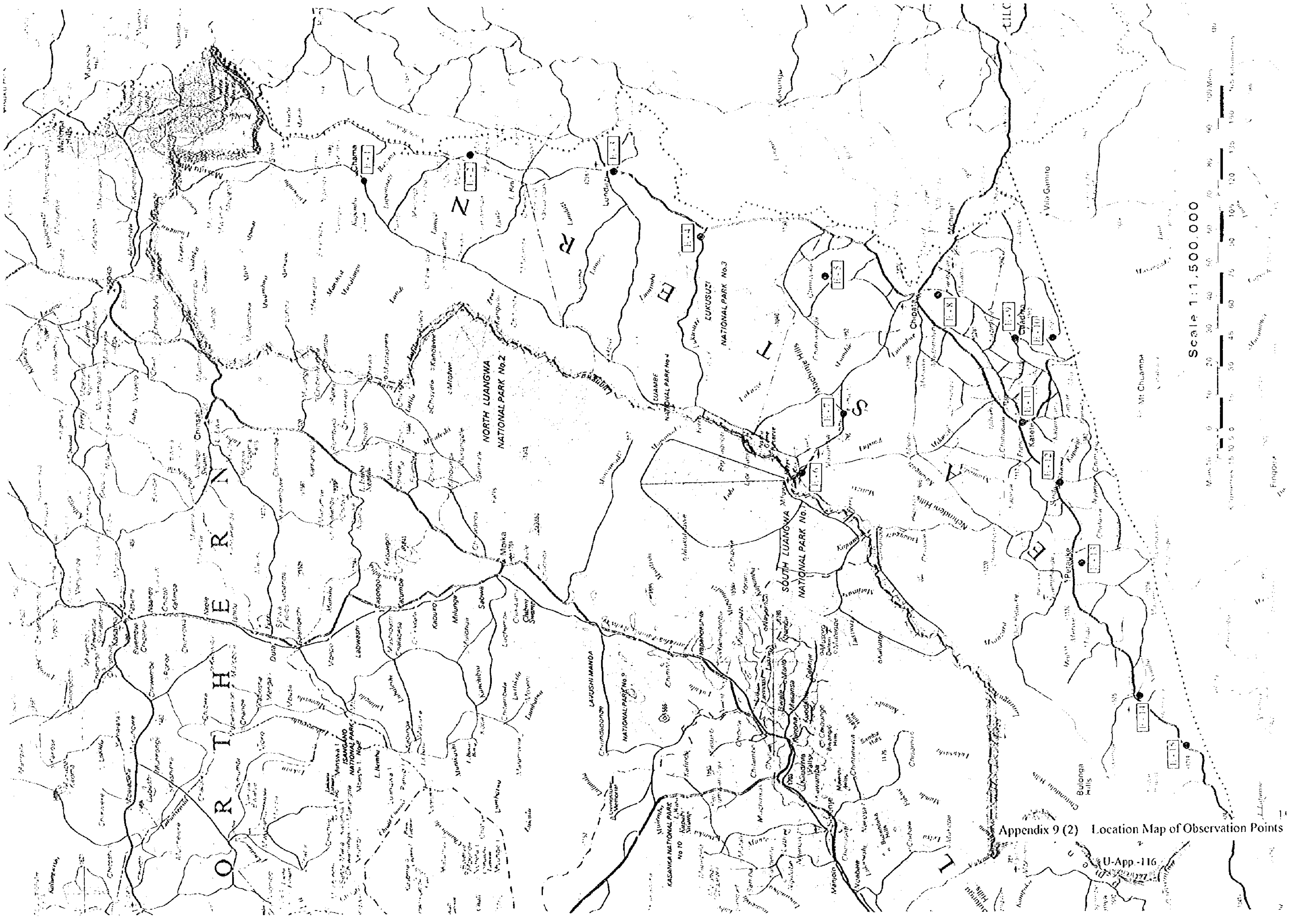


Appendix 9 (2) Location Map of Observation Points

Appendix 9 (3) Result of Nation-wide Groundwater Level Observation

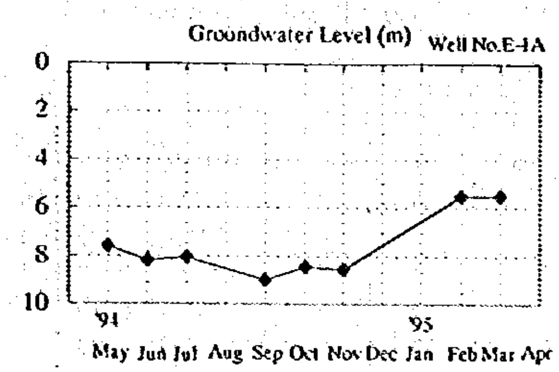
< Eastern Province >

Point No.	Well No.	May. 1994 G.W.D(m)	Jun. G.W.D(m)	Jul. G.W.D(m)	Sep. G.W.D(m)	Oct. G.W.D(m)	Nov. G.W.D(m)	Feb. 1995 G.W.D(m)	Mar. G.W.D(m)
E - 1	A	7.60	8.80	8.50	10.40	9.30	9.50	3.40	3.40
	B	4.60	7.80	9.20	10.20	12.20	10.60	3.50	3.50
E - 2	A	7.90	10.00	10.30	10.30	11.40	9.40	3.60	3.40
	B	5.60	8.90	10.40	12.00	13.30	11.00	4.80	4.40
E - 3	A	7.40	9.60	8.30	9.30	9.50	7.90	5.90	4.70
	B	3.90	5.10	8.00	8.60	12.00	8.60	5.00	4.50
E - 4	A	4.95	6.97	8.35	9.35	9.75	9.35	3.91	3.50
	B	2.88	3.88	9.60	11.10	11.90	9.90	4.40	4.40
E - 5	A	7.90	10.10	10.20	11.20	8.50	10.70	7.70	6.70
	B	4.53	14.20	10.70	10.70	11.30	10.70	8.60	7.80
E - 6	A	4.70	5.53	10.00	13.00	11.20	9.00	3.50	3.40
	B	4.80	7.70	10.60	11.90	12.60	9.80	4.20	3.90
E - 7	A	4.80	4.85	12.00	12.00	14.00	11.00	5.80	4.70
	B	5.33	6.33	7.80	8.80	9.90	8.40	6.20	4.50
E - 8	A	7.30	16.30	11.60	11.60	14.70	11.60	9.90	9.30
	B	7.30	9.35	9.90	11.10	9.60	10.10	6.60	6.40
E - 9	A	3.13	6.20	9.90	11.00	12.40	11.60	5.58	5.40
	B	3.00	4.05	8.90	9.90	7.90	9.30	7.90	6.90
E - 10	A	5.75	7.98	9.78	10.40	11.70	10.00	5.40	4.50
	B	3.25	4.30	9.25	9.40	10.60	9.20	6.40	6.20
E - 11	A	3.10	5.25	11.20	11.70	11.70	8.90	8.52	8.40
	B	2.30	4.45	13.10	13.10	14.80	7.78	7.20	6.60
E - 12	A	5.40	7.40	9.90	10.70	13.90	10.20	6.00	5.60
	B	4.80	6.80	9.50	10.30	12.20	8.30	6.40	6.30
E - 13	A	8.20	10.30	10.20	11.60	13.90	9.40	8.60	7.80
	B	6.80	9.00	9.90	11.20	12.60	10.20	7.40	7.40
E - 14	A	5.53	10.80	11.40	11.64	9.74	12.54	9.44	8.40
	B	3.10	4.20	12.30	13.90	13.20	12.00	11.80	10.60
E - 15	A	7.40	8.60	10.60	11.20	12.30	8.20	6.50	5.30
	B	-	-	10.10	10.60	11.90	8.60	5.40	4.40

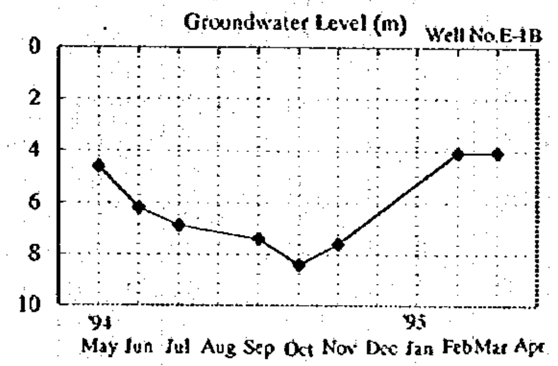
(Note) G.W.D : Groundwater Depth from Surface.

Appendix 9(4) Result of Observation

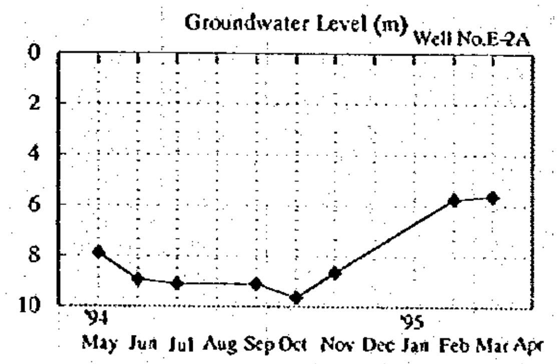
Province:	Eastern	Aquifer:	Alluvium	
District:	Chama			
Site Name:	Rhama Hos.	No.	Month	G.W.L(GL-m)
		1	94May	7.6
Diameter:	1250 mm	2	Jun	8.2
Depth:	15 m	3	Jul	8.05
Yield:	800 l/day	4	Sep	9
Map No.		5	Oct	8.45
Elevation:	760 m	6	Nov	8.55
Grid Ref.:	N=8760Km800m	7	95Feb	5.5
	E=517Km0m	8	Mar	5.5
Maximum Groundwater Level Fluctuation(m)				3.5



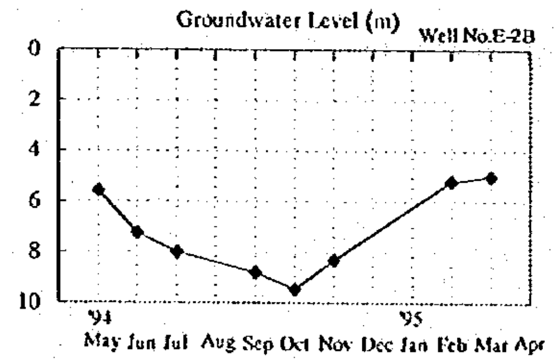
Province:	Eastern	Aquifer:	Alluvium	
District:	Chama			
Site Name:	Bazim	No.	Month	G.W.L(GL-m)
		1	94May	4.6
Diameter:	1250 mm	2	Jun	6.2
Depth:	11 m	3	Jul	6.9
Yield:	1800 l/day	4	Sep	7.4
Map No.	1133A3	5	Oct	8.4
Elevation:	755 m	6	Nov	7.6
Grid Ref.:	N=8754Km0m	7	95Feb	4.05
	E=512Km250m	8	Mar	4.05
Maximum Groundwater Level Fluctuation(m)				4.35



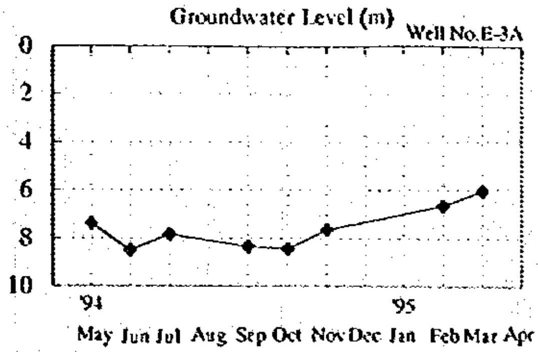
Province:	Eastern	Aquifer:	Gneiss	
District:	Lundazi			
Site Name:	Mwata Sch.	No.	Month	G.W.L(GL-m)
		1	94May	7.9
Diameter:	1250 mm	2	Jun	8.95
Depth:	14.5 m	3	Jul	9.1
Yield:	700 l/day	4	Sep	9.1
Map No.	1133C1	5	Oct	9.65
Elevation:	1.31 m	6	Nov	8.65
Grid Ref.:	N=8703Km600m	7	95Feb	5.75
	E=527Km0m	8	Mar	5.65
Maximum Groundwater Level Fluctuation(m)				4



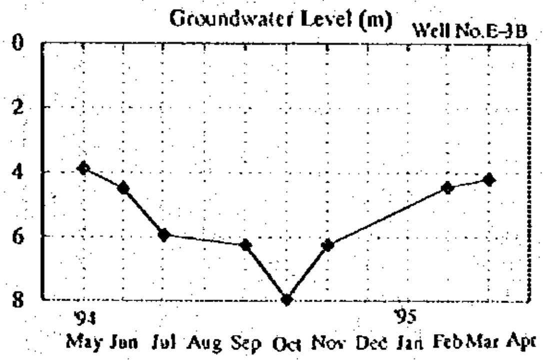
Province:	Eastern	Aquifer:	Gneiss	
District:	Lundazi			
Site Name:	Mwata R.H.C.	No.	Month	G.W.L(GL-m)
		1	94May	5.6
Diameter:	1250 mm	2	Jun	7.25
Depth:	14.5 m	3	Jul	8
Yield:	500 l/day	4	Sep	8.8
Map No.	1133C1	5	Oct	9.45
Elevation:	1120 m	6	Nov	8.3
Grid Ref.:	N=8707Km500m	7	95Feb	5.2
	E=525Km550m	8	Mar	5
Maximum Groundwater Level Fluctuation(m)				4.45



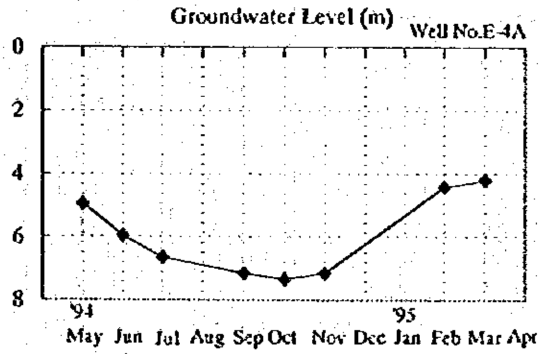
Province: Eastern		Aquifer: Gneiss		
District: Lundazi				
Site Name: Council		No.	Month	G.W.L(GL-m)
		1	'94May	7.4
Diameter:	1250 mm	2	Jun	8.5
Depth:	15 m	3	Jul	7.85
Yield:	1500 l/day	4	Sep	8.35
Map No.	1233A3	5	Oct	8.45
Elevation:	1130 m	6	Nov	7.65
Grid Ref.:	N=8641Km400m	7	'95Feb	6.65
	E=520Km0m	8	Mar	6.05
Maximum Groundwater Level Fluctuation(m) 2.45				



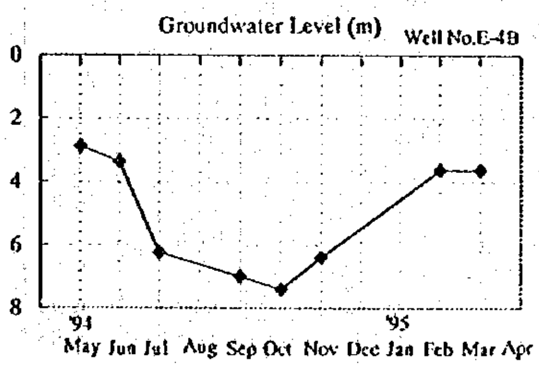
Province: Eastern		Aquifer: Gneiss		
District: Lundazi				
Site Name: Mulla Sch.		No.	Month	G.W.L(GL-m)
		1	'94May	3.9
Diameter:	1310 mm	2	Jun	4.5
Depth:	15 m	3	Jul	5.95
Yield:	1000 l/day	4	Sep	6.25
Map No.	1233A3	5	Oct	7.95
Elevation:	1130 m	6	Nov	6.25
Grid Ref.:	N=8637Km900m	7	'95Feb	4.45
	E=518Km500m	8	Mar	4.2
Maximum Groundwater Level Fluctuation(m) 4.05				



Province: Eastern		Aquifer: Gneiss		
District: Lundazi				
Site Name:		No.	Month	G.W.L(GL-m)
Chkomene W/L		1	'94May	4.95
Diameter:	1160 mm	2	Jun	5.96
Depth:	15 m	3	Jul	6.65
Yield:	600 l/day	4	Sep	7.15
Map No.	1232D2	5	Oct	7.35
Elevation:	1102 m	6	Nov	7.15
Grid Ref.:	N=8597Km0m	7	'95Feb	4.43
	E=486Km0m	8	Mar	4.23
Maximum Groundwater Level Fluctuation(m) 3.12				

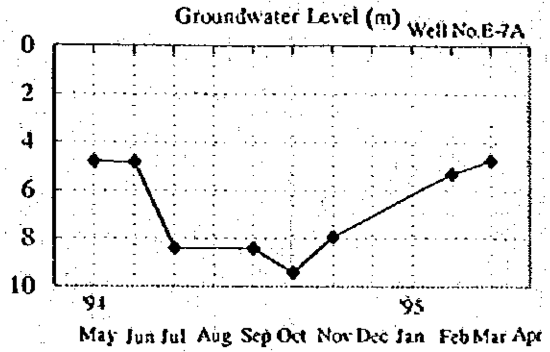


Province: Eastern		Aquifer: Gneiss		
District: Lundazi				
Site Name:		No.	Month	G.W.L(GL-m)
Chkomene Vil.		1	'94May	2.88
Diameter:	1160 mm	2	Jun	3.38
Depth:	15 m	3	Jul	6.24
Yield:	1200 l/day	4	Sep	6.99
Map No.	1232D2	5	Oct	7.39
Elevation:	1100 m	6	Nov	6.39
Grid Ref.:	N=8597Km400m	7	'95Feb	3.64
	E=486Km250m	8	Mar	3.64
Maximum Groundwater Level Fluctuation(m) 4.51				

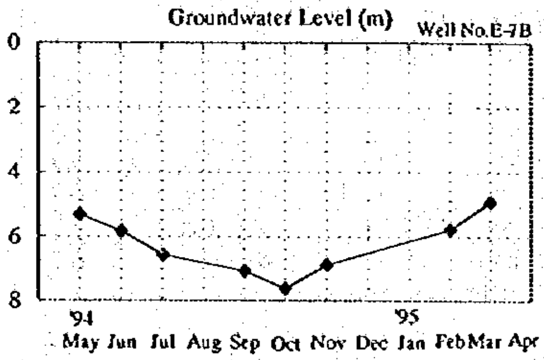


Appendix 9(7) Result of Observation

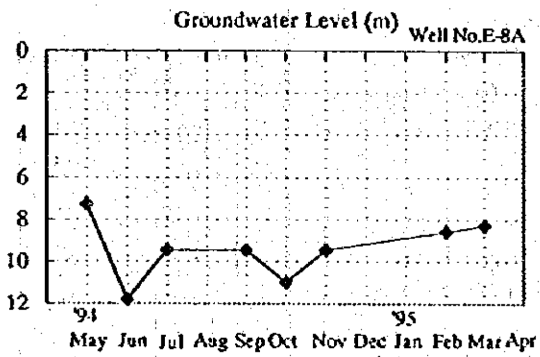
Province: Eastern		Aquifer: Sandstone	
District: Jumbe			
Site Name: Jumbe Vil.	No.	Month	G.W.L(GL-m)
	1	94May	4.8
Diameter: 1160 mm	2	Jun	4.83
Depth: 15 m	3	Jul	8.4
Yield: 600 l/day	4	Sep	8.4
Map No. 1332A3	5	Oct	9.4
Elevation: 600 m	6	Nov	7.9
Grid Ref.: N=8530Km700m	7	95Feb	5.3
E=400Km700m	8	Mar	4.75
Maximum Groundwater Level Fluctuation(m)			4.65



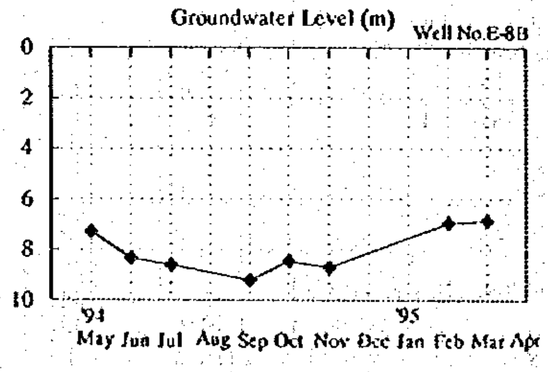
Province: Eastern		Aquifer: Sandstone	
District: Jumbe			
Site Name: Manondo	No.	Month	G.W.L(GL-m)
	1	94May	5.33
Diameter: 1340 mm	2	Jun	5.83
Depth: 15 m	3	Jul	6.57
Yield: 800 l/day	4	Sep	7.07
Map No. 1332A3	5	Oct	7.62
Elevation: 600 m	6	Nov	6.87
Grid Ref.: N=8530Km100m	7	95Feb	5.77
E=400Km400m	8	Mar	4.92
Maximum Groundwater Level Fluctuation(m)			2.7



Province: Eastern		Aquifer: Granite	
District: Chipata			
Site Name: Maguya	No.	Month	G.W.L(GL-m)
	1	94May	7.3
Diameter: 1470 mm	2	Jun	11.8
Depth: 18 m	3	Jul	9.45
Yield: 1000 l/day	4	Sep	9.45
Map No. 1332D3	5	Oct	11
Elevation: 1100 m	6	Nov	9.45
Grid Ref.: N=8468Km650m	7	95Feb	8.6
E=458Km500m	8	Mar	8.3
Maximum Groundwater Level Fluctuation(m)			4.5



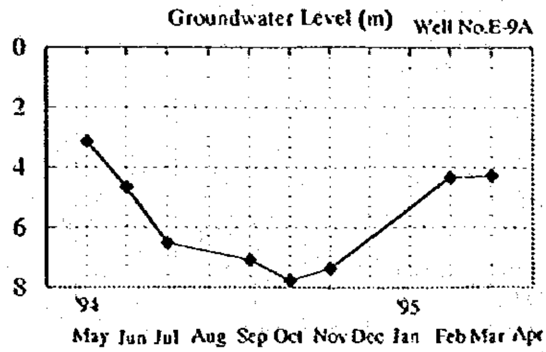
Province: Eastern		Aquifer: Gneiss	
District: Chipata			
Site Name: Nabvutika	No.	Month	G.W.L(GL-m)
	1	94May	7.3
Diameter: 1290 mm	2	Jun	8.33
Depth: 15 m	3	Jul	8.6
Yield: 1100 l/day	4	Sep	9.2
Map No. 1332D1	5	Oct	8.45
Elevation: 1140 m	6	Nov	8.7
Grid Ref.: N=8495Km350m	7	95Feb	6.95
E=461Km350m	8	Mar	6.85
Maximum Groundwater Level Fluctuation(m)			2.35



Province:	Eastern
District:	Chadiza
Site Name:	Kumadzi Vil.
Aquifer:	Granite
Diameter:	1380 mm
Depth:	15 m
Yield:	1600 l/day
Map No.	1432A2
Elevation:	1044 m
Grid Ref.:	N=8448Km150m E=439Km500m

No.	Month	G.W.L(GL-m)
1	'94May	3.13
2	Jun	4.67
3	Jul	6.52
4	Sep	7.07
5	Oct	7.77
6	Nov	7.37
7	'95Feb	4.36
8	Mar	4.27

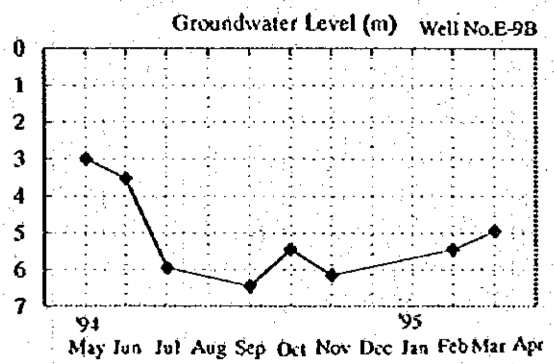
Maximum Groundwater Level Fluctuation(m) 4.64



Province:	Eastern
District:	Chadiza
Site Name:	Chadiza Sec.
Aquifer:	Granite
Diameter:	1370 mm
Depth:	15 m
Yield:	1200 l/day
Map No.	1432A2
Elevation:	1052 m
Grid Ref.:	N=8444Km250m E=438Km450m

No.	Month	G.W.L(GL-m)
1	'94May	3
2	Jun	3.53
3	Jul	5.95
4	Sep	6.45
5	Oct	5.45
6	Nov	6.15
7	'95Feb	5.45
8	Mar	4.95

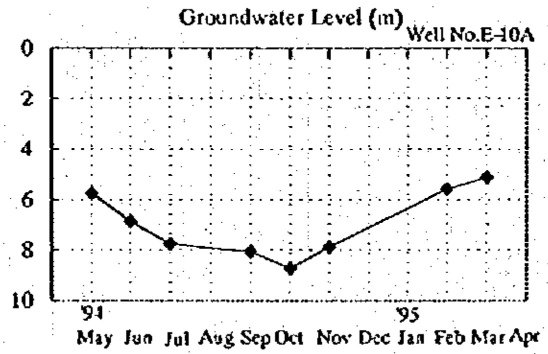
Maximum Groundwater Level Fluctuation(m) 3.45



Province:	Eastern
District:	Chadiza
Site Name:	Chzombe
Aquifer:	Granite
Diameter:	1160 mm
Depth:	15.35 m
Yield:	600 l/day
Map No.	1432A2
Elevation:	1049 m
Grid Ref.:	N=8431Km750m E=437Km250m

No.	Month	G.W.L(GL-m)
1	'94May	5.75
2	Jun	6.87
3	Jul	7.77
4	Sep	8.08
5	Oct	8.73
6	Nov	7.88
7	'95Feb	5.58
8	Mar	5.13

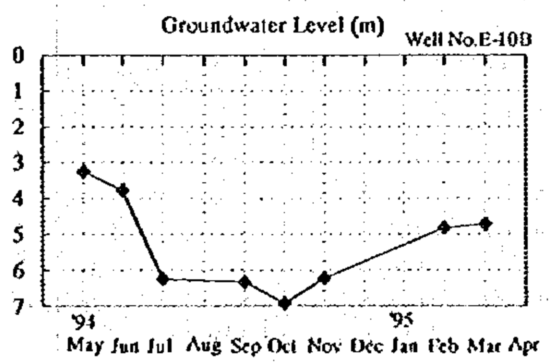
Maximum Groundwater Level Fluctuation(m) 3.6



Province:	Eastern
District:	Chadiza
Site Name:	Basic Sch.
Aquifer:	Granite
Diameter:	1160 mm
Depth:	12.2 m
Yield:	400 l/day
Map No.	1432A2
Elevation:	1055 m
Grid Ref.:	N=8428Km700m E=439Km150m

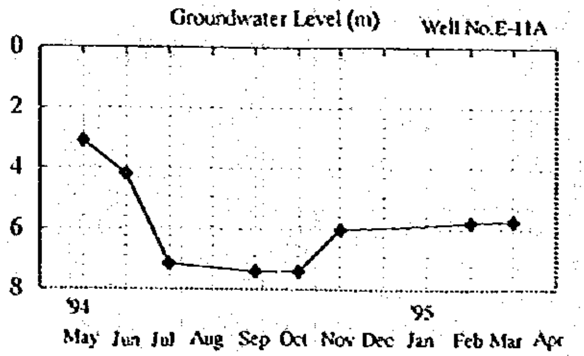
No.	Month	G.W.L(GL-m)
1	'94May	3.25
2	Jun	3.78
3	Jul	6.25
4	Sep	6.33
5	Oct	6.93
6	Nov	6.23
7	'95Feb	4.83
8	Mar	4.73

Maximum Groundwater Level Fluctuation(m) 3.68

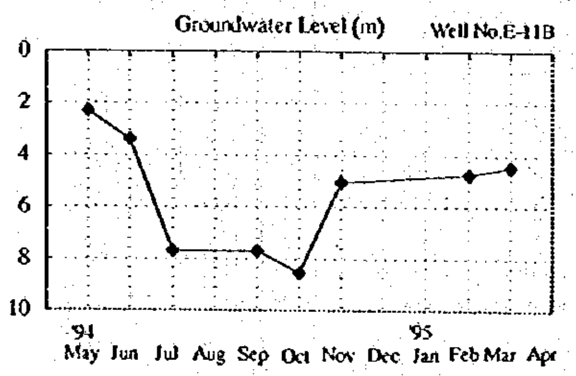


Appendix 9(9) Result of Observation

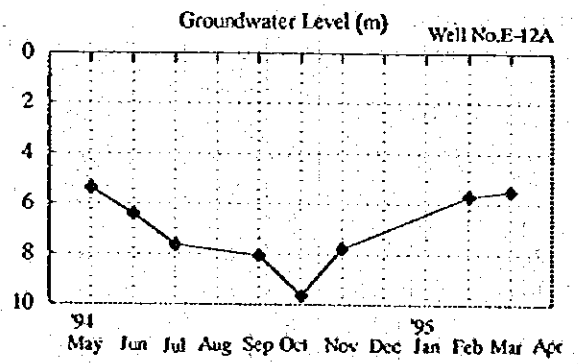
Province: Eastern	Aquifer: Gneiss			
District: Katetle				
Site Name: Basic Sch.		No.	Month	G.W.L(GL-m)
		1	94May	3.1
Diameter:	1160 mm	2	Jun	4.2
Depth:	15 m	3	Jul	7.2
Yield:	1200 l/day	4	Sep	7.4
Map No.	1432A1	5	Oct	7.4
Elevation:	1061 m	6	Nov	6.0
Grid Ref.:	N=8442Km750m	7	95Feb	5.8
	E=398Km200m	8	Mar	5.8
Maximum Groundwater Level Fluctuation(m)				4.3



