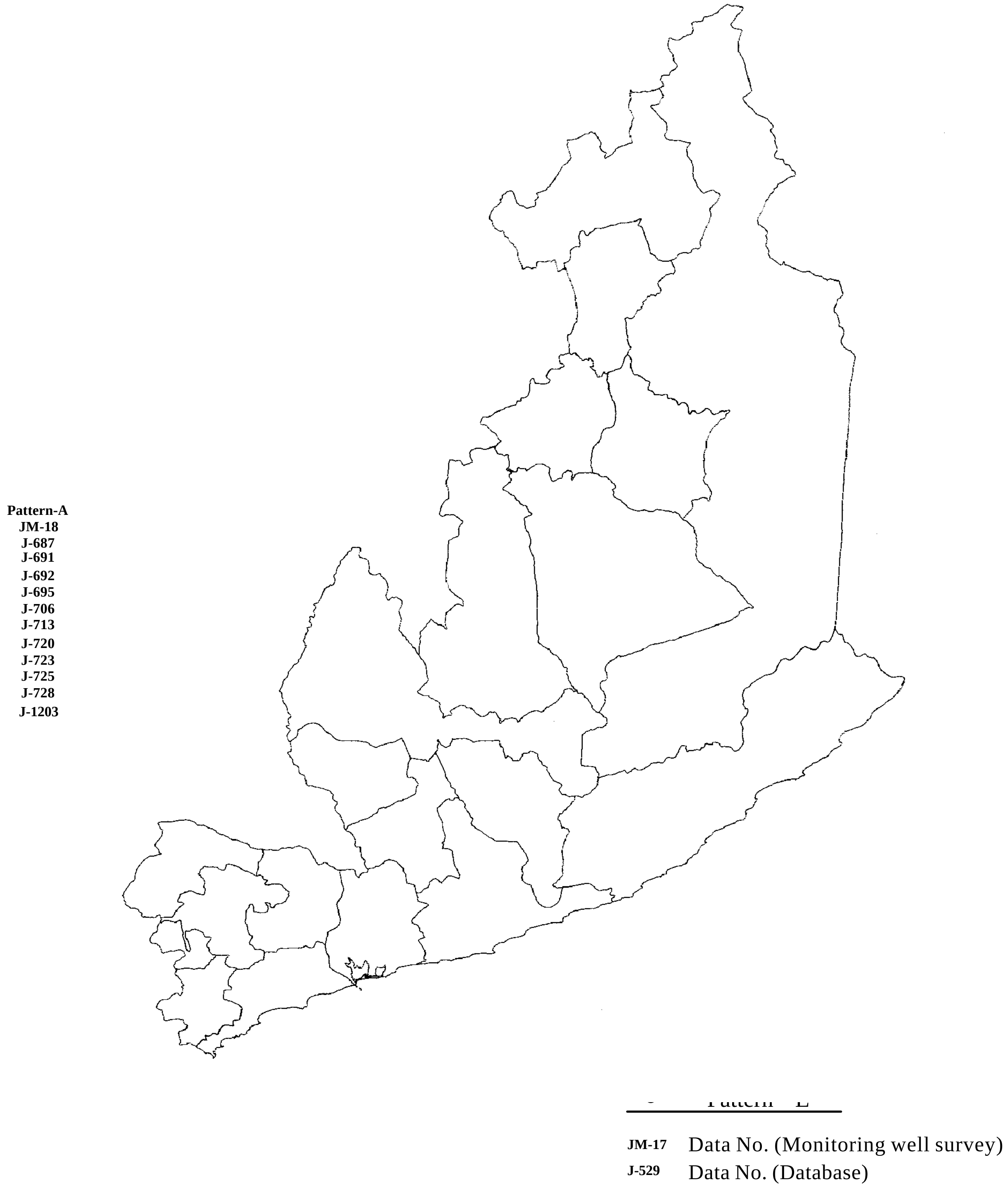

FIGURE 7.18(1) REGIONAL DISTRIBUTION OF STIFF DIAGRAMS (EXISTING WELL)

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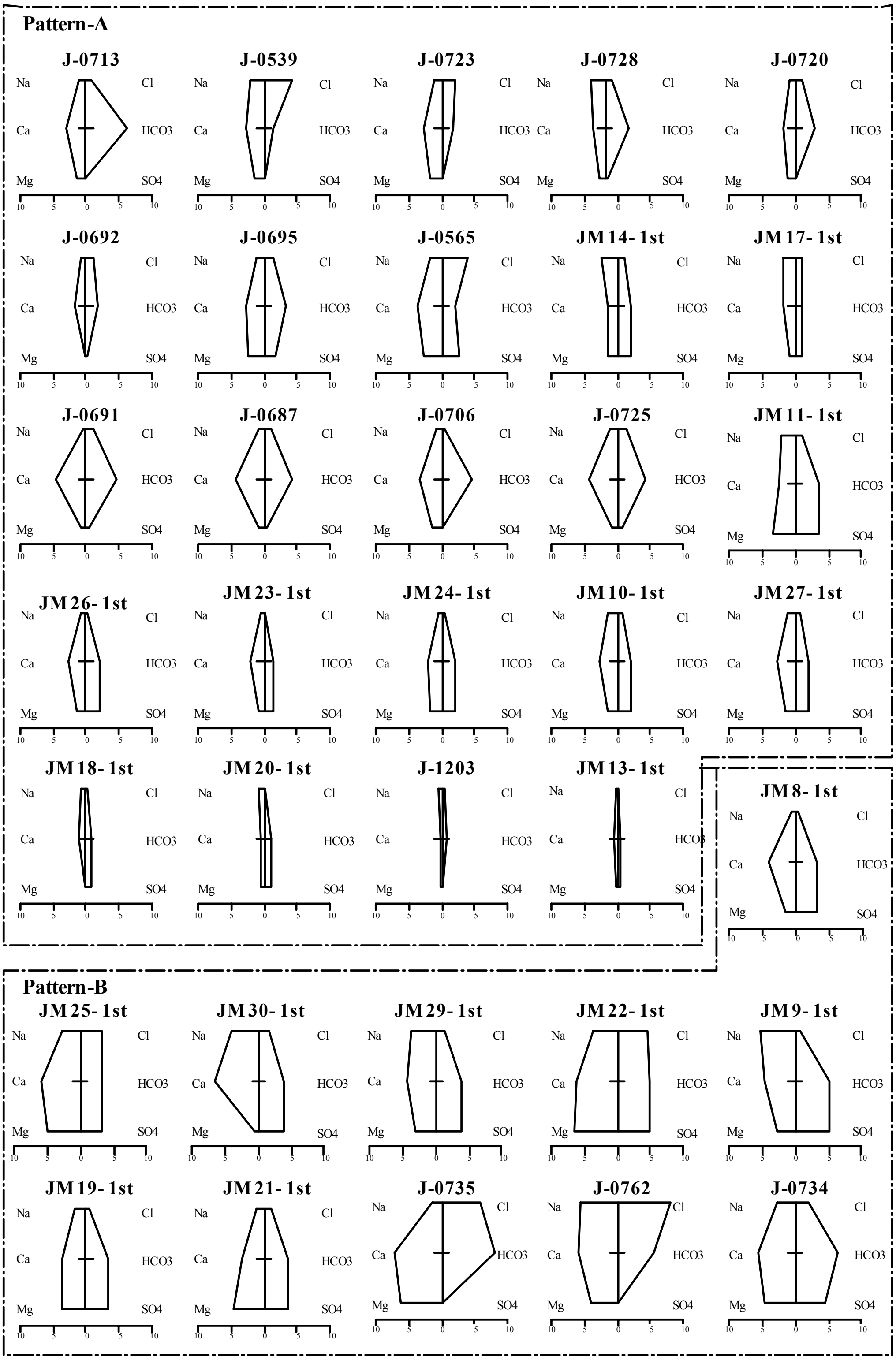

