(2) Aquifer Distribution By Basin

Main aquifer distribution by river basin is outlined as follows.

Luapula River and Tanganyika Basin
Aquifers with good potential for development in Luapula and Tanganyika basins are the alluvial deposits along the Chambeshi and Luapula Rivers. On the other hand, sandstones are the main source of water supply in the plateau area. As well as sandstone, weathered granite often forms aquifers.

Luangwa River Basin
Aquifers with relatively high potential for development in Luangwa basin are the alluvial deposits. All rocks have been weathered to some extent through the process of tectonic deformations and these zones form aquifers. Weathered or fractured gneiss, granite, schist and quartzite are main aquifers for groundwater supply in plateau area. However, groundwater from sandstone underlying the alluvial aquifers are said to be brackish and is not suitable for drinking.

Kafue River Basin
The best aquifers in the Kafue Basin are the Kundelungu limestone formation, dolomites and the Upper Roan dolomites formation. These aquifers are the best in Zambia and are most developed in Lusaka (Lusaka dolomite). The high yield of these formations is due to their karstic nature. Other aquifers with great potential are the alluvial sands and gravels along the Kafue River. Other than those refered to above, schist and quartzite often form good aquifers.

Zambezi River Basin
70% of the Zambezi River Basin is composed of the Kalahari sands. Generally Kalahari sands form good aquifers because of high porosity and permeability. Other aquifers with high yield are limestone and dolomite, but the distribution area of these aquifers is small. Other than the aquifers refered to above, shale, sandstone, quartzite often form aquifers.

4.2.2 Aquifer Characteristics

Hydrogeological characteristics of aquifers are represented by aquifer parameters, that is, coefficient of permeability, transmissivity and specific yield. For obtaining the characteristics, parameters were analyzed for various types of aquifers using pumping test records. Furthermore, these parameters were statistically modified using a great number of data stored in the borehole data-base. The results are as follows:

(1) Aquifer of existing boreholes

Aquifer lithology of existing boreholes stored in the data-base are shown in Figure 4-2.

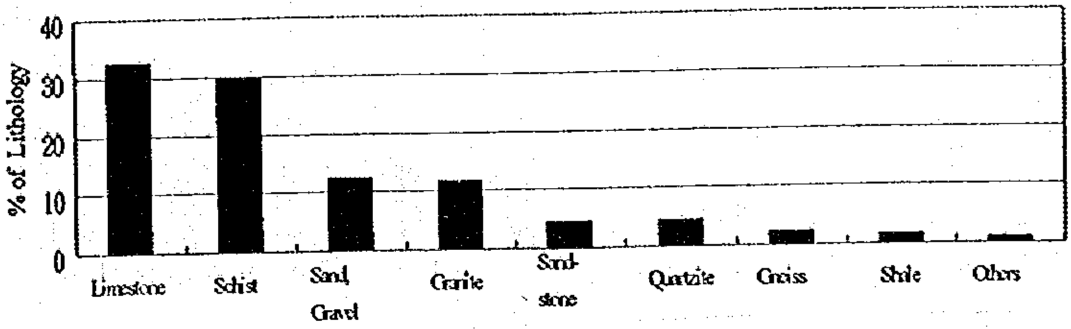


Figure 4-2 Aquifer Lithology stored in Data-Base

Litho-stratigraphical unit of aquifer lithology of existing boreholes stored in the data-base are shown in Figure 4-3.

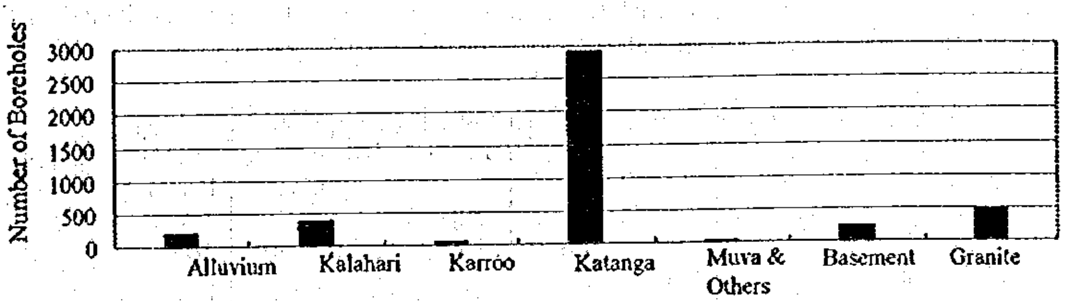


Figure 4-3 Stratigraphic Unit of Aquifer

As shown in Figure 4-2, types of aquifer lithology of existing boreholes are limited. The number of boreholes by lithology / total number of boreholes is;

- Limestone and Dolomite	32%
- Schist	30%
- Sand and Gravel	12%
- Granite	11%
- Sandstone	5%
- Quartzite	5%
- Gneiss	2%
- Others	1%

As the reason for this, following 2 points are considered:

- The rock types with high % listed above are apt to develop fractures and voids more than other rock types.
- There are a great number of boreholes in Lusaka Province, Western Province and Southern Province. The rock types listed above reflect main rock types in these 3 provinces.

The number of existing boreholes by province stored in the Data-Base is shown in Figure 4-4. It should be noted that the number of existing boreholes records stored in the Data-base is smaller than the actual number of existing boreholes. The number of actual existing boreholes are given Figure 5-1.

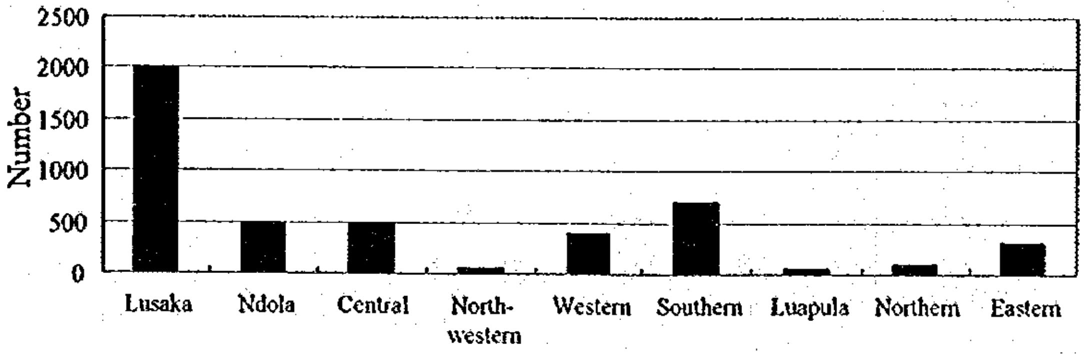


Figure 4-4 Number of Existing Boreholes Records Stored in Data-base

(2) Hydraulic Characteristic by Aquifer

Aquifer lithology of borehole is limited to several kinds of rock types as explained in the previous section and summarized in Table 4-3.

Table 4-3 Average Characteristics of Main Aquifer Lithology

Main Aquifer Lithology	Number of Borehole Data	%	Depth of Borehole (m)	Thickness of Aquifer (m)	Groundwater Level (GL-m)	Yield of Pumping Test (l/sec)	Specific Capacity (m^2/day)
Limestone & Dolomite	1,267	32	51.7	18.0	12.0	4.7	50.2
Schist	1,160	30	60.0	19.4	8.5	1.5	4.2
Sand & Gravel	479	12	39.2	17.0	5.4	1.5	25.9
Granite	448	11	51.8	20.0	9.0	1.1	5.7
Sandstone	175	5	60.0	23.0	8.7	1.8	10.5
Quartzite	176	5	55.0	17.0	8.7	1.6	6.0
Gneiss	88	2	49.0	15.0	8.3	0.7	2.3
Shale, Mudstone, etc.	65	2	60.0	15.5	8.4	1.5	5.7
Others	38	1	60.0	21.0	9.8	2.8	15.6
< Total >	3,896		54.0	21.7	7.1	2.0	9.96

Table 4-3 is summarized as follows:

- Depth of boreholes ranges from 6.1m to 123.3m. The average is 52.6m.
- Thickness of aquifers ranges from 0.1m to 109.3m. The average is 21.7m.
- Groundwater depth from ground surface ranges from 0m to 79m. The average is 7.1m.
- Depth to upper limit of aquifers ranges from 0.3m to 76.2m. The average is 18.0m.
- Yield at pumping test ranges from 0l/sec to 60.6 l/sec. The average is 2.0 l/sec.
- Specific capacities range from 0.001(m^2/day) to 9,070(m^2/day). The average is 9.96(m^2/day). Specific Capacity is defined as a yield(m^3/day) divided by a draw-down(m).

Specific capacity is a good indication of 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 Figure 4-3, it is concluded that Limestone & Dolomite, and Sand & Gravel, but especially Limestone & Dolomite, form far superior aquifers compared with other rock types.

(2) Aquifer Constants by Pumping Test Analysis

Aquifer constants for main lithology were calculated by 270 sets of pumping test analyses. The results are shown in Table 4-4 and Figure 4-5.

Table 4-4 Results of Pumping Test Analysis

Lithology	Data Number	Coefficient of Permeability (m/day)		Specific Yield (m^2/day)	
		Median	Range	Median	Range
Limestone & Dolomite	57	0.10	0.00040 - 97.5	0.030	7.8×10^{-8} - 2.6×10^{-1}
Schist	80	0.13	0.0062 - 14.2	0.030	7.0×10^{-7} - 2.5×10^{-1}
Sand & Gravel	37	0.48	0.013 - 10.8	0.016	3.5×10^{-11} - 2.5×10^{-1}
Granite	84	0.13	0.00013 - 22.1	0.068	6.8×10^{-5} - 2.8×10^{-1}
Sandstone	11	0.28	0.0036 - 18.8	0.045	3.0×10^{-3} - 2.6×10^{-1}
Quartzite	15	0.16	0.0011 - 1.02	0.052	1.7×10^{-8} - 2.6×10^{-1}
Gneiss	25	0.06	0.0020 - 3.51	0.041	1.2×10^{-6} - 1.7×10^{-1}
Argillaceous Rocks	4	0.11	0.024 - 0.47	0.057	4.4×10^{-2} - 7.0×10^{-2}
Others	3	0.04	0.024 - 0.33	0.018	1.8×10^{-2} - 1.8×10^{-2}
< All >	316	0.13	0.00013 - 97.5	0.038	3.5×10^{-11} - 2.8×10^{-1}

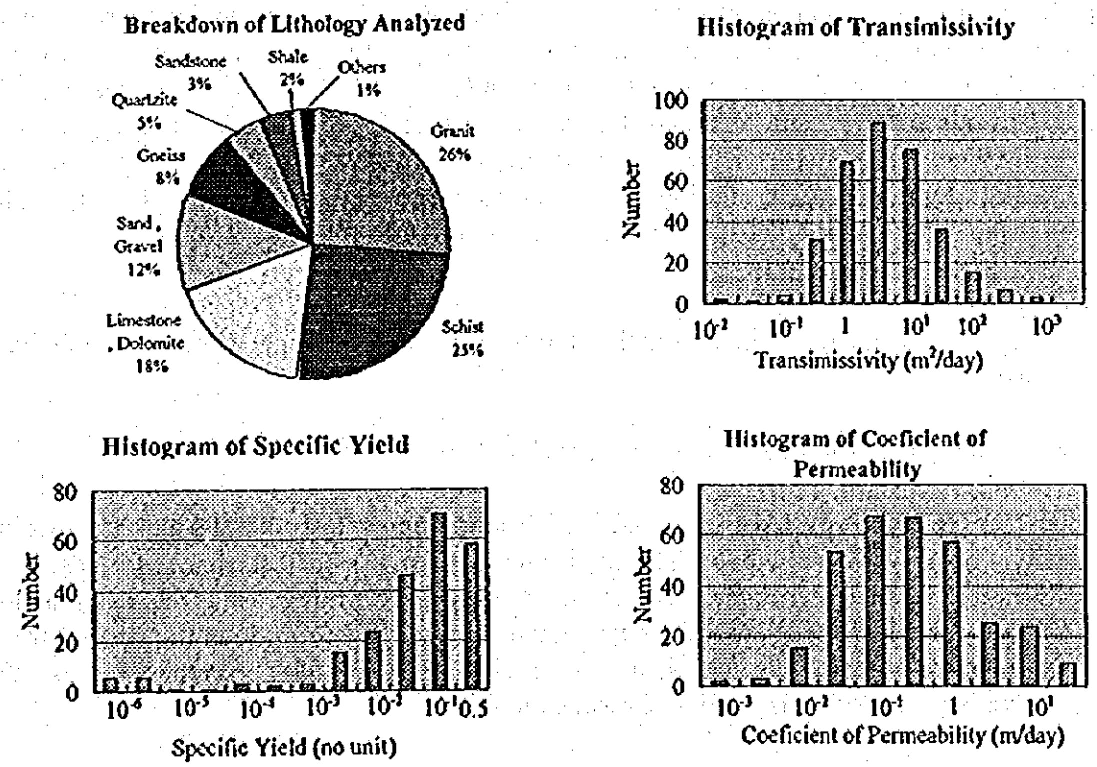


Figure 4-5 Results of Pumping Test Analysis

As shown in Table 4-4, values of aquifer constants by lithology have a wide range. Transmissivity and specific yield as well as specific capacity are general criteria of aquifer capacity. However, results shown in Table 4-4 do not necessarily agree with the general relationship between lithology and capacity. For example, though aquifer capacity of limestone is said to be higher than other lithology , aquifer constants shown in Table 4-4 are not so high compared with other lithology. The reasons are considered to be as follows:

- The number of analyses was not sufficient. As explained previously, values of aquifer constants have wide ranges. A large number of such pumping-test data that have lower aquifer constants have happened to be selected for the analysis.
- Boreholes with low yield were abandoned without pumping tests. It follows that most of the existing boreholes have relatively high aquifer constants and that the difference of aquifer constants among lithology is difficult to distinguish.

Because of the reason mentioned above, values of aquifer constants are unreliable and higher than actual values in those lithologies which have fewer analyzed results.

(3) Relationship between Specific Capacity and Other Aquifer Constants

Specific capacity is defined as follows:

Specific Capacity(m^2/day) = Yield(m^3/day) / Draw down of borehole (m)

Specific capacity is a good indicator of the capacity of a borehole and has been recorded on most borehole data records. Distribution of the values are shown in Figure 4-6. These Figures show that the value of specific capacities are concentrated into certain ranges by lithology. From this, aquifer characteristics by lithology are expressed by representative specific capacity. The relationship between specific capacity and other aquifer constants obtained from the pumping test analysis is shown in Figure 4-7. Specific capacity is strongly related to transmissivity and permeability, but not to specific yield as shown in Figure 4-7. Though values of aquifer constants vary widely, it is necessary to decide representative aquifer constants for each lithology in order to estimate groundwater potential. The relationship between specific capacity and other aquifer constants is as follows:

Transmissivity

From Figure 4-7, the approximate relationship between specific capacity and transmissivity is as follows:

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

Values for transmissivity have been obtained from pumping test analysis and for specific capacity from pumping test data. The total number of pumping test analyses is less than one-twentieth of the total data stored in the data-base. For this reason, 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 capacity has been adopted as the representative value of transmissivity for each lithology.

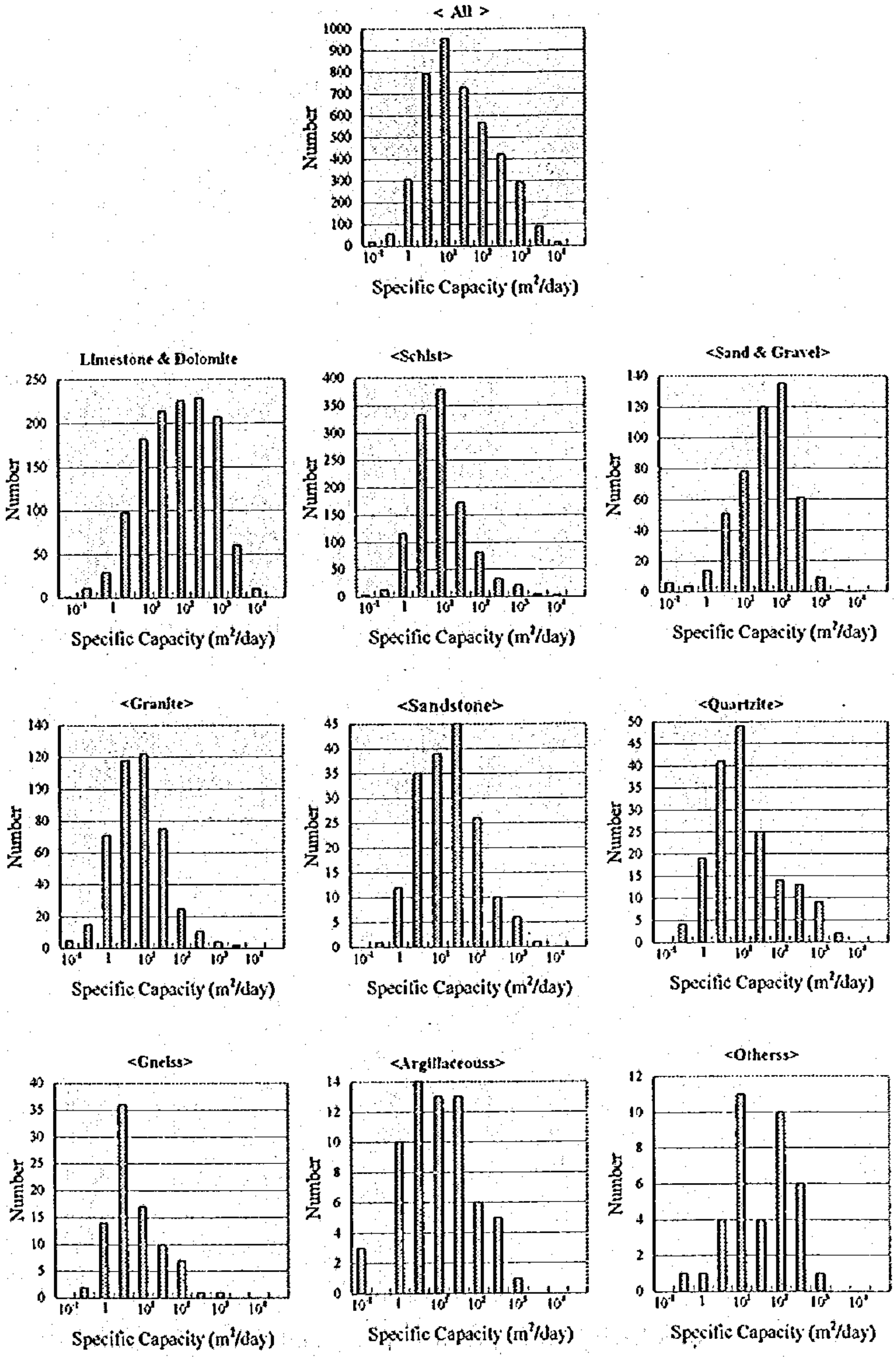


Figure 4-6 Specific Capacity by Lithology

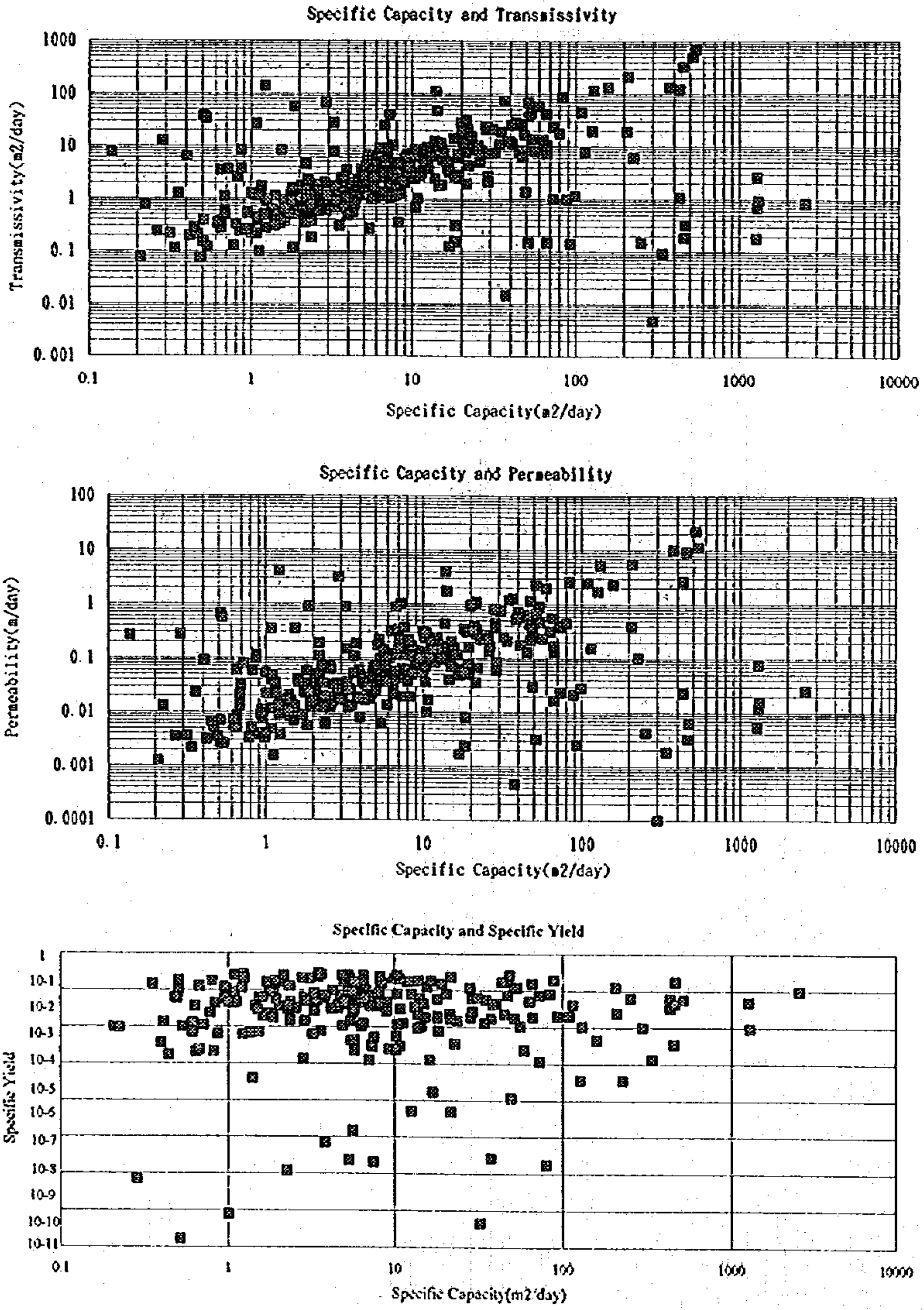


Figure 4-7 Relation between Specific Capacity and Other Constants

Table 4-5 Representative Value of Transmissivity (the same as specific capacity)

Aquifer Lithology	Transmissivity (m^2/day)	Aquifer Lithology	Transmissivity (m^2/day)
Limestone & Dolomite	50.2	Quartzite	6.0
Schist	4.2	Gneiss	2.3
Sand & Gravel	25.9	Shale, Mudstone, etc.	1.9
Granite	5.7	Others	1.9
Sandstone	10.5	< Average >	< 10.0 >

Permeability

Permeability(m/day) is calculated from formula below:

Permeability(m/day) = Transmissivity(m^2/day) / [Total length of borehole(m) - Static groundwater depth from surface(m)]

The distribution median was adopted as the representative value of permeability.