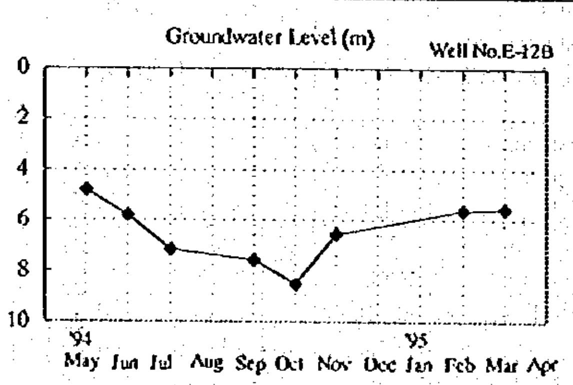
Province: Eastern	Aquifer: Gneiss			
District: Katetle				
Site Name: Katete Boma		No.	Month	G.W.L(GL-m)
		1	94May	2.3
Diameter:	1160 mm	2	Jun	3.4
Depth:	15 m	3	Jul	7.7
Yield:	1300 l/day	4	Sep	7.7
Map No.		5	Oct	8.6
Elevation:	1052 m	6	Nov	5.0
Grid Ref.:	N=8442Km550m	7	95Feb	4.8
	E=398Km750m	8	Mar	4.5
Maximum Groundwater Level Fluctuation(m)				6.3



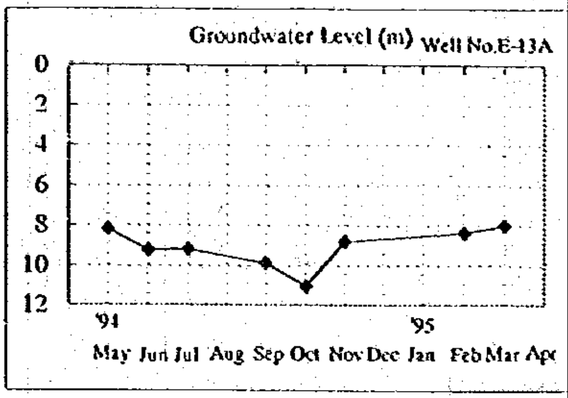
Province: Eastern	Aquifer: Gneiss			
District: Sinda				
Site Name: Post Off.		No.	Month	G.W.L(GL-m)
		1	94May	5.4
Diameter:	1160 mm	2	Jun	6.4
Depth:	15 m	3	Jul	7.7
Yield:	1200 l/day	4	Sep	8.1
Map No.	1431B2	5	Oct	9.7
Elevation:	1100 m	6	Nov	7.8
Grid Ref.:	N=8428Km750m	7	95Feb	5.7
	E=366Km450m	8	Mar	5.5
Maximum Groundwater Level Fluctuation(m)				4.3



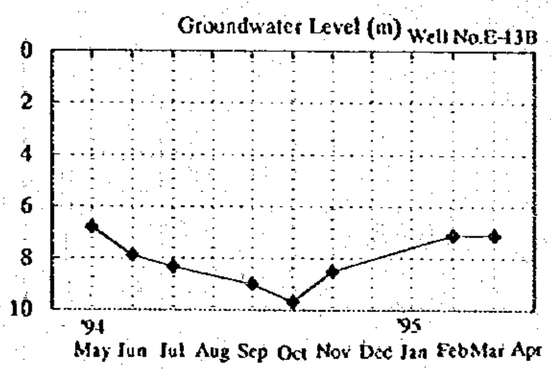
Province: Eastern	Aquifer: Granite			
District: Sinda				
Site Name: Chassa		No.	Month	G.W.L(GL-m)
		1	94May	4.8
Diameter:	1160 mm	2	Jun	5.8
Depth:	14.5 m	3	Jul	7.2
Yield:	600 l/day	4	Sep	7.6
Map No.	1431B2	5	Oct	8.5
Elevation:	1040 m	6	Nov	6.6
Grid Ref.:	N=8424Km600m	7	95Feb	5.6
	E=368Km350m	8	Mar	5.6
Maximum Groundwater Level Fluctuation(m)				3.7



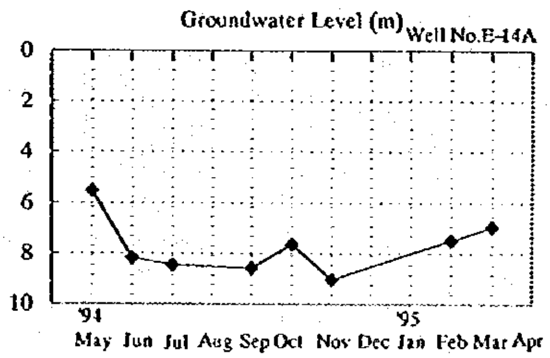
		No.	Month	G.W.L(GL-m)
Province: Eastern	Aquifer: Gneiss			
District: Peatauke				
Site Name: Khande		1	'94May	8.2
Diameter:	1160 mm	2	Jun	9.25
Depth:	18.8 m	3	Jul	9.2
Yield:	700 l/day	4	Sep	9.9
Map No.	1431A4	5	Oct	11.1
Elevation:	970 m	6	Nov	8.8
Grid Ref.:	N=8415Km100m	7	'95Feb	8.4
	E=328Km500m	8	Mar	8
Maximum Groundwater Level Fluctuation(m) 3.05				



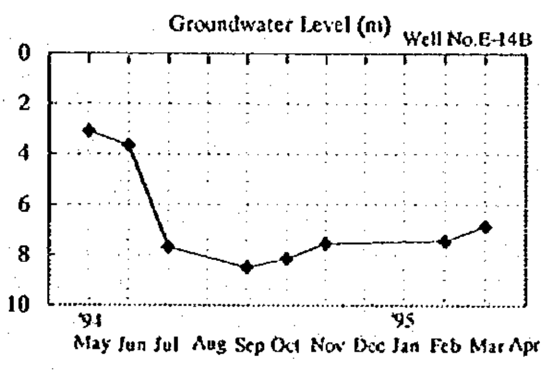
		No.	Month	G.W.L(GL-m)
Province: Eastern	Aquifer: Gneiss			
District: Petauke				
Site Name: Ifosi		1	'94May	6.8
Diameter:	1160 mm	2	Jun	7.9
Depth:	16.6 m	3	Jul	8.35
Yield:	600 l/day	4	Sep	9
Map No.	1431A4	5	Oct	9.7
Elevation:	1018 m	6	Nov	8.5
Grid Ref.:	N=8414Km500m	7	'95Feb	7.1
	E=332Km400m	8	Mar	7.1
Maximum Groundwater Level Fluctuation(m) 2.9				



		No.	Month	G.W.L(GL-m)
Province: Eastern	Aquifer: Gneiss			
District: Myimba				
Site Name: Basic.Sc.		1	'94May	5.53
Diameter:	1160 mm	2	Jun	8.17
Depth:	15.5 m	3	Jul	8.47
Yield:	1900 l/day	4	Sep	8.59
Map No.	1430D2	5	Oct	7.64
Elevation:	708 m	6	Nov	9.04
Grid Ref.:	N=8389km400m	7	'95Feb	7.49
	E=265Km00m	8	Mar	6.97
Maximum Groundwater Level Fluctuation(m) 3.51				

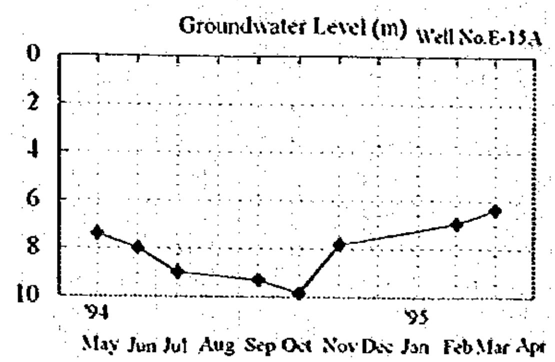


		No.	Month	G.W.L(GL-m)
Province: Eastern	Aquifer: Gneiss			
District: Nyimba Boma				
Site Name: Nyimba Boma		1	'94May	3.1
Diameter:	1160 mm	2	Jun	3.65
Depth:	15 m	3	Jul	7.7
Yield:	1000 l/day	4	Sep	8.5
Map No.	1430D2	5	Oct	8.15
Elevation:	718 m	6	Nov	7.55
Grid Ref.:	N=8389Km0m	7	'95Feb	7.45
	E=265Km750m	8	Mar	6.85
Maximum Groundwater Level Fluctuation(m) 5.4				

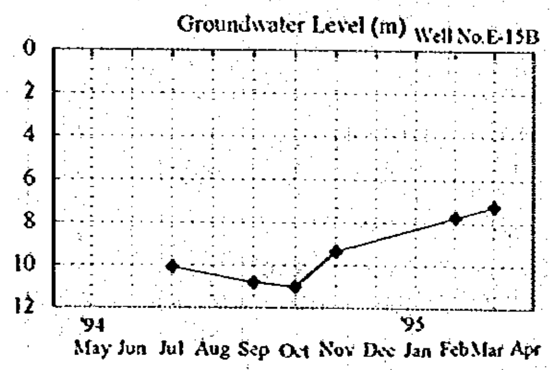


Appendix 9(11) Result of Observation

Province: Eastern	Aquifer: Granite			
District: Kacholola				
Site Name: Mombe Sch.		No.	Month	G.W.L(GL-m)
		1	94May	7.4
Diameter:	1370 mm	2	Jun	8.0
Depth:	15 m	3	Jul	9.0
Yield:	600 l/day	4	Sep	9.3
Map No.	1430D3	5	Oct	9.9
Elevation:	880 m	6	Nov	7.8
Grid Ref.:	N=8365Km800m	7	95Feb	7.0
	E=240Km450m	8	Mar	6.4
Maximum Groundwater Level Fluctuation(m)				3.5

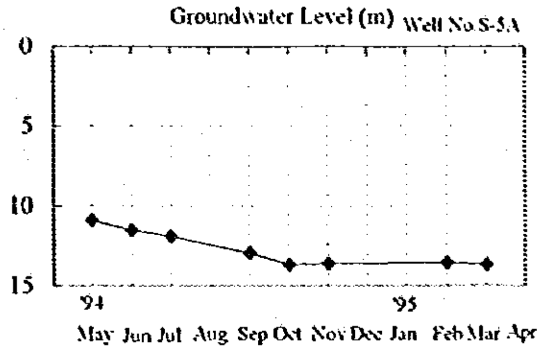


Province: Eastern	Aquifer: Granite			
District: Kasholala				
Site Name: Mwana		No.	Month	G.W.L(GL-m)
		1	94May	
Diameter:	1500 mm	2	Jun	
Depth:	15 m	3	Jul	10.1
Yield:	600 l/day	4	Sep	10.8
Map No.	1430D3	5	Oct	11.0
Elevation:	890 m	6	Nov	9.4
Grid Ref.:	N=8366Km700m	7	95Feb	7.8
	E=242Km500m	8	Mar	7.3
Maximum Groundwater Level Fluctuation(m)				3.8

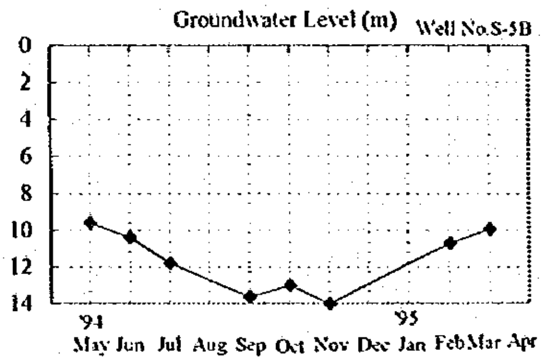


Appendix 9(6) Result of Observation

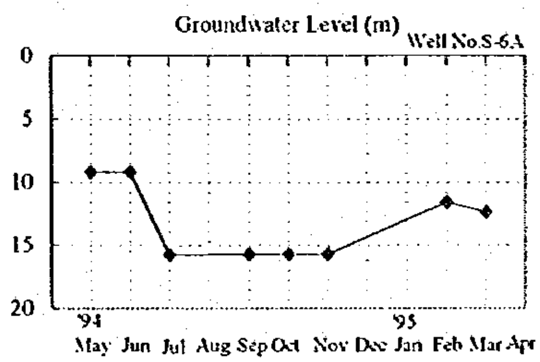
		No.	Month	G.W.L(GL-m)
Province: Southern	Aquifer: Gneiss			
District: Choma				
Site Name: Batoka B.Sch.		No.	Month	G.W.L(GL-m)
		1	94May	10.9
Diameter: 1100 mm		2	Jun	11.5
Depth: m		3	Jul	11.9
Yield: l/day		4	Sep	12.9
Map No. 1627C1		5	Oct	13.7
Elevation: 1190 m		6	Nov	13.6
Grid Ref.: N=8164Km650m		7	95Feb	13.6
E=511Km700m		8	Mar	13.7
Maximum Groundwater Level Fluctuation(m) 2.8				



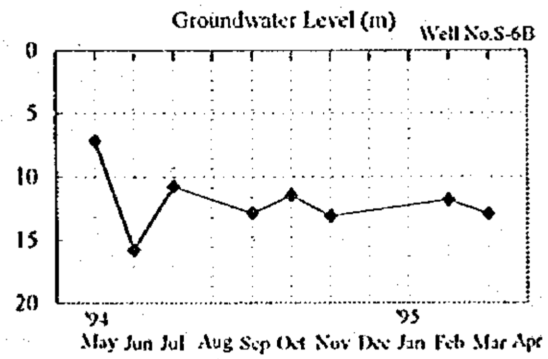
		No.	Month	G.W.L(GL-m)
Province: Southern	Aquifer: Gneiss			
District: Monze				
Site Name:		No.	Month	G.W.L(GL-m)
Batoka A.Comp.		1	94May	9.6
Diameter: 1100 mm		2	Jun	10.4
Depth: 14.8 m		3	Jul	11.8
Yield: l/day		4	Sep	13.7
Map No. 1627C1		5	Oct	13.0
Elevation: 1182 m		6	Nov	14.0
Grid Ref.: N=8146Km950m		7	95Feb	10.7
E=511Km650m		8	Mar	10.0
Maximum Groundwater Level Fluctuation(m) 4.4				



		No.	Month	G.W.L(GL-m)
Province: Southern	Aquifer: Sandstone			
District: Sinazonswe				
Site Name: Siapaka Vil.		No.	Month	G.W.L(GL-m)
		1	94May	9.2
Diameter: 1100 mm		2	Jun	9.2
Depth: m		3	Jul	15.8
Yield: l/day		4	Sep	15.7
Map No. 1727A2		5	Oct	15.7
Elevation: 552 m		6	Nov	15.7
Grid Ref.: N=8102Km800m		7	95Feb	11.6
E=545Km400m		8	Mar	12.4
Maximum Groundwater Level Fluctuation(m) 6.6				



		No.	Month	G.W.L(GL-m)
Province: Southern	Aquifer: Sandstone			
District: Sinazonswe				
Site Name:		No.	Month	G.W.L(GL-m)
Siapaka Comp.		1	94May	7.2
Diameter: 1200 mm		2	Jun	15.8
Depth: 16 m		3	Jul	10.8
Yield: l/day		4	Sep	12.9
Map No. 1727A2		5	Oct	11.5
Elevation: 559 m		6	Nov	13.1
Grid Ref.: N=8102Km900m		7	95Feb	11.9
E=545Km650m		8	Mar	13.0
Maximum Groundwater Level Fluctuation(m) 8.7				



JAPAN INTERNATIONAL COOPERATION AGENCY

REPUBLIC OF ZAMBIA
MINISTRY OF ENERGY AND WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER RESOURCES MASTER PLAN

IN

THE REPUBLIC OF ZAMBIA

FINAL REPORT

SUPPORTING REPORT [V]

WELL INVENTORY SURVEY

OCTOBER, 1995

YACHIYO ENGINEERING CO., LTD.
(YEC)

THE STUDY ON NATIONAL WATER RESOURCES MASTER PLAN
IN THE REPUBLIC OF ZAMBIA

SUPPORTING REPORT (V)
WELL INVENTORY SURVEY

Table of Contents

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CHAPTER 1 INTRODUCTION

1.1 Scope

The results of well inventory survey are summarized in this report. Well inventory survey comprises three items. These are development of new data-Base, analysis of pumping test data and investigation on the current situation of existing boreholes and shallow wells. Most of these results have been stored in a new Data-Base developed by Study Team and a lot of information on hydrogeology were derived from the Data-Base and described in this report.

1.2 Contents of Report

The contents of the report are as follows:
Chapter 1 comprises an introduction of this report.
Chapter 2 describes the Data-Base developed by Study Team.
Chapter 3 describes pumping test data analysis.
Chapter 4 describes the current groundwater use by province and district.
Chapter 5 describes hydrogeological formation derived from the data base.
Chapter 6 describes recommendation on well inventory survey

CHAPTER 2 DEVELOPMENT OF NEW DATA-BASE SYSTEM

2.1 Purpose of New Data-Base System

The purpose of development of a new data-base system is to collect and arrange available hydrogeological data for effective use, including use in a groundwater resources master plan. More than 4,600 borehole data have been collected, arranged and input to computer data-base. The computer data-base program has many functions and is useful for various kinds of purposes related to hydrogeology.

2.2 Existing Borehole Data

Water wells in Zambia are classified into boreholes and shallow wells. The borehole drill log is recorded based on 'Borehole Completion Form of DWA' as shown in Figure 2-1 and 2-2. On the other hand, shallow well has not any completion form. All the borehole records are sent to DWA headquarters and all the shallow well records are sent to Provincial Water Engineers Office. However, only half or two thirds of all the borehole records are actually stored in DWA. These records include important information about hydrogeology. In the case of shallow wells, the conditions of record storage are worse than that of boreholes and the information derived from them is sparse. Therefore, the data-base was developed using borehole records. There are two types of borehole records - one is newly drilled records (about 4,600) and the other is rehabilitation records (about 1,400 records). The newly drilled records were mainly used for the data-base.

2.3 Survey Item

Survey items are divided into 2 categories.

- Information on boreholes and hydrogeology from borehole data stored in DWA.
- Aquifer constant

Survey items on boreholes are shown in Figure 2-3. The items included in the borehole completion form are so important that most of these were stored in the data-base. In addition, new items, results of pumping test analysis and summary of hydrogeological information, were also added to the data-base.

2.4 Survey Method

Borehole data was collected from Drilling Section, Provincial Water Engineers office of DWA and private drilling companies. The total number of borehole data is more than 4,600. Subsequently, several kinds of analysis such as pumping test analysis and classification of aquifer were carried out and these results were input into the computer data-base.

2.5 Data-Base Pogram

A data-base program system was developed by the Study Team. All the items included in the Data base are shown in Figure 2-3. The computer data-base program was developed using Quick-Basic system. The main functions of the data-base are as follows:

1) Input data
2) Display data on computer screen

Form WD/7M (Revised)

REPUBLIC OF ZAMBIA—WATER AFFAIRS DEPARTMENT

Borehole Completion Form

Grid Reference.. Locality......................Chief.................. Borehole Record No.................................

Name of Property.. District.. Site selected by...................Site No............

Name of Owner(s).. Province.. Drill Unit No......................................

Total depth of borehole.......................................metres

Depth from surface at which water first struck..........................metres

" " " of main supply..................................metres

" " " to which water rises..................................metres

Continuous bailer test of........hours gave yield of........litres per second

Continuous pump test of........hours gave yield of........litres per second

Depth of water from surface before test..................................metres

Depth from surface of pump intake.......................................metres

Greatest depth to which water was lowered during test...................metres

Does water return to original level after test?..........................metres

Details of casing left in borehole:

Diameter in mm	Length in Metres	
	Plain	Perforated
....	....	....
....	....	....

Depth from surface to bottom of casing..................................metres

Diameter of unlined portion of borehole below casing....................mm

Quality of water (state fresh, brackish or saline, etc.).........................

Total distance chargeable..........Km at K.......... = K..........

Remarks..

....

Depth in metres		Formations Bored
From	To	
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....
....	....	....

DATE OF:

Arrival on site.....................

Completion.........................

FOR OFFICE USE ONLY

Borehole File No.....................

Schedule No.........................

Office Record Ref.....................

Borehore Serial..../......./......

CHARGES:

Total for Borehole.................

For Casing.........................

Bonus.............................

REMARKS:

The Applicant is requested to sign this Report after having satisfied himself that it is correct.

Signature of Applicant.. ....Drill Foreman.......... Date...................

Figure 2-1 Borehole Completion Form of DWA(1)

BOREHOLE PUMP TEST

Form WD,TN

Borehole No.........................Driller.......................................Date......................

24 hours *PUMPING TEST* started at.....................hours

Rest water level before testing.....................metres from surface to water.

Clock time	Elapsed time	Yield (pumping rate) litres per sec.	Depth from surface to water in metres	Quality of water: Clear	Quality of water: Turbid	Recovery levels after finish of pump test: Clock time	Recovery levels after finish of pump test: Elapsed time when pump stopped	Recovery levels after finish of pump test: Water level in metres
	Start							
	1 min.						1 min.	
	2 min.						2 min.	
	3 min.						3 min.	
	4 min.						4 min.	
	5 min.						5 min.	
	10 min.						6 min.	
	15 min.						7 min.	
	20 min.						8 min.	
	25 min.						9 min.	
	30 min.						10 min.	
	40 min.						12 min.	
	50 min.						14 min.	
	60 min.						16 min.	
	70 min.						18 min.	
	80 min.						20 min.	
	90 min.						25 min.	
	105 min.						30 min.	
	120 min.						35 min.	
	150 min.						40 min.	
	3 hours						45 min.	
	4 hours						50 min.	
	5 hours						55 min.	
	6 hours						60 min.	
	7 hours						70 min.	
	8 hours						80 min.	
	9 hours						90 min.	
	10 hours						105 min.	
	11 hours						120 min.	
	12 hours						135 min.	
	13 hours						150 min.	
	14 hours						180 min.	
	15 hours							
	16 hours							
	17 hours							
	18 hours							
	19 hours							
	20 hours							
	21 hours							
	22 hours							
	23 hours							
	24 hours							
	25 hours							

REMARKS:

The rig left the site at..................................hrs on...(date)

At which time the depth from surface to water level was.......................................metres.

....Drill or Pump Foreman

Figure 2-2

Borehole Completion Form of DWA(2

* * * * * * Borehole Completion Form of DWA * * * * * * * * * * *

Grid Reference :
Name of Property :
Name of Owner :
Localiy :
Province/District
Chief :
Borehole Record Number :
Date of Completion :

Total Depth of Boreholes
Depth from Surface at Which Water First Struck
Depth from Surface of Main Supply
Depth from Surface to Which Water Rises
Test Method : PUMP hours litres
Depth of Water from Surface before Test
Depth from Surface of Pump Intake
Greatest Depth to Which Water was Lowered During Test
Does Water Return to Original Level after Test

Details of Casing Left in Borehole
Diameter in mm

Plain	Perforated
–	
	–
–	
	–
–	

Depth from Surface to Bottom of Casing
Diameter of Unlined Portion of Borehole below Casing
Quality of Water :
Total Distance Chargeable
Remarks :

Lithology

Depth in meters from	to	Lithology	Litho-stratigraphic unit

* * * * * * Additional Information * * * * * * * * * * * * * *

Code :
Map Reference Number
File Name of Analysis :
Drainage Area
Altitude
Thickness of Aquifer from to Total
Main Aquifer Lithology : FRACTUREDGRANITE Litho-stratigraphic unit :
Specific Capacity
Transmisivity
Specific Yield
Coefficient of Permeability
Current Yield
Operating Condition : OPERATING Reason :
Name of Project :
Purpose : COMMERCIAL OTHERS
Donor Agency
Population Supplied
Type of Owner :
Type of Driller :

Figure 2-3

Input Items of Borehole Data-bas

3) Retrieve data
4) Calculate statistical value of data
5) Print out selected data

The data-base program system employs a code system to input data. A number of codes were prepared for many items. The code system prevents an error in input and makes it easy to retrieve data. Table 2-1 and 2-2 show the codes used in the data-base system.

Manuals to operate the data-base have been prepared so that anyone can easily access the data-base. The data-base program is installed in two personal computers provided by JICA in Sheki-Sheki office of DWA.

Province	District	Code
Lusaka	Lusaka-Urban	11
	Lusaka-Rural	12
	Luangwa	13
Copperbelt	Ndola-Urban	21
	Ndola-Rural	22
	Chililabombw	23
	Chingola	24
	Mufulira	25
	Kalulushi	26
	Kitwe	27
	Luanshya	28
Central	Kabwe-Urban	31
	Kabwe-Rural	32
	Mumbwa	33
	Mkushi	34
	Serenje	35
Northwester	Solwezi	41
	Mwinilunga	42
	Zambezi	43
	Kabompo	44
	Mfumbwe	45
	Kasempa	46
Western	Mongu	51
	Lukulu	52
	Kalabo	53
	Kaoma	54
	Senanga	55
	Sesheke	56
Southern	Livingstone	61
	Namwala	62
	Mazabuka	63
	Monze	64
	Choma	65
	Kalomo	66
	Siavonga	67
	Gwembe	68
	Sinazongwe	69

Province	District	Code
Luapula	Mansa	71
	Nchelenge	72
	Kawambwa	73
	Mwense	74
	Samfya	75
Northern	Kasama	81
	Kaputa	82
	Mbala	83
	Mporokoso	84
	Luwingu	85
	Chilubi	86
	Isoka	87
	Chinsali	88
	Mpika	89
Eastern	Chipata	91
	Chama	92
	Lundazi	93
	Chadiza	94
	Katete	95
	Petauke	96

Quality of Water Code

1	fresh
2	brackish
3	saline
4	odour

Table 2-1 Code for Data-base (1)

<Litology(sub)>
(for detail)

01	a	argillaceous
02	c	calcareous
03		cavernous
04		cherty
05		clayey
06		clean
07		coase grained
08		consolidated
09		crystaline
10	f	fault
11		felsic
12		fine grained
13		fractured
14		fresh
15	g	granityic
16		gravelly
17	m	massive
18		medium grained
19		metamorphised
20	p	pelitic
21		poorly-sorted
22		porous
23	s	sandy
24		silty
25	u	unconsolited
26	w	weatherd
27		well-sorted
28		vegetal
29		fissured
30		carstified

<Lithology(main)>
(for detail)

01	a	amphibolite
02		andesite
03		aplite
04		aplite
05		argillite
06		arkose
07	b	basalt
08	c	carbonate rock
09		carbonatite
10		chert
11		clay
12		coal
13		conglomerate
14	d	diorite
15		dolerite
16		dolomite
17	g	gabro
18		gneiss
19		granit
20		gravel
21	i	igneous rock
22	l	limestone
23	m	marl
24		meta-igneous
25		meta-sediment
26		meta-volcanics
27		metamorphic rock
28		migmatite
29		mudstone
30	p	peat
31		pegmatite
32		phillite
33		plutonic rocks
34		porphyry
35		pyroclastics
36	q	quartzite
37	r	rhyolite
38	s	sand
39		sand & gravel
40		sandstone
41		schist
42		sedimentary rock
43		shale
44		silt
45		siltstone
46		slate
47		soil
48		syenite
49	t	tuff
50	v	varves
51		volcanic rock
52		laterite

<Lithl-stratigraphic>
(for deatil & outline)

01	Allvium
02	Kalahari Group
03	Karroo Supper group
04	Upper Karroo Group
05	Lower Karroo Group
06	Katanga Super Group
07	Kundelunga Group
08	Upper Roan Group
09	Lower Roan Group
10	Muva Supper Group
11	Basement Complex
12	Granit
13	Other Igneous rocks
14	Metamorphic rocks

<Lithology(sub)>
(for outline)

01	coase grained
02	crystaline
03	fault
04	fine-grained
05	fractured
06	fresh
07	metamorphised
08	unconsolidated
09	weatherd
10	Cavenous

<Lithology(main)>
(for outline)

01	amphibolite
02	argillite
03	basalt
04	carbonate rocks
05	clay
06	conglomerate
07	dolomite
08	gneiss
09	granit
10	gravel
11	igneous rocks
12	limestone
13	meta-igneous
14	meta-sediment
15	meta-volcanics
16	migmatite
17	quartzite
18	sand
19	sand&gravel
20	sandstone
21	schist
22	shale
23	siltstone
24	laterite
25	Mudstone

<Purопse>

01	Rural Water Supply
02	Urban Water Supply
03	Irrigation
04	Livestock
05	Fisheries
06	Industrial
07	Commercial
08	Exploratory
09	Observation
10	Others
11	Unknown

<Operating Condition>

01	operating
02	not operating
	Reason

<Donor Agency>

01	DUTCH
02	GTZ
03	IRISH
04	JICA
05	KFW
06	NGO
07	NORAD
08	UNICEF
09	WORLD BANK

<Owner Type>

01	Central Gavernment
02	Local Gavernment
03	Private

<Driller Type>

01	GRZ
02	Private

<Drainage Area>

01	Kafue
02	Zambezi
03	Luanga
04	Luapulua
05	Chambeshi
06	Tanganika

Table 2-2 Code for Data-base (2)

CHAPTER 3 PUMPING TEST ANALYSIS

3.1 Purpose of Analysis

Pumping test analysis was carried out to obtain aquifer coefficients. Groundwater storage and flow are strongly dominated by aquifer characteristics and aquifer coefficients, namely transmissivity and specific yield, represent aquifer characteristics. Groundwater storage in aquifer can be calculated using these constants.