FIGURE 7.18 (2) REGIONAL DISTRIBUTION OF STIFF DIAGRAMS (THE EXISTING WELLS)

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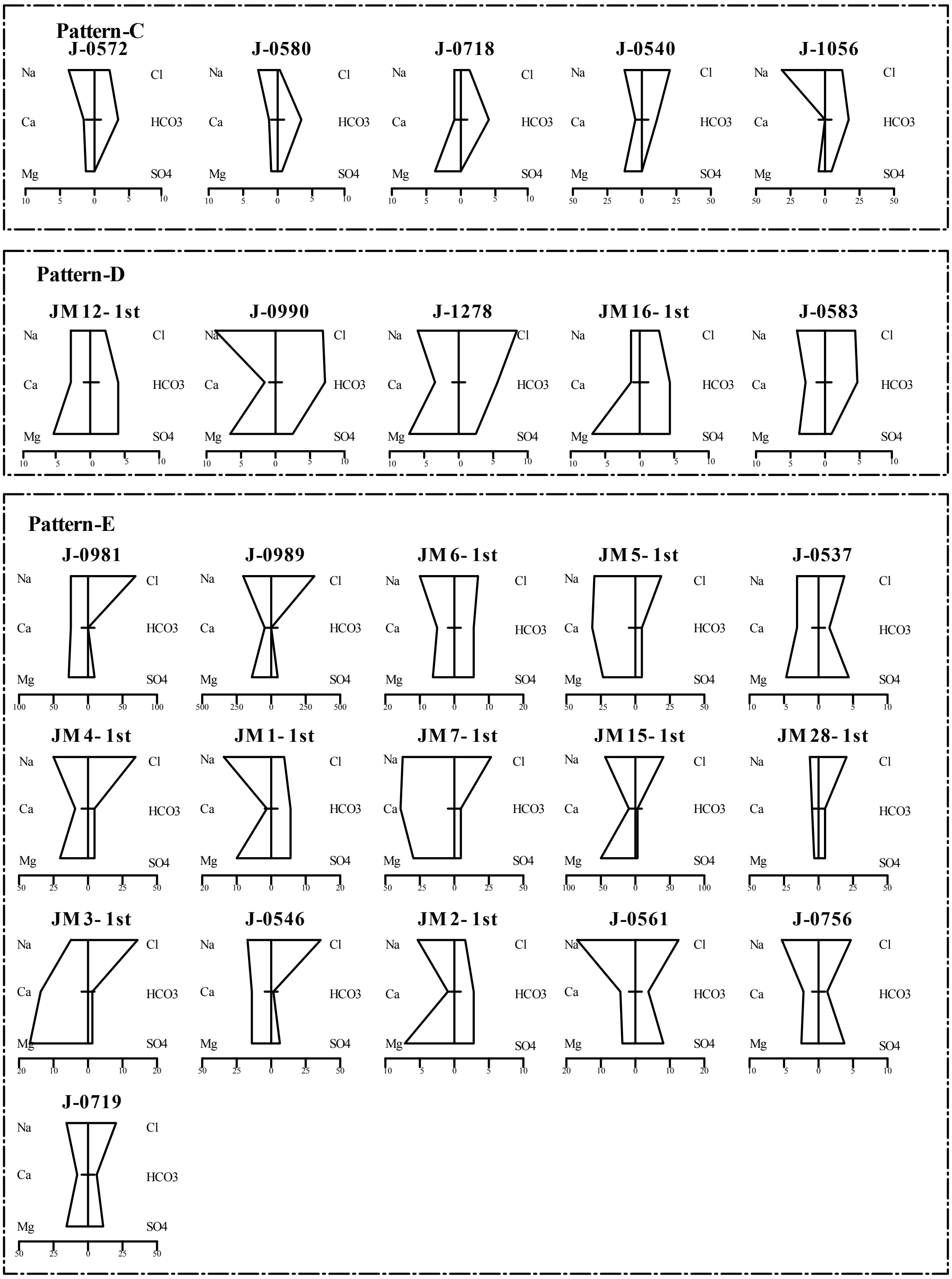

FIGURE 7.18 (3) REGIONAL DISTRIBUTION OF STIFF DIAGRAMS (THE EXISTING WELLS)

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7.5.2 Deep Aquifer Groundwater (as Water Quality Data of Test Well)

The water quality analysis of the test well as deep aquifer groundwater is carried out in this Study. Objective test wells are six test wells in Hambantota and six wells in Monaragala. According to the results of water quality analysis, possibility of utilization for drinking water and its characteristics are described below.

(1) Satisfaction of the Criteria for Drinking Water

Based on the results of water quality analysis of 12 test wells, water quality is described with a point of view of the requirement of the criteria for drinking water.

Comparison between the requirements of criteria for drinking water and the results of water quality analysis, problems of water use for drinking are summarised as below. (See, *Table 7.3(1) and (2)*)

- Pahala Mattala in Hambantota and Yalabowa in Monaragala satisfy the all criteria (Maximum Permissible Level) for drinking water. However, 10 test wells among 12 test wells do not appropriate for drinking purpose without purification.
- From the results of analysis of 12 test wells, it is found that 12 items of the requirements of criteria for drinking water do not satisfy, namely, pH, EC, total hardness, total alkalinity, TDS, calcium, magnesium, total iron, chloride, fluoride, lead and chromium.
- Especially, six test wells have high concentration of salt content, which is expressed by electrical conductivity, total hardness, total dissolved solids and other dissolved substances. It is difficult to purify by an ordinary purification method for water supply system as coagulation-filtration method.
- The above six test wells are Siyambalagaswila North, Wediwewa, Keliyapura, Talunna and Tammennawewa in Hambantota and Bodagama in Monaragala.
- Furthermore, Wediwewa and Keliyapura have chromium, which exceed the criteria for drinking water. And high concentration of lead was detected at Sevanagala. These heavy metals are health-related drinking water contaminants.