Table 4-6 Representative Value of Permeability

Aquifer Lithology	Permeability (m^2/day)	Aquifer Lithology	Permeability (m^2/day)
Limestone & Dolomite	1.31	Quartzite	0.16
Schist	0.11	Gneiss	0.06
Sand & Gravel	0.68	Shale, Mudstone, etc.	0.05
Granite	0.15	Others	0.05
Sandstone	0.27	< Average >	<0.26>

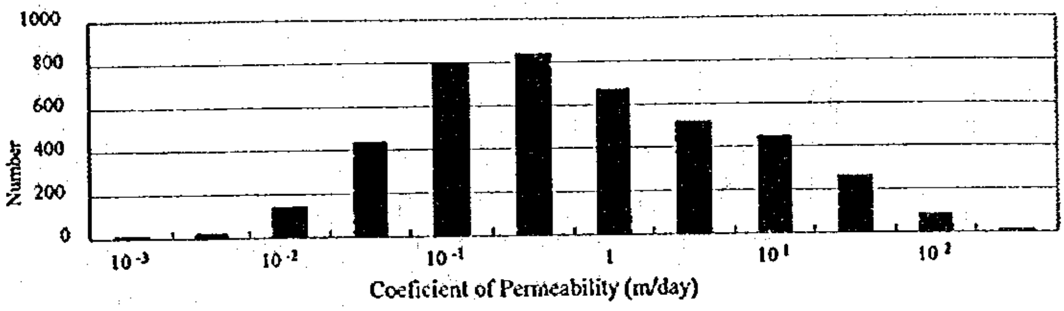


Figure 4-8 Histogram of Permeability (All Lithology)

Specific Yield

Specific capacity does not appear to be related to specific yield as shown in Figure 4-7. Values of specific yield vary widely as shown in Figure 4-7. 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)",

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

However, such a relation is not obvious from Figure 4-7.

Representative value of specific yield for all lithology as obtained from pumping test analysis is 0.04, therefore, actual average specific yields assumed to be around 0.04. The specific yield of each aquifer has been assumed as shown in Table 4-7 considering its permeability.

Table 4-7 Representative Value of Specific Yield

Grade	Specific Yield	Lithology	Grade	Specific Yield	Lithology
Permeability High	0.05	Limestone Dolomite Sand & Gravel	Permeability Medium Low	0.03	Granite Schist Quartzite Amphibolite
Permeability Medium High	0.04	Sandstone	Permeability Low	0.02	Gneiss Shale, Mudstone Others

Yield of borehole

Yields of boreholes range from 0 l/s - 60.6 l/s. Average yield is 2.1 l/s. Histogram of yield is shown in Figure 4-9 by all records and in Figure 4-10 by lithology.

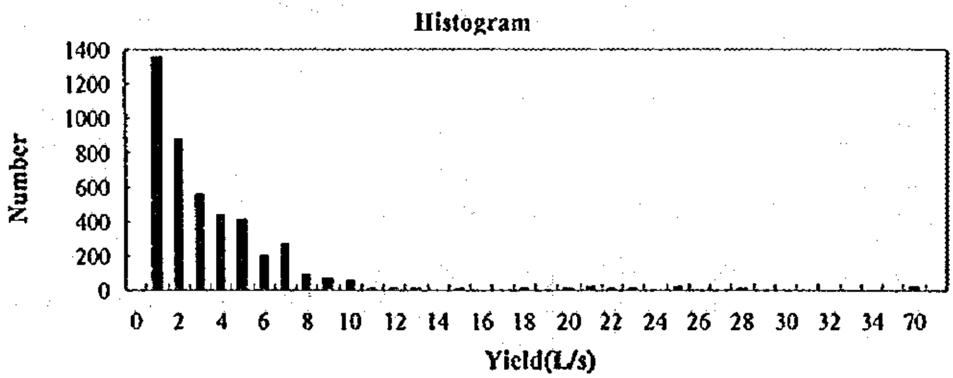
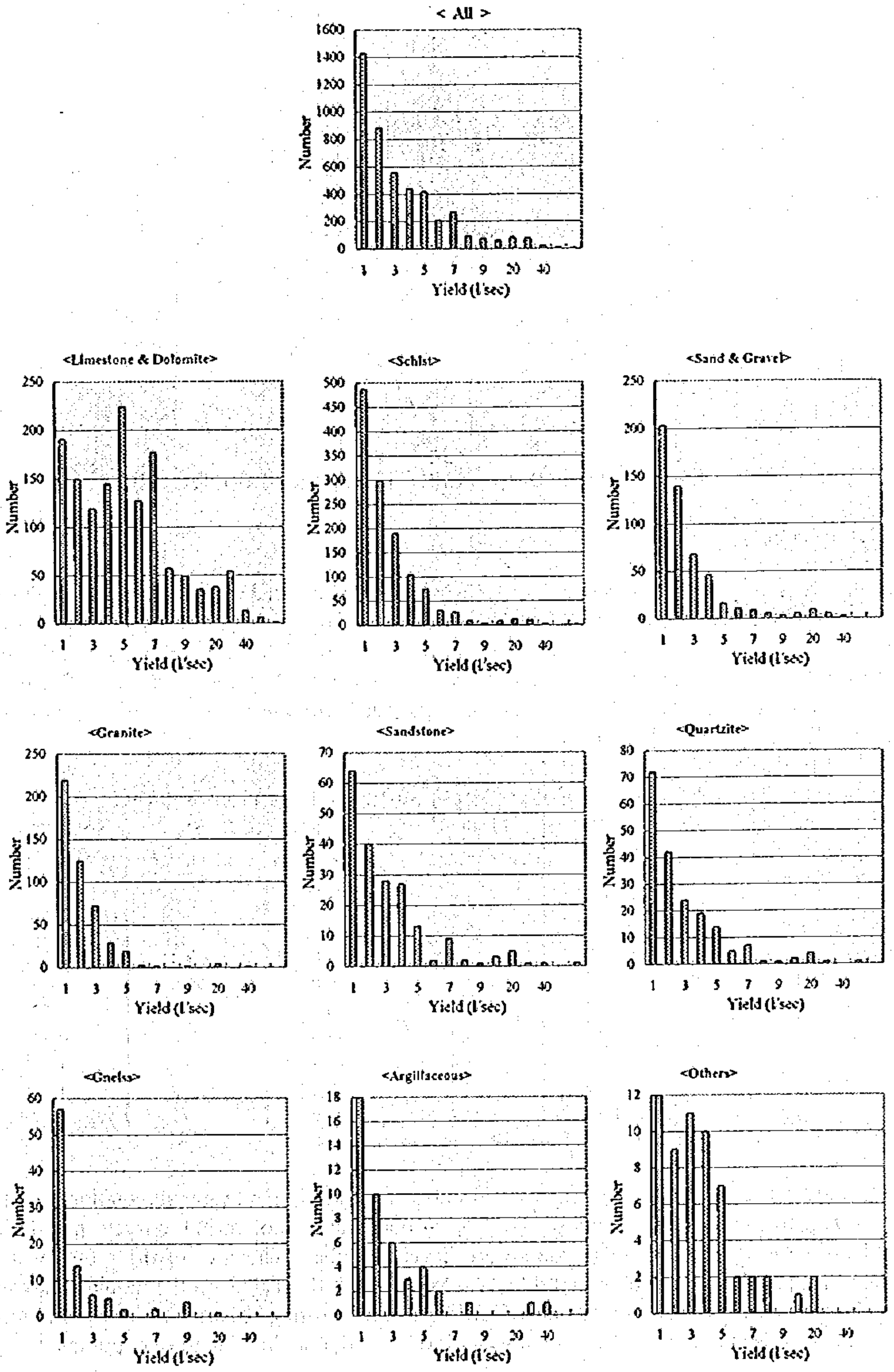


Figure 4-9 Histogram of Yield

The yields shown in Figure 4-9 and 4-10 are those obtained during the pumping test and not actual pumping rate. DWA recommends 70-80% of pumping test yield as the actual pumping rate.

4.3 Aquifer and Groundwater Level

There are some differences between groundwater level of borehole and shallow well. Aquifers for shallow wells consist of soils and strongly weathered rocks. On the other hand, aquifers for boreholes consist of weathered rocks and especially fractured rocks. Therefore, two types of aquifers, deep aquifers for boreholes and shallow aquifers for shallow wells, are illustrated as shown in Figure 4-11. Thickness of shallow aquifers range 5m - 30m with the average thickness of 16.4m. On the other hand, thickness of deep aquifers range 1m - 109m with an average thickness of 21.7m. The average boundary depth from the surface between shallow and deep aquifer ranges 5m - 30m with an average 16m.



< All >

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<Sand & Gravel>

<Granite>

<Sandstone>

<Quartzite>

<Gneiss>

<Argillaceous>

<Others>

Figure 4-10 Yield at Pumping Test by Lithology

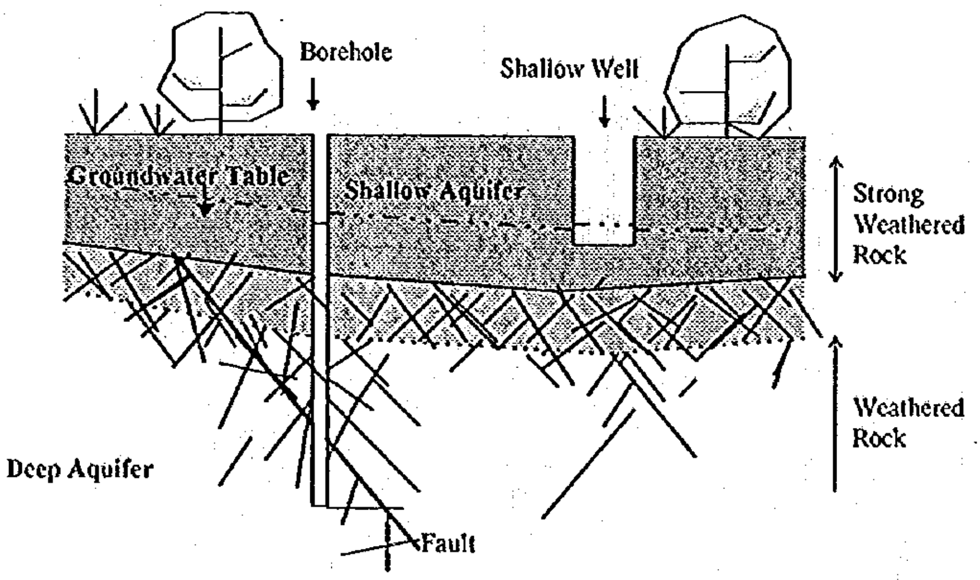


Figure 4-11 Deep Aquifer and Shallow Aquifer

4.3.1 Borehole

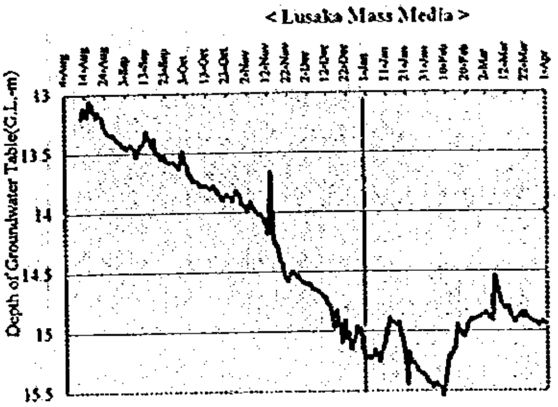
Table 4-8 shows depth of groundwater table in boreholes derived from a data-base analysis. These groundwater depths were those observed at the time of drilling. Of course, groundwater table in a borehole fluctuates in response to rainfall. Therefore, groundwater depths shown in Table 4-8 are not fixed values. As shown in the Table 4-8, depth of groundwater table ranges 0m - 65m and the average is 7.1m. Differences of lithology makes little difference in groundwater level.

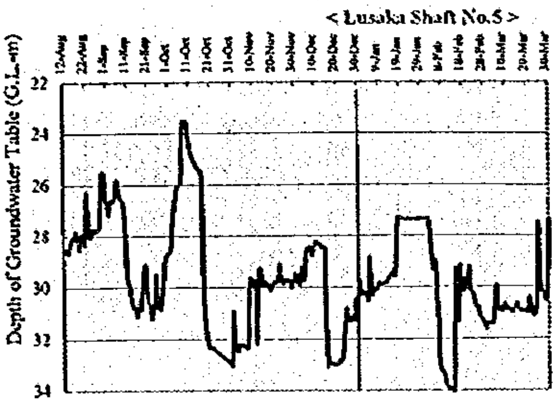
Table 4-8 Depth of Water from Surface before Pumping Test

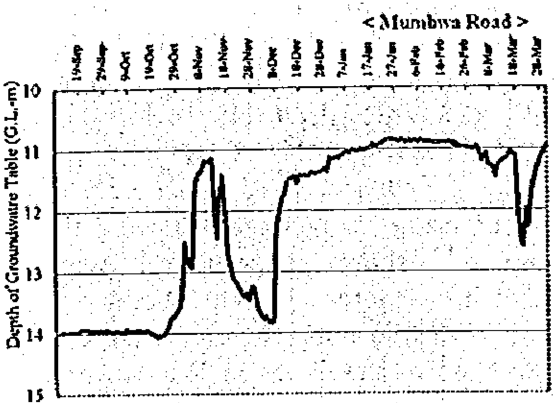
Lithology	Data Number	Medium (G.L.-m)	Range (G.L.-m)		Standard Deviation
			Minimum	Maximum	
Limestone & Dolomite	1386	12.0	4.0	12.0	0.03
Schist	1255	8.5	0.0	48.8	0.25
Sand & Gravel	522	5.4	0.0	55.7	0.42
Granite	476	6.4	0.0	79.0	0.37
Sandstone, Conglomerate	197	8.7	0.0	65.0	0.73
Quartzite	193	8.7	0.0	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
Total	4601	7.1	0	79	0.12

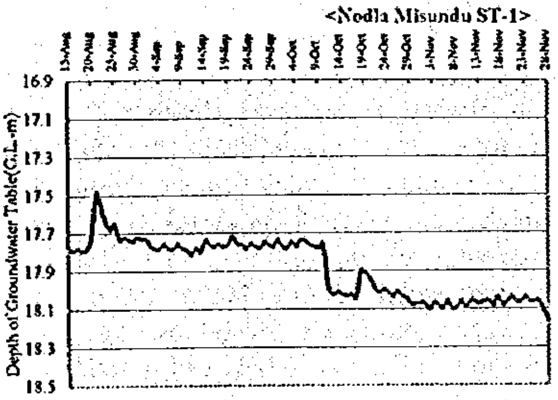
(Note) * Others include Igneous and the other metamorphic rocks

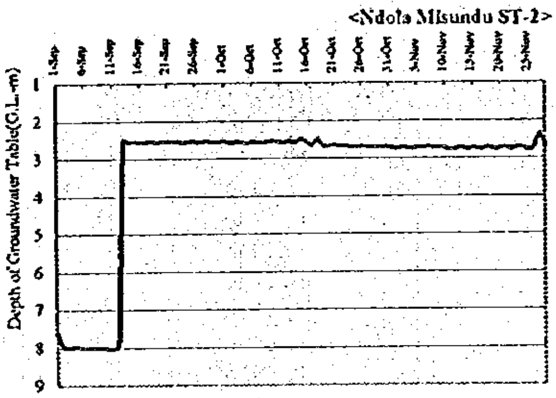
Groundwater level monitoring was carried out to monitor groundwater fluctuation caused by over abstraction of groundwater. The groundwater monitoring survey has been undertaken in four cities using groundwater level recorders. The sites of the groundwater monitoring stations are shown in Table 4-9. As shown in the Table, all the monitoring well are located near production wells in well fields. The monitoring results are shown in Figure 4-12. As shown in Figure 4-12, groundwater levels are fluctuating due to over pumping.

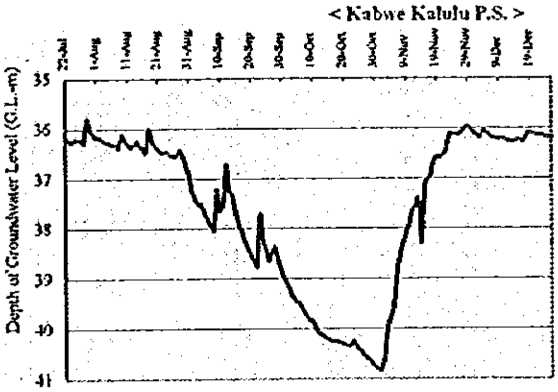












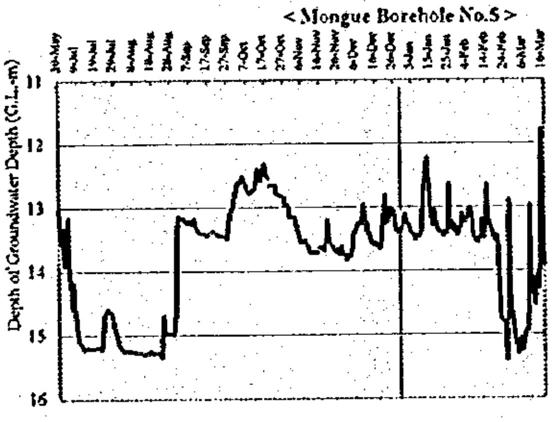


Figure 4-21
Result of Groundwater Monitoring

Table 4-9 Monitoring Stations

No.	City	Name of site	Depth of borehole	Ownership	Date of starting monitoring	Elevation of casing top
1	Lusaka	Mass Media	65m	Lusaka Water and Sewerage Company	12, Aug.	1265.0m
2	Lusaka	Mumbwa Road	39m		11, Aug.	1285.0m
3	Lusaka	Shaft No.5	75m		15, Aug.	1274.4m
4	Kabwe	Kalulu PS	100m	Kabwe Municipal Council	22, July	1187.9m
5	Ndola	Misundu St.1	80m	Ndola City Council	17, Aug.	1252.8m
6	Ndola	Misundu St.2	80m		23, Aug.	1247.0m
7	Mongu	Br No.5	82m	Mongu District Council	29, Jun.	1022.1m

4.3.2 Shallow Well

Groundwater levels of shallow wells have been observed by nation-wide Groundwater observation for almost one year. The observation period is from May 1995 to March 1996. The details of the observation results are explained in Supporting Report Part-U. In this observation, fluctuation of groundwater level in shallow wells was regularly observed in the nation-wide. Figure 4-13 shows the fluctuation of groundwater depth by province and Figure 4-14 is a contour maps showing difference of groundwater level between the highest in May and lowest in November. During this period, the groundwater levels were observed, which were taken 8 times for each point. A contour map was produced showing the maximum difference in groundwater level. Figure 4-15 shows relationship between groundwater level draw down and lithology. As shown in Figure 4-15, The relationship between groundwater level draw down and lithology is unclear or not recognized. Figure 4-16 shows relationship between groundwater level draw down and elevation. As shown in Figure 4-16, the relationship between groundwater level draw down and elevation is also unclear or not recognized.