3.2 Method of Analysis

More than 600 sets of pumping test data stored in borehole records were analyzed. The pumping test data to be analyzed were selected carefully before hand, because some data give unreliable results and are not suitable for analysis. The hydraulic parameters analyzed are as follows:

1) Coefficient of permeability
2) Transmissivity
3) Specific yield

The methods employed for the analysis are as follows:

1) Theis Method
2) Jacob Method
3) Recovery Method

Comparisons of the results analyzed by each method were made and final solutions were determined for each data set. Though the reliability of pumping test data was not always good, finally about 350 sets of 600 sets analyzed were adopted as providing reasonable results. Pumping test records were analyzed by a computer programs which was developed for that purpose. Three methods mentioned above are available in this program and analysis is carried out speedily on a graphic display.

The purpose of pumping test carried out by DWA is to estimate available yield of borehole and not to obtain aquifer parameters. Therefore, the pumping test has some problems listed below in terms of obtaining accurate aquifer parameters

- Yield changes as time passes
- Accuracy of measuring groundwater table is low and some data gave obviously unreasonable results
- Pumping time is short
- Yield and therefore the groundwater flow velocity near the borehole is too large for Darcy's law to hold good.

Actual draw-down curves sometimes diverges from theoretical curve for the reasons mentioned above, which cause error in analysis.

3.3 Results of Analysis

Results of the analysis are attached in Appendix 1 and 2. These figures show that the observed data sometimes diverges from the theoretical curves and the results are not always good. However, it is considered that the values order of these results may be acceptable. Breakdown of lithology analyzed si shown in Figure 3-1.

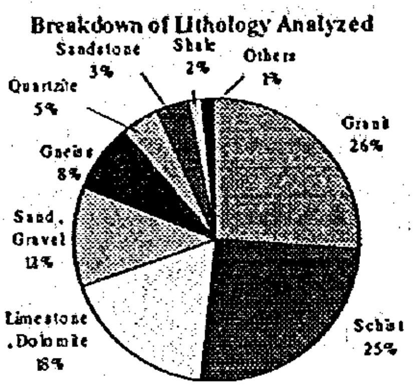


Figure 3-1 Breakdown of Lithology Analyzed

3.3.1 Transimissivity

Analysed result of transimissivity is shown in Table3-1 and Figure3-2.

Table 3-1 Transimissivity by Pumping Test Analysis

Lithology	Data Number	Medium (m2/day)	Range (m2/day)	
			Minimum	Maximum
Limestone & Dolomite	57	2.62	0.00483	488
Schist	80	2.45	0.124	682
Sand & Gravel	37	4.89	0.123	112
Granite	84	1.87	0.00103	85
Sandstone, Conglomerate	11	4.3	0.0961	10.1
Quartzite	15	2.99	0.0143	33.4
Gneiss, Migmatite	25	1.02	0.0731	12.3
Argillaceous Rock	4	1.47	0.564	4.26
Others*	5	1.01	0.115	5.45
< Total >	333	1.87	0.00103	85

(Note) * Others include Igneous and the other metamorphic rocks

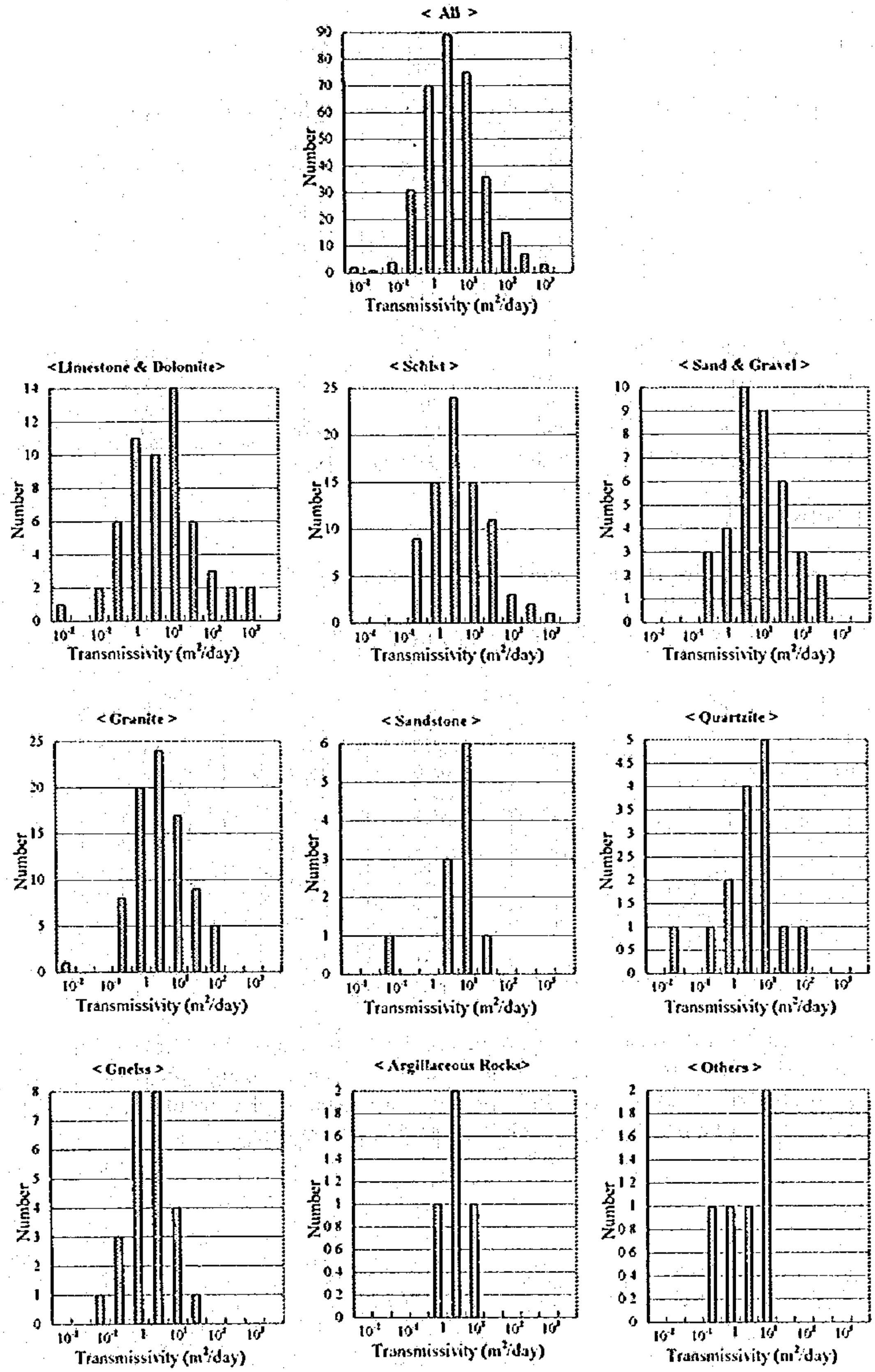


Figure 3-2 Transmissivity by Pumping Test Analysis

3.3.2 Coeficient of Permeability

Analysed result of coeficient of permeability is shown in Table3-2 and Figure3-3.

Table 3-2 Coeficient of Permeability by Pumping Test Analysis

Lithology	Data Number	Medium (m/day)	Range (m/day)	
			Minimum	Maximum
Limestone & Dolomite	56	0.096	0.000403	97.5
Schist	80	0.127	0.0062	14.2
Sand & Gravel	37	0.478	0.0132	10.8
Granite	84	0.128	0.000129	22.1
Sandstone, Conglomerate	11	0.275	0.00356	18.8
Quartzite	15	0.161	0.0011	1.02
Gneiss, Migmatite	25	0.0606	0.00203	3.51
Argillaceous rock	4	0.107	0.0238	0.473
Others*	5	0.0401	0.024	0.331
< Total >	323	0.13	0.000129	97.5

(Note) * Others include Igneous and the other metamorphic rocks

3.3.3 Specific Yield

Analysed result of specific yield is shown in Table3-3 and Figure3-4.

Table 3-3 Specific Yield by Pumping Test Analysis

Lithology	Data Number	Medium	Range	
			Minimum	Maximum
Limestone & Dolomite	45	0.030	7.81×10^{-8}	0.262
Schist	58	0.030	7.03×10^{-7}	0.254
Sand & Gravel	29	0.016	3.46×10^{-11}	0.249
Granite	49	0.068	6.78×10^{-5}	0.284
Sandstone, Conglomerate	11	0.045	2.98×10^{-3}	0.263
Quartzite	10	0.052	1.65×10^{-8}	0.257
Gneiss, Migmatite	15	0.0412	1.18×10^{-6}	0.172
Argillaceous Rock	2	0.057	4.60×10^{-2}	0.0703
Others*	1	0.018	-	-
< Total >	233	0.0381	3.46×10^{-11}	0.284

(Note) * Others include Igneous and the other metamorphic rocks

It should be noted that values of aquifer parameters shown in Table 3-2 to Table 3-4 may be greater than the actual representative value for each rock type. Pumping test is carried out for successful boreholes and unsuccessful boreholes are abandoned without pumping test. The greater the yield of a borehole, the higher the aquifer parameters.

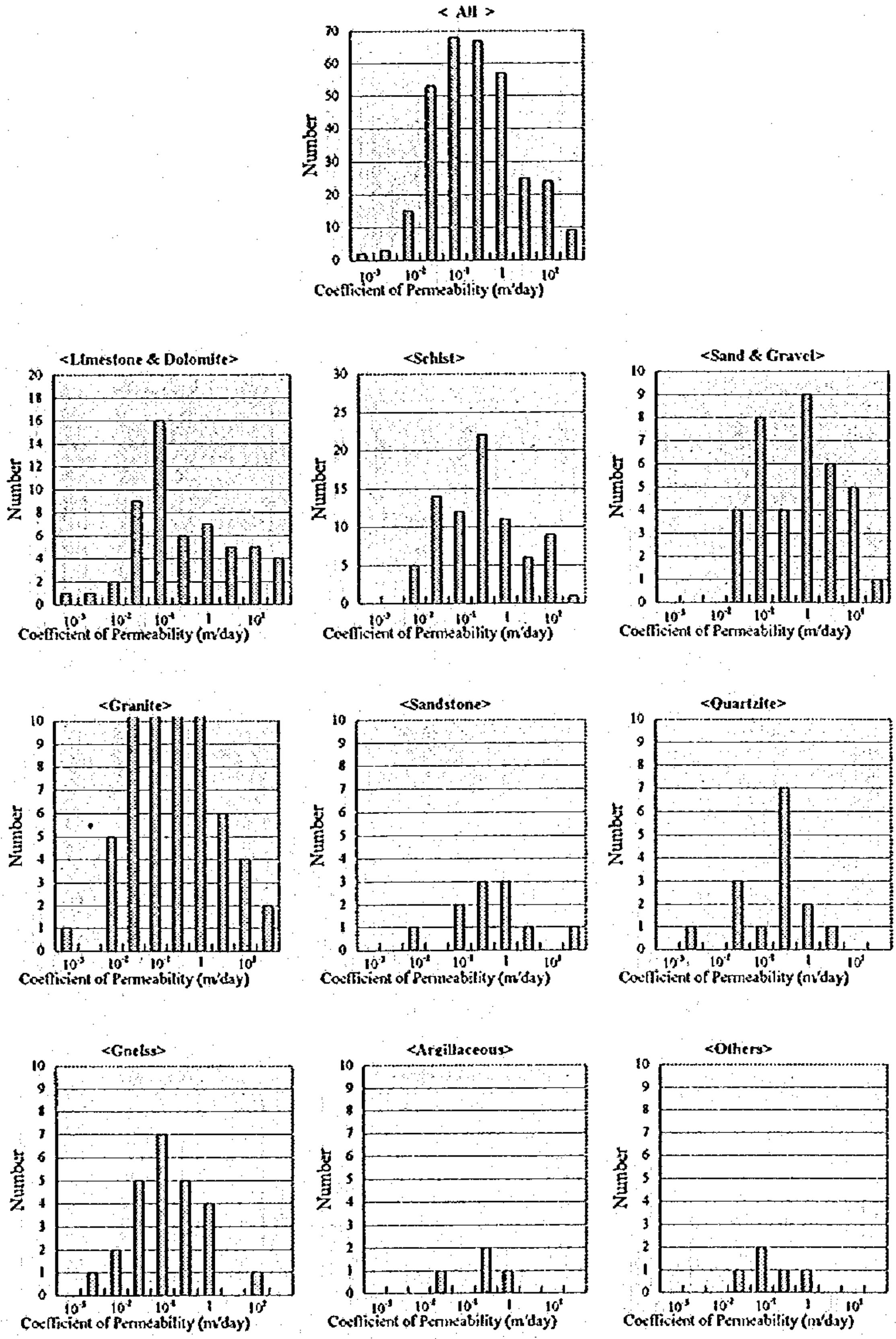


Figure 3-3 Coefficient of Permeability by Pumping Test Analysis

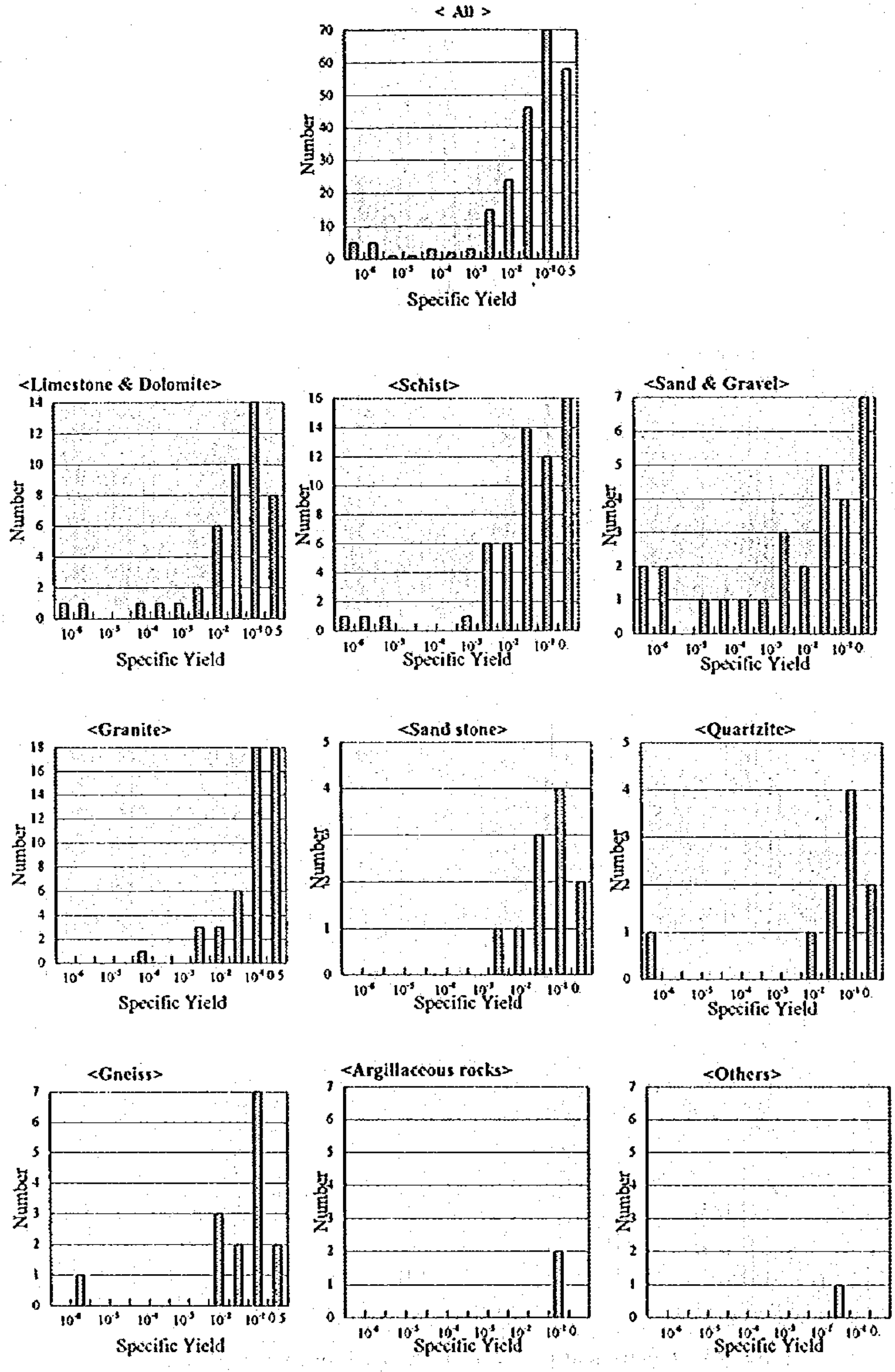


Figure 3-4 Specific Yield by Pumping Test Analysis

CHAPTER 4 GROUNDWATER PRODUCTION SURVEY BY DISTRICT

4.1 Purpose of Survey

The purpose of this survey is to obtain the number of boreholes and shallow wells by district. The results of this survey give the information listed below:

- Current groundwater production rate by district especially in rural areas.
- Relative depth of groundwater table. Ratio of boreholes / shallow wells is closely related to this depth.
- Ratio of groundwater use / surface water use. Groundwater use is inversely related to surface water use.
- Distribution of aquifers for boreholes and shallow wells

4.2 Survey Item and Method

Survey Items are as follows:

1) the number of existing boreholes and shallow wells by district
2) Average yield of boreholes and shallow wells

<u>The method for item 1)</u>

- The survey used the information published by DWA as a basis. This information gives the total number of existing boreholes and shallow wells drilled between 1964 and 1985 by Province.
- The number of boreholes and shallow wells drilled after 1986 by province was estimated from the increase rate of boreholes and shallow wells between 1964 and 1985.
- The number of boreholes and shallow wells by province was divided into each district based on the borehole data-base and investigation at each district office of DWA. The number of townships, villages and population in each district have been utilized as important information for the estimation.

<u>The method for item 2)</u>

- The survey used the information published by CMMU as a basis, which gives the current operation rate of boreholes and shallow wells in rural areas.
- Average yield of boreholes was assumed to be $7m^3$/day based on the capacity of a handpump. On the other hand, average yield of shallow wells is assumed to be one third of that of boreholes, which is based on experience and on the information derived from the result of nation wide groundwater level observation.

4.3 Survey Result

4.3.1 Number of Boreholes and Shallow Wells by District

(1) Number of Boreholes

The number of existing boreholes is shown in Table 4-1 and Figure 4-1. The results are summarized as follows:

- Provinces are divided into 3 groups in terms of the number of boreholes. The first group is Western(2,960), Lusaka(2,570), and Southern(1,490), the second group is Central(870), Copperbelt(840) and Eastern(750), the third group is Northern(190), Luapula(170) and Northwestern(190).
- In Lusaka province, 87% of boreholes are concentrated in the Lusaka Urban District due to high demand for city water supply and the existence of superior aquifers in the dolomite.
- Many boreholes were drilled under NORAD's long term project. Unconsolidated sands of Kalahari formation in Western province made it easy to drill them.
- Southern province often suffered a shortage of water from drought and many boreholes were drilled as a counter-measure by JICA etc.
- Lusaka, Western and Southern provinces are located in the southern part of Zambia often and suffer a shortage of annual precipitation. Therefore, the number of boreholes needed is greater than for other provinces.
- On the contrary, there is heavy precipitation in the third group, Northern, Luapula and Northwestern provinces, and this results in fewer boreholes in these provinces. The second group, Central, Copperbelt and Eastern provinces is intermediate between the first and the third group.

(2) The Number of Shallow Wells

The number of existing shallow wells is shown in Table 4-1 and Figure 4-1. The result is summarized as follows:

- Provinces are divided into 3 groups in terms of the number of shallow wells. The first group is Eastern province(2,140), the second group is Northern(1,080), Luapula(1,100) and Western(1,020) and Southern(800), the third group is Copperbelt(660), Central(600) and Lusaka(390). The number of shallow wells by province is closely related to average depth of groundwater table by province.
- It is noted that there are many shallow wells especially in Eastern province and those provinces which have more shallow wells have fewer boreholes.
- The difference in the number of shallow wells among provinces is not so great as that of boreholes.

4.3.2 Rate and Ratio of Rural Water Supply

(1) Metod to Estimate Groundwater Supply Ratio In Rural Areas

Groundwater supply ratio has been estimated based on the investigation into number and current yield of existing boreholes and shallow wells. The groundwater supply ratio has been estimated as follows:

Table 4-1 Number of Boreholes and Shallow Wells

Province	District	Borehole	shallow well
Lusaka	Lusaka-Urban	2,230	20
	Lusaka-Rural	290	260
	Luangwa	50	120
	Total	2,570	400
Copperbelt	Ndola-Urban	270	
	Ndola-Rural	190	660
	Chililabombwe	50	
	Chingola	60	
	Mufulira	70	
	Kalulushi	50	
	Kitwe	80	
	Luanshya	100	
	Total	870	660
Central	Kabwe-Urban	130	80
	Kabwe-Rural	390	150
	Mumbwa	120	140
	Mkushi	160	140
	Serenje	90	110
	Total	890	620
Northwestern	Solwezi	50	190
	Mwinilunga	20	180
	Zambezi	30	170
	Kabompo	20	160
	Mfumbwe	10	100
	Kasempa	40	150
	Total	170	950
Western	Mongu	570	200
	Lukulu	450	180
	Kalabo	480	160
	Kaoma	450	160
	Senanga	540	190
	Sesheke	510	170
	Toatl	3,000	1,060
Southern	Livingstone	110	20
	Namwala	140	110
	Mazabuka	400	120
	Monze	220	130
	Choma	160	110
	Kalomo	170	100
	Siavonga	100	90
	Gwembe	120	90
	Sinazongwe	100	70
	Total	1,520	840
Luapula	Mansa	60	280
	Nchelenge	40	260
	Kawambwa	30	250
	Mwense	40	200
	Samfya	30	140
	Total	200	1,130
Northern	Kasama	70	180
	Kaputa	30	80
	Mbala	20	120
	Mporokoso	20	140
	Luwingu	20	110
	Chilubi	0	100
	Isoka	20	90
	Chinsali	20	160
	Mpika	40	150
	Total	240	1,130
Eastern	Chipata	230	430
	Chama	90	220
	Lundazi	80	370
	Chadiza	100	350
	Katete	100	390
	Petauke	180	410
	Total	780	2,170
Total		9,968	8,725

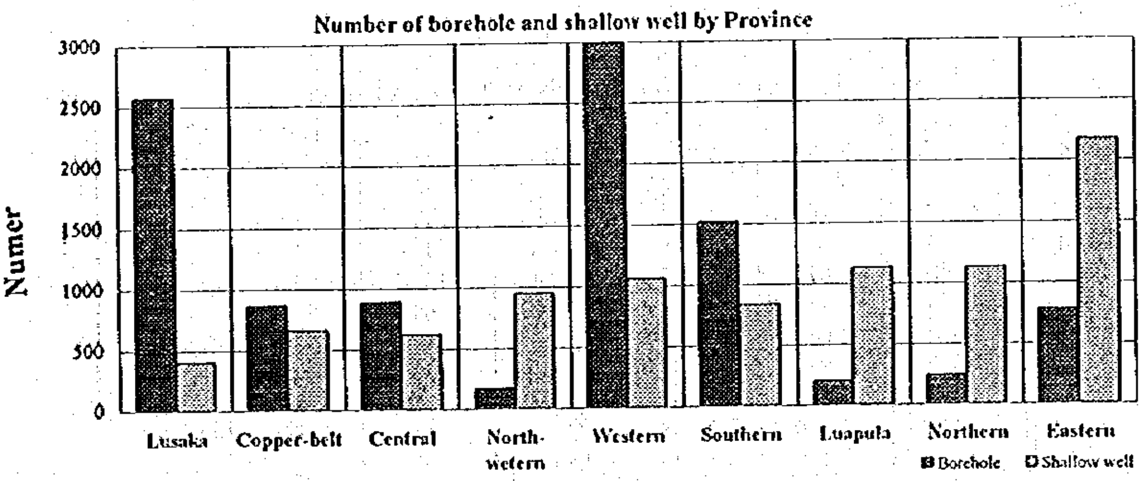


Fig 4-1 The Total Number of Existing Boreholes and Shallow Wells

Groundwater supply ratio
= (Total current groundwater use m^3/day) / (33.85 l/day x population)

33.85l/cap./day is consumption rate including 10% water loss rate in rural areas.

Total current groundwater use(m^3/day)
= (Total number of boreholes + shallow wells) x (Operation rate) x (Unit yield)

Operation rate
Operation rate has been assumed based on the results of investigations carried out by CMMU. Borehole = 0.7, Shallow Well = 0.6

Unit Yield
Unit yields have been estimated as follows,
Borehole = 7.5 m^3/day x 0.8 = 6 m^3/day
Shallow well = (Unit yield of borehole) / 3 = 6 m^3/day / 3=2 m^3/day

Unit supply rate, 38.5l/cap./day is obtained from target supply rate of 35l/cap./day plus water loss rate of 3.5l/cap./day. Unit yield of boreholes, 7.5m^3/day, means standard yield from a handpump with 10 hours' operation a day. Finally, 6m^3/day was decided as unit yield of boreholes on the assumption that handpumps are being operated at 80% of their standard capacities. On the other hand, unit yield of shallow wells, 2m^3/day, was decided on the assumption that yield of shallow wells is almost one third of that of boreholes based on long experience and field survey.

(2) Groundwater Supply Ratio in Rural Areas

Groundwater supply ratio in rural areas has been estimated as shown in Table 4-2 and Figure 4-2 by province and Table 4-3 by district. Water supply in rural areas is summarized as follows:

Table 4-2 Groundwater Supply Rate in Rural Areas

Province	Number of Well		Total Yield (m^3/day)	Population	Water Supply Ratio (%)		
	Borehole	Shallow Well			Ratio by Borehole	Ratio by Shallow Well	Total
Lusaka	2,570	400	1,872	157,633	24%	8%	31%
Copper-belt	870	660	3,308	314,891	21%	7%	27%
Central	890	620	3,821	507,428	16%	3%	20%
North-western	170	950	1,834	333,234	6%	9%	14%
Western	3,000	1,060	13,703	531,072	61%	6%	67%
Southern	1,520	840	7,392	695,166	24%	4%	28%
Luapula	200	1,130	2,161	442,034	5%	8%	13%
Northern	240	1,130	2,305	736,876	4%	5%	8%
Eastern	780	2,170	5,845	883,218	10%	8%	17%
Total	10,240	8,960	42,198	4,601,552	18%	6%	24%

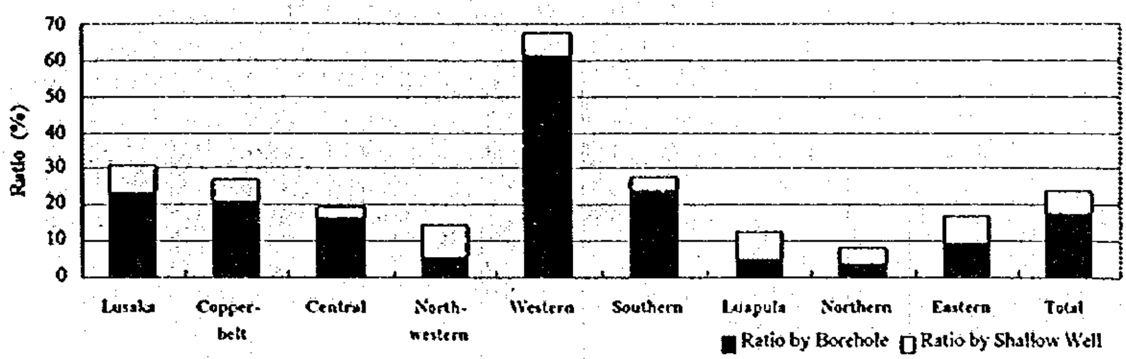


Figure 4-2 Groundwater Supply Ratio inRural Areas

Groundwater is the main resource used for water supply in rural areas. Therefore, water supply ratio in rural areas is proportional to the number of boreholes and shallow wells, especially to that of boreholes. Average water supply ratio in the whole of Zambia is 24%. Water supply ratios by province are, Western province 67%, Lusaka 31%, Copperbelt 27% and Southern 28%, these provinces show higher supply ratio than the country average. On the other hand, water supply ratios for, Central province 20%, Eastern 17%, Northwestern 14% and Luapula 13%, show lower ratios than the country average. Of course it is considered that the shortage of groundwater has been made up for by using surface water in those provinces where water supply ratio is low. However, surface water is less valuable than groundwater in terms of drinking water in rural areas because of unreliable quality and quantity through out year.