Table 7.3 (1) Satisfaction of the Criteria for Drinking Water (Hambantota)

Location	Siyambalagaswila North	Talunna	Wediwewa	Keliyapura	Pahala Mattala	Tammennawewa	Standards for Drinking Water	
Sample No. Labeled	H-1(J-6/H7)	H-2(J-2/H3)	H-3(J-3/H4)	H-4(J-1/H1)	H-5(J-5/H6)	H-6(J-4/H5)	Maximum Desirable Level	Maximum Permissible Level
Date of Collection	16.03.2002	10.03.2002	22.02.2002	23.02.2002	14.03.2002	06.02.2002		
Appearance	turbid	turbid	Clear	turbid	turbid	Turbid	-	-
Temperature (°C)	33.5	32.7	33.2	32	33.9	32.6	-	-
Colour (Hazen Units)	5	5	10	10	5	5	-	-
Odor	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Unobjectionable
Taste	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Objectionable	Unobjectionable	Unobjectionable
pH	7.9	6.8	12.1	12.1	8.7	7.8	7.0 to 8.5	6.5 to 9.0
Electrical Conductivity (mS/cm)	9.1	2.8	9.4	5.9	1.2	4.4	0.75 mS/cm	3.5 mS/cm
Total Hardness as $CaCO_3$ (mg/l)	4,060	1,200	980	1,200	500	1,700	250 mg/l	600 mg/l
Total Alkalinity as $CaCO_3$ (mg/l)	150	50	1,900	1,400	325	200	200 mg/l	400 mg/l
Total Dissolved Solids (mg/l)	4,970	1,380	5,130	3,150	1,060	2,270	500 mg/l	2,000 mg/l
Sodium (Na^+)	750	208	900	130	450	500	-	-
Potassium (K^+) mg/l	130	70	600	90	50	60	-	-
Calcium (Ca^{2+}) mg/l	724	328	164	400	96	360	100 mg/l	240 mg/l
Magnesium (Mg^{2+}) mg/l	1,082	92	138	48	63	194	30 mg/l if SO4 >=250mg/l 150 mg/l if SO4 <250mg/l	140 mg/l
Total Iron (Fe^{3+}) mg/l	0.6	0.1	0.1	1.4	0.6	0.4	0.3 mg/l	1.0 mg/l
Chloride (Cl^-) mg/l	2,800	780	520	100	430	1,200	200 mg/l	1,200 mg/l
Sulphate (SO_4^{2-}) mg/l	880	292	660	350	300	735	200 mg/l	400 mg/l
Fluoride (F^-) mg/l	0.7	0.3	0.6	0.6	0.9	0.6	0.6 mg/l	1.5 mg/l
Bicarbonate (HCO_{3-}) mg/l	150	50	160	120	325	200	-	-
Nitrate (NO_3) mg/l	<0.01	0.40	0.07	0.50	<0.01	0.02	-	10 mg/l
Lead (as Pb) mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	0.05 mg/l *
Cadmium (as Cd) mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.005 mg/l *
Arsenic (as As) mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	0.05 mg/l *
Chromium (as Cr) mg/l	<0.005	<0.005	0.100	0.080	<0.005	<0.005	-	0.05 mg/l *

Note * : the criteria are required as upper limit of concentration.

[shaded box] : This value exceeds the criteria (maximum permissible level) for drinking water.

Table 7.3 (2) Satisfaction of the Criteria for Drinking Water (Monaragala)

Location	Sevanagala	Bodagama	Badalkumbra	Yalabowa	Bodagama	Yalabowa	Standards for Drinking Water	
Sample No. Labeled	M-1(J-10/M7)	M-2(J-7/M2)	M-3(J-9/M6)	M-4(J-8/M5)	Additional[1)]	Additional[1)]	Maximum Desirable Level	Maximum Permissible Level
Date of Collection	02.07.2002	02.07.2002	10.08.2002	19.07.2002	21.10.02	26.09.2002		
Appearance	turbid	Turbid	Clear	Clear	Clear	Clear	-	-
Temperature (^{o}C)	31.0	31.0	-	31.0	26.5	28.2	-	-
Colour (Hazen Units)	5	5	20	5	Colourless	Colourless	-	-
Odor	Unobjectionable	Unobjectionable	None	None	-	-	Unobjectionable	Unobjectionable
Taste	None	Salty	good	Normal	-	-	Unobjectionable	Unobjectionable
pH	10.4	7.9	7.4	7.6	6.8	6.9	7.0 to 8.5	6.5 to 9.0
Electrical Conductivity (mS/cm)	2.1	6.0	0.41	0.71	2.4	0.78	0.75 mS/cm	3.5 mS/cm
Total Hardness as $CaCO_3$ (mg/l)	14	1,220	310	360	361	314	250 mg/l	600 mg/l
Total Alkalinity as $CaCO_3$ (mg/l)	230	355	255	324	995	476	200 mg/l	400 mg/l
Total Dissolved Solids (mg/l)	1,060	3,140	194	835	1,603	515	500 mg/l	2,000 mg/l
Sodium (Na^{+})	290	590	12	31	-	-	-	-
Potassium (K^{+}) mg/l	36	60	5	8	-	-	-	-
Calcium (Ca^{2+}) mg/l	4.8	115	56	90	51	57	100 mg/l	240 mg/l
Magnesium (Mg^{2+}) mg/l	0.6	270	40	33	57	42	30 mg/l if SO4 >=250mg/l 150 mg/l if SO4 <250mg/l	140 mg/l
Total Iron (Fe^{3+}) mg/l	0.6	0.4	1.2	0.5	0.3	0.3	0.3 mg/l	1.0 mg/l
Chloride (Cl^{-}) mg/l	96	860	7	30	244	25	200 mg/l	1,200 mg/l
Sulphate (SO_4^{2-}) mg/l	232	430	4	56	78	95	200 mg/l	400 mg/l
Fluoride (F^{-}) mg/l	1.3	0.9	0.6	0.6	1.7	0.5	0.6 mg/l	1.5 mg/l
Bicarbonate (HCO_{3-}) mg/l	10	354	255	248	-	-	-	-
Nitrate (NO_3-N) mg/l	<0.05	<0.05	0.3	ND	-	-	-	10 mg/l
Lead (as Pb) mg/l	0.062	0.027	<0.01	<0.01	<0.01	<0.01	-	0.05 mg/l *
Cadmium (as Cd) mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	0.005 mg/l *
Arsenic (as As) mg/l	<0.001	<0.001	-	<0.001	-	-	-	0.05 mg/l *
Chromium (as Cr) mg/l	0.027	0.01	<0.005	<0.005	<0.005	<0.005	-	0.05 mg/l *

Note * : the criteria are required as upper limit of concentration. [shaded box] : This value exceeds the criteria (maximum permissible level) for drinking water.

ND : Not detected. It means that the concentration is under the limits of detection. Additional [1)] : Well depth is about 100 m.

(2) Stiff Diagrams and its Distribution

Based on the results of the test well and its neighboring the existing tube well, stiff diagrams of groundwater are illustrated, and are shown in *Figure 7.19.*

The similar diagrams between the existing tube well and the test well are observed (except Keliyapura H-4(J-1/H1), although its depths are different.

The result suggest that the hydrogeological correlation of the upper fractured aquifer of the existing wells and lower fractured aquifer of the test wells.