Table 4-10 Average Groundwater Level Difference

Province	Average Groundwater Level Difference (m)	
	May - Oct, 1994	Oct - Mar, 1995
Lusaka	-2.27 m	+0.54 m
Ccopperbelt	-2.13 m	+0.83 m
Central	-2.64 m	+0.58 m
Northwestern	-1.61 m	+4.38 m
Western	-2.52 m	+0.11 m
Southern	-2.27 m	+0.47 m
Luapula	-2.55 m	+3.63 m
Northern	-1.01 m	+3.49 m
Eastern	-3.19 m	+2.96 m
Average	-2.24 m	+1.89 m

(Note) Values shown in this table is simple average of observed results.
(-) means groundwater level falling, (+) means rising

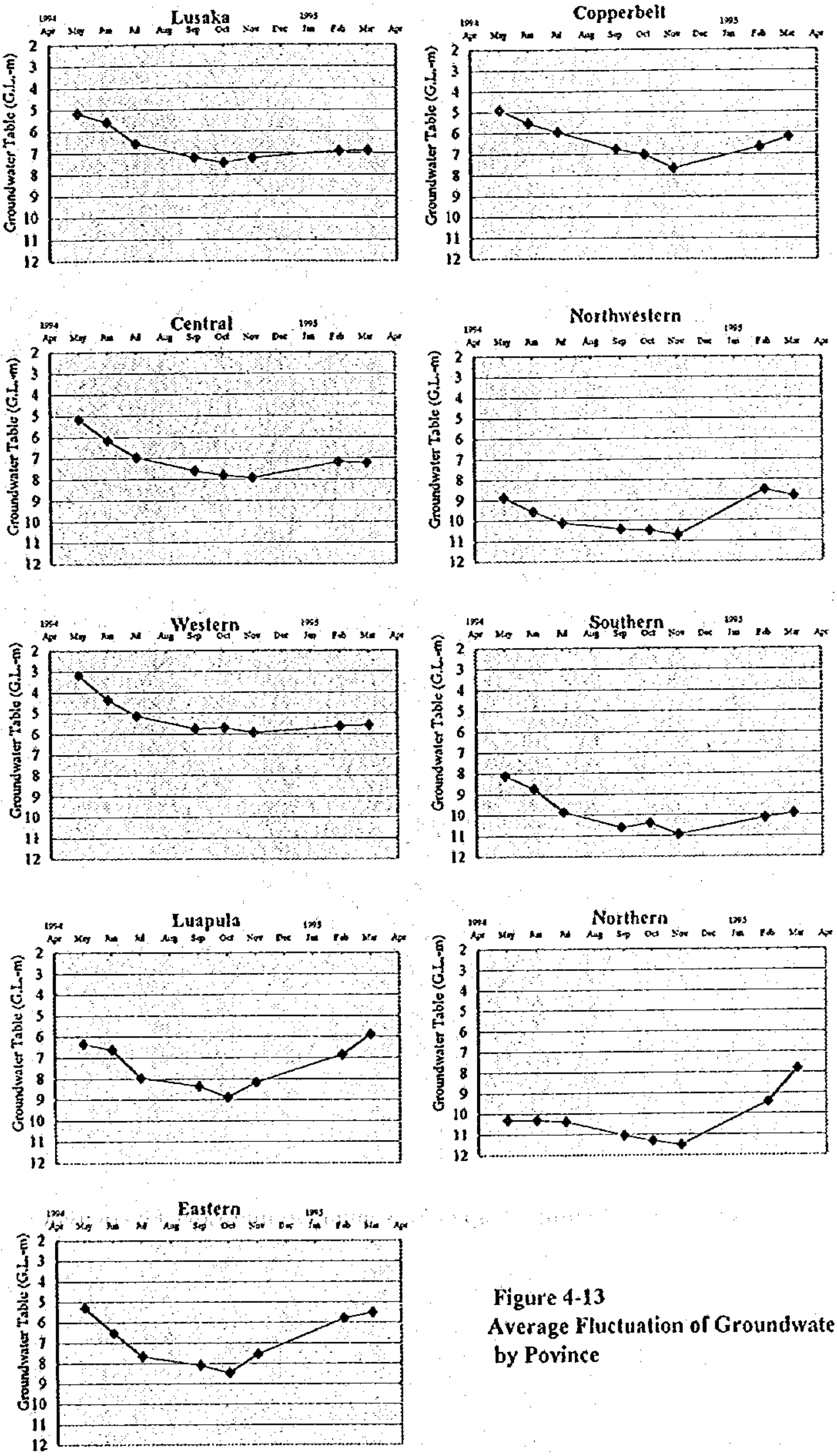


Figure 4-13
Average Fluctuation of Groundwater
by Povince

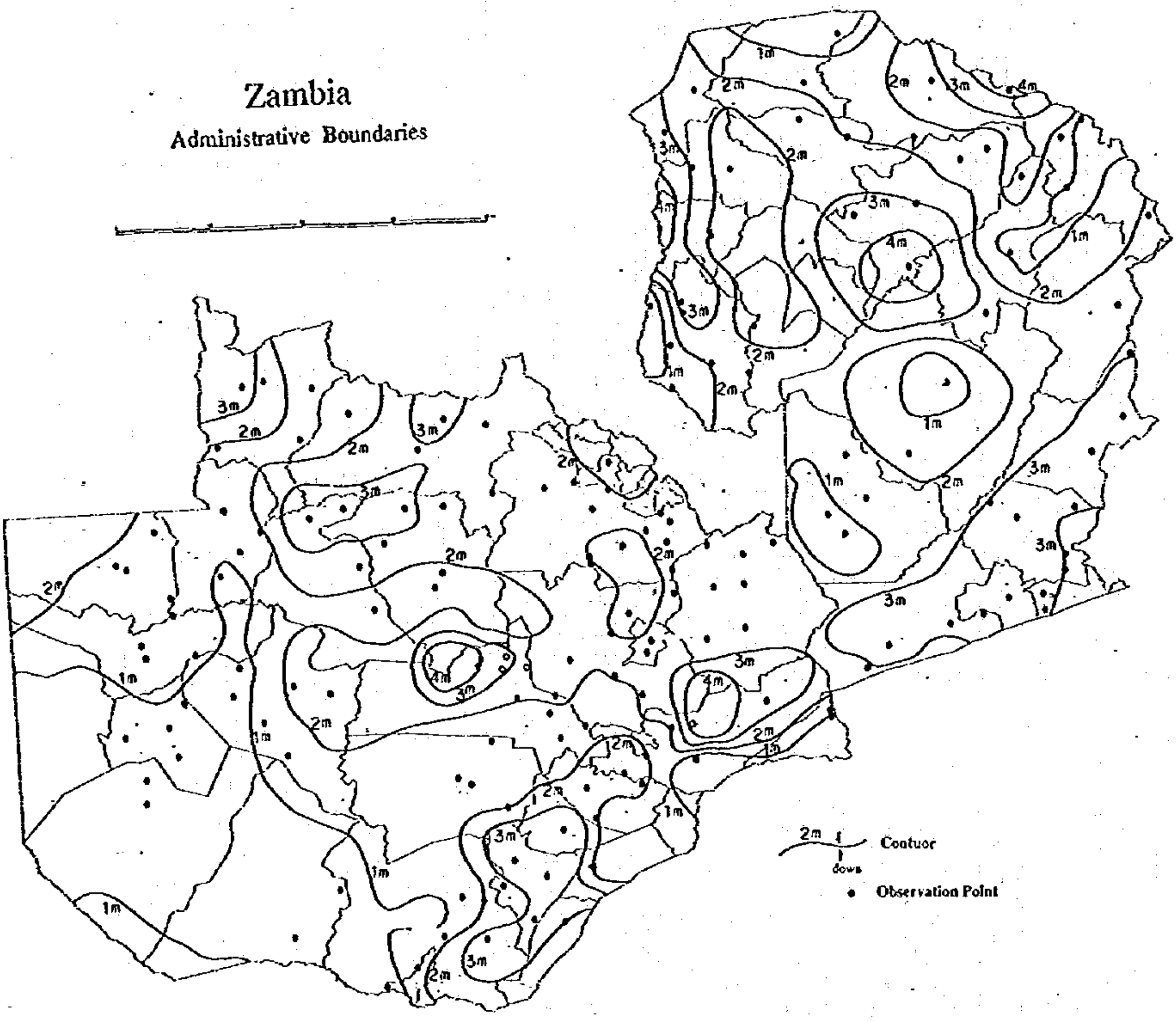


Figure 4-14 Contour Map of Maximum Groundwater Fluctuation

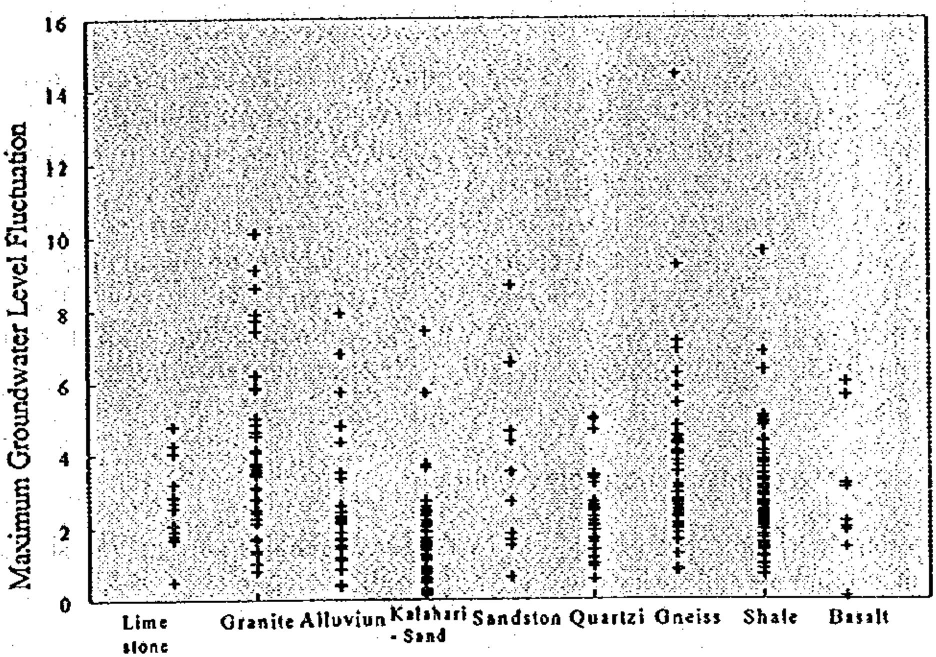


Figure 4-15 Relationship between Groundwater level Draw Down and Lithology

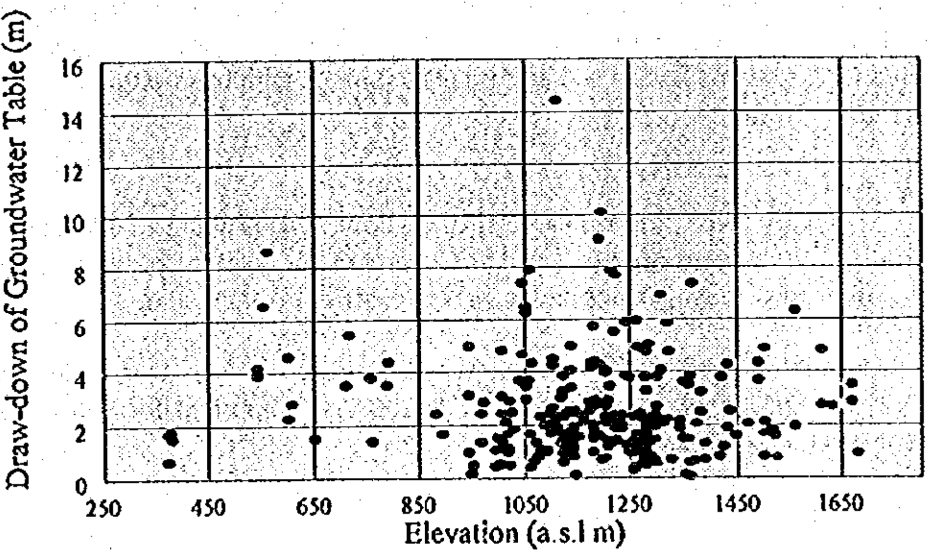


Figure 4-16 Relationship between Groundwater Level and Elevation

4.3.3 Factor of Groundwater Level

Factors dominating groundwater level and fluctuation are thought to be as follows:

- The total precipitation and the seasonal discharge.
- Topography
- Geology

Of the three factors listed above, the total precipitation and the seasonal discharge are the most dominant according to observation results.

CHAPTER 5 CURRENT GROUNDWATER USE

5.1 The Number of Existing Boreholes and Shallow Wells

The total number of existing boreholes and shallow wells have been investigated by district and the result is shown in Figure 5-1. The total number shown in Figure 5-1 is based on information published by DWA, which gives the total number of existing boreholes and shallow wells by province drilled between 1964 and 1985. The number of boreholes and shallow wells drilled after 1986 is estimated from the increase rate . After the total number of boreholes and shallow wells in each province had been estimated, the number was divided into districts based on the borehole data-base and investigations at each district office of DWA. The number of townships, villages and population distribution have been used as important information for estimation of the total number of boreholes and shallow wells by district.

5.2 Existing Groundwater Supply Facilities

Groundwater development is carried out by drilling boreholes and digging shallow wells. Definition of borehole and shallow well are as follows:

<u>Borehole</u>
Water well drilled by drilling rig. Diameter of boreholes is usually 10cm - 40cm and its depths is usually 20m - 100m with an average of 60m. Diameter of 10cm is most common for rural water supply and 15cm-30cm is common for urban water supply. Boreholes are protected by casing and screen and are usually equipped with hand-pump or power pump to abstract groundwater.

<u>Shallow well</u>
Water well dug by mans power. Diameter of shallow wells is 80cm - 200cm and its depth is 5m - 20m. Shallow wells are protected by concrete well liners to prevent collapse and are usually equipped with windlasses and bucket to abstract groundwater.

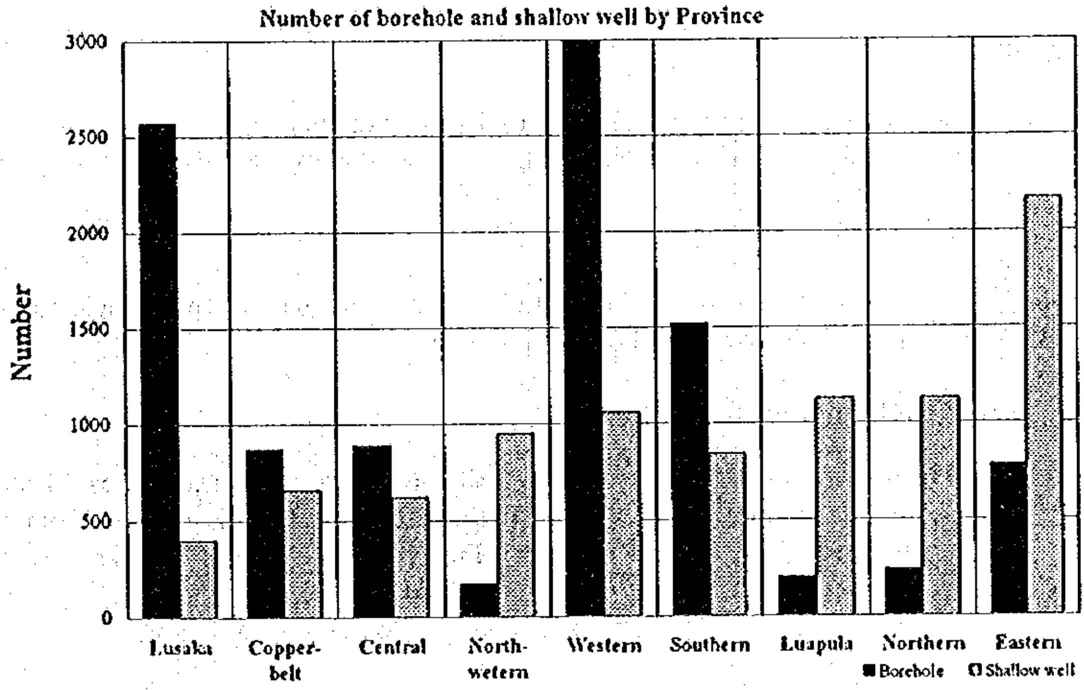
Other than borehole and shallow wells, there are also dug wells. Dug wells have a simple structure with shallow depth and no lining and are not important for public water supply. This report does not deal with dug wells.

5.2.1 Borehole

Boreholes are the most common method to abstract groundwater in Zambia. Merits and demerits of boreholes compared with shallow wells are as follows:

<u>Merits</u>
- -Boreholes do not dry up even in the dry season and are more reliable.
- -Quality of boreholes is superior.
- -Yield is generally higher using hand pumps and power pumps.
- -Boreholes can be used for urban water supply because of high yield.
- -Completion time of boreholes is much shorter than that of 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	660
	Ndola-Rural	190	
	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



FIfure 5-1 The Total Number of Existing Boreholes and Shallow Wells

Demerits

- Drilling rig and high technical skill are needed for drilling.
- Expensive hand pumps or power pumps are needed to abstract groundwater. The maintenance of a such equipment is not easy.
- Cost of drilling a borehole is more than 3 times as high as that of a shallow well. The maintenance cost is also expensive.

Boreholes are used for rural and urban water supply, especially for rural water supply. Most rural water supply is depending on groundwater. A standard structure of borehole for rural water supply is shown in Figure 5-2. Boreholes are usually equipped with hand pumps. Therefore, yield of borehole is decided by capacity of hand pump. Standard capacity of hand pump is said to be 7.5m^3/day on condition of 10 hours operation. If borehole is equipped with power pump, the yield can increase in proportion to aquifer capacity.

5.2.2 Shallow well

Shallow wells are used for rural water supply. Merits and demerits of shallow wells compared with boreholes are as follows;

Merits

- Shallow wells are dug by man power, so it is possible for villagers to construct them
- Maintenance of shallow well is easier. Groundwater is abstracted by windlass and it is possible to deepen a well during dry season.
- Cost is cheaper.

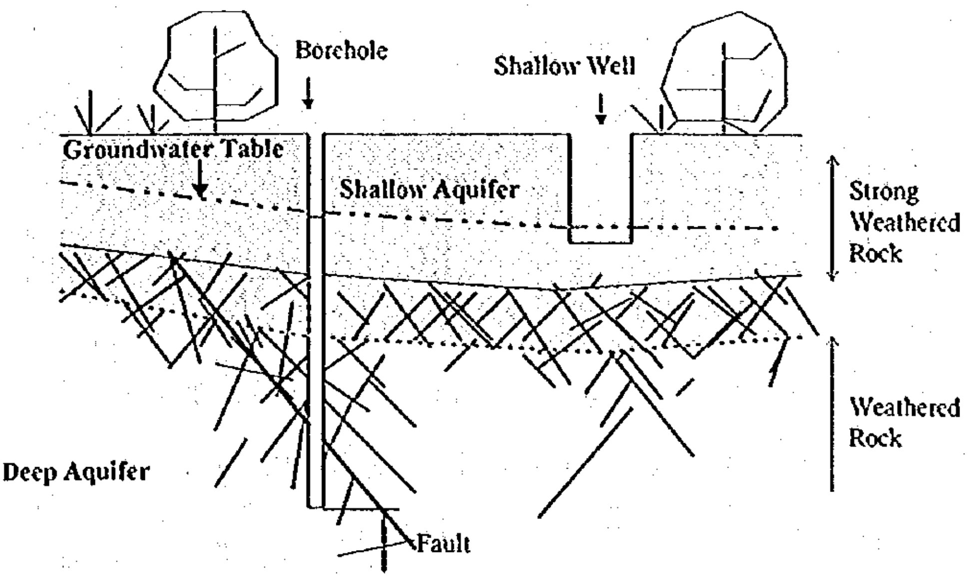
Demerits

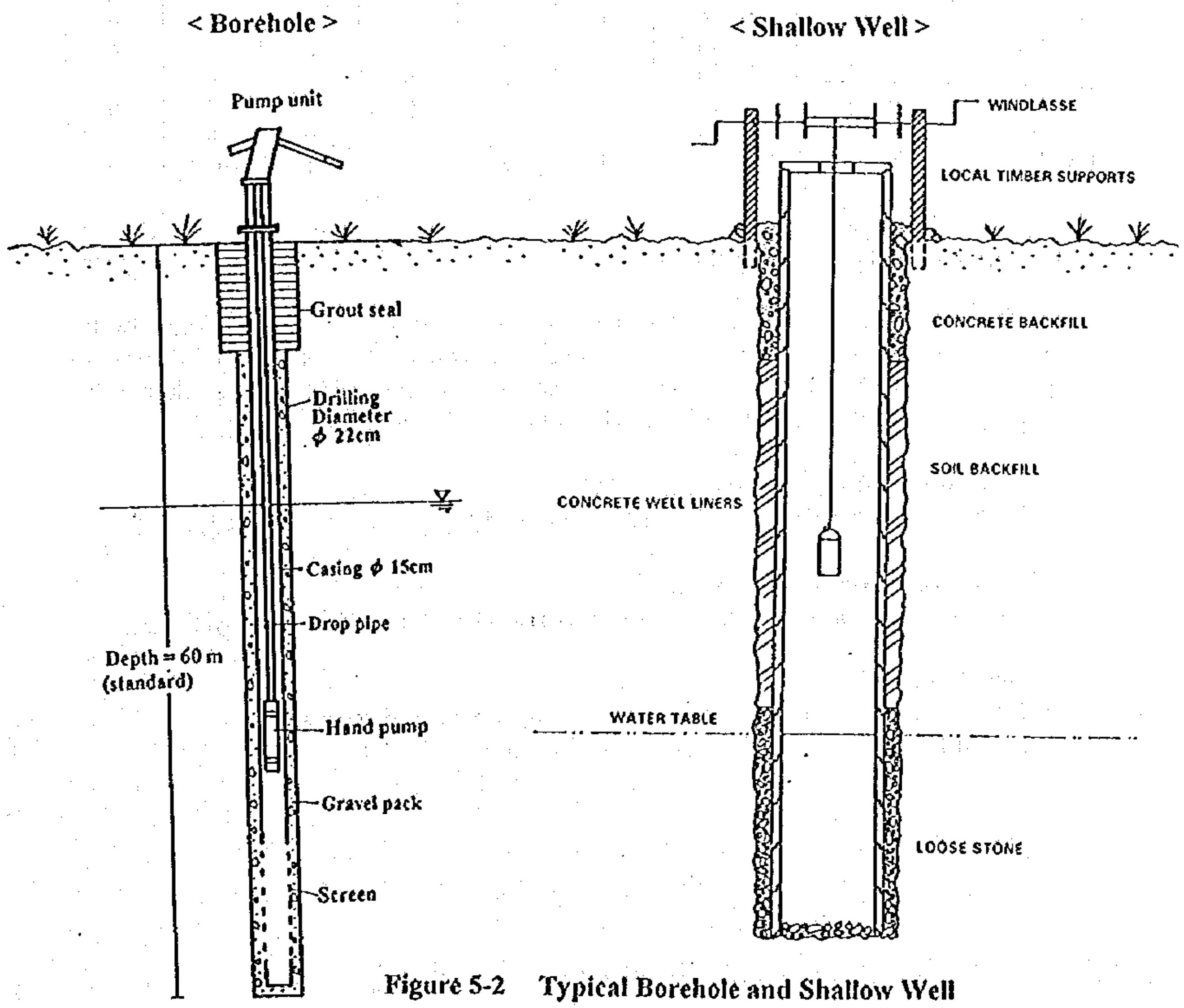
- Shallow wells are shallow and quick to dry up in the dry season.
- Water quality is often a problem, because shallow groundwater is easily contaminated.
- Yields are low.