Table 4-3 Groundwater Supply Ratio in Rural Area

Province	District	Borehole			Shallow Well			Total		Supply
		Total	Operating	Yield (m3/day)	Total	Operating	Yield(m3/day	Yield (m3/day)	Population	Rate(%)
Lusaka	Lusaka-Urban		0	0		0	0	0		
	Lusaka-Rural	290	203	1,218	260	156	312	1,530	142,993	28
	Luangwa	50	35	210	120	72	144	354	14,640	63
	Total	340	238	1,428	380	228	456	1,884	157,633	31
Copperbelt	Ndola-Urban									
	Ndola-Rural	190	133	798	660	396	792	1,590	152,027	27
	Chililabombw	50	35	210		0	0	210	12,728	43
	Chingola	60	42	252		0	0	252	18,679	35
	Mufulira	70	49	294		0	0	294	21,705	35
	Kalulushi	50	35	210		0	0	210	26,804	20
	Kitwe	80	56	336		0	0	336	59,164	15
	Luanshya	100	70	420		0	0	420	23,784	46
	Total	600	420	2,520	660	396	792	3,312	314,891	27
Central	Kabwe-Urban									
	Kabwe-Rural	390	273	1,638	150	90	180	1,818	198,767	24
	Mumbwa	120	84	504	140	84	168	672	112,792	15
	Mkushi	160	112	672	140	84	168	840	100,662	22
	Serenje	90	63	378	110	66	132	510	95,207	14
	Total	760	532	3,192	540	324	648	3,840	507,428	20
Northwestern	Solwezi	50	35	210	190	114	228	438	98,401	12
	Mwinilunga	20	14	84	180	108	216	300	75,154	10
	Zambezi	30	21	126	170	102	204	330	60,626	14
	Kabompo	20	14	84	160	96	192	276	48,192	15
	Mfumbwe	10	7	42	100	60	120	162	18,119	23
	Kasempa	40	28	168	150	90	180	348	32,742	28
	Total	170	119	714	950	570	1,140	1,854	333,234	14
Western	Mongu	570	399	2,394	200	120	240	2,634	105,958	65
	Lukulu	450	315	1,890	180	108	216	2,106	48,824	112
	Kalabo	450	315	1,890	160	96	192	2,082	88,452	61
	Kaoma	450	315	1,890	160	96	192	2,082	102,884	53
	Senanga	540	378	2,268	190	114	228	2,496	128,442	50
	Sesheke	510	357	2,142	170	102	204	2,346	56,512	108
	Total	2,970	2,079	12,474	1,060	636	1,272	13,746	531,072	67
Southern	Livingstone	110	77	462	20	12	24	486	6,077	208
	Namwala	140	98	588	110	66	132	720	74,276	25
	Mazabuka	400	280	1,680	120	72	144	1,824	112,445	42
	Monze	220	154	924	130	78	156	1,080	108,454	26
	Choma	160	112	672	110	66	132	804	127,530	16
	Kalomo	170	119	714	100	60	120	834	152,937	14
	Siavonga	100	70	420	90	54	108	528	27,235	50
	Gwembe	120	84	504	90	54	108	612	33,449	48
	Sinazongwe	100	70	420	70	42	84	504	52,763	25
	Total	1,520	1,064	6,384	840	504	1,008	7,392	695,166	28
Luapula	Mansa	60	42	252	280	168	336	588	103,446	15
	Nchelenge	40	28	168	260	156	312	480	95,641	13
	Kawambwa	30	21	126	250	150	300	426	71,518	15
	Mwense	40	28	168	200	120	240	408	76,661	14
	Samfya	30	21	126	140	84	168	294	94,768	8
	Total	200	140	840	1,130	678	1,356	2,196	442,034	13
Northern	Kasama	70	49	294	180	108	216	510	141,315	9
	Kaputa	30	21	126	80	48	96	222	47,057	12
	Mbala	20	14	84	120	72	144	228	121,167	5
	Mporokoso	20	14	84	140	84	168	252	47,687	14
	Luwingu	20	14	84	110	66	132	216	62,035	9
	Chilubi	0	0	0	100	60	120	120	38,508	8
	Isoka	20	14	84	90	54	108	192	108,782	5
	Chinsali	20	14	84	160	96	192	276	76,150	9
	Mpika	40	28	168	150	90	180	348	94,175	10
	Total	240	168	1,008	1,130	678	1,356	2,364	736,876	8
Eastern	Chipata	230	161	966	430	258	516	1,482	239,159	16
	Chama	90	63	378	220	132	264	642	48,298	35
	Lundazi	80	56	336	370	222	444	780	166,012	12
	Chadiza	100	70	420	350	210	420	840	60,179	36
	Katete	100	70	420	390	234	468	888	131,305	18
	Petauke	180	126	756	410	246	492	1,248	238,265	14
	Total	780	546	3,276	2,170	1,302	2,604	5,880	883,218	17
Total		7,580	5,306	31,836	8,860	5,316	10,632	42,468	4,601,552	24

CHAPTER 5 IMFORMTION DERIVED FROM DATA-BASE

5.1 Lithology of Aquifer

(1) Lithplogy of Aquifer

Aquifer lithology is shown in Table 5-1 and Figure 5-1. As shown in Table 5-1, more than 60% of aquifers are composed of Limestone & Dolomite and Schist.

Table 5-1 Lithology of Aquifer

Main Aquifer Lithology	Number of Borehole Data	%
Limestone & Dolomite	1,267	32
Schist	1,160	30
Sand & Gravel	479	12
Granite	448	11
Sandstone	175	5
Quartzite	176	5
Gneiss	88	2
Shale, Mudstone, etc.	65	2
Others	38	1
< Total >	3,896	

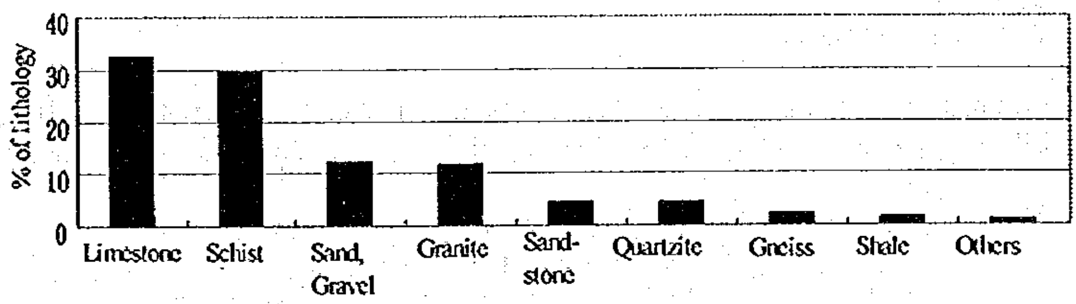


Figure 5-1 Lithology of Aquifer

(2) Litho-stratigraphic Unit of Aquifer

Litho-stratigraphic Unit of Aquifer of existing boreholes are shown in Table 5-2 and Figure 5-2 by lithology. As shown in Table 5-2, about 70 % of aquifers are composed of Katanga Super Group.

Table 5-2 Litho-stratigraphic Unit of Aquifer

Litho-stratigraphic Unit	Number of Boreholes	% of all the Boreholes	Litho-stratigraphic Unit	Number of Boreholes	% of all the Boreholes
Alluvium	190	4.5	Muva	17	0.4
Kalahari	389	9.1	Basement	225	5.3
Karroo	61	1.4	Granite	469	11.0
Katanga	2914	68.3	< Total >	4264	

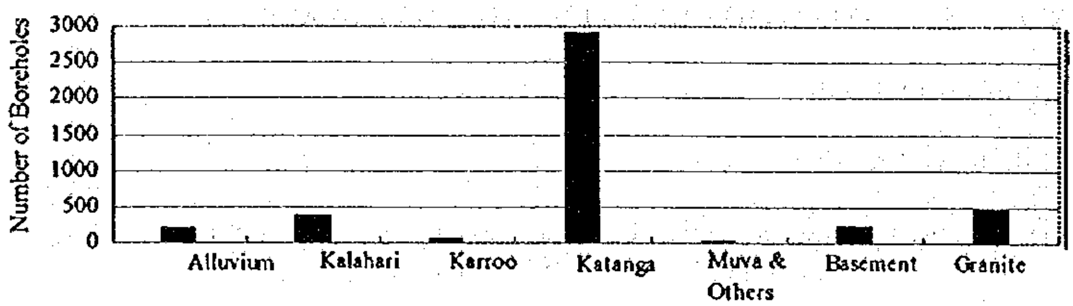


Figure 5-2 Litho-stratigraphic Unit of Aquifer

5.2 Hydraulic Characteristics of Aquifer

(1) Specific Capacity

Specific Capacity of existing boreholes are shown in Table 5-3 and Figure 5-3 by lithology. Specific capacity is a good indicator for the capacity of a borehole. From this point of view, the ranking of capacity by rock type is given as follows:

1) Limestone & Dolomite
2) Sand & Gravel
3) Sandstone
4) Quartzite
5) Schist
6) Granite and Gneiss

As shown in Table 5-3, it is concluded that Limestone & Dolomite, and Sand & Gravel, but especially Limestone & Dolomite, form far superior aquifers compared with other rock types.

Table 5-3 Specific Capacity

Lithology	Data Number	Medium (m2/day)	Range (m2/day) Minimum	Range (m2/day) Maximum
Limestone & Dolomite	1267	50.2	0.016	7200
Schist	1160	4.2	0.061	9070
Sand & Gravel	479	25.9	0.027	1150
Granite	448	5.7	0.001	1800
Sandstone, Conglomerate	175	10.5	0.111	2130
Quartzite	176	6.0	0.147	3090
Gneiss, Migmatite	88	2.3	0.219	468
Argillaceous Rock	65	1.9	0.032	332
Others*	38	1.9	0.291	378
< Total >	4246	9.96	0.001	9070

(Note) * Others include Igneous and the other metamorphic rocks

(2) Transmmissivity

Transmmissivity of existing boreholes analyzed using pumpimg test data are shown in Table 3-1 and Figure 3-1 by lithology.

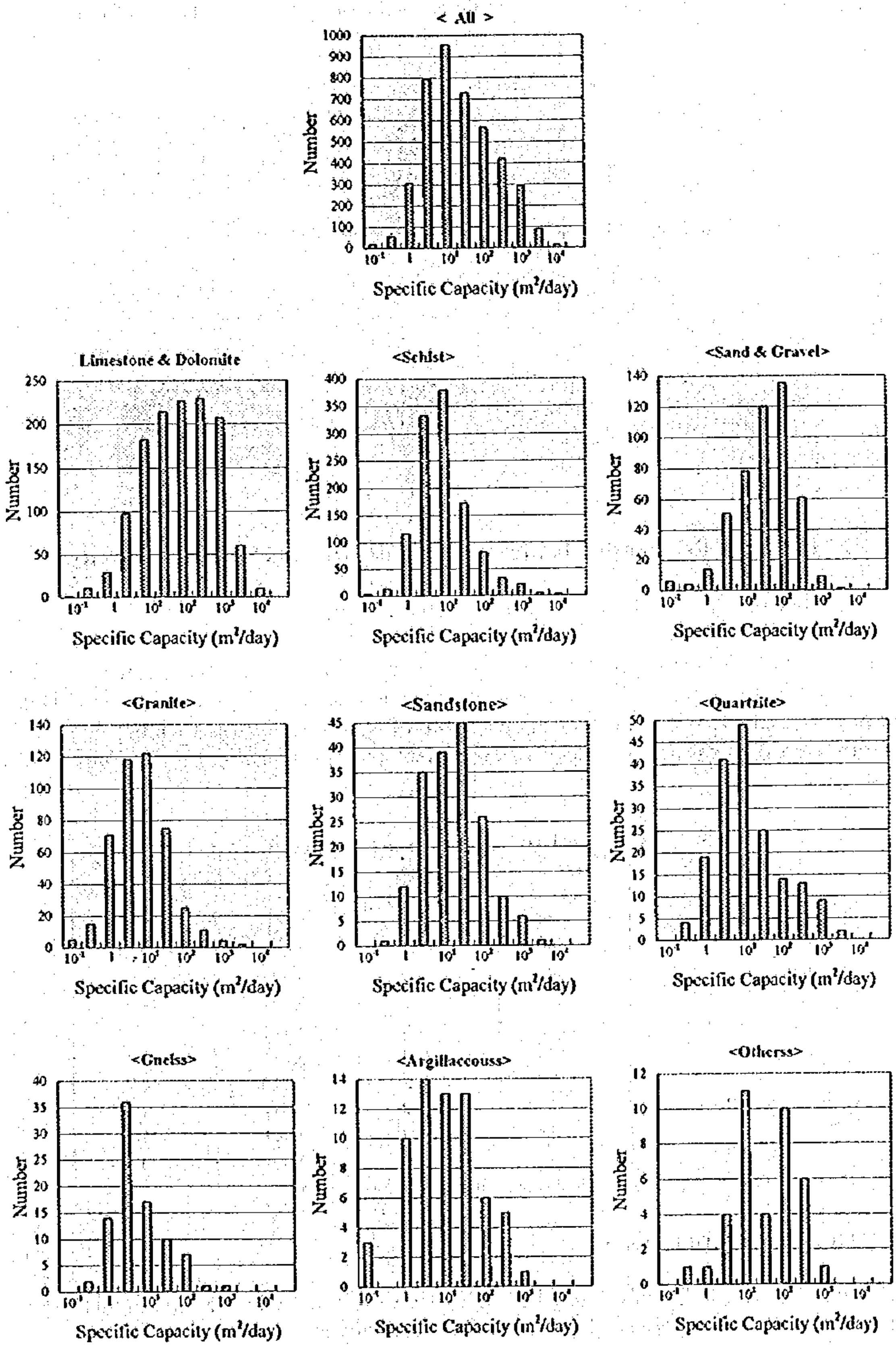


Figure 5-3 Specific Capacity by Lithology

The approximate relationship between specific capacity and transmissivity is as follows:

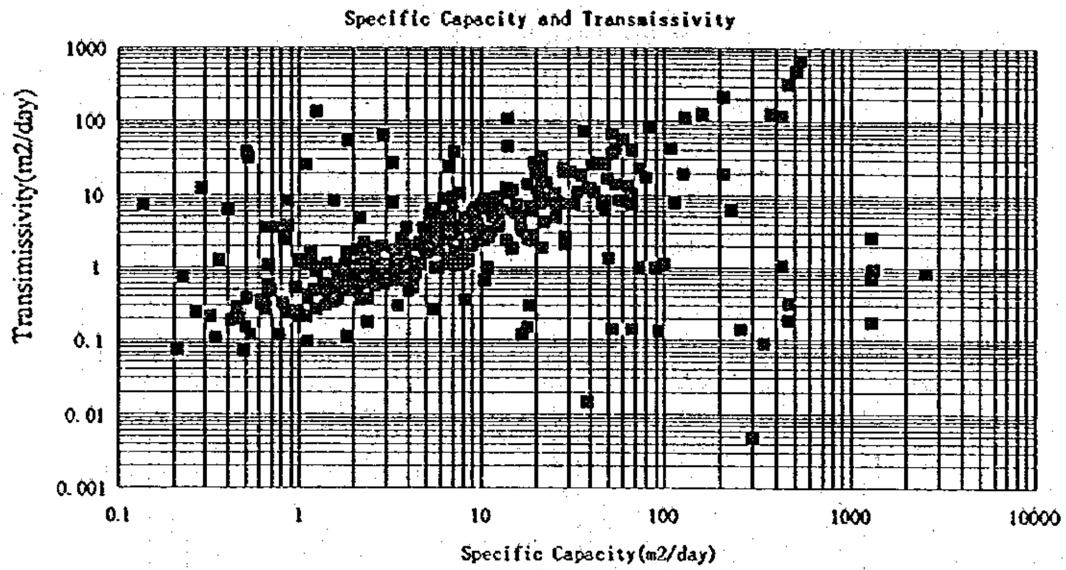


Figure 5-4 Relationship between Transimissivity and Specific Capacity

Specific capacity (m^2/day) = Transmissivity(m^2/day)

The relation that specific capacity is almost the same as transmissivity is adopted to obtain the general trend of transmissivities. The median value of specific capacities stored in Database has been adopted as the representative value of transmissivity for each lithology. It is better to use values shown in Table 5-4 as representative transimissivity than values shown in Table 3-1.

Table 5-4 Transmmissivity (the same as specific capacity)

Lithology	Data Number	Average (m2/day)	Range (m2/day)	
			Minimum	Maximum
Limestone & Dolomite	1267	50.2	0.016	7200
Schist	1160	4.2	0.061	9070
Sand & Gravel	479	25.9	0.027	1150
Granite	448	5.7	0.001	1800
Sandstone, Conglomerate	175	10.5	0.111	2130
Quartzite	176	6.0	0.147	3090
Gneiss, Migmatite	88	2.3	0.219	468
Argillaceous.Rock	65	1.9	0.032	332
Others*	38	1.9	0.291	378
< Total >	4246	9.96	0.001	9070

(Note) * Others include Igneous and the other metamorphic rocks

(3) Coeficient of Permeability

Coefficient of Permeability of existing boreholes are shown in Table 5-5 and Figure 5-6 by lithology. Coefficient of permeability was obtained as follows:

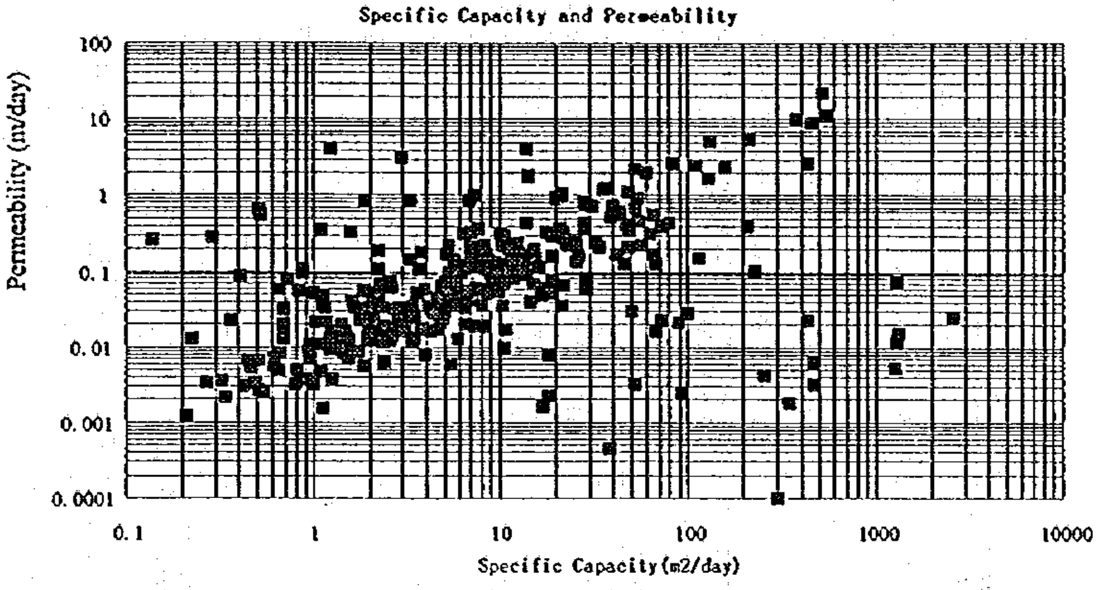


Figure 5-5 Relationship between Permeability and Specific Capacity

Coefficient of permeability (m/day)
= Transimissivity(m2/day) / [Borehole length(m) - Groundwater level from surface before pumping test(m)]

It is better to use values shown in Table 5-5 as representative permeability than values shown in Table 3-2.

Table 5-5 Coeficient of Permeability

Lithology	Data Number	Average (m/day)	Range (m/day) Minimum	Range (m/day) Maximum
Limestone & Dolomite	1,267	1.31	0.00022	356
Schist	1,160	0.11	0.00069	436
Sand & Gravel	479	0.68	0.00061	457
Granite	446	0.15	0.000015	180
Sandstone, Conglomerate	175	0.27	0.0017	39
Quartzite	176	0.16	0.0037	72
Gneiss, Migmatite	88	0.06	0.0038	10
Argillaceous Rock	65	0.05	0.00098	8
Others*	38	0.05	0.00047	15
< Total >	4,244	0.26	1.52×10^{-5}	436.1

(Note) * Others include Igneous and the other metamorphic rocks

(4) Specific Yield

Specific Yields of existing boreholes have been obtained by pumping test analysis for more than 200 data sets. These result are shown in Table 3-3 and Figure 3-4. Relationship between specific yield and specific capacity is shown in Figure 5-7. Specific capacity does not appear to be related to specific yield as shown in Figure 5-7. Values of specific yield vary widely as shown in Figure 3-3. It is difficult to find a trend of specific yield by aquifer and to decide a representative specific yield for each aquifer from only the results of pumping test analysis. The following relation between specific yield and specific capacity was proposed in "Groundwater Resources Inventory of Zambia (1978, Chenov)".

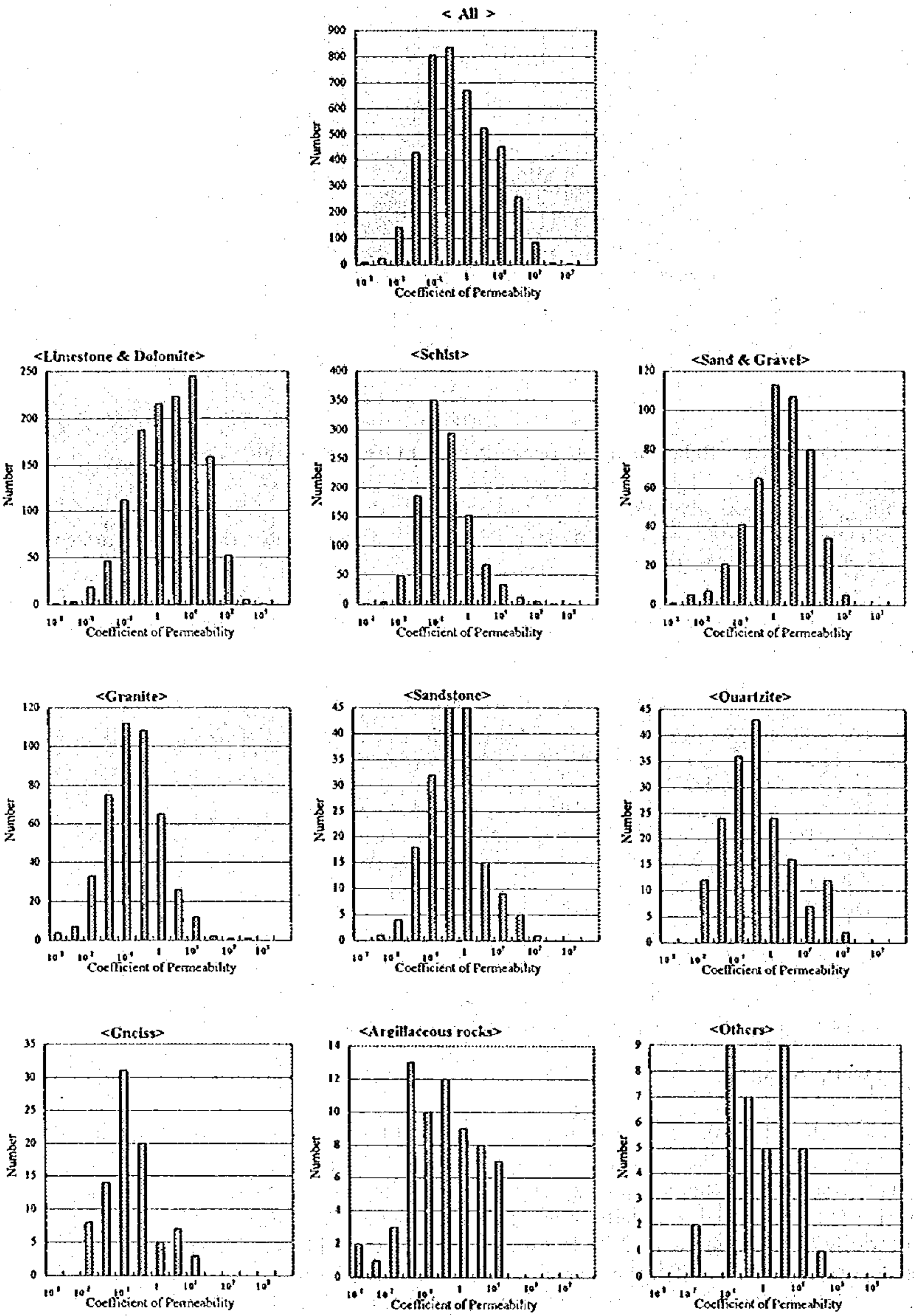


Figure 5-6 Coefficient of Permeability by Lithology

$$\text{Specific Yield} = 0.0934 \times [\text{Permeability (m/day)}]^{(1/7)}$$

However, such a relation is not obvious from Figure 5-7.

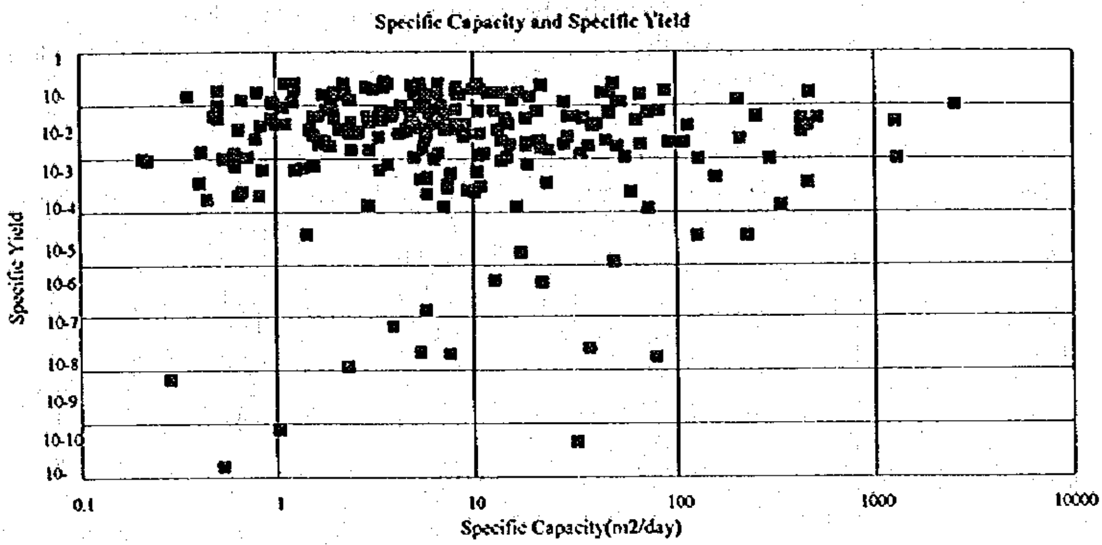


Figure 5-7 Relationship berween Specific Yield and Specfic Capacity

Representative value of specific yield as obtained from pumping test analysis is 4%, therefore, actual average specific yields may be around 4%. The specific yield of each aquifer has been assumed as shown in Table 5-6 considering its permeability.

It is better to use values shown in Table 5-6 as representative specific yield than values shown in Table 3-3.

Table 5-6 Representative Value of Specific Yield

Grade	Specific Yield	Lithology	Grade	Specific Yield	Lithology
Permeability High	5%	Limestone Dolomite Sand & Gravel	Permeability Medium Low	3%	Granite Schist Quartzite
Permeability Medium High	4%	Sandstone	Permeability Low	2%	Gneiss Argillaceous Rocks Others

5.3 Depth of Main Groundwater Supply

(1) Depth from Surface of Main Supply

Depth from surface of main supply of existing boreholes are shown in Table 5-7 and Figure 5-8 by lithology. The depth is shallower in sand & gravel. However, there are little difference among the other lithology.

Table 5-7 Depth of Main Groundwater Supply

Lithology	Data Number	Average (G.L.-m)	Range (G.L.-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1321	28.6	2.0	108.5	0.37
Schist	1176	34.5	0.2	91	0.44
Sand & Gravel	511	24.9	0.74	114.0	1.05
Granite	427	29.4	3.0	85.0	0.72
Sandstone, Conglomerate	182	35.2	1.0	110	1.29
Quartzite	186	33.3	2.0	91	1.17
Gneiss, Migmatite	85	28.1	2.0	70	1.58
Argillaceous Rock	44	33.6	2.7	70.0	2.54
Others*	55	33.3	3.0	70.1	2.33
< The whole >	4343	30.4	0.2	114	0.25

(Note) * Others include Igneous and the other metamorphic rocks

5.4 Thickness of Aquifer

(1) Depth of Upper Limit of Main Aquifer

Depth of upper limit of main aquifer of existing boreholes are shown in Table 5-8 and Figure 5-9 by lithology. The depth is shallower in sand & gravel. However, there are little difference among the other lithology. The depth is usualy less than 30m.

Table 5-8 Depth of Upper Limit of Main Aquifer

Lithology	Data Number	Medium (G.L.-m)	Range (G.L.-m)	
			Minimum	Maximum
Limestone & Dolomite	1380	16.6	1.5	76.2
Schist	1249	21.0	0.3	76.0
Sand & Gravel	521	8.0	0.62	72.0
Granite	476	15.2	1.0	61.0
Sandstone, Conglomerate	193	18.0	1.0	76.0
Quartzite	193	20.0	.0	68.0
Gneiss, Migmatite	91	19	2.0	65.0
< The whole >	4283	18.0	0.3	76.2

(2) Depth of Lower Limit of Main Aquifer

Depth of lower limit of main aquifer of existing boreholes are shown in Table 5-9 and Figure 5-9 by lithology. Depth of lower limit of main aquifer exists usualy about 10m above the bottom of Boreholes.