In contrast, no likeness of stiff diagrams between the existing tube well and the test well in Monaragala are found. It can be said that the groundwater quality in these test wells have a higher concentration of major ionized substances, namely Na^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, HCO_3^{2-} and SO_4^{2-}, than the existing tube well, except Yalabowa M-4(J-8/M5).

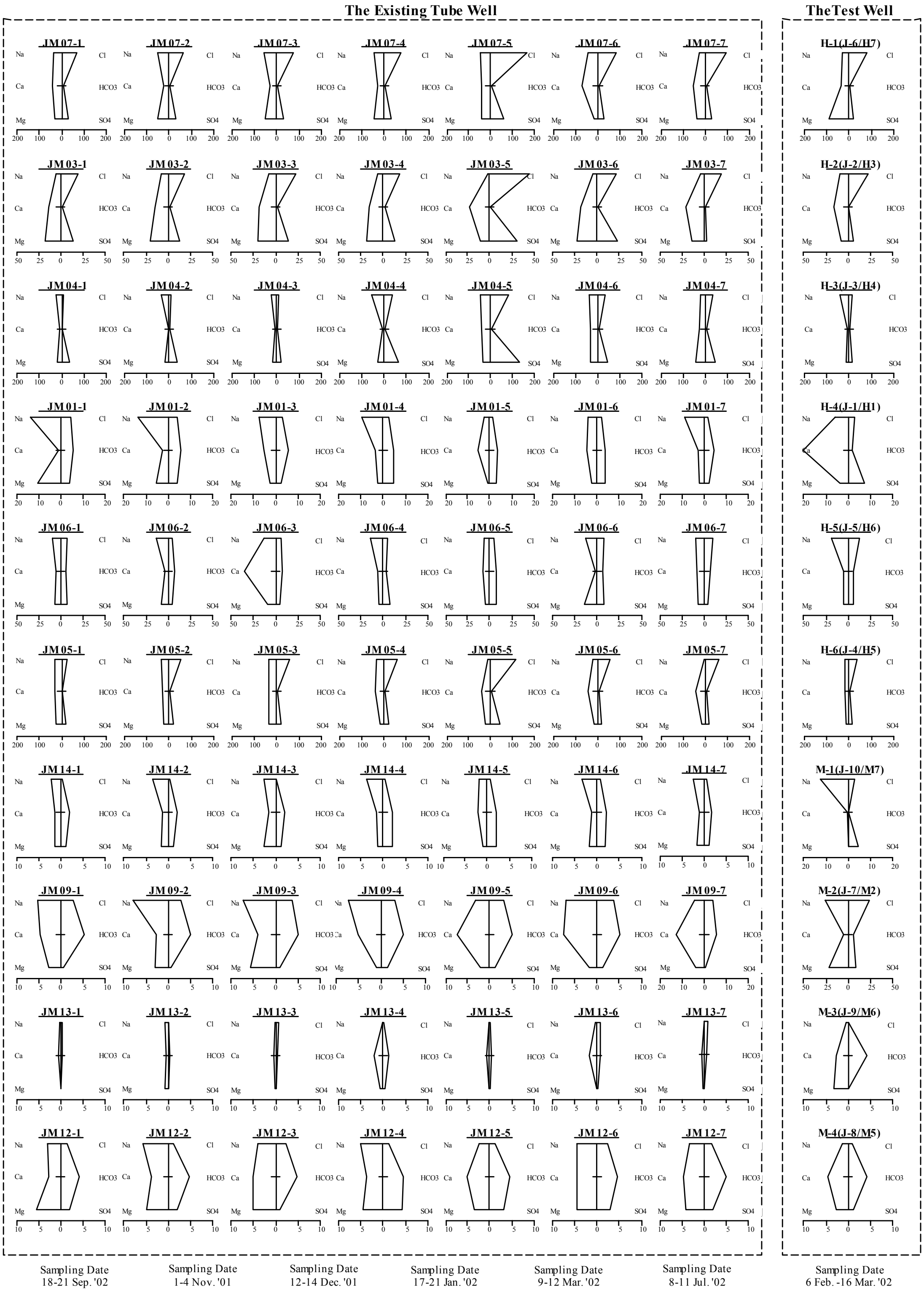

FIGURE 7.19 STIFF DIAGRAMS OF EXISTING WELLS AND TEST WELLS

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(3) Consideration of Purification Method

Based on the results of water quality analysis of the test wells, it is found that groundwater quality of some test wells are not satisfied the water quality standards for drinking water in Sri Lanka. It is necessary to purify the groundwater, if it would be utilized for drinking purpose. In this section, the required purification methods are described.

According to the results of water quality analysis of the test well (refer to *Table 6.5*, *Supporting 6*), objective water quality items of purification process are shown in *Table 7.4*. From this table, major purified items are classified with viewpoint of purification method as below.

Purification method	Major purified item
- Desalination:	salinity as EC, total hardness, TDS, total iron and other dissolved substances.
- Softening:	calcium and magnesium
- Defluoride:	fluoride
- Deferrization:	total iron
- pH control	pH and total alkalinity
- Coagulation-sedimentation and filtration for removal of heavy metals:	lead and chromium

Table 7.4 Required Purification Items for Test Wells

	Required Purification Items	H-1(J-6/H7) Siyambalagaswila North	H-2(J-2/H3) Talunna	H-3(J-3/H4) Wediwewa	H-4(J-1/H1) Keliyapura	H-5(J-5/H6) Pahala Mattala	H-6(J-4/H5) Tammennawewa	M-1(J-10/M7) Sevanagala	M-2(J-7/M2) Bodagama	M-3(J-9/M6) Badalkumbra	M-4(J-8/M5) Yalabowa	Bodagama Additional[1)]	Yalabowa Additional[1)]
	pH			O	O			O					
	EC	O		O	O		O		O				
	Total Hardness	O	O	O	O		O		O				
	Total Alkalinity			O	O							O	O
	TDS	O		O	O		O		O				
	Calcium	O	O		O		O						
	Magnesium	O					O		O				
	Total Iron				O					O			
	Chloride	O											
	Sulphate	O		O			O		O				
	Fluoride											O	
	Nitrate												
	Lead							O					
	Cadmium												
	Arsenic												
	Chromium			O	O								
Purification Process	Desalination	**O**	-	**O**	**O**	-	**O**	-	**O**	-	-		-
	pH control	-	-	-	-	-	-	-	-	-	-	**O**	**O**
	Softening	-	**O**	-	-	-	-	-	-	-	-	-	-
	Defluoride	-	-	-	-	-	-	-	-	-	-	**O**	-
	Deferrization	-	-	-	-	-	-	-	-	**O**	-	-	-
	Removal of Heavy Metals	-	-	-	-	-	-	**O**	-	-	-	-	-

Note: "O" mark shows required treatment for drinking water.
Additional[1)] : Well depth is about 100 m.

The above purification processes are summarized below.