Average yield of shallow wells is considered to be 2m^3/day by experience and field survey. Standard structure of shallow well is shown in Figure 5-2.

5.3 Purpose of Groundwater Use

Groundwater is used for various purposes. Especially boreholes have various uses. Shallow wells are used only for rural water supply. Purpose of boreholes is derived from the borehole data-base and summarized as shown on Figure 5-3 and Table 5-1. Theses results show that purposes of groundwater use are different by province.




< Borehole >

< Shallow Well >

Figure 5-2 Typical Borehole and Shallow Well

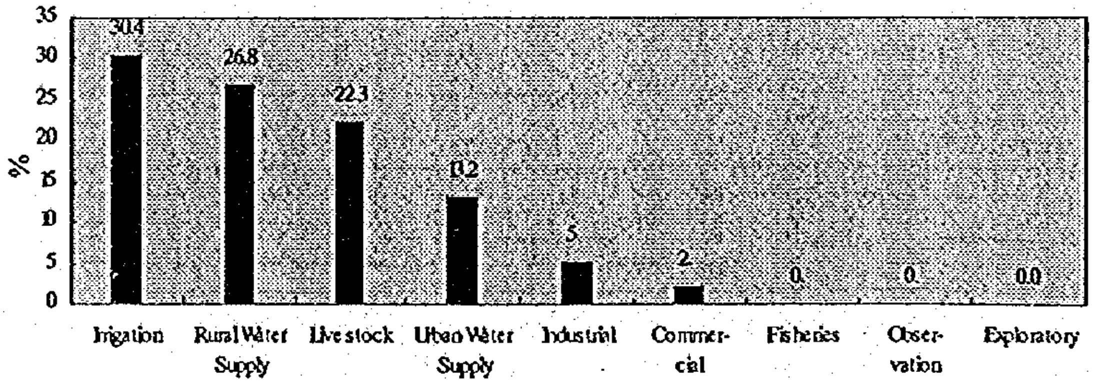


Figure 5-3 Percentage of Groundwater Use by Purpose

Table 5-1 Percentage of Groundwater Use by Purpose

	Irrigation (%)	Rural Water Supply	Live Stock (%)	Urban Water Supply	Industrial (%)	Commer-cial (%)	Fisheries (%)	Explo-ratory (%)	Obser-vation (%)
Lusaka	40	5	26	22	5	2	0	0	0
Copper-belt	20	22	15	20	18	6	0	0	0
Central	40	19	29	5	4	3	0	0	0
North-western	9	80	11	0	0	0	0	0	0
Western	0	99	0	1	0	0	0	0	0
Southern	28	39	26	3	4	0	0	0	0
Luapula	4	79	0	8	9	0	0	0	0
Northern	17	62	14	6	1	0	1	0	0
Eastern	17	57	18	6	1	1	0	0	0
Total	30	27	22	13	5	2	0.1	0.04	0

5.4 Current water supply in Rural Areas

Groundwater is the most important water resources for rural water supply. Groundwater supply ratio has been estimated as shown in Table 5-2 by district, Table 5-3 and Figure 5-4 by province. This estimate is based on the number of existing boreholes and shallow wells. The current groundwater supply ration has been estimated as follows:

Groundwater supply ratio
= [Total current groundwater use (m^3/day) / [33.85 (l/day) x population] x 1,000

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

Table 5-2 Groundwater Supply Ratio in Rural Area

Province	District	Borehole			Shallow Well			Total	Population	Supply Ratio %
		Total	Operating	Yield (m3/day)	Total	Operating	Yield(m3/day	Yield (m3/day)		
Lusaka	Lusaka-Urban									
	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
	Chililabombwe	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

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

As shown in Figure 5-4, water supply ratios differ by province. Supply ratios are high in Lusaka province, Southern province, Eastern province and Western province. However, they are low in Northern province and Northwestern province. Those provinces which have low supply rates are relatively rich in surface water, and this results in low water supply ratio. However, surface water is poor in quality and unreliable in quantity. So it desirable to change the resource of water supply from surface water to groundwater in the future.

Table 5-3 Groundwater Supply Ratio 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%

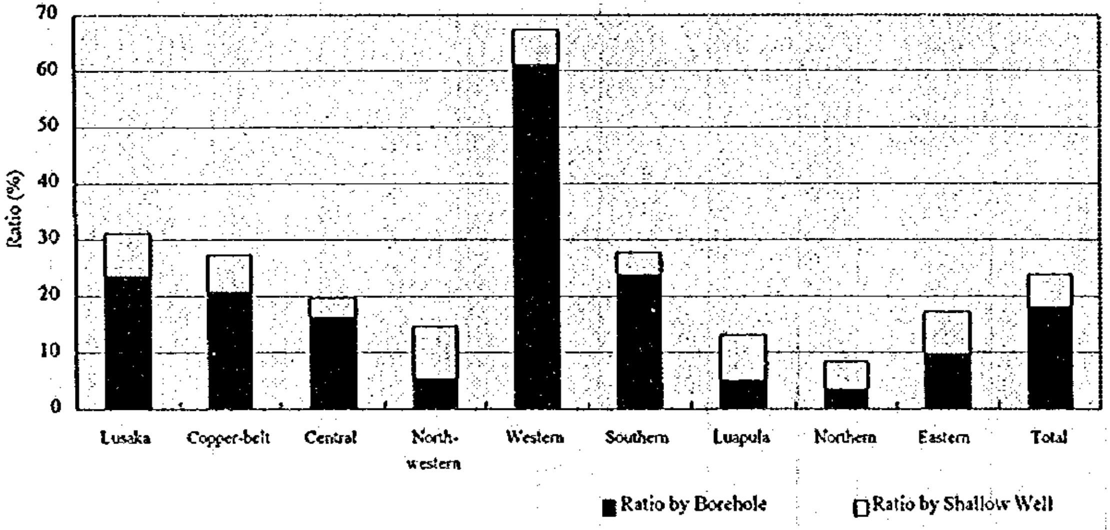


Figure 5-4 Groundwater Supply Ratio in Rural Areas

5.5 Current Water Supply in Urban Area

5.5.1 Large Urban Area

Though main water resources for urban water supply is surface water, however, groundwater is also used for urban water supply. The large urban areas where groundwater is used for water supply is as follows:

Table 5-4 Groundwater Supply Projects in Large Urban Areas (1995)

Province	Project	Managing Body	Population Served	Quantity m^3/day	Note
Lusaka	Lusaka	LWSC	900,000	190,000	B
Copperbelt	Ndola	Council	600,000	147,000	B
Central	Kabwe	Council	120,000	33,000	B
	Kabwe	ZCCM	50,000	16,000	
Southern	Livingstone	Council	80,000		B
Eastern	Chipata	CWSC	---	---	B

Note : (1) B means surface water also used for water supply as well as groundwater.
(2) Data taken from the replies to the Current Water Use questionnaire survey.

Groundwater plays an important role in water supply especially in Lusaka, Nodla, Kabwe. The current public water supply in these 3 cities is as follows:

Table 5-5 Current Groundwater Use in Three large Urban Areas

Lusaka	- 40% of the water supply, 100,000m^3/day, is provided by groundwater from about 40 boreholes.
Kabwe	- 75 % of water supply is provided by groundwater from 2 well fields.
Nodal	- 52 % of the water supply, 110,000m^3/day, is provided by groundwater from 3 well fields.

Other than water supply explained above, especially in Lusaka, a great deal of groundwater is being abstracted privately.

Over-pumping causes regional groundwater level decline. Groundwater level decline has been already reported in Lusaka city. Therefore, there is a possibility of severe effects on groundwater use in the near future unless proper counter-measures are not taken.

5.5.2 Small Urban Area

Groundwater is used for water supply in small urban areas. The current groundwater use in these areas is summarized in Table 5-6.

Table 5-6 Groundwater Supply Projects in Small Urban Areas

Province	Project	Managing Body	Population Served	Quantity m^3/day	Note
Copperbelt	Chililabombwe	Council	25,000	4,175	
	Nchanga	ZCCM	100,000	45,000	B
	Mufulira	ZCCM	110,000	48,000	B
	Kalulushi	ZCCM	30,000	11,000	
	Chib.				
	Luanshya	ZCCM	90,000	33,000	B
	Kasumbalesa	DWA	200	50	
	Mokambo	DWA	500	80	
	Sakania	DWA	200	50	
	Tshisenda	DWA	150	30	
Central	Chibombo	Council	1,000	120	
	Chisamba	DWA	8,996	3,416	
	Mumbwa	DWA	16,000	1,934	B
Northwestern	Solwezi	Council	- - -	- - -	
	Mufumbwe	DWA	1,452	134	
Western	Mongu	Council	- - -	- - -	
	Namushakende	DWA	3,098	177	
	Lukulu	DWA	2,965	600	
	Kaoma	DWA	7,150	1,614	
Southern	Mazabuka	Council	39,430		B
Luapula	Kawambwa	DWA	6,250	1,440	S
Northern	Isoka	DWA	10,000	800	S
Eastern	Chama	DWA	3,000	23	
	Katete	DWA	2,500	200	
	Petauke	DWA	11,237	647	

Note : (1) B means surface water also used for water supply as well as groundwater.
(2) Data taken from the replies to the Current Water Use questionnaire survey.

CHAPTER 6 GROUNDWATER DEVELOPMENT POTENTIAL

6.1 Groundwater Potential Analysis

6.1.1 Purpose of Groundwater Potential Analysis

Groundwater potential analysis has been carried out to estimate the renewable groundwater storage of aquifers. Renewable groundwater is considered to be sustainable groundwater resources.

Groundwater is flowing within a natural water circulation system. A part of the rainfall infiltrates into the ground. Furthermore, a part of this reaches the groundwater table and flows through aquifers and finally runs off into rivers. In other words, rainfall is temporally stored in aquifers as groundwater but finally runs off into rivers ever year. If not, groundwater levels might continue to rise or fall. This is obviously against observation results. The groundwater temporarily stored and renewed every year is called renewable groundwater. Groundwater development potential must be less than renewable groundwater potential in terms of sustainable groundwater development. On the contrary, if groundwater development exceeds the renewable potential, groundwater resources may dry up due to regional groundwater decline.

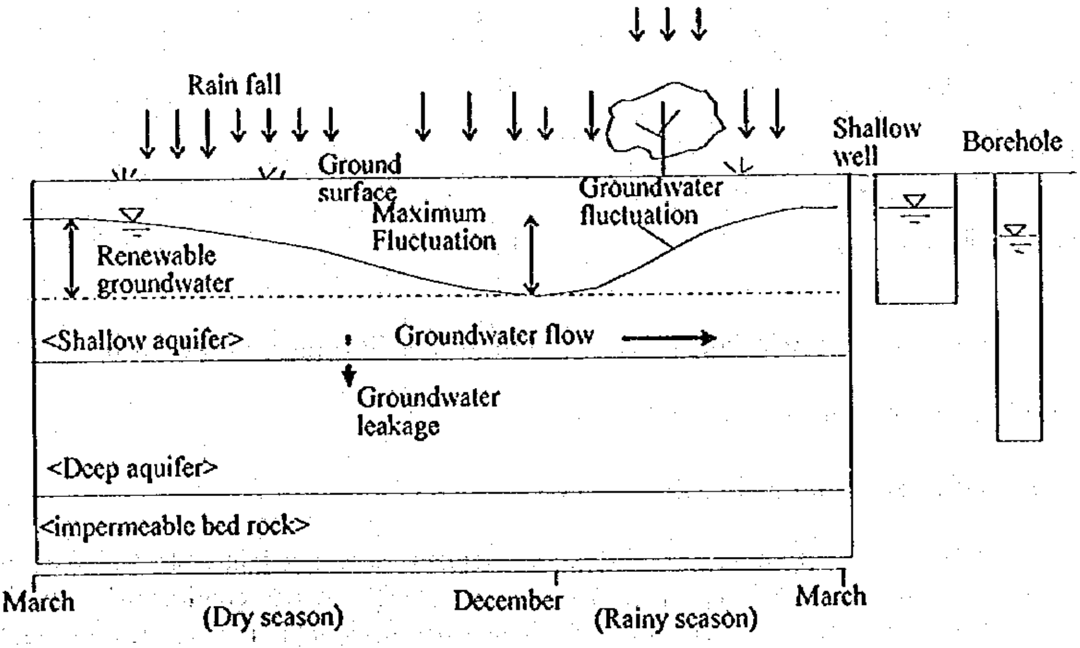


Figure 6-1 Concept of Renewable Groundwater

6.1.2 Relationship between Temporary Groundwater Storage and Run-off

Renewable groundwater volume is calculated from temporary groundwater storage and groundwater run-off. The following relationship holds good:

Renewable groundwater volume = Temporary groundwater storage volume
= Groundwater run-off volume

Figure 6-2 shows the concept of the above relationship.

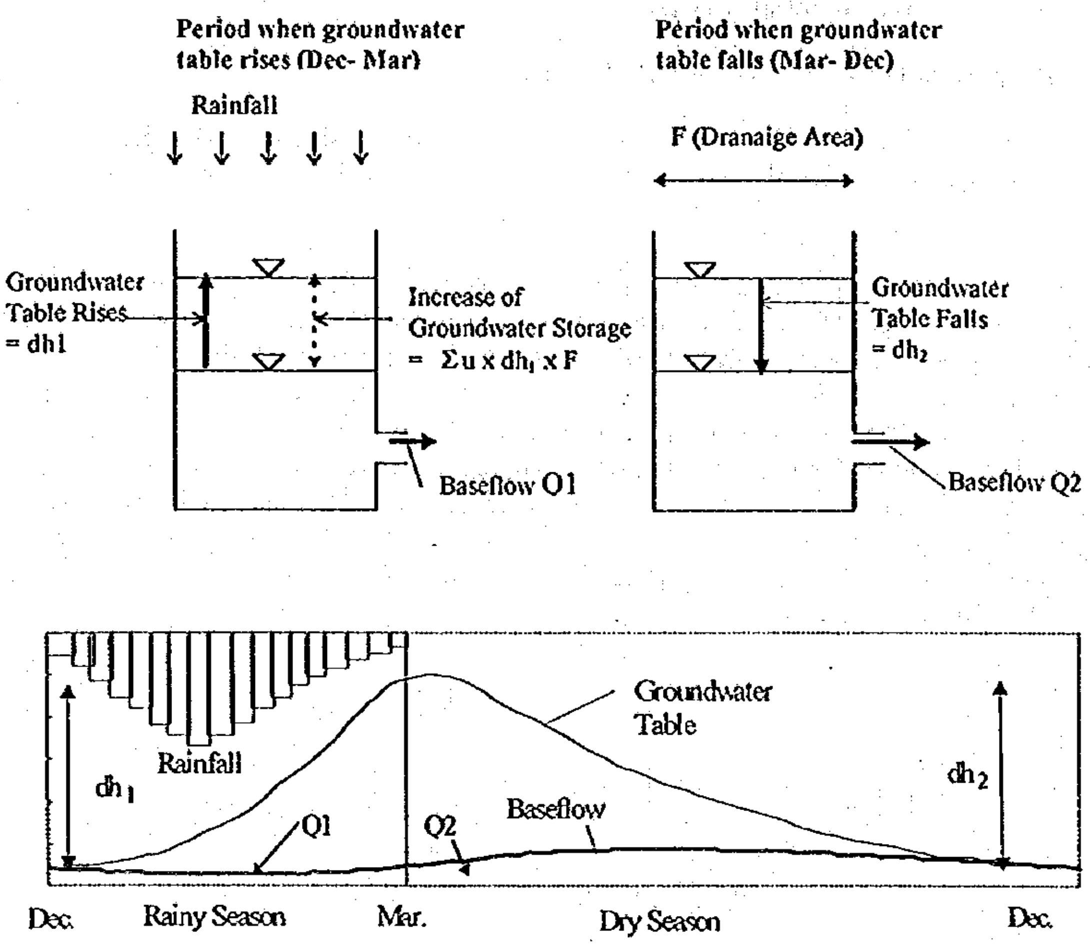


Figure 6-2 Relation Between Groundwater Storage and Baseflow

The explanation of Figure 6-2 is as follows:

(1) Period when groundwater table rises

Some rainfall infiltrates into the ground. Some rainfall is retained in soils and the rest reaches the groundwater table and causes groundwater table to rise continuously. On the other hand, some groundwater runs off into rivers as baseflow while the groundwater table is rising. From this, the following formula will hold good.

Recharge to aquifers during the period when groundwater table rises
= Increase in groundwater storage by groundwater table rising (u x dh1 x F)
+ groundwater run-off into rivers (Q1)

(2) Period when groundwater table falls

During this period, there is almost no rainfall and no recharge to groundwater. Therefore, the groundwater table continuously falls due to groundwater run-off as baseflow(Q2). It takes several months for the process of rainfall - infiltration - groundwater flow - run off.

Therefore, the peak of base-flow may appear during the dry season as shown in Figure 6-2. From this, the following formula will hold good.

Discharge from aquifers
= Reduction in groundwater storage by groundwater table falling (u x dh2 x F)
= Baseflow (Q2)

(3) Relation between seasonal recharge and discharge

After the process explained in (1) and (2), groundwater table is considered to recover to the same level as the previous year. This means dh1= dh2. On condition that dh1 is equal to dh2, the following relationship will be justified:

Renewable groundwater storage during one year
= Increase in groundwater storage by groundwater table rising (u x dh1 x F)
+ Groundwater run-off into rivers (Q1) during groundwater table rising
= Base-flow during groundwater table falling (Q2)

From the above relation, renewable groundwater storage can be calculated. However, there is one problem in using this method, that is the difference between dh1 and dh2. Actually dh1 is not necessarily equal to dh2. On the contrary , the difference will be large in a year such as drought or heavy rain. In order to solve this problem, referring to groundwater fluctuation shown in Figure 6-3 is effective

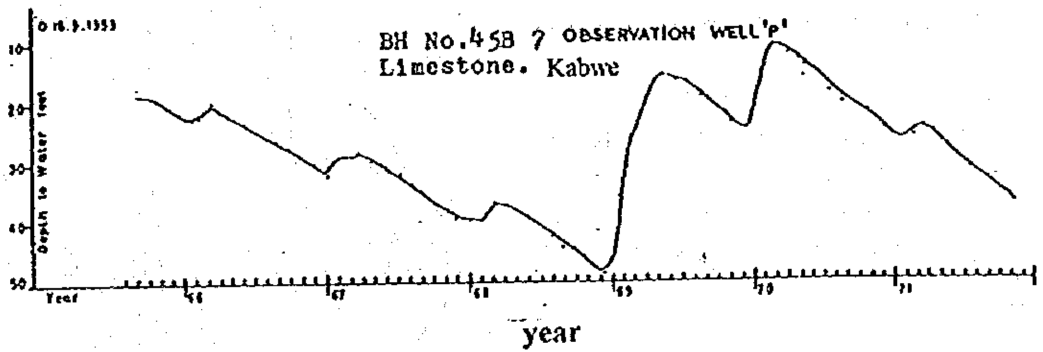


Figure 6-3 Example of Groundwater Fluctuation in Boreholes for Long Period

From long term observation results such as shown in Figure 6-3, it is assumed that dh1 depends on rainfall and changes every year, however, dh2 is almost the same every year. The reason dh2 is almost constant every year is considered as follows:

- Generally speaking, evapotranspiration from the ground surface is more constant than precipitation.
- Groundwater flow is not so changeable because groundwater gradients remain almost constant in spite of groundwater table fluctuation. Average dh1 is considered to be equal to average dh2. Therefore, dh2 should be used instead of dh1 in order to estimate long term renewable groundwater potential.