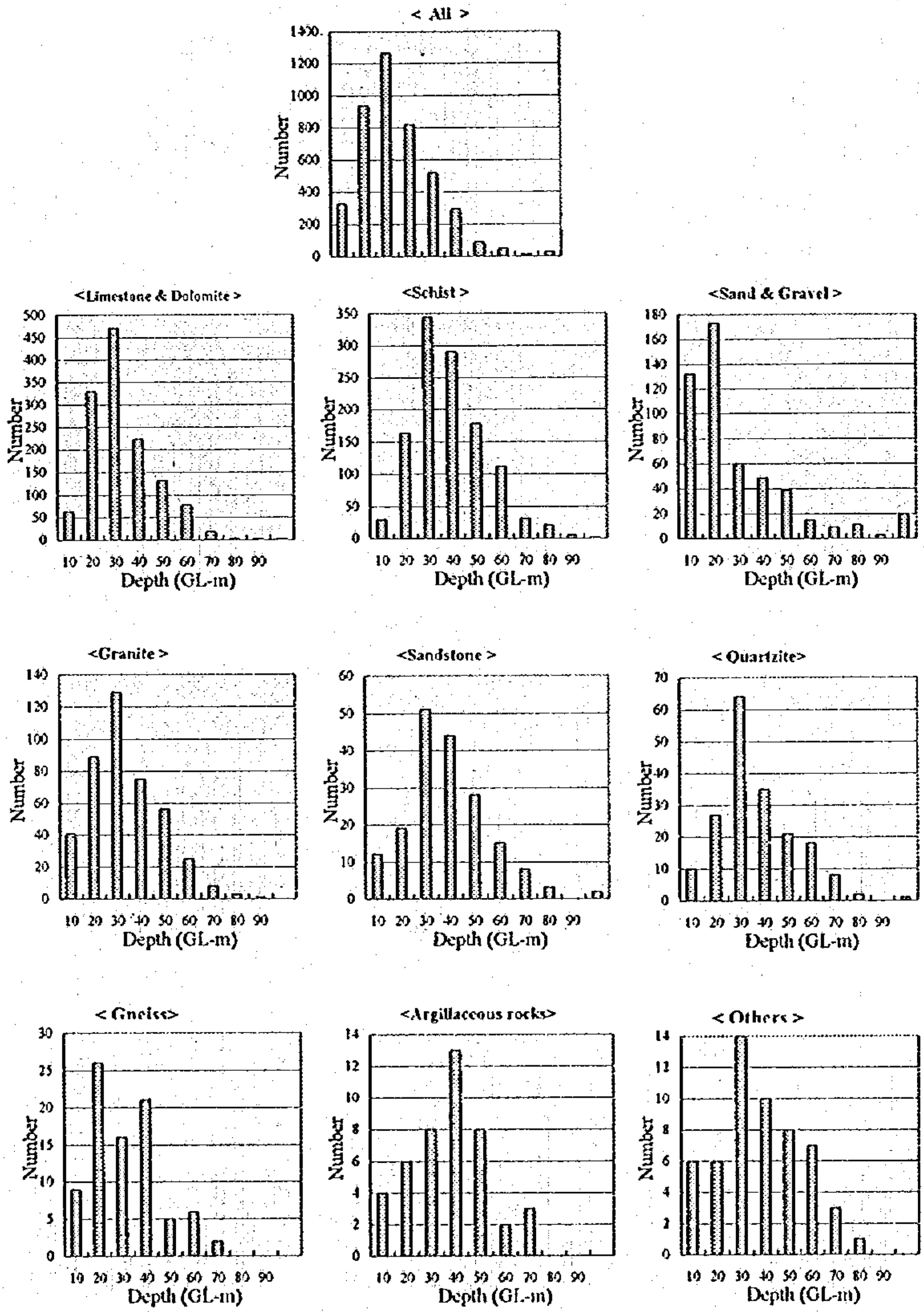


Figure 5-8 Depth from Surface of Main Supply by Lithology

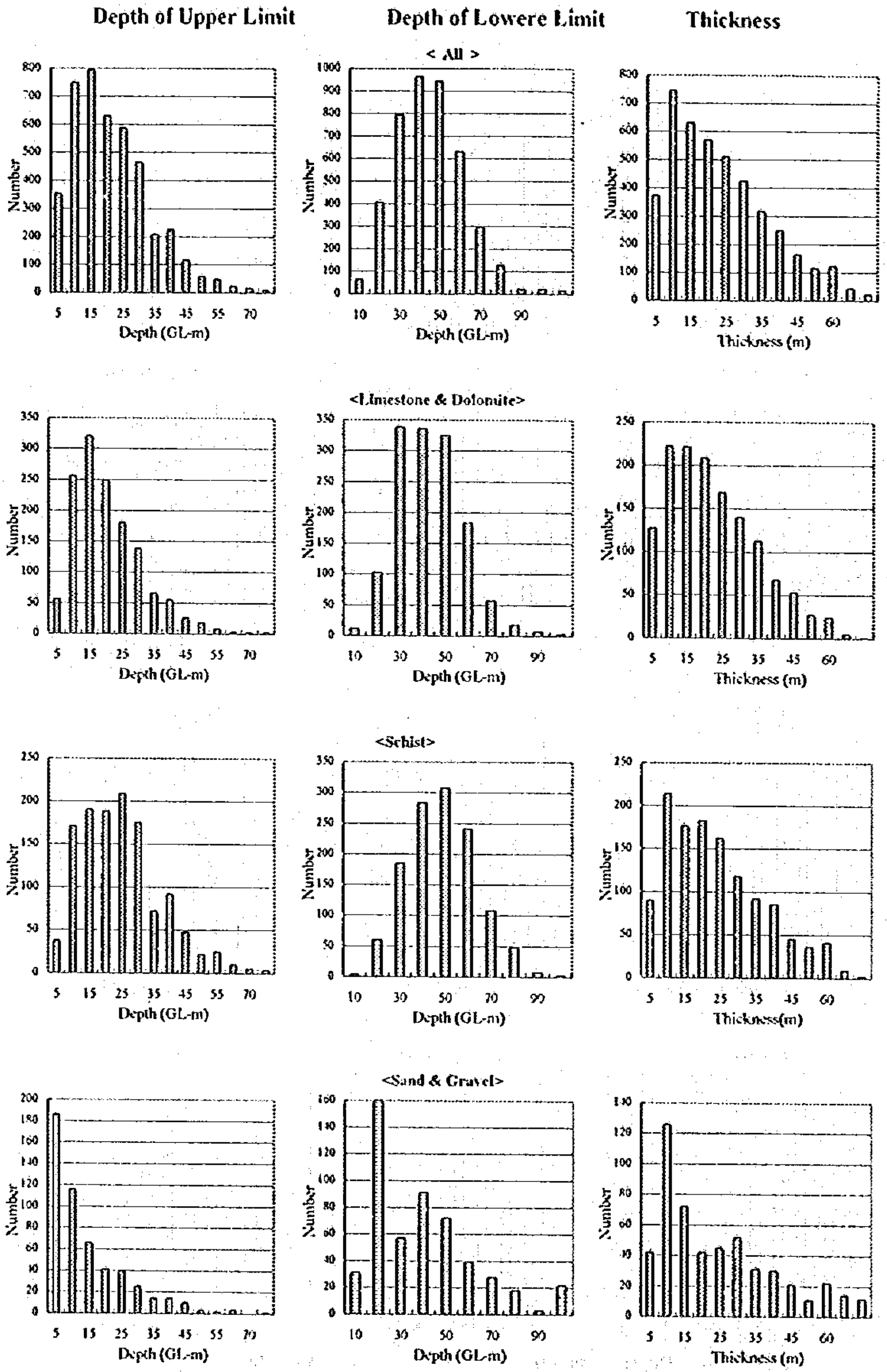


Figure 5-9(1) Depth of Boundary and Thickness of Main Aquifer by Lithology(1)

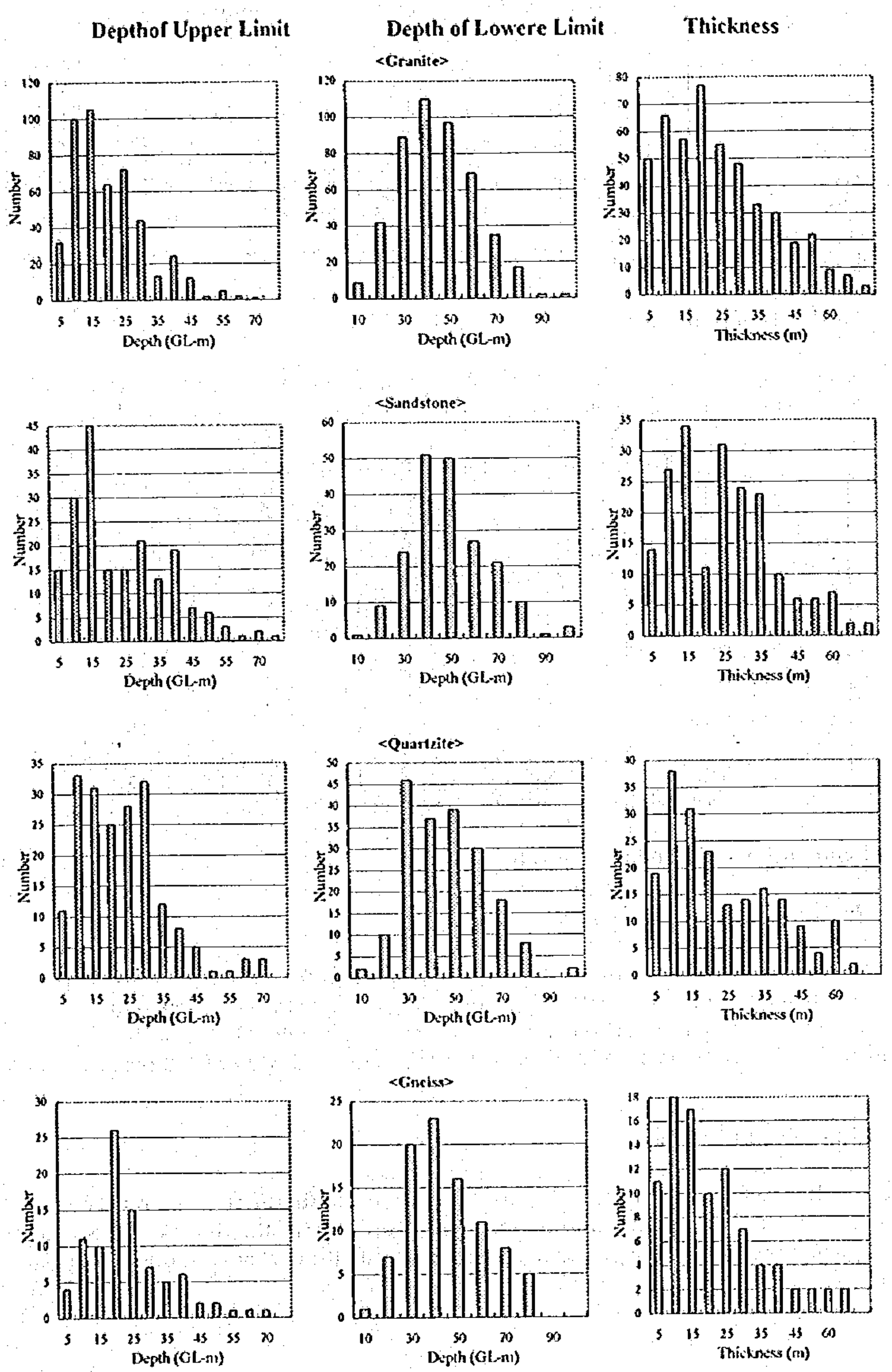


Figure 5-9(2) Depth of Boundary and Thickness of Main Aquifer by Lithology (2)

Table 5-9 Depth of Lower Limit of Main Aquifer

Lithology	Data Number	Average (G.L.-m)	Range (G.L.-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1381	38.8	1.8	108.0	.38
Schist	1248	44.5	4.0	101.9	0.43
Sand & Gravel	521	35.6	4.2	123.3	1.04
Granite	472	41.1	4.0	110.0	0.77
Sandstone, Conglomerate	197	45.7	10.0	110.0	1.21
Quartzite	192	43.1	9.0	91.5	1.24
Gneiss, Migmatite	91	41.2	8.0	80.0	1.69
< The whole >	4284	41.1	1.8	123.3	0.26

(3) Thickness of Main Aquifer

Thickness of main aquifer of existing boreholes are shown in Table 5-10 and Figure 5-9 by lithology. Thickness of main aquifer is usualy less than 30m.

Table 5-10 Thickness of Main Aquifer

Lithology	Data Number	Medium (m)	Range (m)	
			Minimum	Maximum
Limestone & Dolomite	1378	18.0	0.3	81.0
Schist	1251	19.4	0.5	84.9
Sand & Gravel	520	17.0	0.8	109.3
Granite	476	20.0	0.1	85.0
Sandstone, Conglomerate	197	23.0	0.4	104.8
Quartzite	193	17.0	2.0	70.0
Gneiss, Migmatite	91	15.0	0.3	67.6
Argillaceous.Rock	46	15.5	1.0	60.0
Others*	58	21.0	2.0	61.4
<The whole>	4288	21.7	0.1	109.3

(Note) * Others include Igneous and the other metamorphic rocks

5.5 Depth of Layer Boundary and Lithology

(1) Depth of Boundary of Layers

Aquifer are divided into sub-strata in the borehole records. Three or four strata division is the most common. Figure 5-10 shows depth of lower limit from the first stratum to the fourth stratum. The first stratum is considered to be usually composed of strongly weathered rock. The strata underlying the first stratum are composed of fractured and fresh rock.

(2) Lithology of Each Layer

Figure 5-10 shows lithology from the first stratum to the fourth stratum. As shown in Fugure 5-10, the first stratum is usually composed of strongly weathered rock. This stratum forms aquifer providing groundwater to shallow wells and the thickness is usually less than 20m .

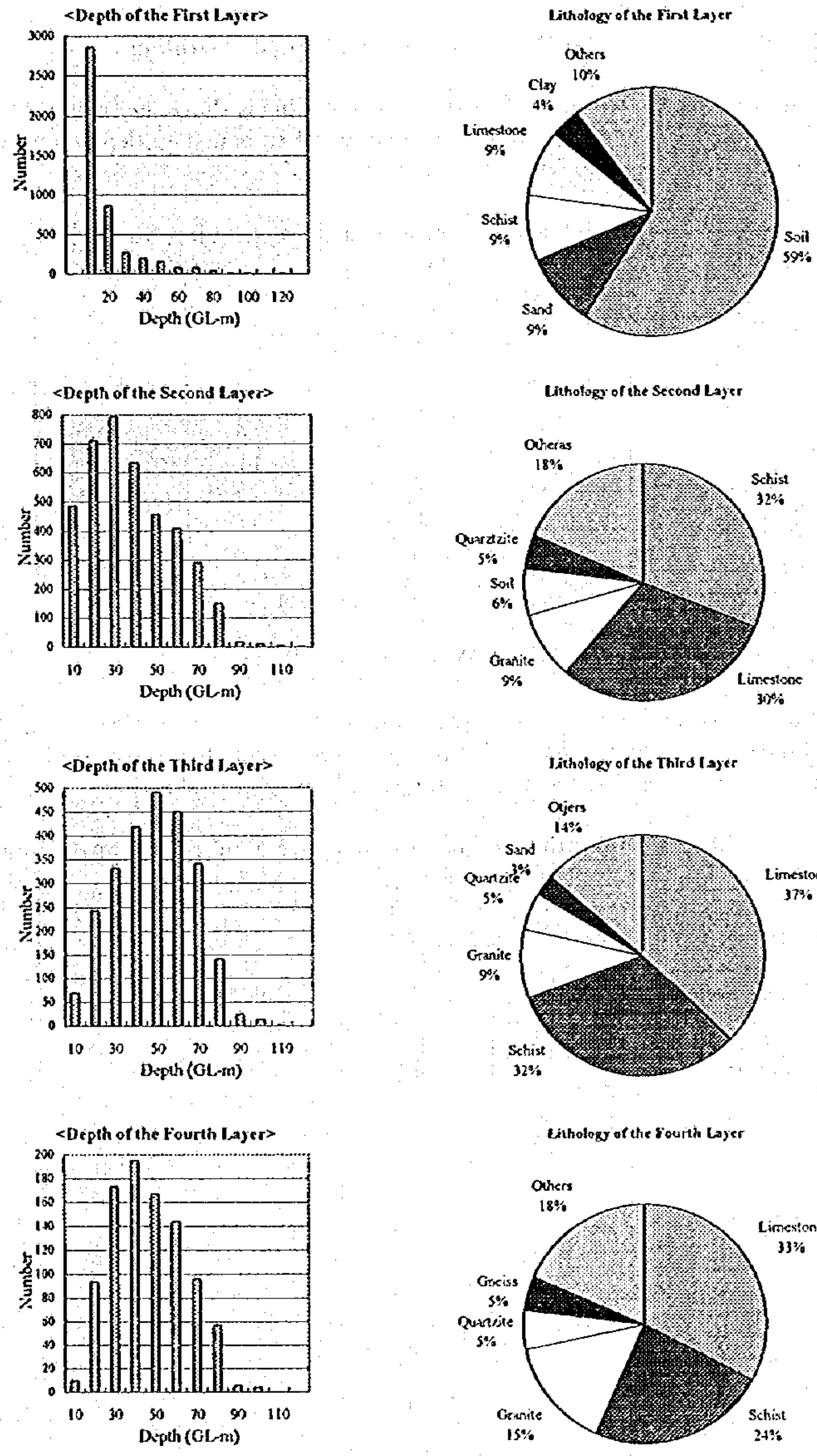


Figure 5-10 Depth of Layer Boundary and Lithology

5.6 Groundwater Level of Borehole

(1) Depth from Surface at Which Water First Struck at Drilling

Depth from surface at which water first struck at drilling is shown in Table 5-11 and Figure 5-11 by lithology. The depth is approximately equal to boundary depth between strongly weathered zone of rock and fractured zone of rock.

Table 5-11 Depth from Surface at Which Water First Struck at Drilling

Lithology	Data Number	Average (G.L.-m)	Range (G.L.-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,374	14.9	1.5	76.2	0.27
Schist	1,238	19.1	0.3	68.5	0.32
Sand & Gravel	519	11.4	0.62	60.5	0.48
Granite	474	15.4	0.25	58	0.45
Sandstone, Conglomerate	192	18.7	1.0	76	0.94
Quartzite	192	18.3	1.5	68	0.87
Gneiss, Migmatite	89	18.4	2.0	65.0	1.23
Argillaceous.Rock	46	19.8	2.4	63	2.01
Others*	58	19.9	3.0	65.0	1.80
< The whole >	4,555	16.2	0.25	76.2	0.16

(Note) * Others include Igneous and the other metamorphic rocks

(2) Depth from Surface to Which Water Rises at Drilling

Depth from surface to which water rises at drilling are shown in Table 5-12 and Figure 5-12 by lithology. The groundwater table rises in a borehole up to near the static groundwater level after the borehole has encountered fractures bearing groundwater.

Table 5-12 Depth from Surface to Which Water Rises at Drilling

Lithology	Data Number	Average (G.L.-m)	Range (G.L.-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,298	9.3	0.2	80.8	0.22
Schist	1,183	11.8	0.3	75	0.27
Sand & Gravel	506	9.3	0.1	64.7	0.44
Granite	436	8.7	0.15	70	0.35
Sandstone, Conglomerate	181	12.4	0.7	65	0.77
< The whole >	4,329	10.2	0.08	80.8	0.13

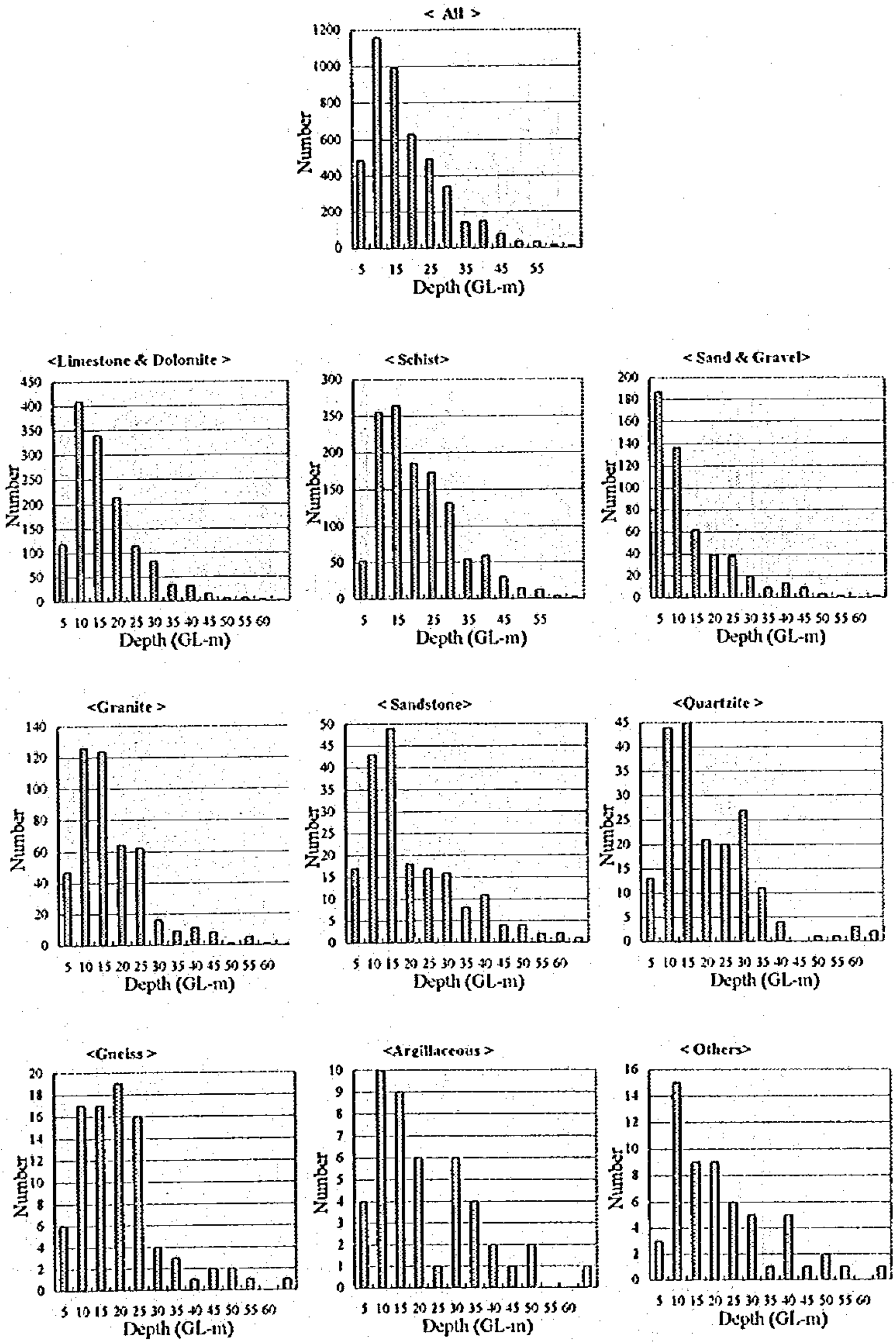


Figure 5-11 Depth from Surface at which Water First Struck by Lithology

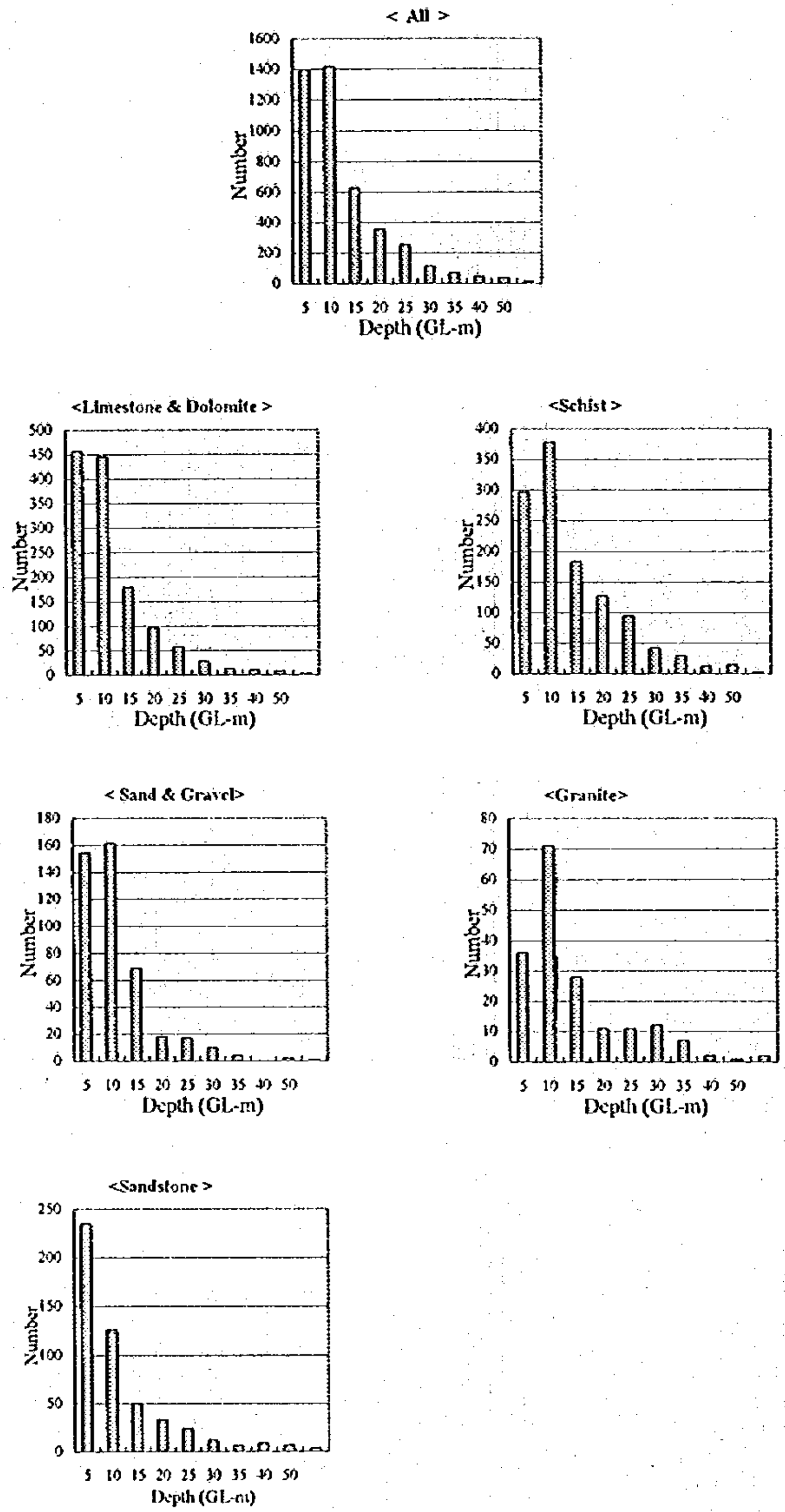


Figure 5-12 Depth from Surface to Which Water Rises by Lithology

(3) Depth of Water from Sirface before Pumping Test

Depth of groundwater from surface before pumping test is shown in Table 5-13 and Figure 5-13 by lithology. The depth is considered to be static groundwater level of boreholes. The level of boreholes shown in Table 5-14 is almost the same as that of shallow wells. Therefore, it may be concluded that the groundwater level in fractured zone of rock is continuously linking to that of strongly weathered zone of rock.

Table 5-13 Depth of Water from Sirface before Pumping Test

Lithology	Data Number	Medium (G.L.-m)	Range (G.L.-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,386	12.0	4.0	12.0	0.03
Schist	1,255	8.5	0.0	48.8	0.25
Sand & Gravel	522	5.4	0.0	55.7	0.42
Granite	476	6.4	0.0	79.0	0.37
Sandstone, Conglomerate	197	8.7	0.0	65.0	0.73
Quartzite	193	8.7	0.0	60.2	0.62
Gneiss, Migmatite	91	8.3	0.08	40.0	0.72
Argillaceous.Rock	46	8.4	1.4	40.1	1.27
Others*	58	9.8	0.1	35.8	1.23
< The whole >	4,601	7.1	0	79	0.12

(Note) * Others include Igneous and the other metamorphic rocks

(4) Greatest Depth to Which Water was Lowred at Pumping Test

Greatest depth to which water was lowered at pumping test are shown in Table 5-14 and Figure 5-14 by lithology. From the difference between the greatest groundwater depth lowered and the static groundwater level shown in Table 5-13, average draw down at pumping test is calculated as follows;

Average draw down at pumping test = 30.7 (m) - 7.1(m) = 23.6 (m)

The draw down is larger in limestone and dolomite aquifers and smaller in schist aquifers than the others.