1) Desalination

Osmosis is the spontaneous passage of liquid from a dilute to a more concentrated solution across a semipermeable membrane that allows passage of the liquid but not of dissolved solids. Reverse osmosis is a process in which the natural osmotic flow is reversed by the application to the concentrated solution of sufficient pressure to overcome the natural osmotic pressure of the less concentrated (dilute) solution.

The primary advantage of reverse osmosis is its high percentage of rejection of dissolved solids from the raw water. The rejection allows contaminated, brackish, and saline water to be desalted for drinking purpose. A schematic of this system is shown in *Figure 7.20*.

Reverse osmosis has several advantages as below.

- High percentage of rejection of almost dissolved solids from the raw water, including chromium, lead and fluoride.
- No generation of sludge.

However, Reverse osmosis has several disadvantages:

- High initial and operation costs.
- Need for pretreatment or turbid raw water treatment with acid and other chemicals to prevent fouling of the membranes by slimes, suspended solids, iron, manganese, and precipitates of calcium carbonate and magnesium hydroxide.
- Need to stabilize finished water with lime or other chemicals to prevent corrosion in distribution systems.
- Disposal of the reject wastewater from reverse osmosis process.

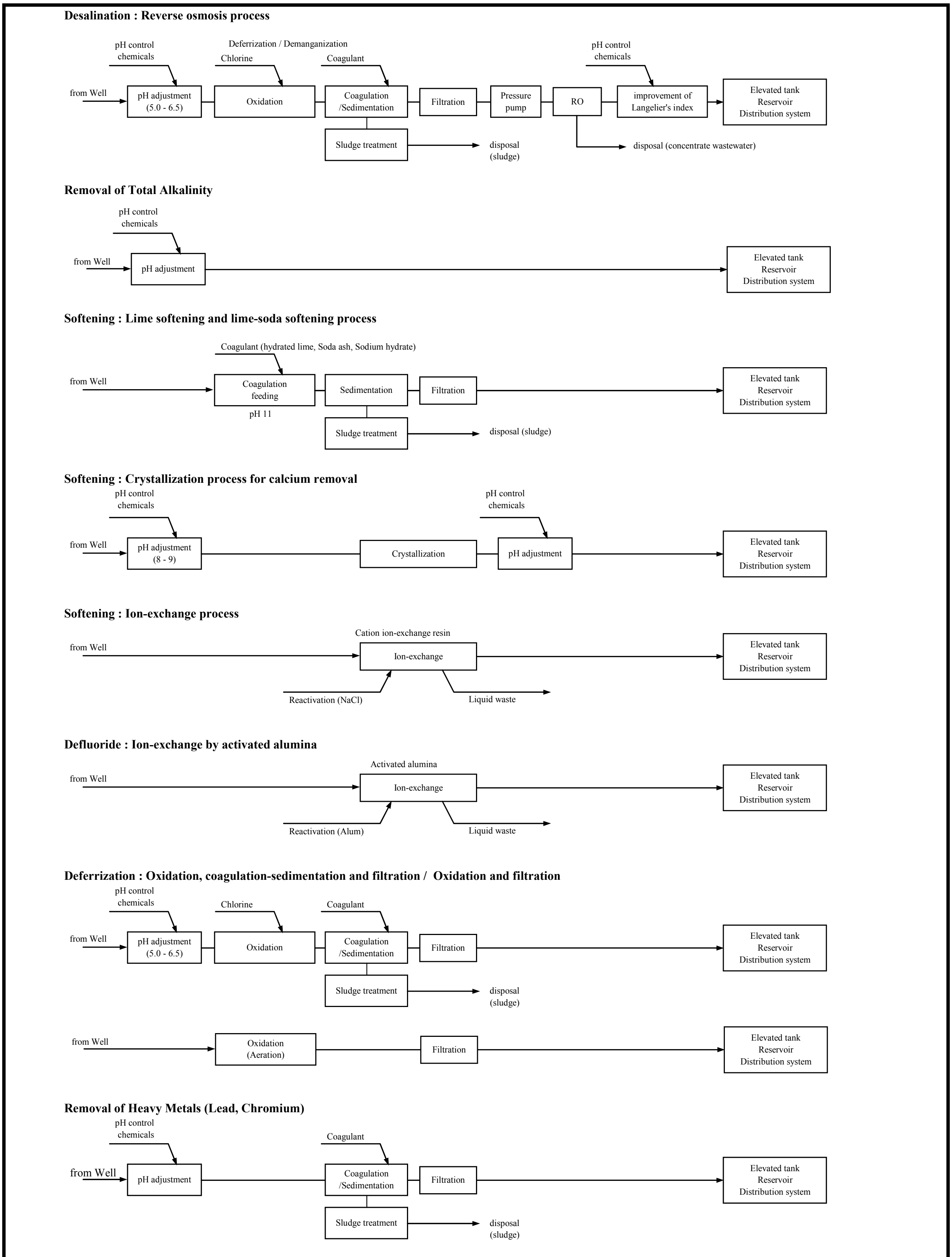

FIGURE 7.20 FLOW SHEET OF PURIFICATION PROCESSES

2) pH Control

Total alkalinity could be improved by addition of pH control chemicals, required treatment facilities are flow meter, flush mixing tank, chemical feeding facilities and pH meter. A schematic of this system is shown in *Figure 7.20*.

3) Water Softening

Hardness is expressed in terms of the sum of the concentration of polyvalent ions, the principal ones being calcium and magnesium. Therefore, removal of calcium and magnesium is required as purification method. There are presently major types of softening processes: lime softening/lime-soda ash softening, crystallization process for calcium removal. These softening processes are summarized below.

Lime softening and lime-soda softening

Lime, the primary chemical used in water softening, is used to neutralize carbon dioxide, to convert bicarbonate to carbonate alkalinity, and to precipitate calcium carbonate and magnesium hydroxide. According to this reaction, temporary hardness could be removed. Additionally, in the lime-soda softening, permanent hardness can be removed by using sodium carbonate. These softening processes have several disadvantages: production of sludge, pH adjustment after softening process and requirement of a large-scale purification plant as same as coagulation-sedimentation and filtration process at the ordinary water supply system. A schematic of this system is shown in *Figure 7.20.*

Crystallization process for calcium removal

Caustic soda (Sodium hydroxide, NaOH) is used to pH adjustment (pH 8-9), and calcium in water could be crystallized on a media of filtration. A schematic of this system is shown in *Figure 7.20*. This process has several advantages: no required sludge treatment and purification plant is comparatively simplicity. However, magnesium as the main ingredient could be not removed.

Total hardness of the objective test well (Talunna) is 1,200 mg/l as $CaCO_3$, and its breakdown is as below.

Ca = 328 mg/l Ca-hardness = 328 x 2.5* = 820 mg/l as $CaCO_3$

Mg = 92 mg/l Mg-hardness = 92 x 4.1* = 377 mg/l as $CaCO_3$

Total Hardness ≒ 1,200 mg/l as $CaCO_3$

*: Constants of 2.5 and 4.1 in the above formulas are calculated by molecular weight of Calcium (Ca = 40.08), Magnesium (Mg = 24.32) and Calcium Carbonate ($CaCO_3$ = 100.09).