6.1.3 Method to Calculate Increase in Groundwater Storage

The increase in groundwater storage in aquifers($u \times dh2 \times F$) during rainy season is calculated as follows:

Increase in Groundwater Storage = $\Sigma u_i \times dh \times F_i$ **(i = 1, n)**

Where

u_i : Specific Yield of Aquifer- i
dh1 : Maximum Groundwater Fluctuation in a district (m)
F_i : Area of aquifer i (m^2)
i : Aquifer number
(see Figure 6-4)

If there are 4 aquifers in a district, the calculation is done as follows:

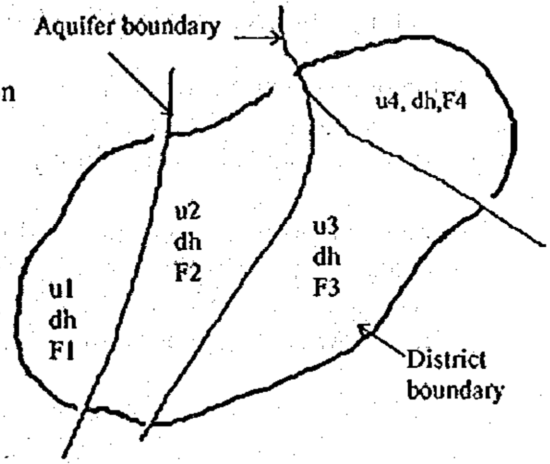


Figure 6-4

Increase in groundwater storage
$= u_1 \times dh \times F_1 + u_2 \times dh \times F_2 + u_3 \times dh \times F_3 + u_4 \times dh \times F_4$

Maximum groundwater fluctuation by district (dh)
$dh = (dh_a \times A_a + dh_b \times A_b + dh_c \times A_c) / (A_a + A_b + A_c)$

Where
dh_i : Maximum Groundwater Fluctuation of area i (m)
A_i : Area of i (m^2)
i : Number of area divided by contour
(see Figure 6-5)

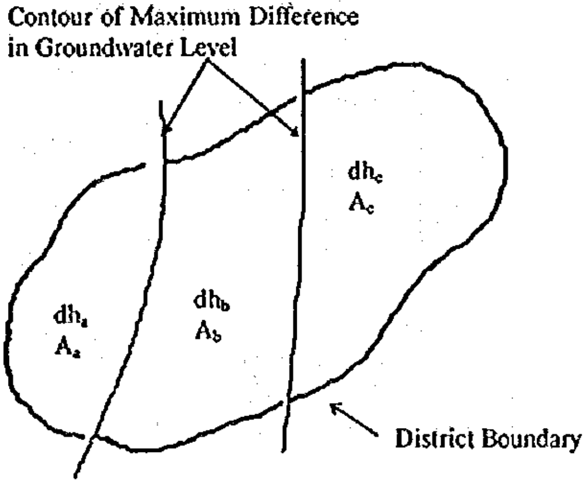


Figure 6-5

u, dh and F were obtained as follows:

u : Obtained from results of well inventory survey shown in Table 4-7.
dh : Obtained from results of nation-wide groundwater level observation. A contour map of maximum difference in groundwater level is shown in Figure 6-6, in Table 6-1 by province, in Table 6-2 by district.
F : Obtained from results of satellite imagery interpretation. Boundary and area (m^2) of each aquifer have been analyzed based on the result of satellite imagery interpretation.

Analyzed increase in groundwater storage during rainy season is shown in Table 6-3 by province and in Table 6-4 by district.

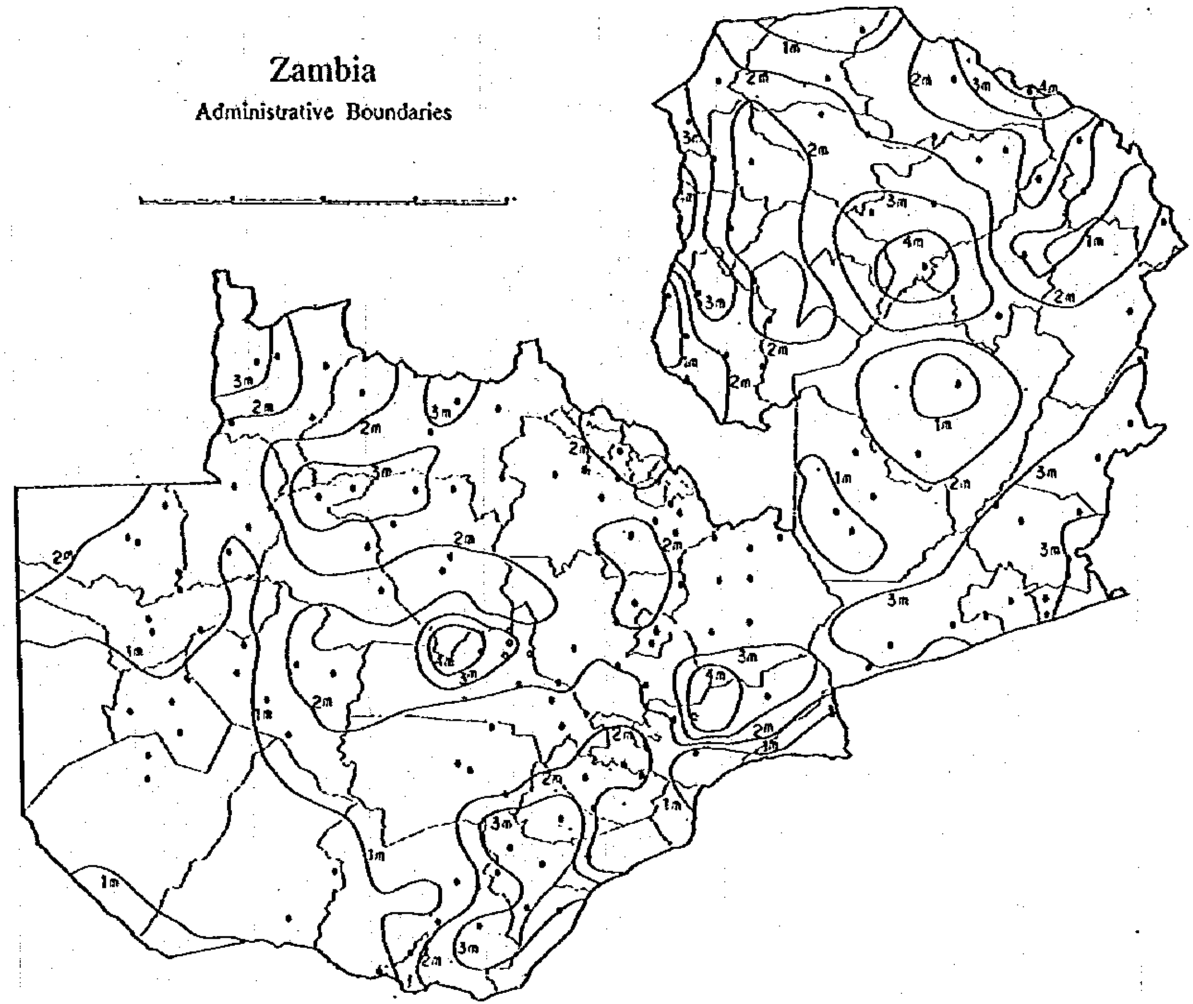


Figure 6-6 Contour Map of Maximum Groundwater Fluctuation

Table 6-1 Maximum Groundwater Fluctuation by Province

Province	Distribution Area of Maximum Fluctuation (km2)					Total Area (km2)	Average dh (m)
	0-1(m)	1-2(m)	2-3(m)	3-4(m)	4-5(m)		
Lusaka	4,994	5,532	4,568	4,565	2,425	22,084	2.2
Copperbelt		4,835	23,037	3,328		31,200	2.5
Central		8,912	70,536	11,258	3,777	94,483	2.6
North wester	1,204	51,608	52,072	19,261	1,135	125,280	2.2
Western	87,897	31,632	7,815			127,344	0.9
Southern	11,340	40,150	16,732	14,393		82,615	1.9
Luapula	2,290	16,685	18,432	6,493	1,392	45,292	2.2
Northern	12,554	52,089	54,598	18,104	5,802	143,146	2.2
Eastern	1,298	5,799	25,993	36,057		69,146	2.9
Total	125,525	218,533	270,553	112,469	13,511	740,590	2.1

Table 6-2 Maximum Groundwater Fluctuation by District

Province	District	Distribution Area of Maximum Fluctuation (km2					Total Area (km2)	Average dh (m)
		0-1(m)	1-2(m)	2-3(m)	3-4(m)	4-5(m)		
Lusaka	Lusaka-Urban		353	88			441	1.7
	Lusaka-Rural	2,663	3,804	4,327	4,565	2,425	17,783	2.5
	Luangwa	2,331	1,376	153			3,859	0.9
Copperbelt	Ndola-Urban		240	754			993	2.3
	Ndola-Rural			20,096	3,328		23,423	2.6
	Chililabombwe		704	302			1,005	1.8
	Chingola		1,081	665			1,747	1.9
	Mufulira		1,273				1,273	1.5
	Kalulushi		673	462			1,135	1.9
	Kitwe		751				751	1.5
	Luanshya		114	759			873	2.4
Central	Kabwe-Urban			1,355	175		1,530	2.6
	Kabwe-Rural		1,868	19,024	3,933	590	25,415	2.6
	Mumbwa		473	14,598	4,019	2,482	21,572	2.9
	Mkushi			18,558	3,132	705	22,395	2.7
	Serenje		6,571	17,001			23,572	2.2
Northwestern	Solwezi		4,069	20,507	5,546		30,122	2.5
	Mwinilunga		9,123	5,381	6,390		20,894	2.4
	Zambezi		9,235	9,511			18,746	2.0
	Kabompo	1,204	12,299	1,032			14,535	1.5
	Mfumbwe		8,893	6,308	3,878		19,078	2.2
	Kasempa		7,988	9,334	3,448	1,135	21,905	2.4
Western	Mongu	9,567	504				10,071	0.6
	Lukulu	2,583	11,813	1,244			15,639	1.4
	Kalabo	15,164	1,983	83			17,230	0.6
	Kaoma	5,442	11,093	6,488			23,024	1.5
	Senanga	28,786	3,071				31,857	0.6
	Sesheke	26,355	3,168				29,522	0.6
Southern	Livingstone	200	761	80			1,041	1.4
	Namwala		19,268	1,839	40		21,147	1.6
	Mazabuka		3,312	3,312			6,625	2.0
	Monze		586	1,591	2,679		4,856	2.9
	Choma			1,208	5,799		7,008	3.3
	Kalomo	10,819	11,067	6,483	3,056		31,425	1.6
	Siavonga	321	2,207				2,529	1.4
	Gwembe		2,947	761	570		4,279	1.9
	Sinazongwe			1,458	2,248		3,706	3.1
Luapula	Mansa	2,206	4,090	7,077	2,619		15,991	2.1
	Nchelenge	85	930	2,791	1,381		5,188	2.6
	Kawambwa		5,432	2,189	1,054	365	9,040	2.1
	Mwense		2,219	1,972	1,438	1,027	6,656	2.7
	Samfya		4,014	4,403			8,417	2.0
Northern	Kasama		5,422	6,901	5,135	2,999	20,457	2.8
	Kaputa	3,469	4,047	2,891			10,407	1.4
	Mbala	602	8,014	5,606	2,408	527	17,156	2.2
	Mporokoso		2,029	9,228	676		11,933	2.4
	Luwingu		3,404	2,648	2,017	756	8,825	2.5
	Chilubi		807	2,346	1,393	110	4,656	2.7
	Isoka	3,535	4,589	3,671	1,836	136	13,767	1.8
	Chinsali	1,344	5,725	5,074	2,515	781	15,440	2.2
	Mpika	3,603	18,053	16,232	2,124	493	40,505	2.0
Eastern	Chipata			2,776	9,413		12,189	3.3
	Chama	1,298	5,799	10,706			17,803	2.0
	Lundazi			4,589	9,098		13,687	3.2
	Chadiza			850	1,652		2,502	3.2
	Katete				3,842		3,842	3.5
	Petauke			7,072	12,052		19,123	3.1
Total		125,525	218,533	270,553	112,469	13,511	740,590	2.1

Table 6-3 Increase of Groundwater Storage (u x dh x F)

Province	Metamorphic Rocks	Granite (km^2)	Basement	Muva		Katanga	
	Metamorphic Rocks(km2)		Gneiss (km^2)	Shale (km^2)	Quartzite (km^2)	Mine series(km2)	Lower Roan(km2)
	0.02	0.03	0.02	0.02	0.02	0.02	0.02
Lusaka	2,189	372	7,615	2,330		3,840	
Copperbelt	578	105	4,725		2,942	1,266	3,654
Central	5,451	5,642	27,676	3,430	8,020	5,154	870
North wester	380	848	5,144			5,570	1,600
Western		109	22				
Southern	3,964	12,570	20,270			6,120	
Luapula	4,945	11,649		3,076	8,056		
Northern	20,669	32,385	13,074	4,329	26,734		
Eastern	3,930	9,171	33,894	653	1,537		
Total	42,107	72,851	112,420	13,819	47,289	21,948	6,124

Province	Katanga				Karroo		
	Upper Roan(km2)	Undifferential Kundelungu	Kundelungu Limestone	Kundelungu Shale(km2)	Shale (km^2)	Sandstone (km^2)	Basalt (km^2)
	0.05	0.02	0.05	0.02	0.02	0.04	0.02
Lusaka			1,609		494	2,952	56
Copperbelt	1,580	8,661	4,979				
Central	121	15,050	2,790	209	665	8,808	
North westen	151	50,139	3,785	387		3,123	39
Western		655				148	19
Southern		1,851	512	·	1,784	6,770	3,168
Luapula		3,917	99	4,779			
Northern		14,269			1,738	10,889	
Eastern			594		4,251	13,692	
Total	1,852	94,599	14,367	5,375	8,933	46,383	3,283

Province	Kalahari	Allvium	Total Area (F)	u x F	dh	dh x u x F
	Sand (km2)	Sand & Gravel(km2				
	0.05	0.05	(km^2)	(km^2)	(m/year)	($10^9 m^3$/year)
Lusaka		627	22,084	571	2.2	1.25
Copperbelt	388	2,264	31,200	901	2.5	2.21
Central	1,786	8,811	94,483	2,527	2.6	6.63
North western	47,775	6,342	125,280	4,318	2.2	9.37
Western	107,513	18,877	127,344	6,343	0.9	5.51
Southern	17,236	8,369	82,615	2,697	1.9	4.95
Luapula		8,771	45,292	1,288	2.2	2.85
Northern		19,059	143,146	3,976	2.2	8.71
Eastern	1	1,422	69,146	1,809	2.9	5.18
Total	174,699	74,542	740,590	24,432	2.1	46.66

Note; ▨ Specific Yield

Table 6-4 Increase of Groundwater Storage by District (u x dh x F)

Province	District	Metamorphic Rocks		Basement	Muva		Katanga						Karroo			Kalahari	Allvium				
		Metamorphic Rocks(km2)	Granite (km2)	Gneiss (km2)	Shale (km2)	Quartzite (km2)	Mine series(km2)	Lower Roan(km2)	Upper Roan(km2)	Undifferentia Kundelungu	Kundelung Limestone	Kundelungu Shale(km2)	Shale (km2)	Sandstone (km2)	Basalt (km2)	Sand (km2)	Sand & Gravel(km2)	F (Area)	u x F	dh	dh x u x F
		0.020	0.030	0.020	0.020	0.020	0.020	0.020	0.050	0.020	0.050	0.020	0.020	0.040	0.020	0.050	0.050	(km^2)	(km^2)	(m/year)	(10^9m3/year)
Lusaka	Lusaka-Urban						240				202							441.1	14.9	1.70	0.03
	Lusaka-Rural	1,971	287	5,854	2,109		3,600				1,407		494	1,636	56		368	17,783.4	444.5	2.52	1.12
	Luangwa	218	85	1,761	221									1,316			259	3,859.3	112.1	0.94	0.10
Copperbelt	Ndola-Urban			199		101		113	70	58	452							993.3	35.5	2.26	0.08
	Ndola-Rural	457	7	2,719		2,653	1,015	2,967	1,117	6,962	2,994					388	2,144	23,423.5	667.8	2.64	1.76
	Chililabombwe			312				99	50	339	146						60	1,005.3	27.8	1.80	0.05
	Chingola		98	373		35	148	92	46	748	145						61	1,746.7	43.5	1.88	0.08
	Mufulira	67		480				58	70	402	197							1,273.1	33.5	1.50	0.05
	Kalulushi	52		205		64	93	248	207	148	117							1,135.1	32.4	1.91	0.06
	Kitwe			345		37	9	24	20	16	301							750.7	24.6	1.50	0.04
	Luanshya	1		91		52		53		47	628							872.7	36.3	2.37	0.09
Central	Kabwe-Urban	65		595	133		547				190							1,529.9	36.3	2.61	0.09
	Kabwe-Rural	576		5,338	1,698	354	2,169	870	124	6,035	1,615	173	181			128	6,154	25,414.7	748.9	2.63	1.97
	Mumbwa	419	5,612	116			2,351			5,529	984	37		3,495		1,658	1,340	21,571.6	677.2	2.89	1.96
	Mkushi	2,579		11,944	1,389	3,149	87			286			481	2,351			128	22,394.8	498.8	2.70	1.35
	Serenje	1,812		9,684	210	4,517				3,200				2,962			1,188	23,572.1	566.3	2.22	1.26
Northwestern	Solwezi	79		2,151			3,073	1,060	151	18,323	3,091					1,079	1,117	30,121.9	765.5	2.55	1.95
	Mwinilunga	301		2,858			2,060	513		5,418	51					8,588	1,106	20,894.5	710.2	2.37	1.68
	Zambezi															16,025	2,722	18,746.2	937.3	2.01	1.88
	Kabompo			135			437	26		1,484				188	39	11,374	854	14,535.0	661.2	1.49	0.98
	Mfumbwe		523							7,772		289		600		9,708	185	19,078.2	695.6	2.24	1.56
	Kasempa		324							17,142	643	98		2,335		1,004	359	21,904.5	548.2	2.40	1.31
Western	Mongu															6,770	3,301	10,070.9	503.5	0.55	0.28
	Lukulu									154				148	19	12,134	3,184	15,639.5	775.3	1.41	1.10
	Kalabo															14,127	3,104	17,230.4	861.5	0.62	0.54
	Kaoma		109							501						21,290	1,123	23,023.6	1,134.0	1.55	1.75
	Senanga															26,739	5,118	31,857.1	1,592.9	0.60	0.95
	Sesheke			22												26,454	3,047	29,522.3	1,475.5	0.61	0.90
Southern	Livingstone			147											621	205	68	1,041.3	29.0	1.38	0.04
	Namwala	365	4,282				1,025			1,851				1,233		7,775	4,615	21,147.3	862.2	1.59	1.37
	Mazabuka	2,340	6	1,120			1,317				325			144	29		1,344	6,624.6	185.5	2.00	0.37
	Monze	367		1,590			2,264				122			65			450	4,856.3	115.6	2.90	0.34
	Choma	282	1,915	4,146			372						293					7,007.5	159.3	3.30	0.53
	Kalomo	567	6,367	10,194			646				17		77	237	2,172	9,255	1,893	31,424.7	1,031.8	1.56	1.61
	Siavonga	22		584			120				28		431	1,302	41			2,528.5	77.5	1.37	0.11
	Gwembe	22		1,299			376				20		738	1,824				4,278.6	122.6	1.94	0.24
	Sinazongwe			1,190									245	1,965	305			3,705.6	113.4	3.11	0.35
Luapula	Mansa	1,771	7,957		241	447				2,290	99	2,808					379	15,991.3	413.7	2.13	0.88
	Nchelenge	1,768	1,338		9	130				346		930					666	5,187.5	137.1	2.55	0.35
	Kawambwa	361	97		2,072	4,798						442					1,270	9,039.7	219.9	2.10	0.46
	Mwense	1,045	1,034		754	2,682						599					542	6,655.8	159.7	2.69	0.43
	Samfya		1,222							1,281							5,914	8,417.4	358.0	2.02	0.72
Northern	Kasama		10,530	1,010		3,349				1,906							3,663	20,457.5	624.3	2.78	1.74
	Kaputa	7,910	1		1,511	438											548	10,406.8	224.6	1.44	0.32
	Mbala	8,611	4,122	612	922	2,539											350	17,155.9	394.8	2.16	0.85
	Mporokoso	29	2,312	258	1,897	6,728											709	11,932.9	283.1	2.39	0.68
	Luwingu	341	6,519			376				402							1,187	8,825.1	277.3	2.51	0.70
	Chilubi		1,574							309							2,773	4,656.3	192.0	2.67	0.51
	Isoka	355	4,894	3,882		1,239							1,312	152			1,932	13,767.5	385.3	1.81	0.70
	Chinsali	2,088	1,443			9,511				550			18				1,830	15,439.6	378.1	2.22	0.84
	Mpika	1,335	990	7,311		2,555				11,102			408	10,737			6,067	40,504.7	1,216.7	1.95	2.38
Eastern	Chipata	412	2,524	7,255	5						26			1,918			50	12,189.4	309.7	3.27	1.01
	Chama	218	520	4,517		1,537							3,675	6,423			914	17,803.1	517.1	2.03	1.05
	Lundazi	307	287	10,607							47			2,363			77	13,687.2	327.6	3.16	1.04
	Chadiza		2,270	232														2,501.6	72.7	3.16	0.23
	Katete	173	991	2,677														3,841.6	86.7	3.50	0.30
	Petauke	2,820	2,579	8,607	648						520		576	2,988		1	382	19,123.4	495.2	3.13	1.55
Total		42,106.8	72,850.7	112,419.9	13,818.6	47,288.8	21,918.4	6,123.6	1,851.9	94,599.5	14,366.8	5,375.2	8,932.8	46,383.2	3,282.6	174,699.5	74,542.0	740,590.1	24,431.8	2.1	46.66

Note; ☐ Specific Yield

6.1.4Method to Obtain Base-flow

Base-flow, namely groundwater run-off into rivers, is obtained by separating the total runoff into direct run-off and base-flow. The method employed for the separation is low-frequency pass filter method.

(1) Low-Frequency Pass Filter Method

Method to separate base-flow from total run-off is as follows:

Figure 6-7 shows general relationship between total run-off and time.