Table 5-14 Greatest Depth to Which Water was Lowred at Pumping Test

Lithology	Data Number	Average (G.L.-m)	Range (G.L-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,275	22.8	0.8	85	0.45
Schist	1,163	40.3	1.5	97.0	0.49
Sand & Gravel	542	20.3	1.8	77.0	0.64
Granite	451	36.2	0.61	80.0	0.78
Sandstone, Conglomerate	181	32.7	1.5	91	1.38
Quartzite	175	36.0	1.0	82.0	1.41
Gneiss, Migmatite	89	35.9	9.5	75.0	1.61
Argillaceous.Rock	40	30.7	5.0	58.6	2.41
Others*	53	31.4	4.6	67.0	2.42
< The whole >	4,266	30.7	0.61	97.0	0.28

(Note) * Others include Igneous and the other metamorphic rocks

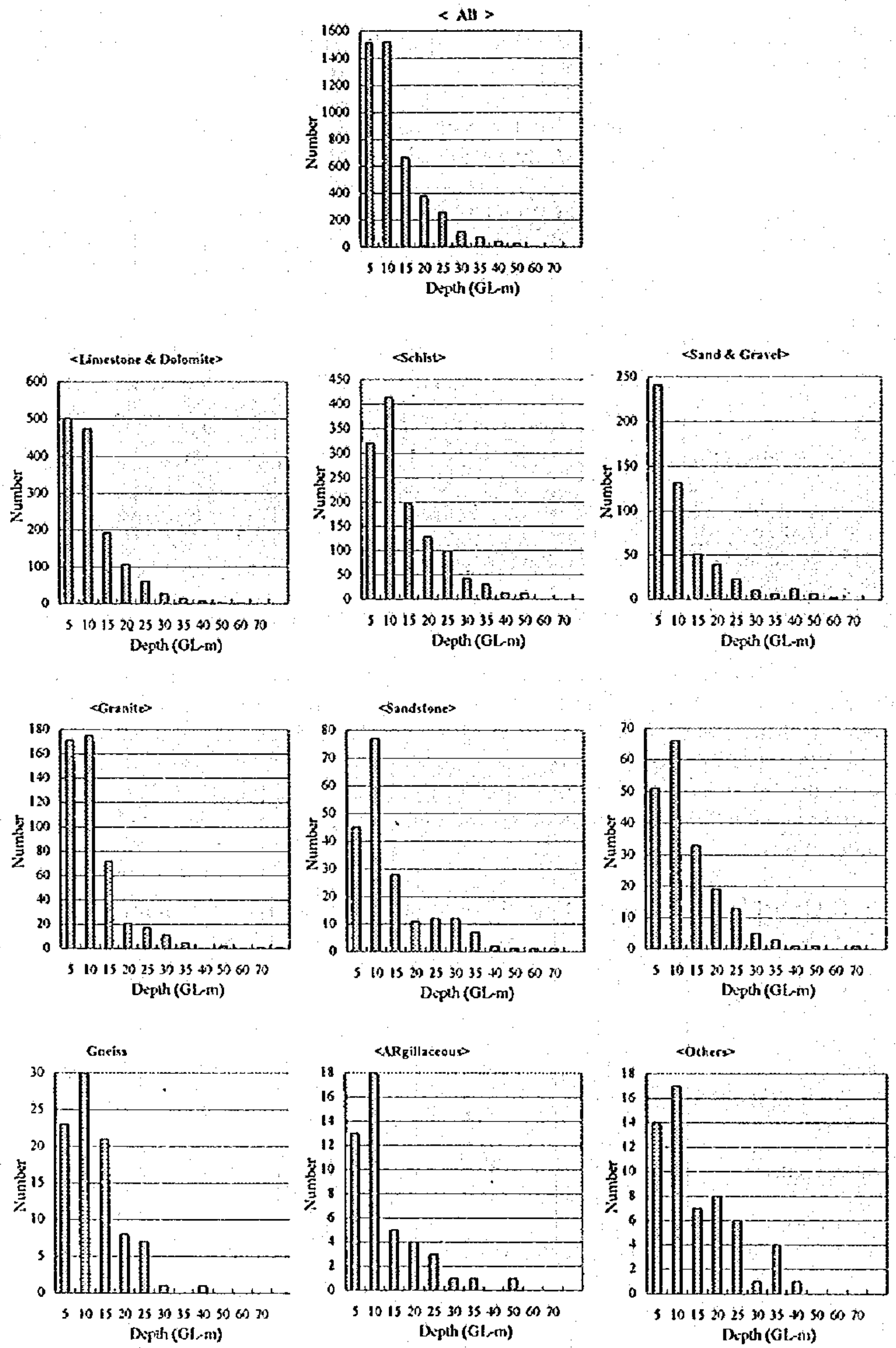


Figure 5-13 Depth of Water from Surface before Test by Lithology

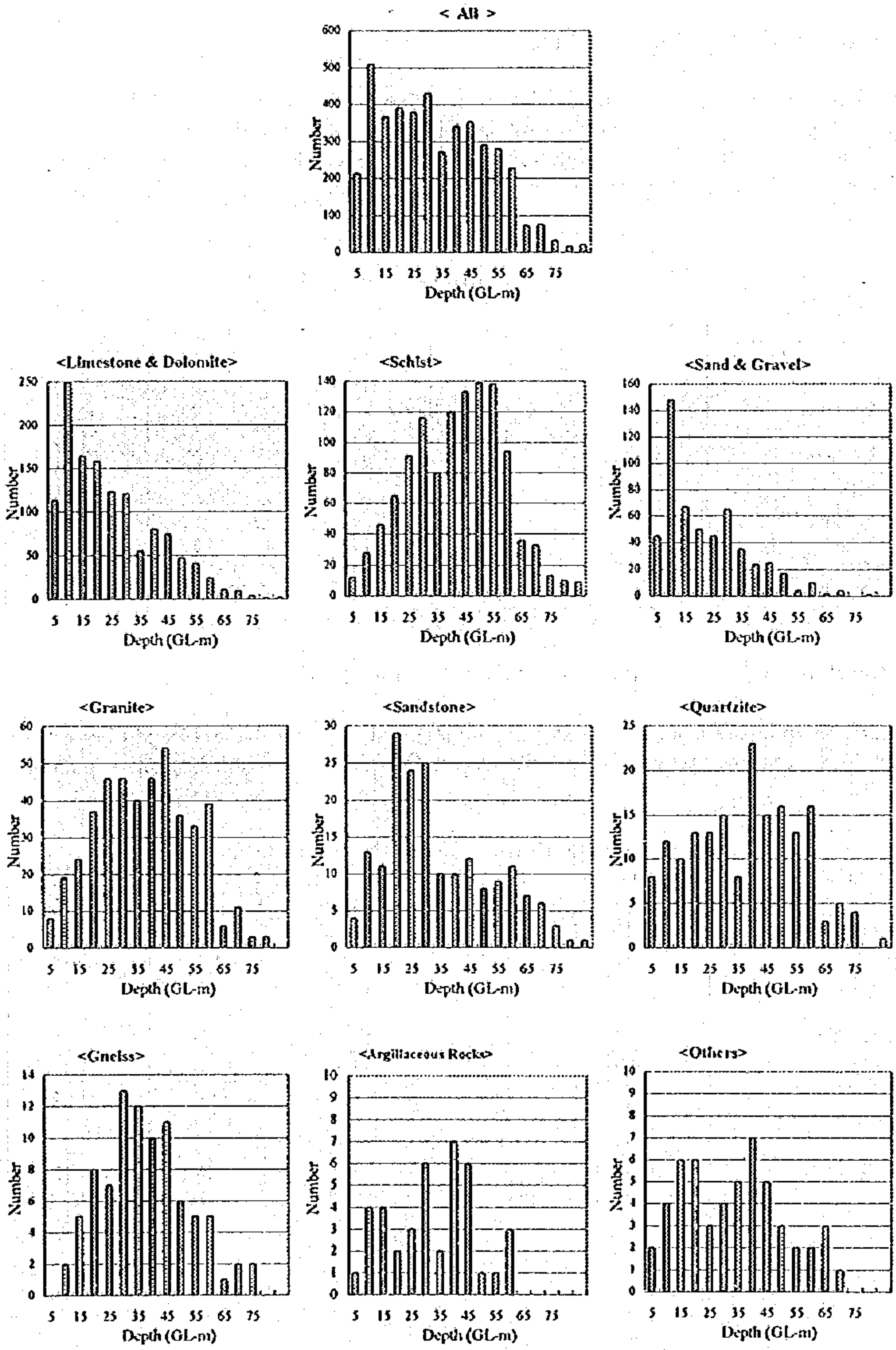


Figure 5-14 Greatest Depth to Which Water was Lowered During Pumping Test

5.7 Borehole Design

(1) Total Depth of Existing Borehole

Total depth of existing boreholes is shown in Table 5-15 and Figure 5-15 by lithology. Average depth of existing boreholes is 52.6m with large variety of the values. The average total depth by lithology has little difference among different lithology type. However, the total depth of boreholes drilled in sandstone and conglomerate aquifers is smaller than others.

Table 5-15 Total Depth of Existing Borehole

Lithology	Data Number	Average (m)	Range (m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,386	52.3	12.5	108.5	0.37
Schist	1,255	57.8	18.2	122.0	0.41
Sand & Gravel	522	40.2	6.1	123.3	1.06
Granite	476	52.1	11.6	110	0.72
Sandstone, Conglomerate	197	56.4	21.4	119.9	1.26
Quartzite	193	54.4	10.3	106.7	1.10
Gneiss, Migmatite	91	50.6	18.1	80.0	1.56
Argillaceous Rock	46	53.5	10.4	80.0	2.16
Others*	58	58.2	25.6	104.5	2.14
< The whole >	4,602	52.6	6.1	123.3	0.25

(Note) * Others include Igneous and the other metamorphic rocks

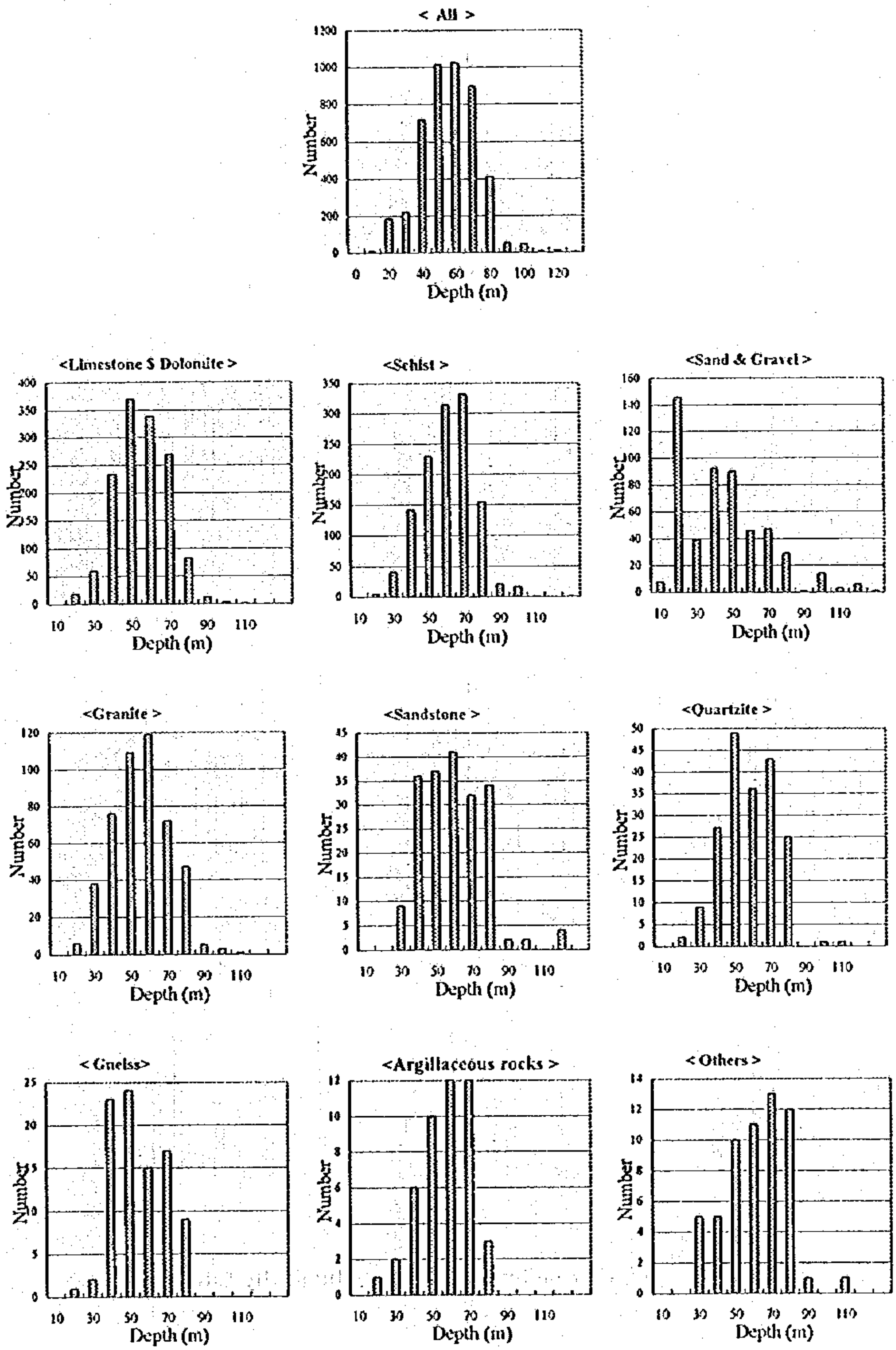
(2) Depth from Surface of Pump Intake at Pumping Test

Depth of pump intake from surface at pumping test is shown in Table 5-16 and Figure 5-16 by lithology. It seems that well pumps are set usually 7m over borehole bottom at pumping test.

Table 5-16 Depth from Surface of Pump Intake

Lithology	Data Number	Average (G.L.-m)	Range (G.L-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,343	43.0	2.5	85.0	0.34
Schist	1,234	48.4	2.8	118.0	0.38
Sand & Gravel	181	40.8	15.0	100.0	1.17
Granite	457	44.7	2.7	105.0	0.67
Sandstone, Conglomerate	159	49.0	11.0	91.0	1.3
Quartzite	189	47.2	9.0	100.0	1.14
Gneiss, Migmatite	87	43.8	3.9	77.5	1.64
Argillaceous Rock	41	42.9	2.8	67.0	2.31
Others*	57	48.0	17.5	74.0	1.96
< The whole >	4,105	45.4	2.5	118	0.22

(Note) * Others include Igneous and the other metamorphic rocks



Fugure 5-15 Total Depth of Borehole by Lithology

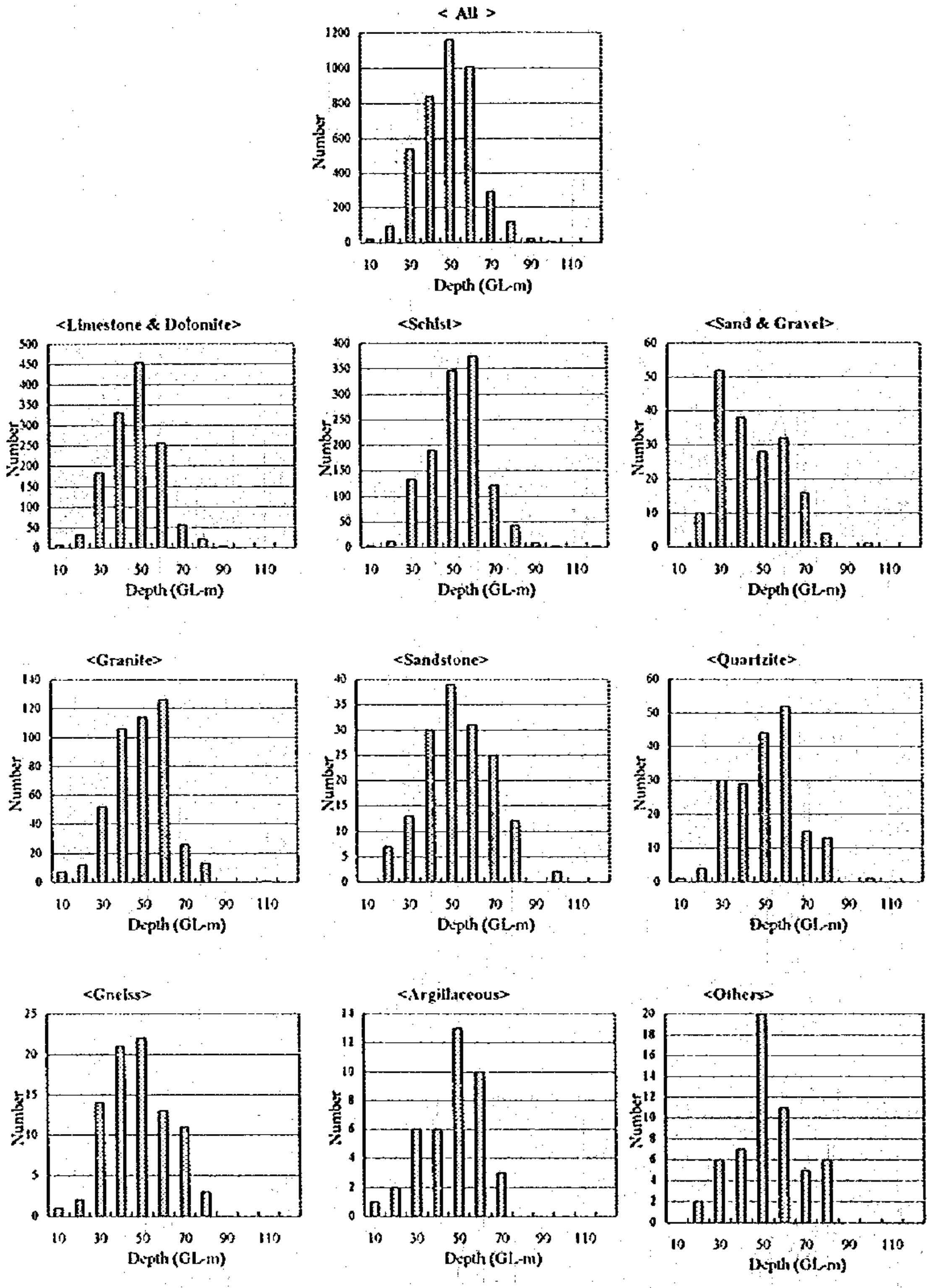


Figure 5-16 Depth from Surface of Pump Intake by Lithology

(3) Diameter

Diameter of existing boreholes is shown in Table 5-17 and Figure 5-17 by lithology. From the results, it is concluded that almost 80% of drilling diameter of the existing boreholes is 150mm.

Table 5-17 Diameter

Lithology	Data Number	Average (mm)	Range (mm)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1358	150	100	300	0.47
< The whole >	4517	150	75	300	0.25

(4) Length of Plain Part of Casing

Length of plain part of casing of existing boreholes is shown in Table 5-18 and Figure 5-18 by lithology.

Table 5-18 Length of Plain Part of Casing

Lithology	Data Number	Average (m)	Range (m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,358	9.0	0.3	50.0	-
Schist	1,226	12.2	0.7	59.8	-
Sand & Gravel	518	12.1	1.0	63.3	-
Granite	458	12.0	0.28	67.3	-
Sandstone, Conglomerate	195	15.0	2.0	68.2	-
< The whole >	4,508	11.4	0.28	68.2	-

(5) Length of Perforated Part of Casing

Length of perforated part of casing of existing boreholes is shown in Table 5-19 and Figure 5-19 by lithology. From this result, it is concluded that screen part occupies almost 35% of total length of boreholes.

Table 5-19 Length of perforated Part of Casing

Lithology	Data Number	Average (m)	Range (m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1,358	16.7	0.0	65.9	0.33
Schist	1,226	20.4	0.0	79.0	0.36
Sand & Gravel	518	16.8	0.0	68.0	0.60
Granite	458	15.8	0.0	50.0	0.54
Sandstone, Conglomerate	195	22.4	0	75.2	1.14
< The whole >	4,508	18.0	0.0	79.0	0.19

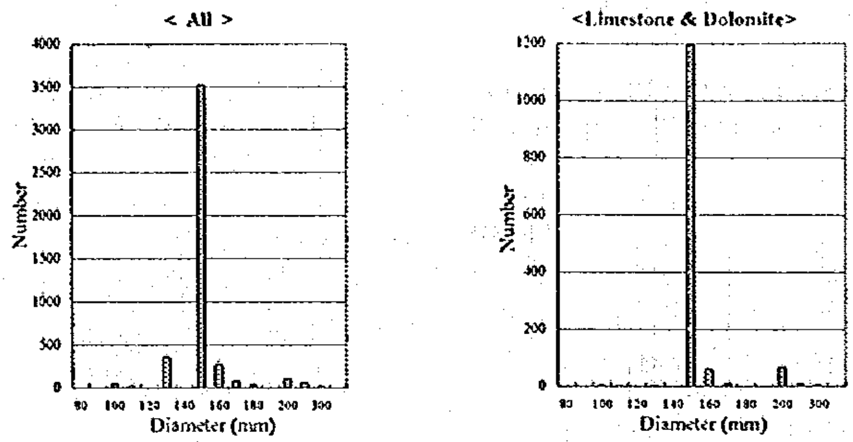


Figure 5-17 Diameter of Borehole

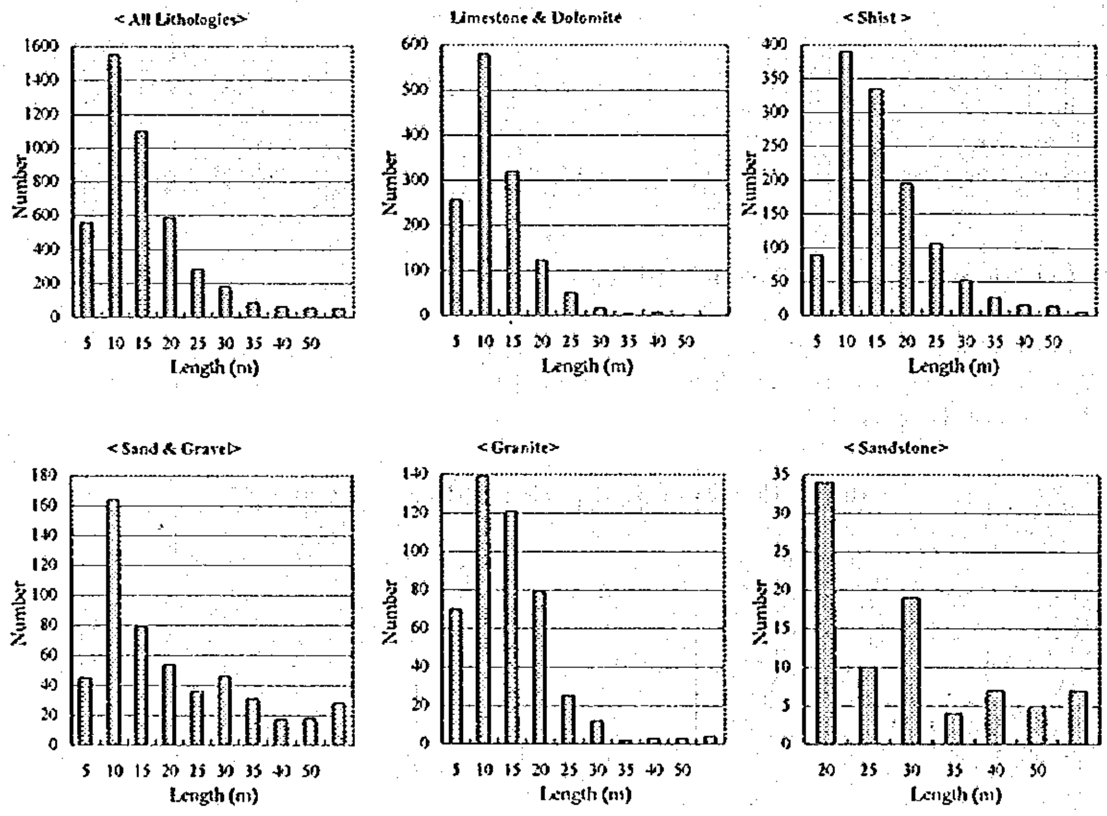


Figure 5-18 Plain Portion of Casing by Lithology

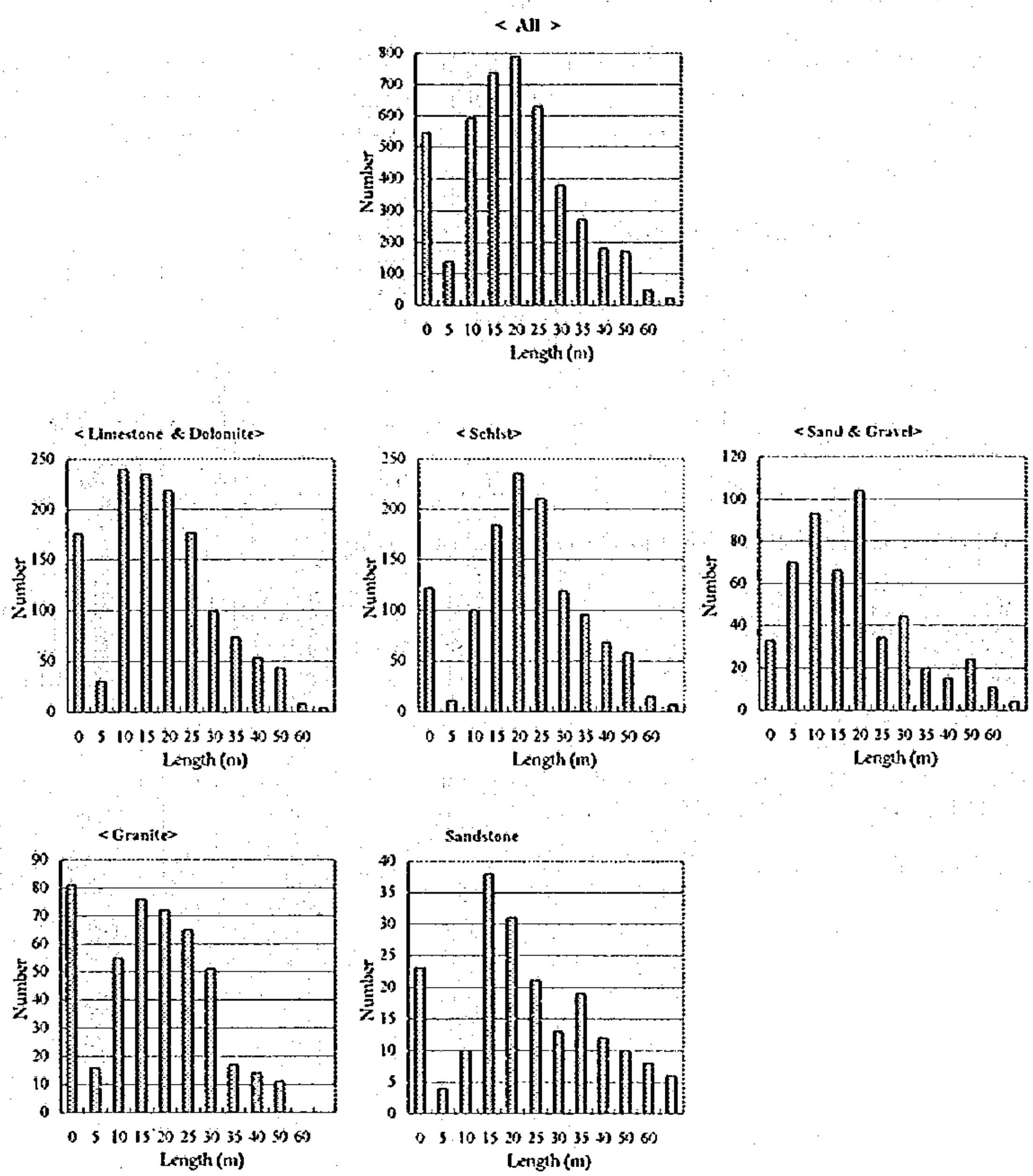


Figure 5-19 Perforated Portion of Casing by Lithology

(6) Depth from Surface to Bottom of Casing

Depth from surface to bottom of casing of existing boreholes is shown in Table 5-20 and Figure 5-20 by lithology. From this result, it is concluded that average length of open hole part of existing boreholes is 21.5m and rock of this part is thought to be hard and does not need any casing.

Table 5-20 Depth from Surface to Bottom of Casing

Lithology	Data Number	Average (G.L.-m)	Range (G.L-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1352	26.6	0.6	80.5	0.38
Schist	1206	34.5	2.0	92.0	0.41
Sand & Gravel	513	33.5	5.6	99.6	0.91
Granite	456	28.7	1.5	80.6	0.65
Sandstone, Conglomerate	195	39.8	5.0	90.9	1.21
< The whole >	4470	31.2	0.6	99.6	0.24

(7) Diameter of Unlined Portion of Borehole below Casing

Diameter of unlined portion of borehole below casing of existing boreholes is shown in Table 5-21 and Figure 5-21 by lithology. The diameter is almost the same as that of lined portion. It seems that drilling diameter is usually 150mm from borehole top to bottom except top soil part subject to collapse.