Thus, the standards for drinking water (Maximum Permissible Level: Total Hardness is 600 mg/l as $CaCO_3$) could be satisfied to remove approximately 75 percent of calcium by the crystallization process for calcium removal process. It is necessary to introduce the lime-soda ash softening or ion-exchange process, if consumers (users) in the planning area require the maximum desirable level in the Standards for drinking water.

4) Defluoride

There are some major types of purification processes for fluoride as reverse osmosis process, lime softening process and ion exchange by activated alumina. As others process, fluoride could also be removed by alum coagulation; however, extremely high coagulation doses were required, and the process was not considered to be economical. The reverse osmosis process and lime softening process are described the above. The ion exchange by activated alumina is summarized below.

Ion exchange by activated alumina

Activated alumina is the exchange medium of choice for fluoride removal because of its low cost compared with bone char or synthetic resins and its greater ion-exchange capacity. This process has several advantages: no required sludge treatment simplified operation/maintenance and small-scale plant, and activation of exchange medium by alum is easily. Therefore, this process is an excellent process for small utilities. It can be installed on a rural water system and individual purification unit for POU (point of use) /POE (point of entry). A schematic of this system is shown in *Figure 7.20.*

There is precedent of individual purification unit for POU (point of use) in Mongolia, China (JICA, 1999). For reference, the specifications of individual purification unit for fluoride are as below.

Purpose / Installation:	Drinking water / Household
Design capacity (ability):	12 – 20 L/household/day (15 litter/hr.) x 2 series
Concentration of Fluoride:	Raw water = 1.5 – 5.0 mg/l (max. 10 mg/l)
	Treated water = less than 1.0 mg/l
Activation process:	Chemicals (Alum)
Operation / Maintenance:	User
Frequency of activation:	once for from 1.5 to 7 months
Equipment costs :	560 – 660 china currency unit (about 67-79 dollar)
Exchange medium:	60 china currency unit/3-14 years (about 7.2 dollar)
Chemicals for activation:	0.2 china currency unit (about 0.02 dollar)

(Assuming that 100 china currency unit equals 12 US dollar)

5) Deferrization

Generally, groundwater contains iron as ferrous compound in solution. The typical removal process of iron in water consists of two stages, first stage is oxidation by chlorination or aeration from the dissoluble ferrous compound to the non-dissoluble ferric compound, and second stage is coagulation-sedimentation and filtration process or filtration process only. A schematic of this system is shown in *Figure 7.20.*

6) Coagulation-sedimentation and filtration for removal of heavy metals

Lead could be removed from water by coagulation-sedimentation and filtration and by softening process. Coagulation and quick filtration process as a commonly purification process for water supply system is recommended for removal of lead, and this process is expects more than 95 percent of removal efficiency.

Chromium (trivalent state, $Cr+3$) is easily removed from water using alum and ferric sulphate coagulation, and by lime softening as lead. Lime softening achieved 98 percent removal in the pH range of 10.6 to 11.3. Neither alum, ferric sulphate coagulation nor lime softening is effective for removal chromium (hexavalent state, $Cr+6$) from water. Ferrous sulphate has shown to be effective because of its ability to reduce chromium ($Cr+6$) to chromium ($Cr+3$). Therefore, it necessary to analysis a component ratio of chromium ($Cr+6$) and chromium ($Cr+3$).

Recommendation: Purification Method for the rural water supply system

The groundwater development plan in this Study aims for establishment of the rural water supply system. Therefore, the groundwater development plan should be planned paying attention to small-scale facilities, simplified operation/maintenance and low costs. Generally, it is an ordinary way in the groundwater development plan that the other water resources would be selected as alternatives, if groundwater quality would be not satisfied the drinking water standards. However, it is difficult to found the other water resources for water supply system in the Study area.

According to the above background, it would be attempted that as much as possible the deep aquifer groundwater would be utilized for the rural water supply system. Required purification processes are compared with the coagulation-sedimentation and filtration process as ordinary purification process of water supply system, and shown in *Table 7.5*.

From judgement in *Table 7.5*, it is not difficult to introduce the following purification methods as the rural water supply system.

- Removal of total alkalinity by pH control process.
- Softening by crystallization process.
- Defluoride by ion exchange process using activated alumina.
- Deferrization by oxidation and filtration process.

While, from the viewpoint of costly, high-consumption of energy and requirement of an accurate operation/maintenance, desalination process and coagulation-filtration process for heavy metals are not feasible method for the rural water supply system.

Table 7.5 Comparison between Required Purification Method and the Ordinary Process for Water Supply System

Purification Method	Costs	Consumption of Energy	Applicable to POU/POE	Generation of Sludge	Difficulty of Operation /Maintenance	Overall
Desalination						
Reverse osmosis	Higher	Higher	Possible	No	Same Level	Disadvantage
Removal of Total Alkalinity						
pH control process	Lower	Lower	Possible	No	Simplified	Advantage
Softening						
Lime softening /lime-soda ash softening	Same Level	Same Level	Uncertain	Yes	Same Level	Same level
Crystallization process for calcium removal	Lower	Lower	Possible	No	Simplified	Advantage
Defluoride						
Ion-exchange by activated alumina	Lower	Lower	Possible	No	Simplified	Advantage
Coagulation -Sedimentation	Same Level	Same Level	Uncertain	Yes	Same Level	Same level
Lime softening process	Same Level	Same Level	Uncertain	Yes	Same Level	Same level
Deferrization						
Oxidation and Coagulation -Sedimentation / Filtration	Same Level	Same Level	Uncertain	Yes	Same Level	Disadvantage
Oxidation and Filtration	Lower	Lower	Uncertain	No	Simplified	Advantage
Removal of Heavy Metals						
Coagulation -Sedimentation / Filtration	Same Level	Same Level	Uncertain	Yes	Same Level	Same level
Lime softening process	Same Level	Same Level	Uncertain	Yes	Same Level	Same level
Reverse osmosis process	Higher	Higher	Possible	No	Same Level	Disadvantage

Note: The ordinary purification process is coagulation-sedimentation and filtration process.
POU and POE are abbreviation for point of use and point of entrance, respectively.