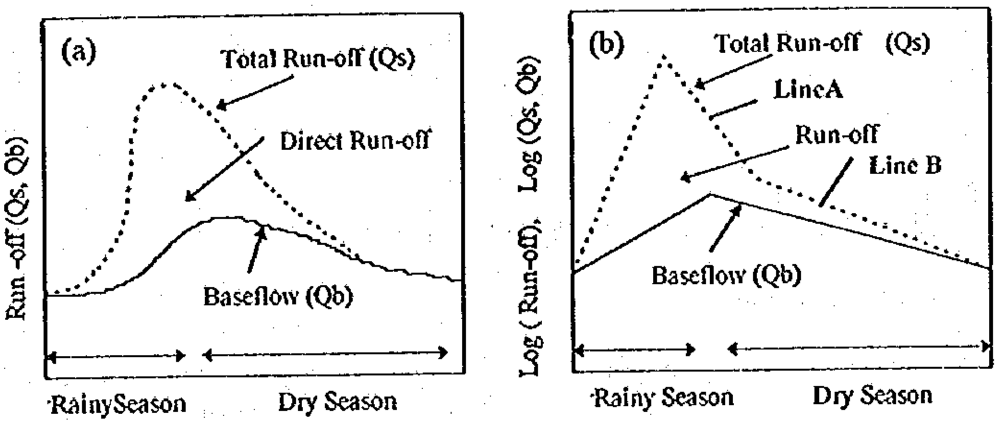


Figure 6-7 Concept of Runoff Curve

Log (Qs) curve in reducing period is approximated by 2 lines, i.e. line A and B, as shown in Figure 6-7 (b). Line A is mainly composed of direct run-off and line B is mainly composed of base-flow. A special kind of filter transforms Qs curve into base-flow curve Qb. Such a filter must have the following characteristics:

- Filtered curve (Qb) is approximated by $Qb = Qo \exp(-t / Tc)$ in reducing period, because natural base-flow curve has the same characteristics.
- Filter has the characteristic of decreasing high frequency waves of Qs curve because base-flow curve consists of lower frequency waves.

A concept of filtering operation is shown in Figure 6-8.

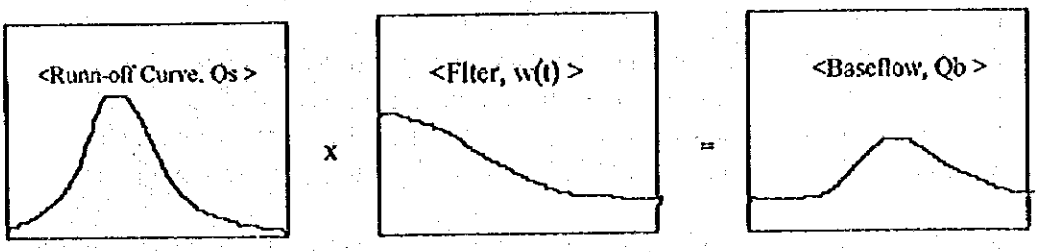


Figure 6-8 Concept of Filtering

Fliltering is defined to total runoff(Qs) and baseflow(Qb) as follows:

$$Qb = \alpha \int_0^{\infty} w(\tau) Qs(t-\tau) d\tau$$

The filter w(t) adopted for separating baseflow(Qb) from total runoff(Qs) is as follows:

$$w(t) = c_o / \{ (2\sqrt{\,}(c_1^2/4 - c_o) \exp[-(c_o/c_1)\, t] \}$$

Where

α = constant
$c_o = (2.5/Tc)^2$
$c_1 = 2.52^2\, Tc$
t = time (day)
Tc = constant decided from actual observed Qs curve.

(2) Method of Separation

Baseflow has been derived from long-term river flow data. Forty-one representative observation points have been selected from the six river basins as shown in Table 6-5. Based on the river flow data, baseflow has been separated from direct runoff using low-frequency pass filter method as shown in Figure 6-9. The data used for the analysis are 5-days average run off (m^3/s) obtained from daily-runoff (m^3/s) data over all the observation periods. After separation , baseflow is divided into 2 parts, one is the groundwater-table rising period and the other is the falling period. The results are shown in Table 6-5 by each observation point and Table 6-6 by river basin. Average baseflow volume in the period when the groundwater table rises and falls have been calculated for each district using the formula below:

$$Q1 = R \times f \times Rb \times S_1$$
$$Q2 = R \times f \times Rb \times S_2$$

where,
Q1 : baseflow (m^3) in groundwater rising period by district
Q2 : baseflow (m^3) in groundwater falling period by district
R : average annual rainfall (m^3/year) by district
f : coefficient of runoff in small drainage area = 0.28 for all districts
Rb : baseflow rate (= annual base flow/ annual runoff) by district
S_1 : (base flow in groundwater rising period) / (annual baseflow) by district
S_2 : (base flow in groundwater falling period) / (anual baseflow) by district

Coefficient of runoff reduces in inverse proportion to the size of drainage area as shown in Figure 6-10. The coefficient of small drainage area should be used for assessing groundwater potential and the value 0.28 is suggested from the hydrological analysis. The ratio of annual baseflow/ annual runoff is shown in Figure 6-11. This implies that values of the rate are concentrated into around 0.27 (27%) and has little relationship with size of drainage areas. The result of the baseflow analysis is shown in Table 6-7 by province and Table 6-8 by district.

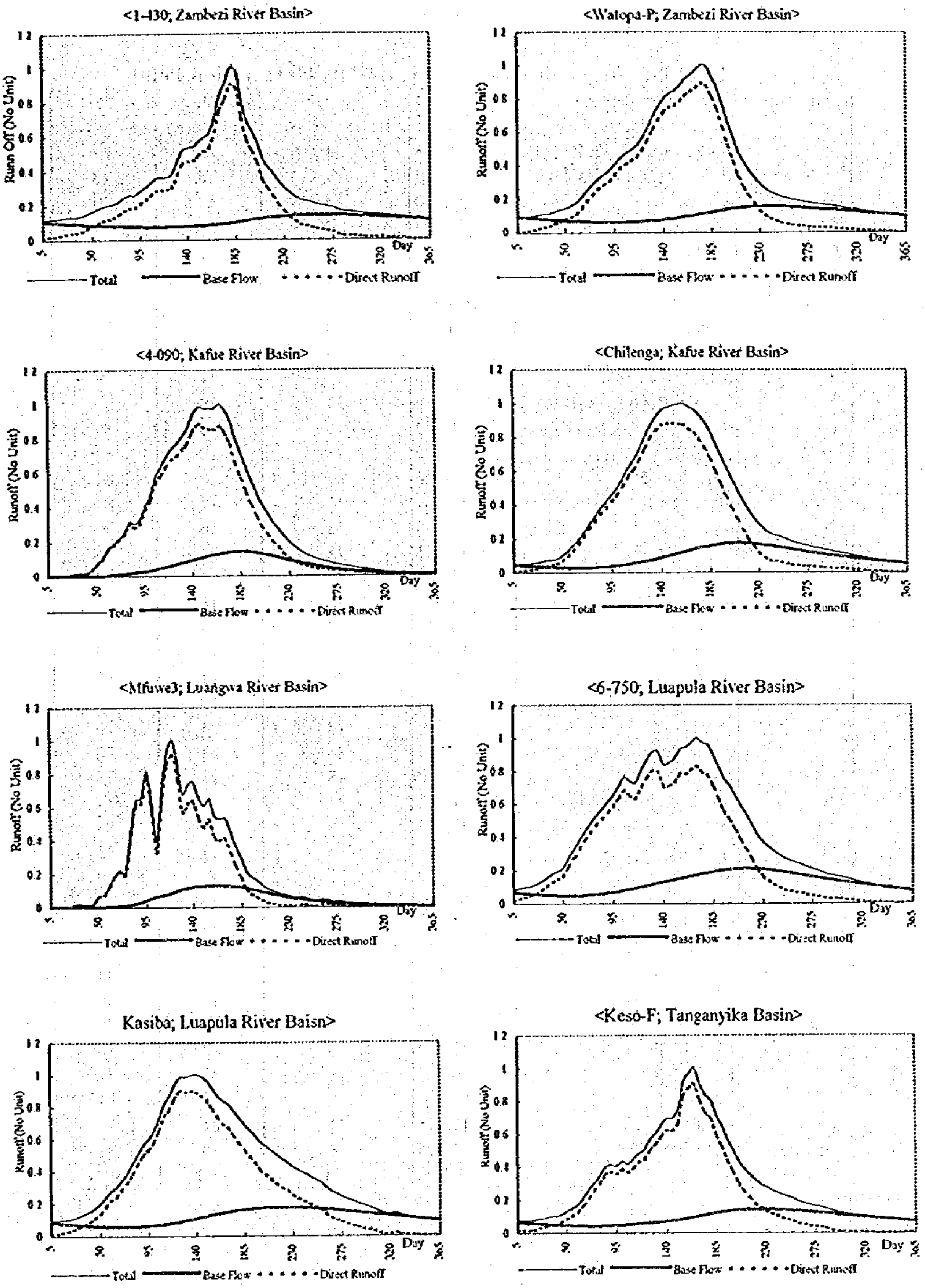


Figure 6-9 Example of Baseflow Separation

Table 6-5 Result of Baseflow Analysis by Observation Point

Basin	Observation Point (Station Name or No.)	Drainage Area(km2)	Annual Baseflow/ Annuall Runoff (%)	Seasonal / Annual Baseflow	
				Dec - Mar (%)	Apr - Oct (%)
Zambezi	Mwinilunga(1-430)	4,538	34	26	74
	Kalomo Dam site(3-130)	1,899	6	28	72
	Kalabo	34,620	18	10	90
	Senanga	278,298	29	21	79
	VFBT2493		27	18	82
	Kabompo	42,740	32	20	80
	Lukulu	206,531	33	25	75
	Watopa-P	66,449	29	22	78
	Zambezi	43,030	29	10	90
Kafue	Kafironda(4-090)	7,148	17	11	89
	Masaiti Road Bridge(4-245	1,375	33	20	80
	Kasempa P.House(4-620)	1,062	18	14	86
	(4-940)		13	20	80
	Machiya - F	22,920	24	16	84
	Mwambashi	869	26	17	83
	Raglam -F	4,999	22	10	90
	Chifumpa -P	21,445	28	22	78
	Chilenga	34,162	25	14	86
	Kafue-HB	95,053	26	18	82
	Lubungu	54,442	25	15	85
	Mpatamat	11,655	26	15	85
	Smith's-B	8,599	26	14	86
Luangwa	Ngwerere(5-024)	1,002	22	19	81
	(5-029)		14	24	76
	Masase(5-670)	995	34	22	78
	(5-755)		48	28	72
	Mulungushi(5-815)	1,448	24	17	83
	Luangwa -RB	143,781	16	17	83
	Ndevu-C	97,000	14	17	83
	M'fuwe	65,000	32	20	80
	M'fuwe	65,000	20	15	85
Chambeshi & Luapula	Chishimba Falls(6-330-2)	2,548	40	23	77
	Chishimba Falls(6-330-3)	2,548	33	22	78
	Mwenda Kashiba RB(6-75(	4,170	29	17	83
	Chipil(6-765)	1,220	30	15	85
	Chambeshi -OP	34,188	22	21	79
	Chembe-F	122,507	30	12	88
	Kasama-RB	6,527	40	27	73
	Kashiba		28	19	81
	Kunda-Falls	12,018	35	21	79
Tanganyika	Keso-Falls	6,475	28	19	81
Average		41,896	27.0	19.2	80.8

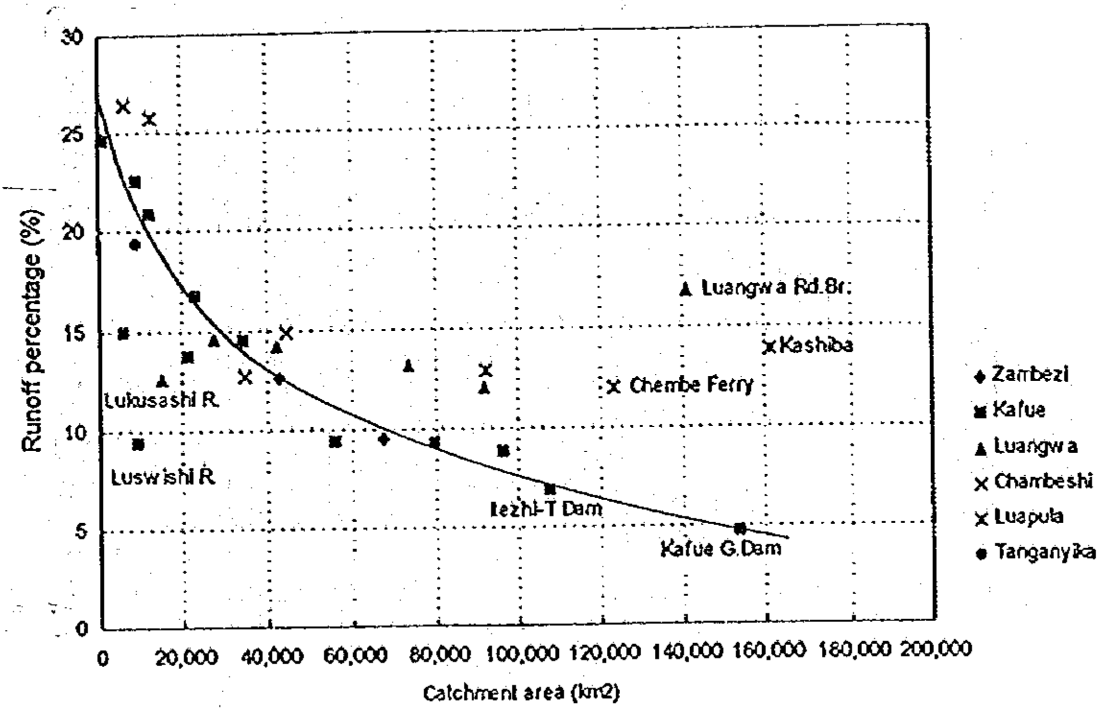


Figure 6-10 Runoff Percentage of River Basin

Table 6-6 Result of Baseflow Analysis by Basin

Basin	Number of observation points	Annual baseflow / Annual runoff	Seasonal baseflow / Annual baseflow	
			Dec. -Mar.	Apr. - Oct.
Zambezi	9	26.3%	20.0%	80.0%
Kafue	13	23.8%	15.9%	84.1%
Luangwa	9	24.9%	19.9%	80.1%
Chambeshi &	9	31.9%	19.7%	80.3%
Tanganyika	1	28.0%	19.0%	81.0%
Average	41	27.0%	19.2%	80.8%

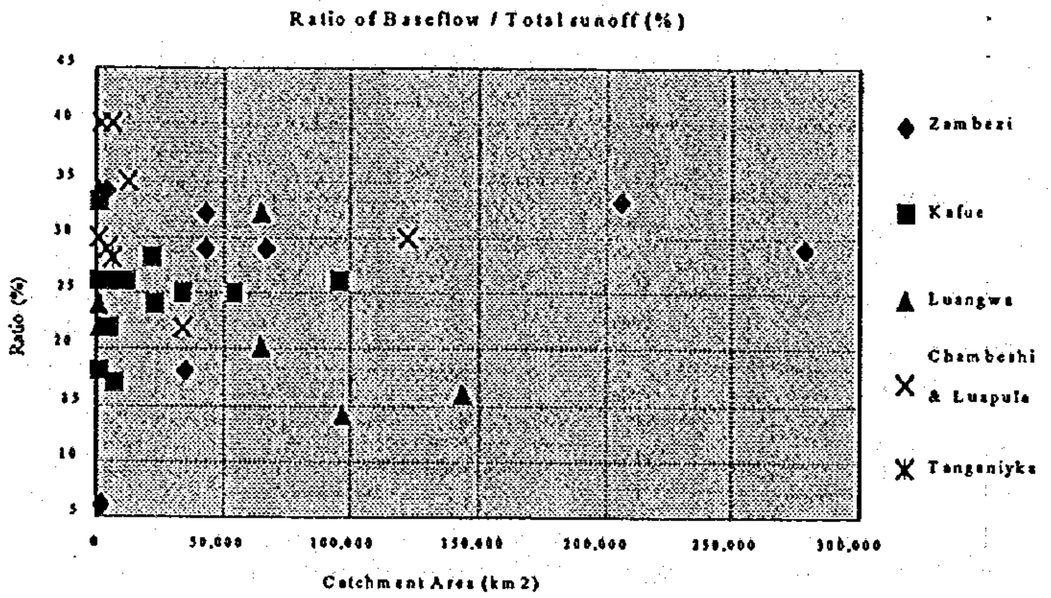


Figure 6-11 Ratio of Annual Baseflow / Annual Runoff

Table 6-7 Baseflow by Province

Province	Area (km^2)	Annual Rainfall (mm/year)	Baseflow in Rainy Season (10^9m^3/year)	Baseflow in Dry Season (10^9m^3/year)	Annual Baseflow (10^9m^3/year)
Lusaka	22,084	857	0.3	1.1	1.3
Copperbelt	31,200	1,231	0.4	2.2	2.6
Central	94,483	947	1.1	5.0	6.1
Northwestern	125,280	1,173	2.1	8.6	10.6
Western	127,344	808	1.5	6.1	7.6
Southern	82,615	737	0.8	3.5	4.3
Luapula	45,292	1,259	1.0	4.1	5.1
Northern	143,146	1,138	2.7	11.3	14.0
Eastern	69,146	961	0.9	3.7	4.6
Total	740,590		10.8	45.5	56.3

6.1.5 Results of Groundwater Potential Analysis

Analyzed groundwater recharge is summarized as shown in Figure 6-12 and Table 6-9. Though increase of groundwater storage and base-flow were calculated independently, both results are consistent with one another.

Table 6-8 Baseflow by District

District	Area (km2)	Annual Rain (10^6m3/year)	Name of Drainage Basin	Runoff coefficient in small Drainage (%)	Annual Baseflow / Annual Runoff (%)	Annual Bseflow (10^6m3/year)	Baseflow in rainy season / Annual baseflow (%)	Baseflow in Rainy Season (10^6m3/year)	Baseflow in Dry Season (10^6m3/year)
Lusaka-Urba	441	0.38	Kafue	28	23.8	0.025	15.9	0.004	0.021
Lusaka-Rural	17,783	15.24	Luangwa	28	24.9	1.063	19.9	0.211	0.851
Luangwa	3,859	3.31	Luangwa	28	24.9	0.231	19.9	0.046	0.185
Ndola-Urban	993	1.22	Kafue	28	23.8	0.081	15.9	0.013	0.069
Ndola-Rural	23,423	28.83	Kafue	28	23.8	1.922	15.9	0.306	1.616
Chililabomb	1,005	1.24	Kafue	28	23.8	0.082	15.9	0.013	0.069
Chingola	1,747	2.15	Kafue	28	23.8	0.143	15.9	0.023	0.121
Mufulira	1,273	1.57	Kafue	28	23.8	0.104	15.9	0.017	0.088
Kalulushi	1,135	1.40	Kafue	28	23.8	0.093	15.9	0.015	0.078
Kitwe	751	0.92	Kafue	28	23.8	0.062	15.9	0.010	0.052
Luanshya	873	1.07	Kafue	28	23.8	0.072	15.9	0.011	0.060
Kabwe-Urba	1,530	1.45	Luangwa	28	24.9	0.101	19.9	0.020	0.081
Kabwe-Rural	25,415	24.07	Kafue	28	23.8	1.604	15.9	0.255	1.349
Mumbwa	21,572	20.43	Kafue	28	23.8	1.361	15.9	0.216	1.145
Mkushi	22,395	21.21	Luangwa	28	24.9	1.479	19.9	0.294	1.184
Serenje	23,572	22.32	Luangwa	28	24.9	1.556	19.9	0.310	1.247
Solwezi	30,122	35.33	Zambezi	28	26.3	2.602	20.0	0.520	2.082
Mwinilunga	20,894	24.51	Zambezi	28	26.3	1.805	20.0	0.361	1.444
Zambezi	18,746	21.99	Zambezi	28	26.3	1.619	20.0	0.324	1.295
Kabompo	14,535	17.05	Zambezi	28	26.3	1.256	20.0	0.251	1.004
Mfumbwe	19,078	22.38	Zambezi	28	26.3	1.648	20.0	0.330	1.318
Kasempa	21,905	25.69	Kafue	28	23.8	1.712	15.9	0.272	1.440
Mongu	10,071	8.14	Zambezi	28	26.3	0.599	20.0	0.120	0.479
Lukulu	15,639	12.64	Zambezi	28	26.3	0.931	20.0	0.186	0.744
Kalabo	17,230	13.92	Zambezi	28	26.3	1.025	20.0	0.205	0.820
Kaoma	23,024	18.60	Zambezi	28	26.3	1.370	20.0	0.274	1.096
Senanga	31,857	25.74	Zambezi	28	26.3	1.896	20.0	0.379	1.516
Sesheke	29,522	23.85	Zambezi	28	26.3	1.757	20.0	0.351	1.405
Livingstone	1,041	0.77	Zambezi	28	26.3	0.057	20.0	0.011	0.045
Namwala	21,147	15.59	Kafue	28	23.8	1.039	15.9	0.165	0.873
Mazabuka	6,625	4.88	Kafue	28	23.8	0.325	15.9	0.052	0.274
Monze	4,856	3.58	Kafue	28	23.8	0.239	15.9	0.038	0.201
Choma	7,008	5.16	Zambezi	28	26.3	0.380	20.0	0.076	0.304
Kalomo	31,425	23.16	Zambezi	28	26.3	1.706	20.0	0.341	1.364
Siavonga	2,529	1.86	Zambezi	28	26.3	0.137	20.0	0.027	0.110
Gwembe	4,279	3.15	Zambezi	28	26.3	0.232	20.0	0.046	0.186
Sinazongwe	3,706	2.73	Zambezi	28	26.3	0.201	20.0	0.040	0.161
Mansa	15,991	20.13	Luapula	28	31.9	1.798	19.7	0.354	1.444
Nchelenge	5,188	6.53	Luapula	28	31.9	0.583	19.7	0.115	0.468
Kawambwa	9,040	11.38	Luapula	28	31.9	1.017	19.7	0.200	0.816
Mwense	6,656	8.38	Luapula	28	31.9	0.748	19.7	0.147	0.601
Samfya	8,417	10.60	Luapula	28	31.9	0.947	19.7	0.186	0.760
Kasama	20,457	23.28	Chambesi	28	31.9	2.079	19.7	0.410	1.670
Kaputa	10,407	11.84	Luapula	28	31.9	1.058	19.7	0.208	0.849
Mbala	17,156	19.52	Tanganyika	28	28.0	1.531	18.6	0.285	1.246
Mporokoso	11,933	13.58	Luapula	28	31.9	1.213	19.7	0.239	0.974
Luwingu	8,825	10.04	Luapula	28	31.9	0.897	19.7	0.177	0.720
Chilubi	4,656	5.30	Luapula	28	31.9	0.473	19.7	0.093	0.380
Isoka	13,767	15.67	Luangwa	28	24.9	1.092	19.9	0.217	0.875
Chinsali	15,440	17.57	Chambesi	28	31.9	1.569	19.7	0.309	1.260
Mpika	40,505	46.09	Luapula	28	31.9	4.117	19.7	0.811	3.306
Chipata	12,189	11.71	Luangwa	28	24.9	0.817	19.9	0.163	0.654
Chama	17,803	17.11	Luangwa	28	24.9	1.193	19.9	0.237	0.955
Lundazi	13,687	13.15	Luangwa	28	24.9	0.917	19.9	0.182	0.735
Chadiza	2,502	2.40	Luangwa	28	24.9	0.168	19.9	0.033	0.134
Katete	3,842	3.69	Luangwa	28	24.9	0.257	19.9	0.051	0.206
Petauke	19,123	18.38	Luangwa	28	24.9	1.281	19.9	0.255	1.026
	740,590	743.92		28	26.5	56.269	19.2	10.809	45.460