Table 5-21 Diameter of Unlined Portion of Borehole below Casing

Lithology	Data Number	Average (mm)	Range (mm)		Standard Deviation
			Minimum	Maximum	
< The whole >	4,337	150	43	300	.23

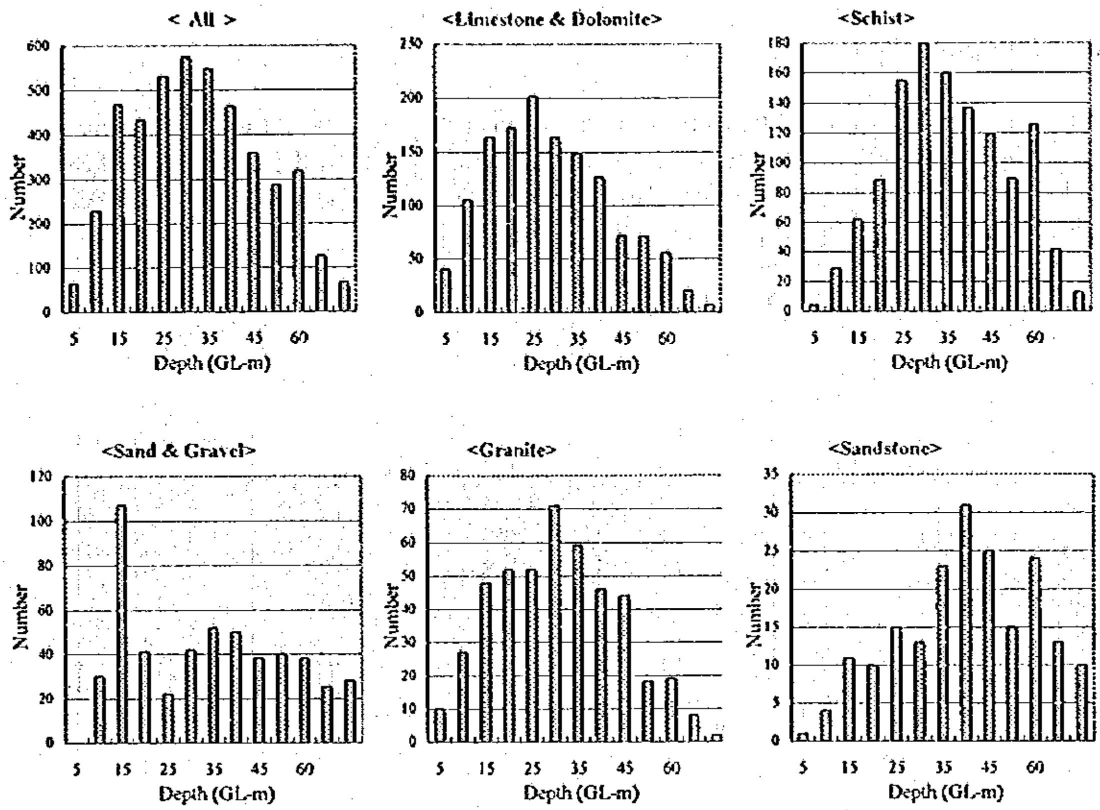


Figure 5-20 Depth from Surface to Bottom of casing by Lithology

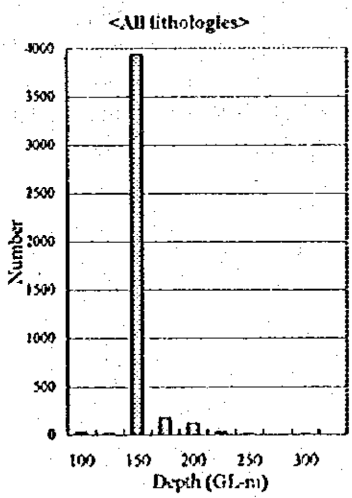


Figure 5-21 Diameter of Unlined Portion of Borehole below Casing

5.8 Yield of Borehole

(1) Yield at Pumpimg Test

Yield at pumpimg test of existing boreholes is shown in Table 5-22 and Figure 5-22 by lithology. Limestone and dolomite aquifers show much higher yield than the others, and the average yield is twice as large as the average yield of all aquifres. However, yields vary widely even within same lithology type as shown in Figure 5-22 .

Table 5-22 Yield at Pumpimg Test

Lithology	Data Number	Medium		Range (l/sec)	
		(l/sec)	(m^3/day)	Minimum	Maximum
Limestone & Dolomite	1,386	4.7	406	0	60.6
Schist	1,255	1.5	130	0	60.0
Sand & Gravel	522	1.5	130	0	40.0
Granite	476	1.1	95	0	39.7
Sandstone, Conglomerate	197	1.8	156	0	55.8
Quartzite	193	1.6	138	0	50
Gneiss, Migmatite	91	0.7	60	0.08	11.0
Argillaceous Rock	46	1.5	130	0	40
Others*	58	2.8	242	0.2	12.0
< The whole >	4,601	2.0	173	0	66

(Note) * Others include Igneous and the other metamorphic rocks

5.9 Quality of Water

(1) Quality of Water

Borehole water quality is as follows;

Table 5-23 Water Quality (Data number =4,600)

Fresh	Brackish	Saline	Odour	Turbid
99.84%	0.09%	0.02%	0%	0.05%

According to the data-base, borehole water quality is considered to be suitable for drinking.

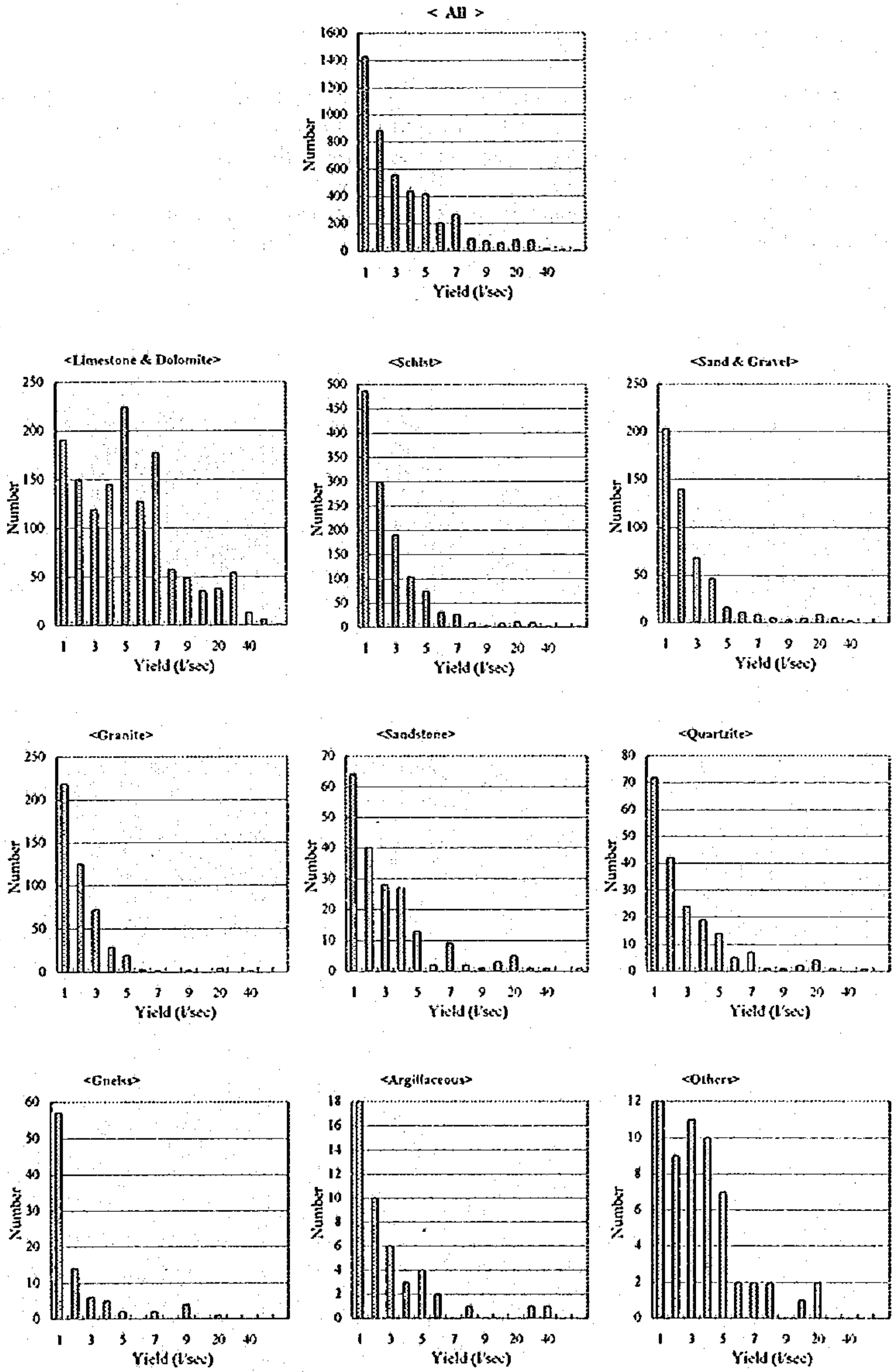


Figure 5-22 Yield at Pumping Test by Lithology

5.10 Purpose of Groundwater Usage

(1) Purpose of Groundwater Usage

Purpose of existing boreholes are shown in Table 5-24 and Figure 5-23 and 5-24 by lithology. As shown in the Table and Figure, the purposes of groundwater usage is different by province. Purposes for irrigation, urban water supply and the others except rural water supply is dominant in Lusaka and Copperbelt provinces. On the other hand, purpose for rural water supply is much dominant in Western, Eastern Northern, Luapula Provinces. Purposes in Southern and Central Provinces are intermediate between 2 groups mentioned above.

Table 5-24 Purpose of Groundwater Usage

Lusaka

Purpose	Number	%
Irrigation	976	40.0
Live-stock	640	26.2
Urban Water Supply	535	21.9
Rural Water Supply	117	4.8
Industrial	111	4.5
Commer-cial	57	2.3
Fisheries	3	0.1
Obser-vation	3	0.1
Exploratory	1	0.0
Total	2443	

Copperbelt

Purpose	Number	%
Rural Water Supply	123	21.5
Urban Water Supply	115	20.1
Irrigation	113	19.8
Industrial	100	17.5
Live-stock	84	14.7
Commer-cial	35	6.1
Explo-ratory	1	0.2
Fisheries	0	0.0
Observation	0	0.0
	571	

Central

Purpose	Number	%
Irrigation	285	40.4
Live-stock	203	28.8
Rural Water Supply	132	18.7
Urban Water Supply	36	5.1
Industrial	31	4.4
Commer-cial	19	2.7
Fisheries	0	0.0
Explo-ratory	0	0.0
Observation	0	0.0
	706	

Northwestern

Purpose	Number	%
Rural Water Supply	45	80.4
Live-stock	6	10.7
Irrigation	5	8.9
Urban Water Supply	0	0.0
Fisheries	0	0.0
Industrial	0	0.0
Commer-cial	0	0.0
Explo-ratory	0	0.0
Observation	0	0.0
Total	56	

Western

Purpose	Number	%
Rural Water Supply	394	98.5
Urban Water Supply	5	1.3
Industrial	0	0.3
Irrigation	0	0.0
Live-stock	0	0.0
Fisheries	0	0.0
Commer-cial	0	0.0
Explo-ratory	0	0.0
Observation	0	0.0
	399	

Southern

Purpose	Number	%
Rural Water Supply	366	39.1
Irrigation	262	28.0
Live-stock	247	26.4
Industrial	34	3.6
Urban Water Supply	25	2.7
Commer-cial	2	0.2
Fisheries	1	0.1
Explo-ratory	0	0.0
Observation	0	0.0
	937	

Luapula

Purpose	Number	%
Rural Water Supply	42	79.2
Industrial	5	9.4
Urban Water Supply	4	7.5
Irrigation	2	3.8
Live-stock	0	0.0
Fisheries	0	0.0
Commer-cial	0	0.0
Explo-ratory	0	0.0
Observation	0	0.0
Total	53	

Nothern

Purpose	Number	%
Rural Water Supply	66	61.7
Irrigation	18	16.8
Live-stock	15	14.0
Urban Water Supply	6	5.6
Fisheries	1	0.9
Industrial	1	0.9
Commer-cial	0	0.0
Explo-ratory	0	0.0
Observation	0	0.0
	107	

Eastern

Purpose	Number	%
Rural Water Supply	203	57.2
Live-stock	63	17.7
Irrigation	61	17.2
Urban Water Supply	21	5.9
Industrial	4	1.1
Commer-cial	3	0.8
Fisheries	0	0.0
Explo-ratory	0	0.0
Observation	0	0.0
	355	

The Whole Country

Purpose	Number	%
Irrigation	1528	30.37
Rural Water Supply	754	26.8
Commer-cial	1732	2.1
Live-stock	1270	0.5
Urban Water Supply	5	0.5
Fisheries	289	0.1
Explo-ratory	120	0.0
Industrial	2	0.0
Observation	3	0.0
total	5703	

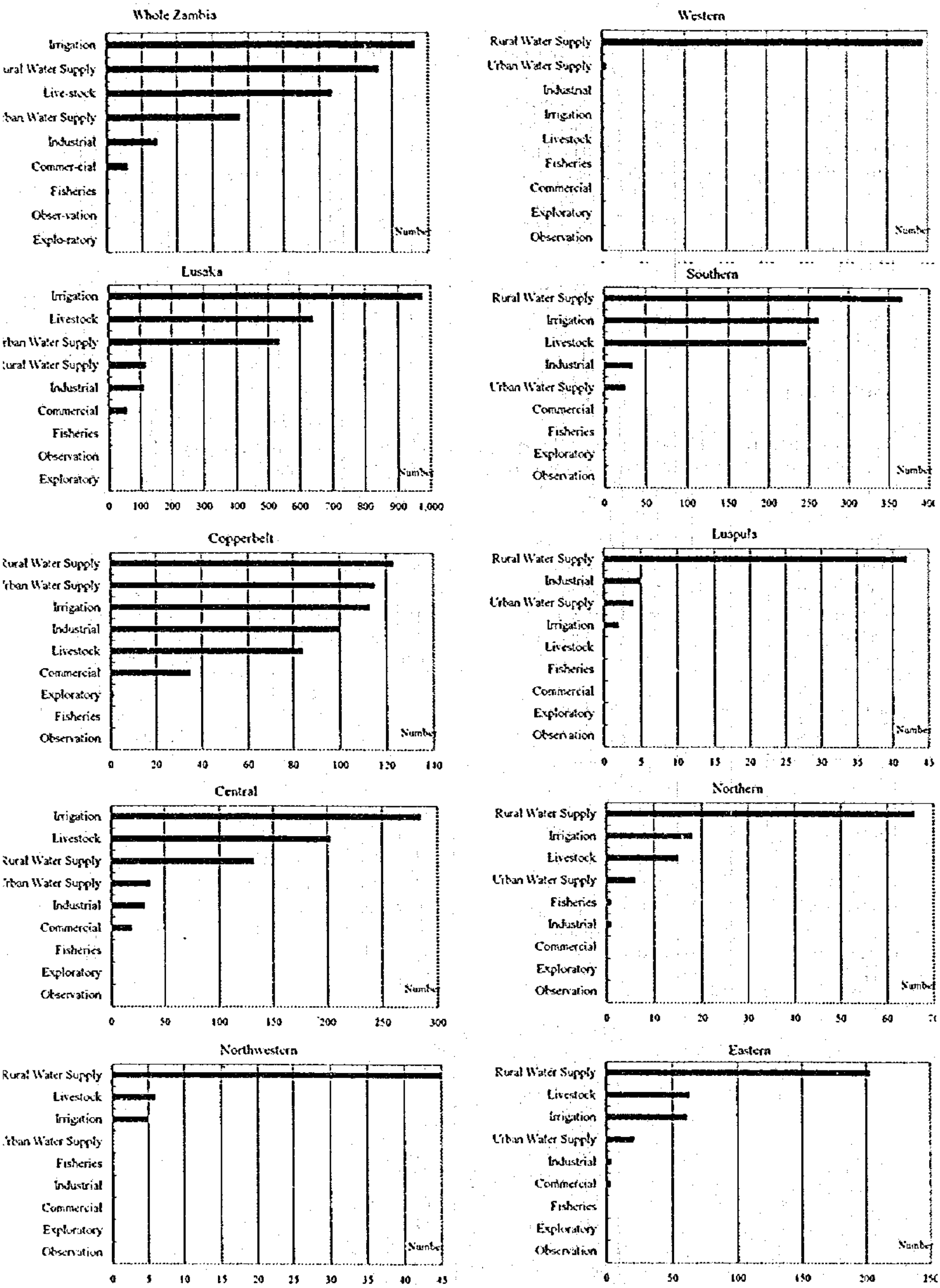


Figure 5-23 Purpose of Groundwater Use by Province

CHAPTER 6 RECOMMENDATION

6.1 Effective Use of Borehole Data-Base

The effective use of borehole data-base is desirable for future groundwater development. The advantages of using the data-base are as follows;

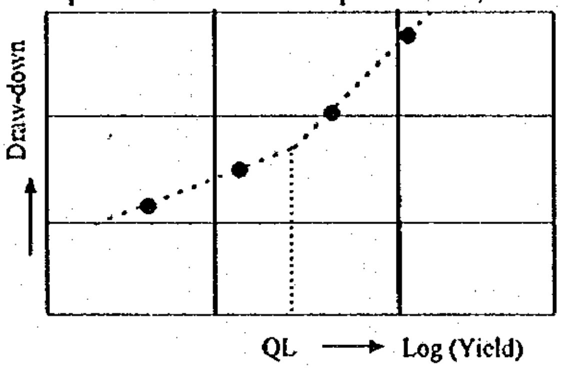
1) It is easy to retrieve information about aquifers and existing boreholes near new groundwater development sites. From this, the planning of new boreholes, expected yield, length, casing program, etc., are easily carried out according to information derived from the data-base. Borehole data necessary for users are instantly found and printed out. The computer data-base has greatly reduced the time for searching out borehole data..
2) Statistical information on aquifers hydrogeology and boreholes capacity by district or province are easily obtained from the data-base. These information is useful not only for actual groundwater development planning but also for scientific hydrogeological study aiming at making clear characteristics of aquifers throughout Zambia.

6.2 Execution of Adequate Pumping Test

6.2.1 Execution of Step Draw-down Test

Step draw-down test is carried out to determine safe yield of a borehole. Step draw-down test is defined as a pumping test to observe draw-downs of borehole with different yields. Safe yield of a borehole is determined as shown in Figure 6-1.

If pumping rate exceeds safe yield, rock fragments enter into the borehole and are deposited on the bottom. If the worst comes to the worst, the wall of borehole and ground surface may collapse. Other than these phenomena, the efficiency of pumping ratio may be reduced



Safe Yield = QL x (0.7 - 0.8)

QL= An intersecting point of two lines as shown in Figure6-1.

Figure 6-1 Concept of Step Draw-down Test

inverse proportion to the pumping rate leading to uneconomical condition. These phenomena mentioned above occur especially in boreholes equipped with power pumps. On the other hand, such the cases occur rarely in boreholes equipped with hand pumps, because yield of handpump is low. However, proper yields of such boreholes with hand pumps also should be determined in the case of future exchange from hand pump to power pump for rural water supply.

6.2.2 Proper Pumping Test for Aquifer Constants

It is necessary to obtain aquifer hydraulic constants precisely for planning large scale groundwater development. For this purpose, execution of proper pumping test is necessary. As a matter of course, pumping tests are always carried out after completion of boreholes, but those tests are not carried out in an appropriate method in terms of testing the aquifer and obtain the aquifer constants. Important points in execution of a pumping test for that purpose are as follows:

1) To drill observation boreholes and to observe groundwater level fluctuation in the observation boreholes during pumping test.
2) To keep yield of pumping well constant.
3) Before the pumping test, a stepped draw-down test should be carried out to decide the appropriate pumping rate for aquifer constants.

APPENDICES

APPENDICES

Appendix 1 (1) List of Pumping Test Analysis Result (1)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
1690	Dolomite	0.878	0.025	0.101	0.871	0.025	0.1	0.699	0.02	0.816	0.023	0.101
1934(B)	Dolomite							1.042	0.095	1.042	0.095	
LS-8	Dolomite							5.87	1.96	5.87	1.96	
2390-1	Dolomite	54.6	9.099	0.113	54.55	9.091	0.123			36.38	6.063	0.118
2623C	Dolomite	29	4.14	4E-05	28.1	4.01	6E-05	9.57	1.37	22.22	3.173	5E-05
2626D	Dolomite	1.329	0.063	8E-08	1.33	0.063	8E-08	0.892	0.043	1.184	0.056	8E-08
2680A	Dolomite	11.32	0.943	0.012	11.18	0.931	0.013	9.585	0.799	10.69	0.891	0.013
1630	Limestone							1.41	0.023	1.41	0.023	
2198	Limestone							11	0.272	11	0.272	
1692	Limestone	121	2.33	3E-07	137	2.64	2E-08			86	1.657	2E-07
2670-1	Limestone	0.383	0.015	0.036	0.381	0.015	0.035	0.231	0.009	0.332	0.013	0.036
2671-1	Limestone	2.287	0.127	0.022	2.345	0.13	0.022	1.099	0.061	1.91	0.106	0.022
2625-1	Limestone	0.16	0.005	0.021	0.158	0.005	0.019	0.129	0.004	0.149	0.005	0.02
2015	Limestone							26.1	13	26.1	13	
2012	Limestone	10.5	0.553	0.006	10.5	0.554	0.006	3.75	0.197	8.25	0.435	0.006
2013	Limestone	7.65	0.219	0.004	7.8	0.223	0.003	3.57	0.102	6.34	0.181	0.004
CH3	Limestone							3.514	0.227	3.514	0.227	
MW1	Limestone							9.35	1.34	9.35	1.34	
2669-1	Limestone	0.379	0.025	0.048	0.379	0.025	0.048	0.354	0.024	0.371	0.025	0.048
2668-1	Limestone	1.057	0.151	0.001	1.059	0.151	0.001	0.628	0.09	0.915	0.131	0.001
2637	Limestone	2.736	0.391	0.01	2.725	0.389	0.011	1.087	0.155	2.183	0.312	0.011
MAK13	Limestone							2.86	0.476	2.86	0.476	
LUSC10	Limestone							131	26.3	131	26.3	
LUSC13	Limestone	733	147	0.055	730	146	0.057			487.7	97.67	0.056
LUSC16	Limestone							12.2	4.07	12.2	4.07	
2663	Limestone	0.729	0.017	0.03	0.718	0.017	0.03	0.928	0.022	0.792	0.019	0.03
2147-3	Limestone	0.113	0.019	0.063	0.111	0.019	0.06	0.214	0.036	0.146	0.024	0.061
LE6	Limestone	0.097	0.011	0.01	0.097	0.011	0.009	0.034	0.004	0.076	0.008	0.01
1839	Limestone	1	0.018	0.278	0.987	0.017	0.247	0.655	0.012	0.881	0.015	0.263
1375	Limestone	4.23	0.113	0.026	4.23	0.112	0.025	1.74	0.046	3.4	0.09	0.025
2136C	Limestone	167	11.1	0.032	168	11.2	0.034	29.2	1.95	121.4	8.083	0.033
2604	Limestone	484	16.7	0.003	484	16.7	0.004			322.7	11.13	0.003
1532-1	Limestone	1.12	0.023	0.077	1.13	0.024	0.071	0.74	0.015	0.997	0.021	0.074
2667	Limestone	1.335	0.334	1E-04	1.34	0.335	1E-04	1.36	0.34	1.345	0.336	1E-04
2631-1	Limestone	8.39	0.28	0.011	8.3	0.277	0.01	7.6	0.253	8.097	0.27	0.01
2135B	Limestone	2.1	0.058	0.035	2.07	0.058	0.037	0.956	0.027	1.709	0.047	0.036
1947	Limestone							0.881	0.059	0.881	0.059	
1889-1	Limestone											
1720	Limestone							27.62	0.952	27.62	0.952	
2615-1	Limestone				6.08	0.105	3E-04			0	0	2E-04
2228-2	Limestone							2.62	0.056	2.62	0.056	

Appendix 2 (2) List of Pumping Test Analysis Result (2)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
2605C	Limestone	4.53	2.27	0.077	4.26	2.13	0.091	1.89	0.947	3.56	1.782	0.084
2607B	Limestone	2.18	0.07	0.037	2.07	0.067	0.039	2.51	0.081	2.253	0.073	0.038
2608A	Limestone	0.936	0.078	0.016	0.933	0.078	0.014	0.759	0.063	0.876	0.073	0.015
2614A	Limestone	7.74	1.29	0.125	7.65	1.28	0.122	6.15	1.02	7.18	1.197	0.124
1662	Limestone	1.5	0.034	0.164	1.5	0.034	0.154	1.76	0.04	1.587	0.036	0.159
1948-2	Limestone											
2088	Limestone				0.307	0.307	0.085	0.186	0.186	0.186	0.186	0.043
2286-1	Limestone	0.007	1E-04	0.01	0.007	1E-04	0.01			0.005	1E-04	0.01
2162-1	Limestone							7.552	5.594	7.552	5.594	
3003	Limestone	0.706	0.023	0.125	0.726	0.023	0.128	0.5	0.016	0.644	0.021	0.127
2678-1	Limestone	0.076	0.002	0.024	0.109	0.003	0.015	0.23	0.007	0.138	0.004	0.019
1630	Limestone	4.58	0.075	0.067	4.64	0.076	0.069	1.46	0.024	3.56	0.058	0.068
2228-1	Limestone	0.172	0.004	0.048	0.164	0.003	0.048	0.207	0.004	0.181	0.004	0.048
MB-14	Schist							2.084	0.11	2.084	0.11	
1429	Schist							0.561	0.014	0.561	0.014	
1670	Schist	0.231	0.019	0.008	0.247	0.021	0.006	0.505	0.042	0.328	0.027	0.007
2037	Schist	44	0.62	0.159	43.9	0.618	0.154	34.6	0.487	40.83	0.575	0.157
2205	Schist	0.374	0.019	0.256	0.37	0.019	0.252	0.403	0.02	0.382	0.019	0.254
2204	Schist	0.217	0.009	0.127	0.208	0.008	0.125	0.123	0.005	0.183	0.007	0.126
2555	Schist							682	31	682	31	
2147	Schist	0.114	0.019	0.059	0.113	0.019	0.059	0.22	0.037	0.149	0.025	0.059
2136	Schist	196	13	0.004	197	13.1	0.005			131	8.7	0.004
2012	Schist	7.07	0.372	0.168	6.99	0.368	0.171	4.08	0.215	6.047	0.318	0.17
1648	Schist	2.22	0.089	0.038	2.15	0.086	0.041	1.98	0.079	2.117	0.085	0.039
1532	Schist											
1428	Schist				4	0.114	1E-05	0.779	0.022	0.779	0.022	7E-06
1442	Schist	1.87	0.069	0.154	1.86	0.069	0.155	2.3	0.085	2.01	0.074	0.155
2603	Schist	1.65	0.165	4E-04	1.66	0.166	4E-04			1.103	0.11	4E-04
1748	Schist	0.219	0.007	0.048	0.224	0.008	0.039	0.196	0.007	0.213	0.007	0.043
1728	Schist	1.227	0.123	0.224	1.22	0.122	0.222	1.23	0.123	1.226	0.123	0.223
1679	Schist	1.278	0.035	0.203	1.245	0.034	0.208	0.275	0.007	0.933	0.025	0.206
1633	Schist	0.104	0.007	0.013	0.104	0.007	0.013	0.376	0.024	0.195	0.012	0.013
2627	Schist	71.24	30.32	0.017	71.42	30.39	0.017	23.32	9.924	55.33	23.54	0.017
KB05	Schist							3.06	0.383	3.06	0.383	
KB02	Schist	1.86	0.932	0.253	1.74	0.872	0.255	1.89	0.943	1.83	0.916	0.254
CH2	Schist							1.97	0.328	1.97	0.328	
MW2	Schist							5.08	0.282	5.08	0.282	
MW03	Schist	30.7	2.05	0.169	30.5	2.03	0.169	23.2	1.55	28.13	1.877	0.169
MW04	Schist	4.45	0.227	0.005	4.46	0.228	0.004	3.04	0.155	3.983	0.203	0.004
2638	Schist	2.462	0.308	0.076	2.469	0.309	0.079	6.235	0.779	3.722	0.465	0.077
2640	Schist	2.548	0.182	0.015	2.562	0.183	0.014	2.663	0.19	2.591	0.185	0.014