7.5.3 MAJOR FINDINGS

As the results of the groundwater quality survey in the Study area, the following major findings are obtained.

i) In the existing wells, high values of EC, total hardness and ionized substances, which do not satisfy the criteria for drinking water were observed in the central part to the western part of Hambantota (See, *Figure 7.15*).

ii) In the existing wells, high concentrations of fluoride and total iron are distributed in the western part of Hambantota to the western part of Monaragala and the northern part of Monaragala (See *Figure 7.16* and *Figure 7.17*).

iii) According to the results of groundwater analysis of 12 test wells in the Study area, it became clear that Pahala Mattala in Hambantota and Yalabowa in Monaragala satisfy the criteria (Maximum permissible level) for drinking water.

iv) However, six test wells contain high salt content, which is expressed by EC, total hardness and TDS. Moreover, high concentration of chromium was detected at two test wells (Keliyapura and Wediwewa in Hambantota), and one test well (Bodagama in Monaragala) contaminated with lead.

v) From the comparison between stiff diagrams of the test wells and its neighbouring the existing tube well, hydrogeological correlation between the upper and lower fractured aquifer can be expected (See, *Figure 7.19*). In contrast, no likeness of stiff diagrams between the existing tube well and the test well in Monaragala are found.

vi) From viewpoint of costs, energy consumption and operation/maintenance, it is suggested that the following purification processes could be applied for the rural water supply systems in Hambantota and Monaragala.
- Removal of total alkalinity by pH control process.
- Softening by crystallization process.
- Defluoride by ion exchange process using activated alumina.
- Deferrization by oxidation and filtration process.

vii) However, from the same viewpoint, it seems that an introduction of purification method for desalination and removal of heavy metals are not feasible. It is recommended to consider alternatives of water resources or the study of the comprehensive of water resources development plan.

7.6 AQUIFER PROPERTIES

Although a lot of wells were drilled in the area, a pumping test had not been carried out for all wells. Only a few studies had reported on the pumping test to estimate aquifer properties. According to the studies, the transmissivity varied from 0.6 to 28.8m^2/day in the area (*Silva 1984, Karunaratne 1994*).

In the Study, the pumping tests were conducted after the completion of the test wells, which was already described in the *section of 5.5* and *6.4* in this report. The obtained aquifer properties of each well were summarized in *Table 7.6*. The specific capacity was calculated using the result of the constant discharge test. The tabulated values of the transmissivity are the mean value of the result of three kinds of analysis. The transmissivity divided by the screen length, if installed screen pipes, or the length of open hole part was considered to be the estimated hydraulic conductivity. In addition, if water level changing of the existing well was observed during the pumping from a test well, the analysed results were tabulated. The distribution of transmissivity was shown in *Figure 7.21*.

Table 7.6 Aquifer Properties (Transmissivity; *T*, Hydraulic Conductivity; *k*, Storativity; *S*)

Location	Well	Well Depth	Open Hole/ Screen Length	***Q/s***	***T***	***k***	***S***
		(m)	(m)	(l/min/m)	(m^2/day)	(m/day)	
Siyambalagaswila	H-1	200.4	20	(0.75)	0.14	7.00E-03	---
	JM07	33.53	23.17	2.04	2.02	8.72E-02	---
Talunna (Vitalandeniya)	H-2	194.4	16	15.34	25.29	1.58E+00	---
	JM02	36	25	1.81	4.09	1.64E-01	---
Wediwewa	H-3	200.4	20	(0.65)	0.18	9.00E-03	---
	JM04	44	(35)	0.07	0.17	4.86E-03	---
Keliyapura	H-4	200.2	32	(0.21)	0.14	4.38E-03	---
	JM01	33	(28)	1.72	1.30	4.64E-02	---
Mattala	H-5	200.4	32	0.72	0.85	2.66E-02	
				---	6.77	2.12E-01	2.72E-04
	H-5(2)	52.5	45.7	6.98	9.45	2.07E-01	
				---	4.74	1.04E-01	5.74E-04
	JM06	38	30.5	0.09	0.03	1.08E-03	---
Tammennawewa	H-6	102	20	13.98	31.93	1.60E+00	---
				---	18.83	9.42E-01	1.23E-04
	JM05	35.97	21.34	1.03	1.14	5.34E-02	---
Sevanagala	M-1	200.4	48	0.23	0.06	1.27E-03	---
	M-1(2)	40.8	35	3.05	1.10	3.14E-02	---
	JM14	45	(34)	2.24	1.55	4.56E-02	---
Bodagama	M-2	200.2	32	0.31	0.10	3.13E-03	---
	M-2(2)	100	60	15.40	53.20	8.87E-01	---
				---	81.90	1.37E+00	3.23E-04
	JM09	25.17	21.12	3.09	1.89	8.95E-02	---
Badalkumbra	M-3	88.3	20	215.91	741.00	3.70E+01	---
	JM13b	24.7	(18.7)	3.50	(2.56)	1.37E-01	---
Yalabowa	M-4	195	36	0.73	0.58	1.61E-02	---
	M-4(2)	100	64	46.92	53.70	8.39E-01	---
				---	89.40	1.40E+00	1.87E-03
	JM12	34.69	(22.69)	2.49	1.73	7.62E-02	---

*; Estimated figures **; Test conducted with an observation well.
(o.h); Open Hole