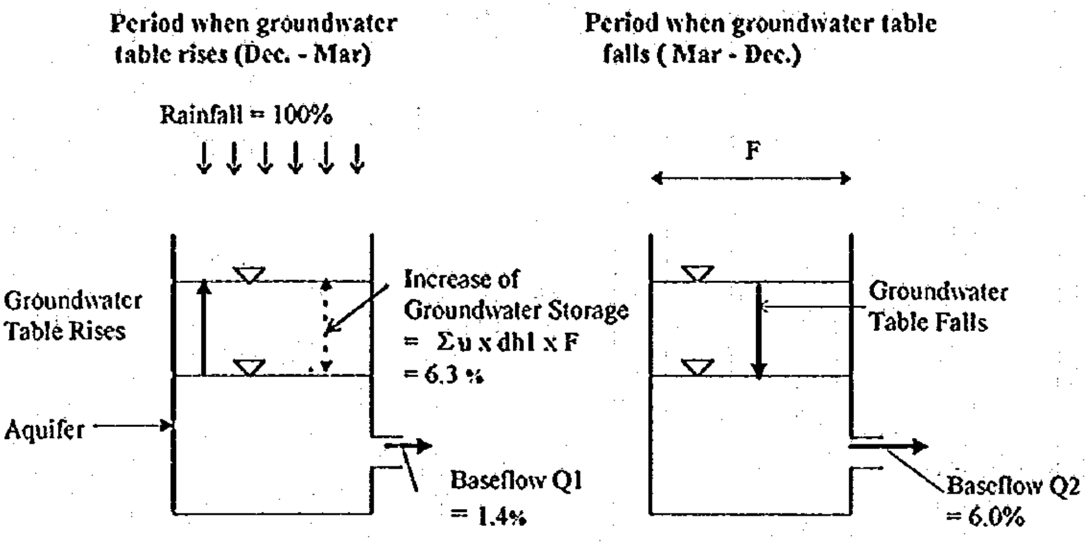


Figure 6-12 Analyzed Seasnal Groundwater Recharge

Table 6-9 Analyzed Seasonal Groundwater Recharge

Period	Period when groundwater table rises (December to February)	Period when groundwater table falls (March to November)
Change in ground-water storage	6.3(%) of annual rainfall	- 6.3(%) of annual rainfall
Baseflow	1.4(%) of annual rainfall	6.0(%) of annual rainfall
Recharge into groundwater table	6.3(%)+1.4(%) = 7.7(%) = 8 (%)	-6.3(%)+6.0(%) = -0.3(%)= 0(%)

Note; Recharge into groundwater table = Change in ground-water storage + Baseflow

6.1.6 Groundwater Development Potential

Groundwater development potential must be less than renewable groundwater storage. If more groundwater is abstracted than renewable groundwater storage, environmental effect such as regional groundwater level decline may occur. Therefore, the groundwater development potential must be less than renewable groundwater storage. The groundwater development potential is shown in Table 6-10 by province and in Table 6-11 by district, and Figure 6-13 and 6-14 by province. These figures are expressed in 3 different ways in Table 6-10 and 6-11, that is;

1) mm/year
2) m^3/year
3) % of annual rainfall

Table 6-10 Annual Groundwater Potential by Province

Province	Area	Annual Rainfall		Increas in groundwater storage	Baseflow in Rainy Season	Groundwater Potential (Annual Recharge)		
		(mm/year)	(10^9m^3/year)	(10^9m^3/year)	(10^9m^3/year)	(10^9m^3/year)	% of Rain	(mm/year)
	(km^2)	R		P1	P2	(P1 + P2)/R		
Lusaka	22,084	857	18.9	1.2	0.3	1.5	8%	68
Copperbelt	31,200	1,231	38.4	2.2	0.4	2.6	7%	84
Central	94,483	947	89.5	6.6	1.1	7.7	9%	82
N- western	125,280	1,173	147.0	9.4	2.1	11.4	8%	91
Western	127,344	808	102.9	5.5	1.5	7.0	7%	55
Southern	82,615	737	60.9	4.9	0.8	5.7	9%	70
Luapula	45,292	1,259	57.0	2.8	1.0	3.9	7%	85
Northern	143,146	1,138	162.9	8.7	2.7	11.5	7%	80
Eastern	69,146	961	66.4	5.2	0.9	6.1	9%	88
Total	740,590		743.9	46.7	10.8	57.5	8%	78

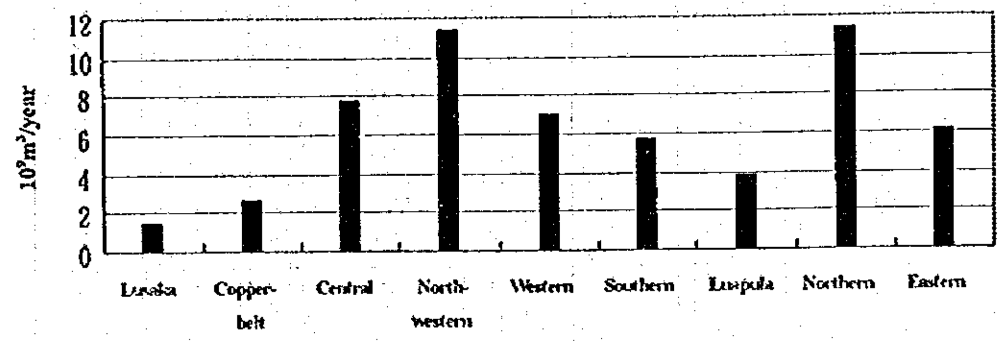


Figure 6-13 Annual Groundwater potential Represented by m^3/year

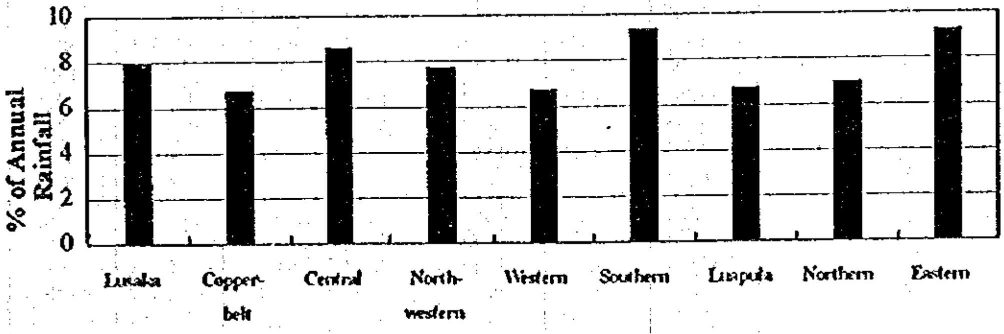


Figure 6-14 Annual Groundwater Potential Represented by % of Annual Rainfall

As shown in Figure 6-13, groundwater potential is higher in Northern province and Northwestern province, but relatively lower in Southern province and Western province.

Table 6-11 Groundwater Potential by District

Province	District	Area	Average Annual Rainfall		Increase in Groudwater Storage	Base Flow in Rainy Season	Annual Groundwater Potential		
		(km2)	mm/year	10^9m3/year	10^9m3/year	10^9m3/year	10^9m3/year	% of Rain	mm/year
Lusaka	Lusaka-Urban	441	857	0.38	0.025	0.004	0.029	8%	66.4
	Lusaka-Rural	17,783	857	15.24	1.118	0.211	1.330	9%	74.8
	Luangwa	3,859	857	3.31	0.105	0.046	0.151	5%	39.1
Copperbelt	Ndola-Urban	993	1,231	1.22	0.080	0.013	0.093	8%	93.8
	Ndola-Rural	23,423	1,231	28.83	1.764	0.306	2.070	7%	88.4
	Chililabombwe	1,005	1,231	1.24	0.050	0.013	0.063	5%	62.7
	Chingola	1,747	1,231	2.15	0.082	0.023	0.105	5%	59.9
	Mufulira	1,273	1,231	1.57	0.050	0.017	0.067	4%	52.5
	Kalulushi	1,135	1,231	1.40	0.062	0.015	0.077	5%	67.5
	Kitwe	751	1,231	0.92	0.037	0.010	0.047	5%	62.3
	Luanshya	873	1,231	1.07	0.086	0.011	0.097	9%	111.6
Central	Kabwe-Urban	1,530	947	1.45	0.095	0.020	0.115	8%	75.2
	Kabwe-Rural	25,415	947	24.07	1.968	0.255	2.223	9%	87.5
	Mumbwa	21,572	947	20.43	1.960	0.216	2.177	11%	100.9
	Mkushi	22,395	947	21.21	1.348	0.294	1.642	8%	73.3
	Serenje	23,572	947	22.32	1.258	0.310	1.568	7%	66.5
Northwestern	Solwezi	30,122	1,173	35.33	1.951	0.520	2.472	7%	82.1
	Mwinilunga	20,894	1,173	24.51	1.683	0.361	2.044	8%	97.8
	Zambezi	18,746	1,173	21.99	1.882	0.324	2.205	10%	117.6
	Kabompo	14,535	1,173	17.05	0.984	0.251	1.235	7%	85.0
	Mfumbwe	19,078	1,173	22.38	1.556	0.330	1.886	8%	98.8
	Kasempa	21,905	1,173	25.69	1.314	0.272	1.586	6%	72.4
Western	Mongu	10,071	808	8.14	0.277	0.120	0.397	5%	39.4
	Lukulu	15,639	808	12.64	1.097	0.186	1.283	10%	82.0
	Kalabo	17,230	808	13.92	0.538	0.205	0.743	5%	43.1
	Kaoma	23,024	808	18.60	1.752	0.274	2.026	11%	88.0
	Senanga	31,857	808	25.74	0.950	0.379	1.329	5%	41.7
	Sesheke	29,522	808	23.85	0.896	0.351	1.247	5%	42.3
Southern	Livingstone	1,041	737	0.77	0.040	0.011	0.051	7%	49.4
	Namwala	21,147	737	15.59	1.371	0.165	1.537	10%	72.7
	Mazabuka	6,625	737	4.88	0.371	0.052	0.423	9%	63.8
	Monze	4,856	737	3.58	0.335	0.038	0.373	10%	76.8
	Choma	7,008	737	5.16	0.526	0.076	0.602	12%	85.9
	Kalomo	31,425	737	23.16	1.606	0.341	1.947	8%	62.0
	Siavonga	2,529	737	1.86	0.106	0.027	0.134	7%	52.9
	Gwembe	4,279	737	3.15	0.238	0.046	0.285	9%	66.6
	Sinazongwe	3,706	737	2.73	0.352	0.040	0.393	14%	105.9
Luapula	Mansa	15,991	1,259	20.13	0.882	0.354	1.236	6%	77.3
	Nchelenge	5,188	1,259	6.53	0.350	0.115	0.465	7%	89.7
	Kawambwa	9,040	1,259	11.38	0.461	0.200	0.661	6%	73.1
	Mwense	6,656	1,259	8.38	0.430	0.147	0.577	7%	86.7
	Samfya	8,417	1,259	10.60	0.724	0.186	0.911	9%	108.2
Northern	Kasama	20,457	1,138	23.28	1.735	0.410	2.145	9%	104.8
	Kaputa	10,407	1,138	11.84	0.324	0.208	0.533	4%	51.2
	Mbala	17,156	1,138	19.52	0.855	0.285	1.139	6%	66.4
	Mporokoso	11,933	1,138	13.58	0.676	0.239	0.915	7%	76.6
	Luwingu	8,825	1,138	10.04	0.697	0.177	0.874	9%	99.0
	Chilubi	4,656	1,138	5.30	0.513	0.093	0.607	11%	130.3
	Isoka	13,767	1,138	15.67	0.696	0.217	0.913	6%	66.3
	Chinsali	15,440	1,138	17.57	0.839	0.309	1.148	7%	74.4
	Mpika	40,505	1,138	46.09	2.377	0.811	3.188	7%	78.7
Eastern	Chipata	12,189	961	11.71	1.013	0.163	1.176	10%	96.5
	Chama	17,803	961	17.11	1.049	0.237	1.286	8%	72.3
	Lundazi	13,687	961	13.15	1.037	0.182	1.219	9%	89.1
	Chadiza	2,502	961	2.40	0.230	0.033	0.263	11%	105.2
	Katete	3,842	961	3.69	0.304	0.051	0.355	10%	92.4
	Petauke	19,123	961	18.38	1.550	0.255	1.805	10%	94.4
Total		740,590		743.92	46.657	10.809	57.466	8%	77.6

*) Note: Rainy season means the period when groundwater level rises

6.2 Groundwater Computer Simulation

6.2.1 Purpose of Simulation

Numerical simulation of groundwater flow in Kafue Basin has been carried out to verify the groundwater potential analysis. Recharge rate into groundwater was calculated by the simulation and was compared with the recharge rate derived from groundwater potential analysis. Through this process, the accuracy of groundwater potential analysis was verified.

6.2.2 Simulation Model

The outline of the simulation is listed below.

- Numerical simulation method : Finite element method
- Number of nodes : 771 points
- Number of elements : 806 elements
- Numerical model : Two(2)- dimensional unsteady unlinear flow model

The differential equation defining the groundwater flow in this model is as follows:

$$\frac{\partial}{\partial x}(kh\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(kh\frac{\partial h}{\partial y})=S\frac{\partial h}{\partial t}+q$$

Where

h : Groundwater level (m)
k : Coefficient of permeability (m/day)
S : Specific yield (no unit)
q : Recharge and discharge comprising rainfall, evapotranspiration and run off (m^3/day/m^2)
x, y : Co-ordinates (m)
t : Time (day)

General method of a finite element method available in this model is as follows:

1) Area analysed is divided into many small elements whose shapes are triangles or squares. Each corner of the elements is called a node.
2) Each element has a coefficient of permeability(k), specific yield(S) and aquifer thickness(H).
3) Boundary conditions must be defined for perimeter of the analysed area. The conditions are limited to 2 types. One is that groundwater level is constant, the other is that groundwater flow through the boundary is constant.
4) The initial groundwater level at nodes must be given t for iteration of calculation.
5) Recharge into groundwater table from rainfall must be given to all the nodes.
6) The differential equation is solved for each element under the conditions explained above. Finally, groundwater levels are solved at all the nodes.
7) After groundwater level are solved for each node, groundwater flow vectors are calculated. Groundwater levels are calculated for each time step to simulate seasonal groundwater level fluctuation. After a calculation for one time step is finished, the calculation for the next time step is started.

6.2.3 Condition of Analysis

(1) Analyzed area

The analyzed area is the entire Kafue basin. Therefore, the boundary of the analyzed area corresponds to watershed of Kafue basin.

(2) Aquifer constant for simulation

Aquifer constants were given to each element according to aquifer distribution as shown in Figure 6-16(c). Aquifer constants given to elements are coefficient of permeability, specific yield and aquifer thickness. Coefficient of permeability and specific yield were given by aquifer type according to Table 4-6 and Table 4-7. On the other hand, thickness of aquifer was assumed 50m for all aquifers based on results derived from the data-base

(3) Boundary condition

Boundary condition was given as no flow boundary, because the boundary corresponds to watershed of Kafue basin. Other than this condition, the constant head condition was given to main course/main tributaries of Kafue river (see Figure 6-16(a)).

(4) Initial groundwater level

Initial groundwater level was given as G.L.-10m to most of the nodes. However, in Kafue flood plain and Lukaga swamp, initial groundwater level was given as between G.L.-10m and G.L.0m.

(5) Period for simulation

Period for simulation is one year. The simulation started at the beginning of April 1994 and finished at the beginning of the next April.

(6) Condition of rainfall

Rainfall was assigned to each node. Annual rainfall was simplified into 3 patterns as shown in Figure 6-16(c); 1,300mm in northern part of Kafue basin, 1,100mm in the central part, 900mm in the southern part. The distribution of monthly rainfall is simplified as shown in Figure 6-15.