Appendix 1 (3) List of Pumping Test Analysis Result (3)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
LUSC3	Schist	8.15	0.34	2E-06	8.16	0.34	2E-06	3.4	0.142	6.57	0.274	2E-06
LUSC12	Schist							0.544	0.136	0.544	0.136	
2634	Schist	34.89	2.052	0.001	34.88	2.052	0.001			23.26	1.368	0.001
2635	Schist	0.253	0.013	0.002	0.253	0.013	0.002	0.592	0.03	0.366	0.018	0.002
LN5	Schist	37.9	3.44	0.045	38.5	3.5	0.044			25.47	2.313	0.044
LN6	Schist	228	20.7	0.025	231	21	0.023	171	15.6	210	19.1	0.024
2273	Schist	4.02	1.34	0.004	4.04	1.35	0.004	2.02	0.672	3.36	1.121	0.004
KAL02	Schist							3.46	0.089	3.46	0.089	
2282	Schist	0.369	0.041	0.103	0.359	0.04	0.11			0.243	0.027	0.107
2127	Schist	0.293	0.029	0.036	0.293	0.029	0.036	0.231	0.023	0.272	0.027	0.036
KAL01	Schist							2.36	0.147	2.36	0.147	
2660-3	Schist	1.67	0.032	0.028	1.62	0.031	0.036			1.097	0.021	0.032
2619	Schist							1.88	0.313	1.88	0.313	
CHS_02	Schist	12.44	6.222	0.015	12.53	6.266	0.015			8.325	4.163	0.015
2070	Schist							0.687	0.031	0.687	0.031	
3151	Schist	19.1	0.616	0.055	19.08	0.615	0.058	3.673	0.118	13.95	0.45	0.056
2255	Schist	6.017	0.231	0.03	6.058	0.233	0.03	5.798	0.223	5.958	0.229	0.03
1957-1	Schist											
2148-1	Schist							0.466	0.058	0.466	0.058	
2612A	Schist	1.95	0.061	0.025	1.96	0.061	0.027	1.28	0.04	1.73	0.054	0.026
2617C	Schist	2.29	0.104	0.001	2.31	0.105	0.001	1.44	0.065	2.013	0.091	0.001
2618B	Schist	3.86	0.482	0.003	3.82	0.477	0.003	3.63	0.453	3.77	0.471	0.003
2622-C	Schist	7.4	0.569	0.031	7.4	0.569	0.03	6.04	0.464	6.947	0.534	0.031
2165	Schist							23.6	0.655	23.6	0.655	
1947	Schist							0.644	0.043	0.644	0.043	
1889	Schist	1.28	0.031	0.203	1.28	0.03	0.21	0.363	0.009	0.974	0.023	0.207
1846	Schist							1.56	0.13	1.56	0.13	
1609	Schist							0.218	0.005	0.218	0.005	
1660	Schist	3.58	0.073	0.169	3.28	0.067	0.19	4.03	0.082	3.63	0.074	0.18
1238	Schist	2.36	0.105	0.012	2.36	0.106	0.013	2.57	0.115	2.43	0.109	0.013
1964-1	Schist											
2598	Schist	4.71	27.7	0.206	4.72	27.8	0.2			3.143	18.5	0.203
1993	Schist	11.8	0.843	0.021	11.76	0.84	0.021	13.38	0.956	12.31	0.88	0.021
2950	Schist							19.06	3.465	19.06	3.465	
3047	Schist							0.684	0.114	0.684	0.114	
1365	Schist	2.36	0.139	0.046	2.34	0.138	0.048	3.24	0.191	2.647	0.156	0.047
1368	Schist							0.477	0.011	0.477	0.011	
1354	Schist	2.85	0.109	0.242	2.86	0.11	0.257	3.45	0.133	3.053	0.117	0.25
1813	Schist							27.5	72.5	27.5	72.5	
2628	Schist				0.257	0.064	0.047	0.124	0.031	0.124	0.031	0.024
1578	Schist	10.4	0.217	0.1	9.99	0.208	0.115	11.3	0.235	10.56	0.22	0.108

Appendix 1 (4) List of Pumping Test Analysis Result (4)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
MUM03	Schist							0.787	0.262	0.787	0.262	
MB093	Schist	1.36	0.136	0.035	1.32	0.132	0.038	0.71	0.071	1.13	0.113	0.037
MB094	Schist							2.65	0.106	2.65	0.106	
MB001	Schist							6.91	0.432	6.91	0.432	
2783	Schist	3.69	0.184	0.03	3.73	0.187	0.03			2.473	0.124	0.03
1755	Schist	0.295	0.015	0.002	0.306	0.016	0.002	0.248	0.013	0.283	0.015	0.002
2310	Schist	18.8	0.447	8E-07	19.1	0.455	6E-07			12.63	0.301	7E-07
KB04	Schist	11.3	6.44	0.012	11.7	6.63	0.012	2.8	1.59	8.6	4.887	0.012
MUMO7	Schist							10.3	0.278	10.3	0.278	
2658-1	Gravel				7.829	1.957	4E-06	2.803	0.701	2.803	0.701	2E-06
LN13	Gravel	2.88	0.303	0.002	2.87	0.302	0.002	1.44	0.152	2.397	0.252	0.002
1466	Gravel	1.94	0.045	0.16	1.89	0.044	0.165	1.08	0.025	1.637	0.038	0.163
2765	Sand	27.87	9.288	0.055	27.64	9.212	0.056			18.5	6.167	0.055
2154	Sand				0.461	0.092	3E-04	0.123	0.025	0.123	0.025	2E-04
2128	Sand				22.5	1.607	7E-11	7.961	0.569	7.961	0.569	3E-11
2078	Sand	14.3	1.02	0.004	14.3	1.02	0.003	16.2	1.16	14.93	1.067	0.003
2271	Sand	0.61	0.022	0.079	0.581	0.021	0.079	0.841	0.03	0.677	0.024	0.079
1608	Sand	9.19	0.224	0.07	9.22	0.225	0.075	6.66	0.163	8.357	0.204	0.073
1607	Sand	0.14	0.003	0.02	0.14	0.003	0.017	0.152	0.003	0.144	0.003	0.019
1902	Sand							1.12	0.043	1.12	0.043	
2203	Sand	23.2	1.78	5E-04	24.7	1.9	2E-04	10.4	0.799	19.43	1.493	4E-04
2205	Sand	0.437	0.022	0.252	0.426	0.021	0.246	0.419	0.021	0.427	0.021	0.249
1601	Sand											
2629C	Sand				44.79	1.493	4E-06	17.23	0.574	17.23	0.574	2E-06
2059	Sand	3.11	0.345	0.044	2.75	0.305	0.074	2.45	0.272	2.77	0.307	0.059
2636	Sand	4.545	0.303	5E-05	4.535	0.302	5E-05	3.365	0.224	4.148	0.276	5E-05
2048	Sand	0.403	0.134	0.196	0.406	0.135	0.201			0.27	0.09	0.199
1737	Sand	134	479	0.01	133	477	0.01	69.9	250	112.3	402	0.01
3097	Sand	1.76	0.586	0.132	1.56	0.52	0.206	0.981	0.327	1.434	0.478	0.169
3052	Sand				64.87	5.406	9E-08	7.333	0.611	7.333	0.611	4E-08
3051	Sand							1.233	0.457	1.233	0.457	
2972	Sand	0.532	0.133	0.225	0.531	0.133	0.232			0.354	0.089	0.229
2162	Sand							1.168	0.04	1.168	0.04	
1934	Sand							1.127	0.045	1.127	0.045	
1964	Sand							1.76	0.041	1.76	0.041	
1268	Sand							4.886	0.168	4.886	0.168	
1305(A)	Sand	9.993	0.833	0.006	10.04	0.837	0.006			6.677	0.557	0.006
2263	Sand	114	8.79	0.179	114	8.78	0.18	91.7	7.06	106.6	8.21	0.18
MAK15	Sand & Gravel				379.5	94.87	0.039	43.37	10.84	43.37	10.84	0.02
2015	Sand & Gravel											
2610A	Sand & Gravel	19	2.38	0.019	19.2	2.4	0.017	23.9	2.99	20.7	2.59	0.018

Appendix 1 (5) List of Pumping Test Analysis Result (5)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
2611A	Sand & Gravel	0.728	0.014	0.176	0.726	0.014	0.171	0.639	0.012	0.698	0.013	0.174
1710	Sand & Gravel							24.9	77.9	24.9	77.9	
2311	Sand & Gravel	47.5	1.64	0.016	47.7	1.65	0.016			31.73	1.097	0.016
1720	Sand & Gravel	72.98	2.517	0.002	72.7	2.507	0.003	25	0.862	56.89	1.962	0.002
1613	Granite	38.4	0.662	0.176	38.3	0.661	0.163			25.57	0.441	0.17
2013	Granite	8.02	0.229	0.003	8.18	0.234	0.002	3.99	0.114	6.73	0.192	0.002
1742	Granite	1.13	0.564	0.023	1.13	0.567	0.022	1.13	0.564	1.13	0.565	0.022
1647	Granite	0.619	0.031	0.058	0.62	0.031	0.055	0.327	0.016	0.522	0.026	0.057
1762	Granite	0.228	0.008	0.044	0.227	0.008	0.041	0.255	0.009	0.237	0.009	0.042
KB03	Granite							8.29	31.9	8.29	31.9	
2633-1	Granite	34.6	3.14	0.19	34.5	3.14	0.174	44.4	4.04	37.83	3.44	0.182
2294	Granite	0.394	0.131	0.109	0.397	0.132	0.095	0.377	0.126	0.389	0.13	0.102
2749	Granite	2.01	0.223	0.059	1.99	0.221	0.06			1.333	0.148	0.06
1691	Granite							3.44	1.32	3.44	1.32	
2867	Granite	0.873	0.04	0.15	0.855	0.04	0.159			0.576	0.027	0.155
KSM08	Granite	3.559	0.297	0.009	3.58	0.298	0.009			2.38	0.198	0.009
1601	Granite							7.24	0.13	7.24	0.13	
2269	Granite	28.22	2.315	0.123	28.73	2.357	0.123			18.98	1.557	0.123
1916-1	Granite											
2048-1	Granite											
2613A	Granite	2.3	0.056	0.029	2.3	0.056	0.031	1.21	0.03	1.937	0.047	0.03
2665B	Granite	0.314	0.157	0.02	0.314	0.157	0.018	0.474	0.237	0.367	0.184	0.019
1610	Granite	0.302	0.009	0.03	0.304	0.009	0.028	0.388	0.012	0.331	0.01	0.029
3086	Granite	20.7	0.863	0.036	19	0.792	0.066			13.23	0.552	0.051
2268	Granite	1.18	0.393	0.196	1.17	0.391	0.164	1.57	0.523	1.307	0.436	0.18
2601	Granite	0.352	0.024	0.037	0.301	0.02	0.052			0.218	0.015	0.044
2522-1	Granite	1.12	0.02	0.141	1.12	0.02	0.147	1.471	0.026	1.237	0.022	0.144
2074	Granite	3.128	1.564	0.061	3.126	1.563	0.061			2.085	1.042	0.061
2022	Granite							4.262	0.425	4.262	0.425	
1932	Granite							15.64	1.955	15.64	1.955	
1754	Granite	31.12	1.596	0.061	31.51	1.616	0.064			20.88	1.071	0.063
1789	Granite	97.42	4.235	0.079	94.87	4.125	0.08	62.62	2.723	84.97	3.694	0.079
1878	Granite	4.359	0.726	0.155	4.347	0.725	0.156	4.042	0.674	4.249	0.708	0.156
1882	Granite							7.452	0.932	7.452	0.932	
1791	Granite							13.5	45.1	13.5	45.1	
2830	Granite							2.12	0.096	2.12	0.096	
2769	Granite							6.95	0.451	6.95	0.451	
2833	Granite	3.85	0.193	0.095	3.84	0.192	0.09	7.78	0.389	5.157	0.258	0.092
2739	Granite							66.9	2.57	66.9	2.57	
2734	Granite							0.64	0.016	0.64	0.016	
2308	Granite							1.49	0.063	1.49	0.063	

Appendix 1 (6) List of Pumping Test Analysis Result (6)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
2307	Granite	0.428	0.014	0.007	0.427	0.014	0.007	0.297	0.01	0.384	0.013	0.007
2262	Granite							1.33	0.042	1.33	0.042	
2246	Granite	69.2	5.33	0.059	67.6	5.2	0.057	3.62	0.279	46.81	3.603	0.058
2309	Granite	4.64	0.309	0.085	4.64	0.309	0.084	1.37	0.092	3.55	0.237	0.084
2161	Granite	24.1	0.985	0.11	24.2	0.987	0.123	20.9	0.852	23.07	0.941	0.117
2139	Granite							0.977	0.039	0.977	0.039	
3134	Granite							1.84	0.92	1.84	0.92	
2949	Granite	0.286	0.03	0.28	0.251	0.026	0.288	0.375	0.039	0.304	0.031	0.284
1859	Granite	0.198	0.009	0.134	0.198	0.009	0.103	0.377	0.016	0.258	0.011	0.119
1793	Granite							1.68	0.023	1.68	0.023	
1794	Granite							3.13	0.313	3.13	0.313	
1523	Granite	10.1	0.259	0.013	10.2	0.262	0.012	5.36	0.137	8.553	0.219	0.012
1490	Granite							0.475	0.015	0.475	0.015	
1477	Granite							0.251	0.011	0.251	0.011	
1456	Granite							0.479	0.038	0.479	0.038	
1479	Granite							0.698	0.013	0.698	0.013	
1475	Granite							0.236	0.004	0.236	0.004	
2052	Granite							2.49	0.225	2.49	0.225	
3002	Granite							1.85	2.31	1.85	2.31	
2266	Granite	9.86	0.448	0.005	10	0.455	0.005	10.8	0.489	10.22	0.464	0.005
1862	Granite	3	0.116	0.002	2.98	0.115	0.002	1.58	0.061	2.52	0.097	0.002
1856	Granite							0.208	0.014	0.208	0.014	
1325	Granite	7.65	0.183	0.093	7.44	0.178	0.104			5.03	0.12	0.099
1804	Granite	0.648	0.023	0.094	0.567	0.02	0.098	0.404	0.014	0.54	0.019	0.096
1809	Granite	1.127	0.063	0.248	1.136	0.063	0.24	1.013	0.056	1.092	0.061	0.244
1334	Granite	1.48	0.185	0.03	1.43	0.179	0.035	1.22	0.152	1.377	0.172	0.032
1294	Granite							3.66	0.178	3.66	0.178	
1327	Granite	4.46	1.06	0.07	4.47	1.06	0.067			2.977	0.707	0.068
1326	Granite							0.933	0.067	0.933	0.067	
1272	Granite							1.44	0.086	1.44	0.086	
1275	Granite							0.604	0.027	0.604	0.027	
2210	Granite							2.15	0.075	2.15	0.075	
1753	Granite				36.2	1.65	0.159	11.3	0.512	11.3	0.512	0.08
1558	Granite							0.569	0.078	0.569	0.078	
1296	Granite							1.11	0.044	1.11	0.044	
1297	Granite							0.489	0.035	0.489	0.035	
1948	Granite	6.02	2.01	0.043	6.08	2.03	0.044	1.45	0.485	4.517	1.508	0.043
2931	Granite	3.86	0.115	0.059	3.86	0.115	0.056	1.54	0.046	3.087	0.092	0.058
MB117	Granite	90	5	0.014	91.8	5.1	0.015	17	0.946	66.27	3.682	0.015
SER03	Granite	0.001	1E-04	7E-05	0.001	2E-04	7E-05	0.001	1E-04	0.001	1E-04	7E-05
1866	Granite	1.05	0.102	0.254	1.06	0.102	0.241	0.706	0.068	0.939	0.091	0.248

Appendix 1 (7) List of Pumping Test Analysis Result (7)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
1726	Granite	0.873	0.097	0.139	0.924	0.103	0.116	0.498	0.055	0.765	0.085	0.128
2	Granite							6.93	0.33	6.93	0.33	
1647(A)	Granite	0.582	0.029	0.067	0.582	0.029	0.058	0.344	0.017	0.503	0.025	0.062
2146	Sandstone	3.82	0.153	0.037	3.61	0.144	0.062	2.07	0.083	3.167	0.127	0.05
2135	Sandstone	1.98	0.055	0.051	1.95	0.054	0.052	1.16	0.032	1.697	0.047	0.051
2017	Sandstone	11	0.366	0.004	11.5	0.382	0.002	2.25	0.075	8.25	0.274	0.003
1773	Sandstone	15.2	0.371	0.009	15.2	0.37	0.012			10.13	0.247	0.01
2749-1	Sandstone	1.79	0.198	0.092	1.83	0.204	0.086			1.207	0.134	0.089
2716	Sandstone	11.28	28.21	0.022	11.25	28.12	0.022			7.51	18.78	0.022
2231	Sandstone	0.098	0.01	0.053	0.19	0.019	0.038			0.096	0.01	0.045
1305(A)	Sandstone	9.537	0.795	0.011	9.528	0.794	0.01	7.856	0.655	8.974	0.748	0.01
2615B	Sandstone	5.37	1.07	0.004	5.47	1.09	0.005	2.06	0.412	4.3	0.857	0.004
1957	Sandstone	3.687	0.176	0.265	3.72	0.177	0.261			2.469	0.118	0.263
2212	Quartzite	4.601	0.307	0.039	4.505	0.3	0.049	5.406	0.36	4.837	0.322	0.044
LS-2	Quartzite							7.23	0.831	7.23	0.831	
1823	Quartzite	0.021	4E-04	0.018	0.022	4E-04	0.016			0.014	3E-04	0.017
1950	Quartzite							2.37	0.215	2.37	0.215	
1988	Quartzite	1.11	0.222	0.248	1.11	0.223	0.265	1.08	0.215	1.1	0.22	0.257
2289	Quartzite	0.467	0.013	0.065	0.433	0.012	0.058	0.469	0.013	0.456	0.012	0.061
1566	Quartzite	5.95	0.139	0.176	5.93	0.138	0.176	2.54	0.059	4.807	0.112	0.176
2203	Quartzite	43.7	3.36	2E-08	43.6	3.36	2E-08	12.8	0.987	33.37	2.569	2E-08
1667	Quartzite	0.356	0.03	0.011	0.298	0.025	0.015	0.391	0.033	0.348	0.029	0.013
1666	Quartzite							2.06	0.229	2.06	0.229	
1665	Quartzite							10.5	0.269	10.5	0.269	
1653	Quartzite	6.53	0.126	0.076	6.53	0.126	0.081	5.61	0.108	6.223	0.12	0.078
2937	Quartzite							4.57	0.117	4.57	0.117	
2630	Quartzite	2.91	0.121	0.071	2.91	0.121	0.073	3.16	0.132	2.993	0.125	0.072
2617	Gneiss	0.106	0.003	0.01	0.097	0.003	0.01	0.152	0.004	0.118	0.003	0.01
1916	Gneiss	0.307	0.045	0.172	0.308	0.045	0.173	0.361	0.052	0.325	0.047	0.173
1917	Gneiss							4.2	0.346	4.2	0.346	
2158	Gneiss	2.56	0.088	0.008	2.58	0.089	0.007	1.18	0.041	2.107	0.073	0.008
1880	Gneiss	8.37	19.47	0.025	8.419	19.58	0.027			5.596	13.02	0.026
1450	Gneiss	3.79	0.087	0.017	3.74	0.086	0.017			2.51	0.058	0.017
1487	Gneiss							0.598	0.066	0.598	0.066	
2140	Gneiss	12.6	0.354	0.04	12.5	0.351	0.043	11.8	0.33	12.3	0.345	0.041
1787	Gneiss	7.15	0.14	0.036	7.18	0.141	0.034	4.42	0.087	6.25	0.123	0.035
1476	Gneiss							0.111	0.002	0.111	0.002	
1489	Gneiss							0.353	0.011	0.353	0.011	
1524	Gneiss	0	0	0	0	0	0	1.24	0.084	1.24	0.084	
1860	Gneiss							0.73	0.046	0.73	0.046	
1483	Gneiss	1.17	0.065	0.054	1.17	0.065	0.056	0.716	0.039	1.019	0.056	0.055

Appendix 1 (8) List of Pumping Test Analysis Result (8)

Borehole Number	Lithology	Theis Method			Yacobu Method			Recovery Method		Final Value		
		T	k	s	T	k	s	T	k	T	k	s
1526	Gneiss	0.086	0.006	0.068	0.088	0.006	0.053	0.055	0.004	0.076	0.005	0.061
1594	Gneiss							0.493	0.07	0.493	0.07	
1559	Gneiss							1.56	4.72	1.56	4.72	
1557	Gneiss							0.303	0.061	0.303	0.061	
1555	Gneiss							1.32	0.063	1.32	0.063	
1350	Gneiss	1.24	0.052	0.049	1.23	0.051	0.05	0.88	0.037	1.117	0.047	0.049
1352	Gneiss	0.976	0.019	0.009	0.984	0.019	0.009	0.343	0.007	0.768	0.015	0.009
1348	Gneiss	0.553	0.019	0.154	0.531	0.018	0.16	0.489	0.017	0.524	0.018	0.157
MB003	Gneiss	2.947	0.134	0.087	2.912	0.132	0.092	4.417	0.201	3.425	0.156	0.09
MB12	Gneiss	3.144	0.126	1E-06	3.172	0.127	1E-06	0.351	0.014	2.222	0.089	1E-06
MB13	Gneiss	0.706	0.044	0.064	0.711	0.044	0.061	0.504	0.032	0.64	0.04	0.062
3048	Clay							0.564	0.113	0.564	0.113	
2244	Clay							4.26	0.474	4.26	0.474	
1731	Siltstone	0.962	0.021	0.072	0.971	0.022	0.069	1.13	0.025	1.021	0.023	0.07
1731	Siltstone	0.929	0.021	0.071	0.946	0.021	0.07	1.34	0.03	1.072	0.024	0.07
1731	Siltstone	0.962	0.021	0.072	0.971	0.022	0.069	1.13	0.025	1.021	0.023	0.07
1731	Siltstone	0.929	0.021	0.071	0.946	0.021	0.07	1.34	0.03	1.072	0.024	0.07
1842	Igneous Rock							0.115	0.023	0.115	0.023	
1843	Igneous Rock							0.762	0.04	0.762	0.04	
2038	Meta-Igneous							1.01	0.034	1.01	0.034	
2679	Meta-Igneous	5.868	0.309	0.019	6.05	0.318	0.018	4.422	0.233	5.447	0.287	0.018
1942	Meta-Sediment							3.97	0.331	3.97	0.331	
1942	Meta-Sediment							3.95	0.329	3.95	0.329	
1649	Unknown	1.111	0.036	0.212	1.107	0.036	0.212	0.58	0.019	0.933	0.03	0.212
1258	Unknown	3.033	0.142	0.157	3.022	0.141	0.145	1.112	0.052	2.389	0.112	0.151
2672-1	Unknown	0.695	0.116	0.009	0.693	0.116	0.01	0.709	0.118	0.699	0.117	0.009
1639	Unknown	2.915	0.243	0.011	2.973	0.248	0.011	4.685	0.39	3.524	0.294	0.011
2148	Unknown	1.094	0.137	0.057	1.046	0.131	0.06	1.003	0.125	1.048	0.131	0.058
2135R	Unknown	2.1	0.233	0.035	2.08	0.231	0.035	0.995	0.111	1.725	0.192	0.035
KSM13	Unknown							3.19	6.37	3.19	6.37	
1781	Unknown	16.09	1.867	0.263	16.74	1.942	0.262	15.88	1.843	16.24	1.884	0.263
2136-2	Unknown	191	12.7	0.007	195	13	0.005	26.7	1.78	137.6	9.16	0.006
2095	Unknown	0.722	0.014	0.03	0.724	0.014	0.029	0.582	0.011	0.676	0.013	0.029
2229-2	Unknown							0.933	0.023	0.933	0.023	
1989	Unknown	1.03	0.54	0.082	1.03	0.541	0.082	0.61	0.321	0.89	0.467	0.082
1531(B)	Unknown	0.41	0.683	0.092	0.31	0.517	0.099	1.76	2.93	0.827	1.377	0.095

Appendix 2 (1) Explanation of Analyzed Figures

No. 2205 (Borehole Number in Data-base)

T= 4.37E-01 k= 2.19E-02 S= 2.52E-01

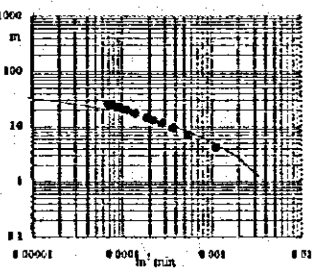
T : Transissivity By Theis Meth
k : Coefficient of Permeability by Theis Method
s : Specific Yield by Theis Method

T= 0.426 k= 0.0213 S= 0.246

T : Transissivity By Jacob Method
k : Coefficient of Permeability by Jacob Me
s : Specific Yield by Jacob Meth

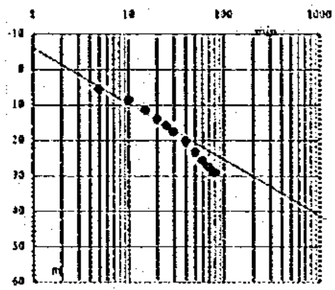
T= 0.419 k= 0.02009

T : Transissivity By Jacob Method
k : Coefficient of Permeability
by Jacob Method



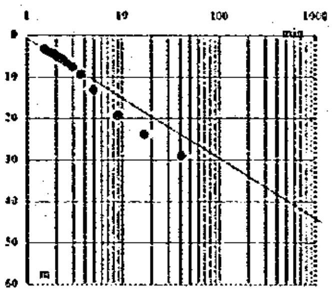
x - axis is r²/t(m2/min)
y - axis is draw down (m)

< Theis Method >



x - axis is t (min)
y - axis is draw down (m)

< Jacob Method >



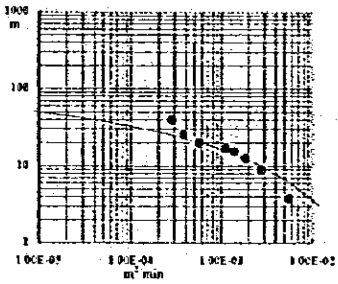
x - axis is t (min)
y - axis is draw down (m)

< Recovery Method >

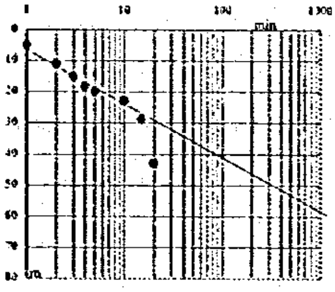
Appendix 2 (2) Result of Pumping Test Analysis

No. 1690

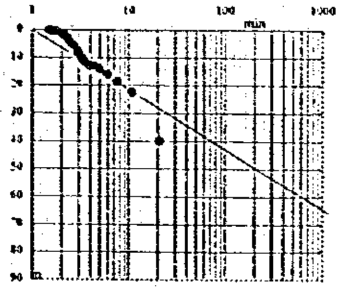
T= 0.878 k= 0.0251 S= 0.101



T= 8.71E-01 k= 0.0249 S= 1.00E-01



T= 0.699 k= 0.02



No. 1934A

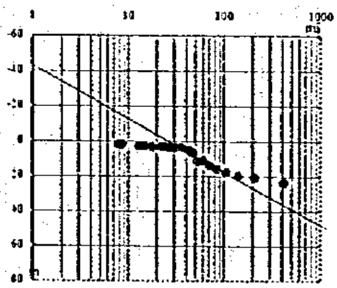
T= k= S=

<Not Suitable For Analysis>

T= k= S=

<Not Suitable For Analysis>

T= 1.04 k= 0.0947



No. LS-8

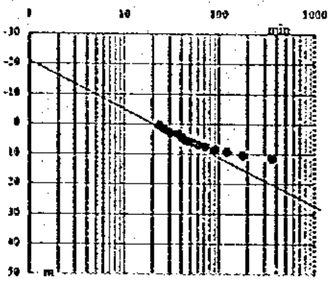
T= k= S=

<Not Suitable For Analysis>

T= k= S=

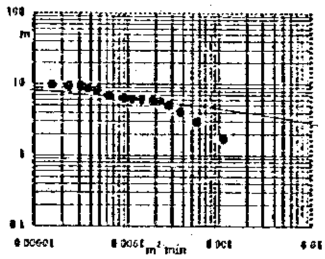
<Not Suitable For Analysis>

T= 5.87 k= 1.96

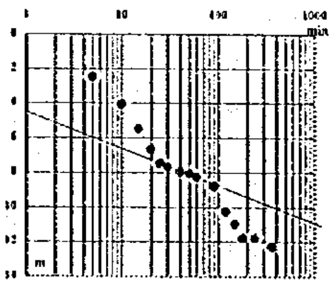


No. 2390-1

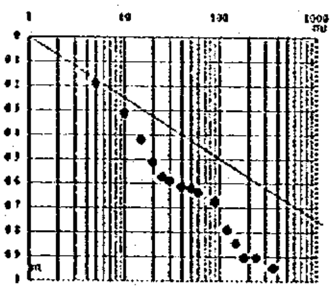
T= 5.46E+01 k= 9.10E+00 S= 1.13E-01



T= 54.5 k= 9.09 S= 0.123

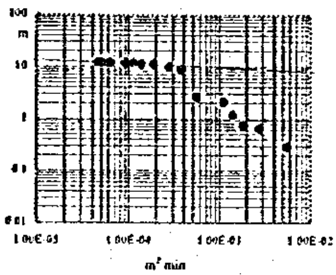


T= 468 k= 78

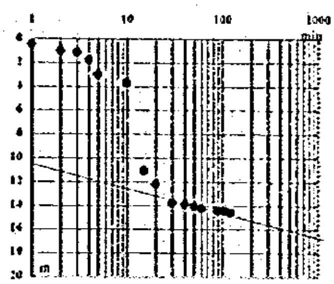


No. 2623C

T= 2.90E+01 k= 4.14E+00 S= 3.58E-05



T= 28.1 k= 4.01 S= 0.0000606



T= 2.57 k= 1.37