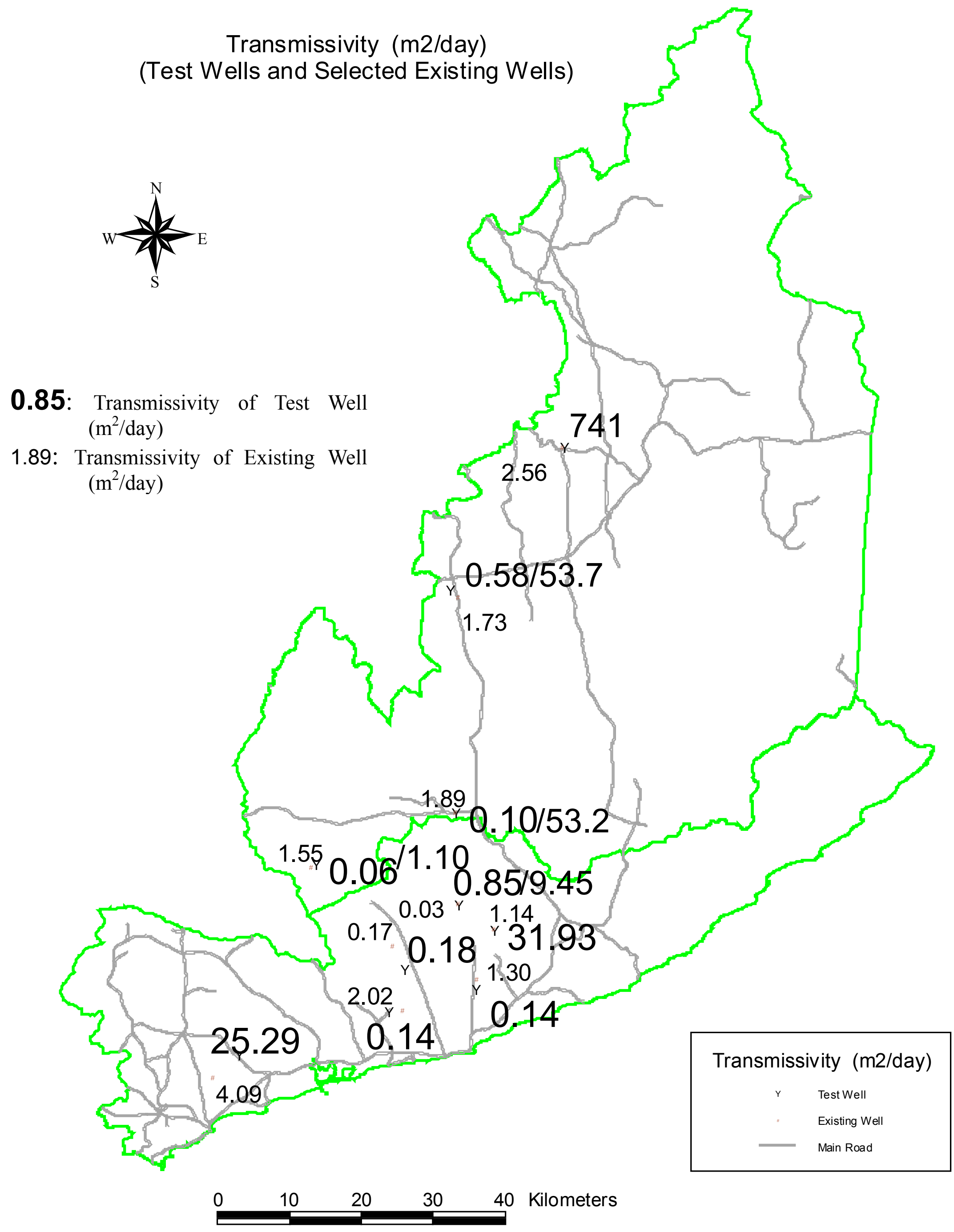

FIGURE 7.21 TRANSMISSIVITY

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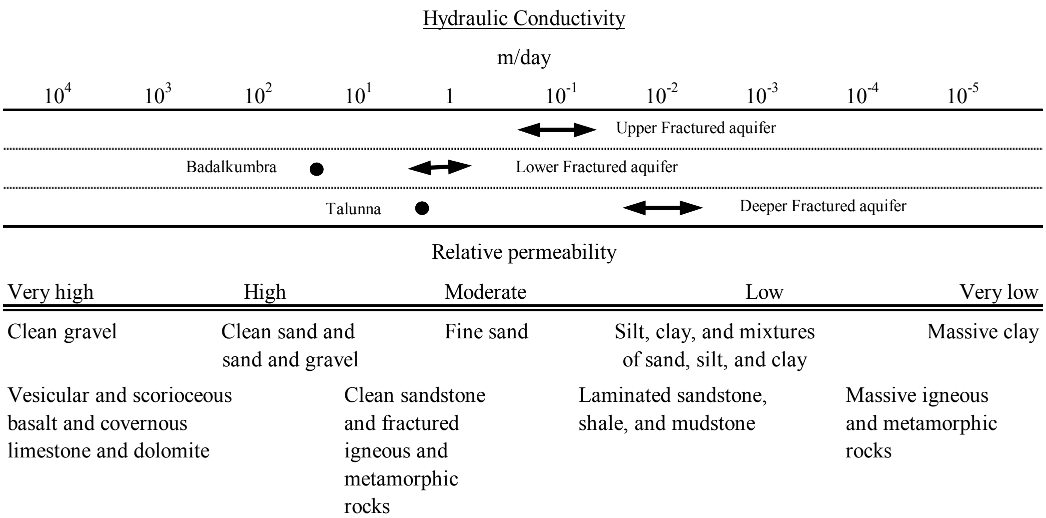
(1) Upper Fractured Aquifer (G.L.- 70 m)

Physical properties of the upper fractured aquifer were estimated mainly based on the pumping tests of the existing wells. The lowest transmissivity was 0.03 m^2/day in Pahala Mattala (JM06), the second lowest was 0.17 m^2/day in Wediwewa (JM04). In other areas, transmissivity ranges from 1.14 to 4.09 m^2/day. In Pahala Mattala, another pumping test was carried out for the additional well drilled by WRB. The estimated transmissivity was 9.45 m^2/day. And also, the analysis using the data of water level change in the test well No.H-5 was done. The transmissivity was estimated at 4.74 m^2/day. Either value was very high compared with the result derived from the existing well test (JM06). The additional test well was only 180 m from the JM06. It means that the developed level of fractured aquifer vary from place to place. Storativity, or storage coefficient, was obtained to be at 5.74 x 10^{-4} based on this analysis.

The estimated, or apparent, hydraulic conductivity ranges from 4.64 x 10-2 m/day (Keliyapura) to 1.64 x 10-1 m/day (Vitalandeniya) except Mattala, where the estimated value was 1.08 x 10-3 m/day.

The table below shows the general ranges of hydraulic conductivity for soils and rocks. The values of massive to fractured metamorphic rocks vary from 10^{-5} to 10^1 m/day. The foremost range of the obtained values in the Study area was also shown in the table.



after Kashef, A.I, GROUNDWATER ENGINEERING, 1987,
(U. S. Bureau of Reclamation, Ground Water Manual, U.S. Department of Interior, Washington, 1977.)

(2) Lower Fractured Aquifer (70 – 100 m)

There are four test wells installed screen pipes in the lower fractured aquifer, namely No.H-6 Tammennawewa, No.M-2(2) Bodagama, No.M-3 Badalkumbura, and No.M-4(2) Yalabowa.

The highest transmissivity was 741 m^2/day in Badalkumbra (No.M-3). In three other areas, the values of transmissivity were 31.9 (Tammennawewa), 53.2 (Bodagama) and 53.7 (Yalabowa) m^2/day. In Tammennawewa, the transmissivity of 18.8 m^2/day was another estimated result based on the analysis using the data of the observation well that was 77 m away from the pumped test well. Additional estimation of the transmissivity was conducted using the drilled test well as an observation well for Bodagama and Yalabowa, too. The results were 81.9 m^2/day in Bodagama and 89.4 m^2/day in Yalabowa. S, storativity, was obtained to be 1.23 x 10^{-4} from the pumping test of Well No.H-6 Tammennawewa, 3.23 x 10-4 from the test of No.M-2(2) Bodagama, and 1.87 x 10-3 from the test of No.M-4(4) Yalabowa.

The estimated, or apparent, hydraulic conductivity ranges from 8.39 x 10^{-1} m/day (Yalabowa) to 1.6 m/day (Tammennawewa) except Badalkumbra, where the estimated value of 3.70 x 10^1

m/day was outstanding.

(3) Deeper Fractured Aquifer (100 – 200 m)

The pumping tests of eight test wells have been completed for the deeper fractured aquifer. The highest value of the estimated transmissivity was 25.3 m^2/day in Talunna. The other estimated values range from 0.06 to 0.85 m^2/day. Generally the obtained values were rather low except Talunna. The presumed, or apparent, hydraulic conductivity varies mostly from 1.27 x 10^{-3} to 2.66 x 10^{-2} m/day and it suggests that the fractures in deeper zone develop poorly in general. Well No.H-2, Talunna, however, showed the presumed hydraulic conductivity was 1.58 m/day, which were a relatively high value. S, storativity, was estimated at 1.23 x 10^{-4} from the pumping test of Well No.H-5.

The estimated storativity by the Study varies from 1.23 x 10^{-4} to 5.74 x 10^{-4}. The fractured aquifer in the study area may be considered to have this range of storativity values.