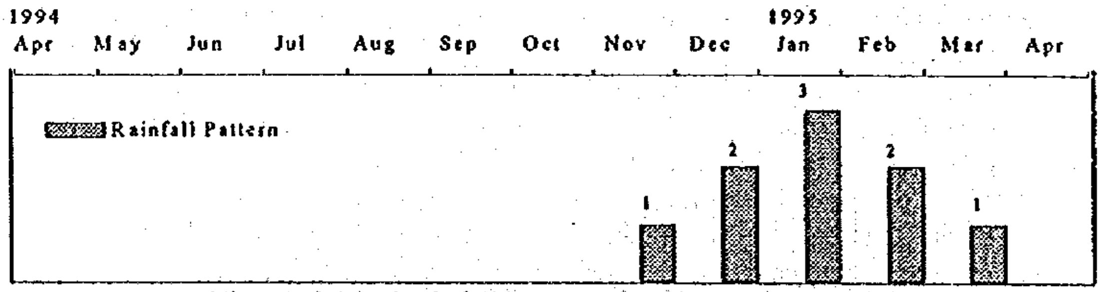
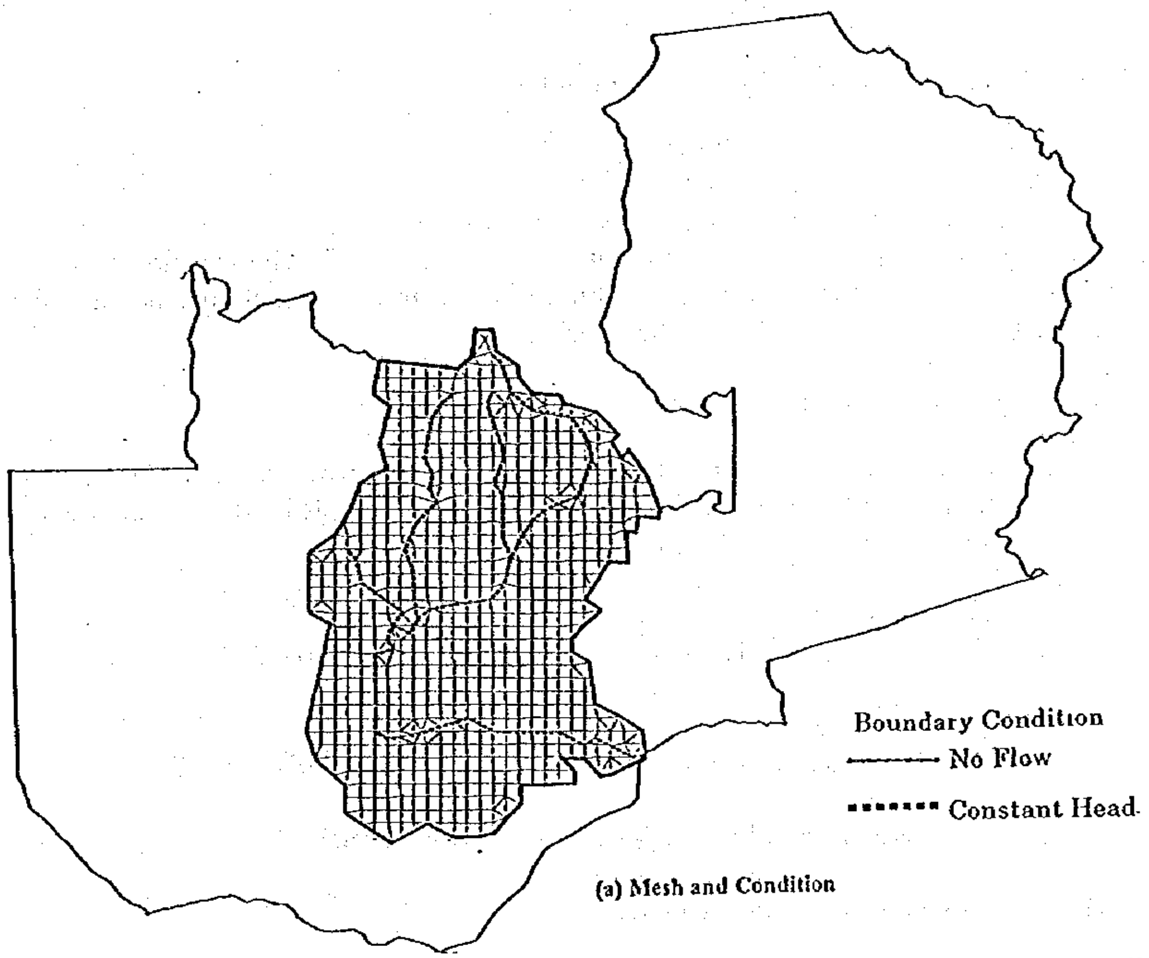
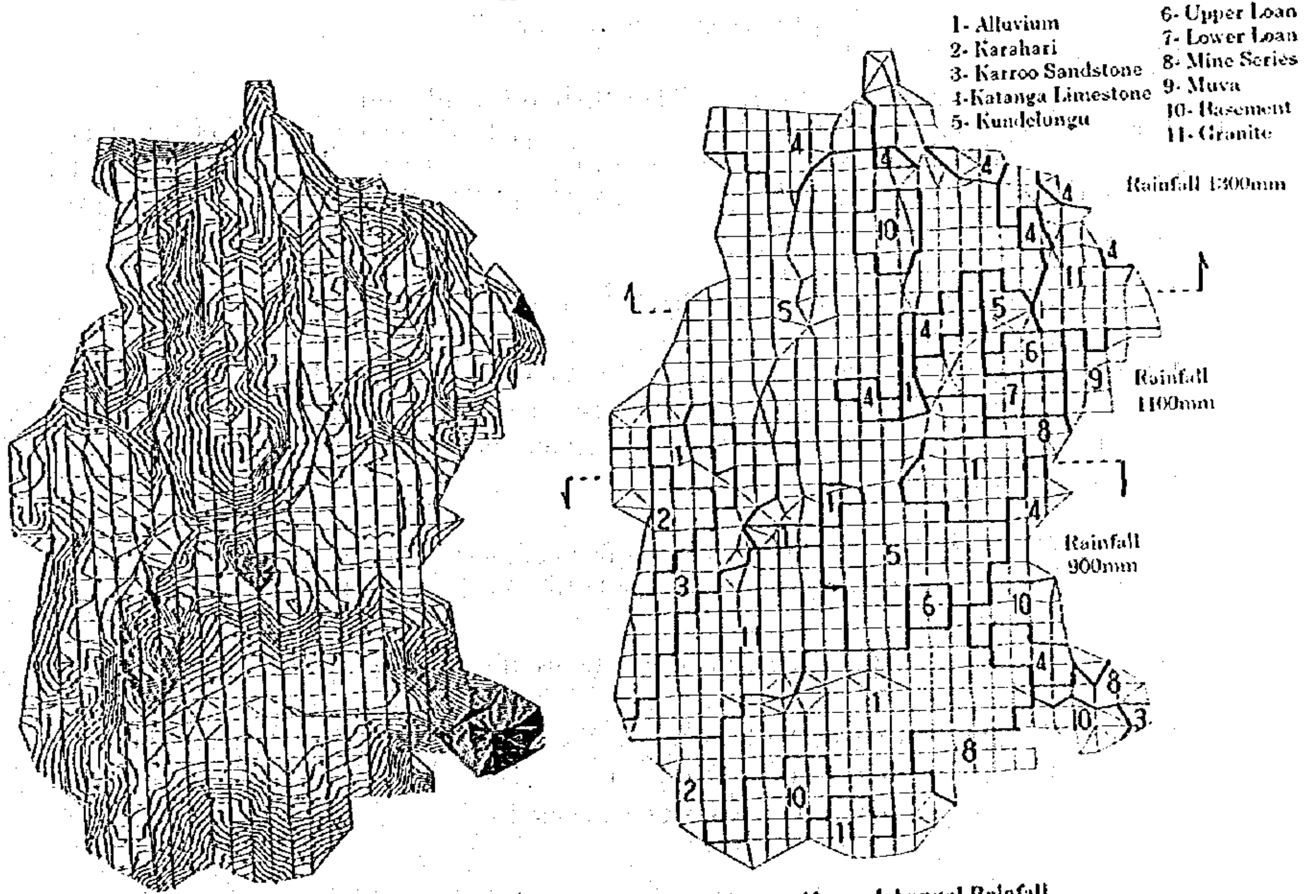


Figure 6-15 Rainfall Pattern for Simulation Model

Ratio of rainfall during rainy season is as follows:
Nov. : Dec. : Jan : Feb. : Mar = 1 : 2 : 3 : 2 : 1.



(a) Mesh and Condition



(b) Topographical Contour with spacing 10m

(c) Aquifer and Annual Rainfall

Figure 6-16 Model of Groundwater Simulation

(7) Recharge into groundwater from rainfall

Recharge was represented as follows:

Recharge = F x Annual rainfall.

F is recharge rate and the solution of this simulation and was obtained by trial and error. F was assigned different values in this simulation and the results of each simulation were compared to actual observed results. The value of F was finaly selected from the simulation results which most closely followed the actual results.

(8) Groundwater discharge

Groundwater runs off into rivers as base-flow. This discharge was simulated by extracting groundwater from each node. The extracting rate (D) was decided based on the results of base-flow analysis explained at the previous section:

<u>April to October</u>

D (m/day) = Annual Recharge (m)/(30 day x 7 months) x (20% / 100%)

<u>November to March</u>

D (m/day) = Annual Recharge (m)/(30 day x 5 months) x (80% / 100%)

Annual rainfall has 3 values within analyzed ares as already explained.

(9) Time step for unsteady calculation

Calculation was carried out by time steps shown below:

Table 6-12 Time Step of Calculation

Step	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Time (day)	1st, Apr.	2nd, Apr.	4th, Apr.	8th, Apr.	15th, Apr.	1st, May.	1st, Jun.	1st, Jun.	1st, Aug.	1st, Sep.	1st, Oct.	1st, Nov.	1st, Dec.	1st, Jan	1st, Feb.	1st, Mar	1st, Apr.

(10) Execution of calculation and Criteria for completion of calculation

Calculation was carried out changing recharge rate (F). After a number of trial and error, the most applicable result has been obtained. The accuracy of the simulation was judged by comparing the results with actual observed results during rainy season. The criteria of accuracy is as follows:

Average of calculated maximum groundwater fluctuation at each node
= Average of actual observed maximum groundwater fluctuation in Kafue basin

On the other hand, the results were verified in terms of calculation error. Criteria for this is as follows:

Error = Σ { (Initial groundwater table level at the beginning of April) - (Final groundwater table level at the end of March) } = 0

Σ means the total of all nodes in the model.

6.2.4 Result of Simulation

After much trial and error, the most applicable result has been obtained. The result is shown in Table 6-13. The calculated average groundwater fluctuation over one year in Kafue basin is as shown in Figure 6-17 compared with actual observed result.

Table 6-13 Simulation Results (1)

Items	Actual Result	Simulated Result
Infiltration rate into aquifer as % of annual rainfall	8%	10%
Groundwater runoff rate from aquifer as % of annual rainfall	Differ every year	10%
Average groundwater fluctuation during rainy season in Kafue basin	-2.2 (m)	-2.13 (m)
Average groundwater level difference between April and next April	Differ every year	0.0005 (m)

The simulated result of groundwater levels and movement are shown in Figure 6-18. There are some differences between the simulated groundwater fluctuation and the observed groundwater fluctuation. However, the trends of calculated groundwater fluctuation are considered to be close to the actual groundwater fluctuations The recharge rate (8%) in Kafue basin obtained from groundwater potential analysis and that obtained from the simulation (10%) are almost the same. Therefore, the results of groundwater potential analysis is considered to be correct. The actual groundwater fluctuation in Southern and Eastern provinces shown in Figure 6-6 is much larger than the simulation result. This means that the actual observation results may have been influenced by abstracting groundwater from shallow wells.

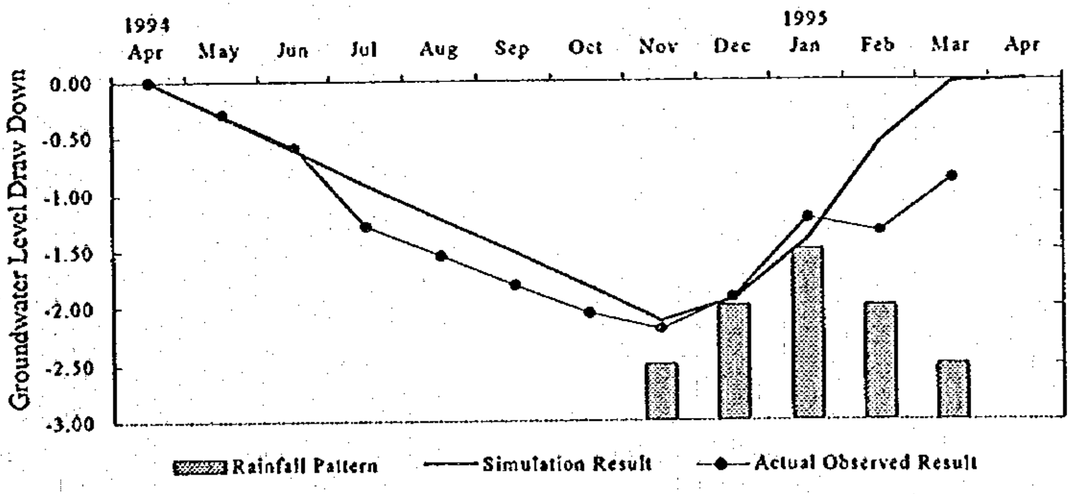
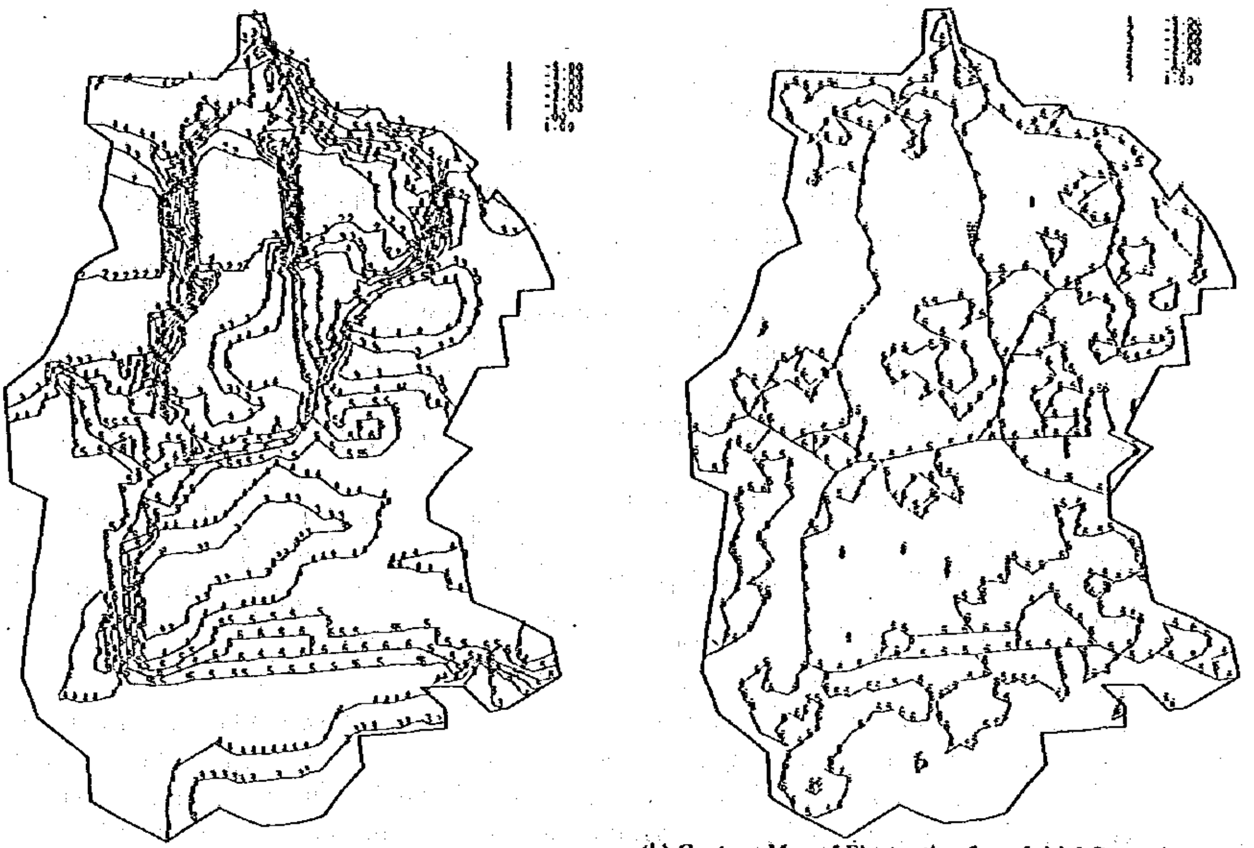
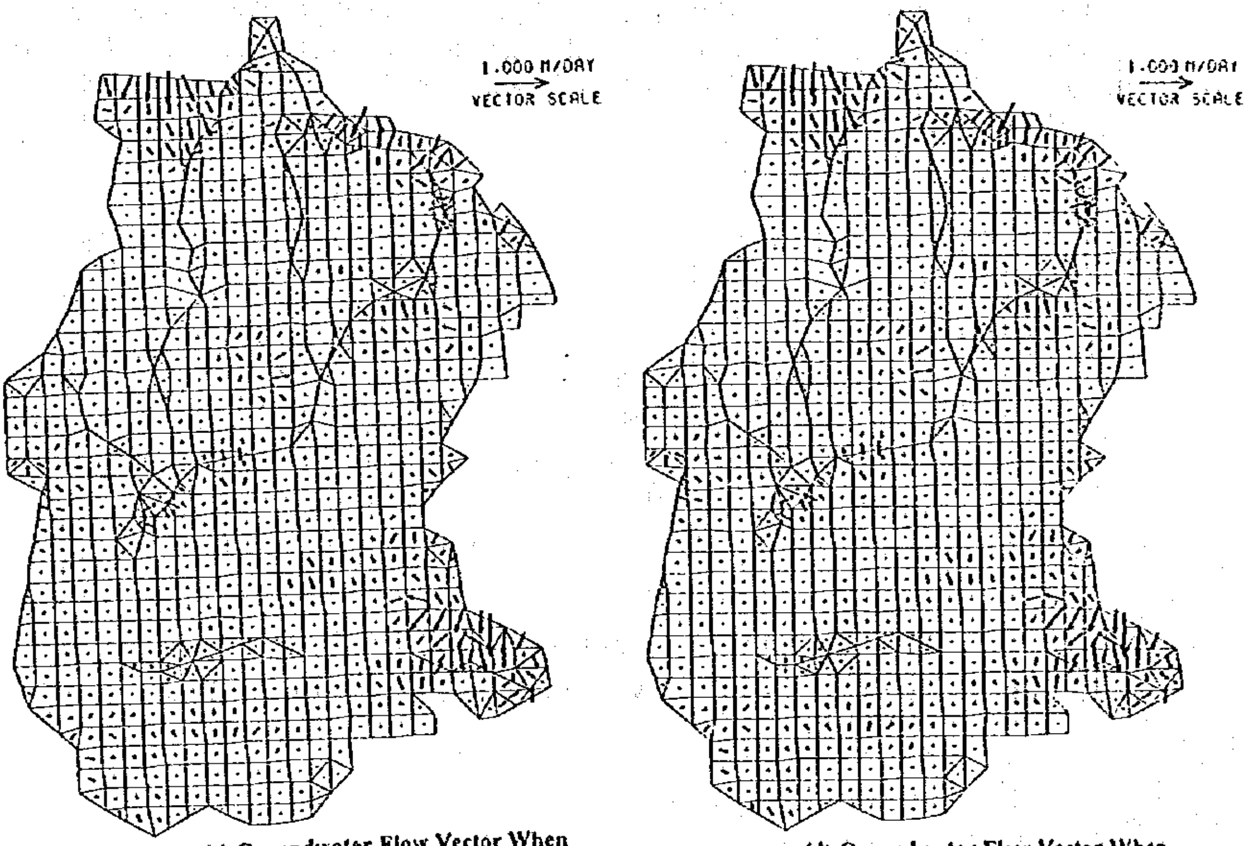


Figure 6-17 Simulated and Actual Average Groundwater Fluctuation in Kafue Basin (1)



(a) Contour Map of Fluctuation from Initial Groundwater Table When Groundwater Table is the Lowest

(b) Contour Map of Fluctuation from Initial Groundwater Tabl When Groundwater Table is the Highest



(c) Groundwater Flow Vector When Groundwater Table is the Lowest

(d) Groundwater Flow Vector When Groundwater Table is the Highest

Figure 6-18 Results of Simulation

Groundwater simulation described above is based on a assumption that every year the total recharge into aquifers during rainy season is the same as total discharge into rivers during dry season. This assumption is considered to be correct in terms of estimating long term groundwater potential. However, groundwater recharge is not equal every year though discharge is almost equal every year. For example as shown in Figure 6-17, actual groundwater table at April 1995 is lower than actual groundwater level at April 1994. It means that total groundwater recharge during November 1994 - March 1995 was smaller than the total discharge during December 1994 - February 1995 which is assumed to be the same every year. The groundwater discharge during April 1994 - April 1995 and the recharge during November 1994 - March 1995 were calculated by groundwater simulation. Results are shown in Figure 6-19 and Table 6-14.

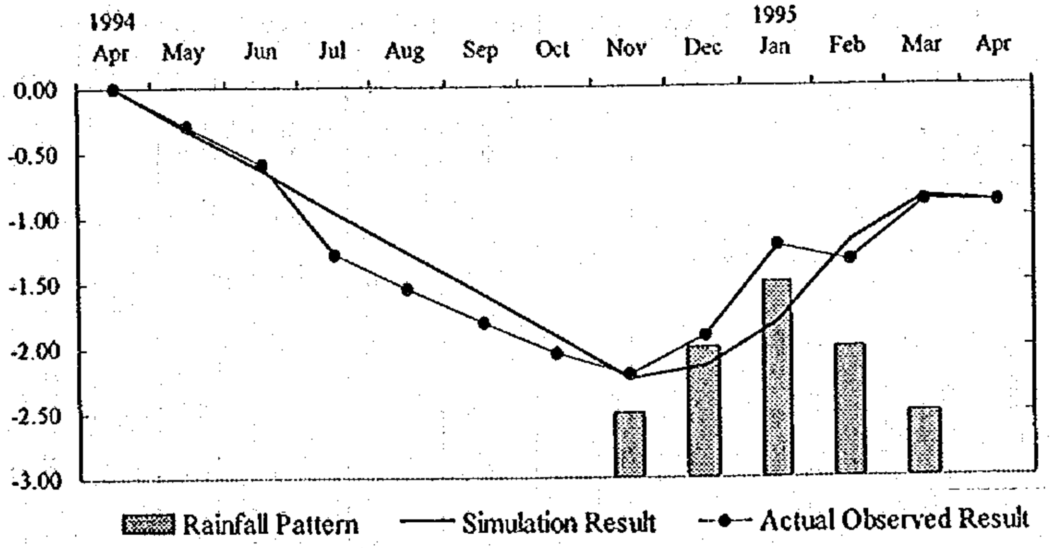


Figure 6-19 Simulated and Actual Average Groundwater Fluctuation in Kafue Basin (2)

Table 6-14 Simulation Result (2)

Items	Actual Result	Simulated Result
Infiltration rate into aquifer as % of annual rainfall	8%	8%
Groundwater run off rate from aquifer as % of annual rainfall during April 1994 to April 1995	is assumed 8%	10%
Average groundwater fluctuation during dry season 1994 in Kafue basin	-2.2 (m)	-2.23 (m)
Groundwater level difference between April 1994 and April 1995 in Kafue basin	-0.88 (m)	-0.896 (m)

It is concluded from Table 6-14 that recharge was smaller than discharge by 2% of annual rainfall during April 1994 to April 1995. It is concluded that groundwater storage was decreased by 2% of annual rainfall during April 1994 to April 1995.

CHAPTER 7 GROUNDWATER DEVELOPMENT PLAN

7.1 Existing Groundwater Development Plan

7.1.1 Capital Expenditure for Groundwater Development Project

More than 9,000 boreholes and more than 8,000 shallow wells were completed for public and private water supply, and large part of these boreholes and shallow wells were completed for rural water supply. Of all these boreholes and shallow wells, more than 3,000 boreholes and shallow wells were completed or rehabilitated for public water supply by foreign donors' funds. Existing groundwater development projects for public water supply from 1989 to 1993 are shown in Table 7-1.

Table 7.1 Capital Expenditure for Groundwater Development Project

(Unit: K' Million)

Project	1989 Actual	1990 Actual	1991 Actual	1992 Actual	1993 Actual	1994 Estimation	Organization
Rural Water Supply Programme (Northern Province)	0.0	0.0	0.0	0.0	76.0	33.4	DWA
Groundwater Supply Development (Central, Lusaka & Copperbelt)	0.0	2.4	3.4	0.3	74.3	3,290.8	DWA
Rural Water for Health Project (North-western Province)	-	0.0	0.0	0.0	186.0	291.1	DWA
Rehabilitation of Well & Boreholes	-	-	-	20.0	0.0	870.0	DWA
Procurement of Rigs	-	-	-	-	0.0	450.0	DWA
Borehole for Rural Area (Lusaka Province)	-	-	-	-	0.0	107.5	DWA
Kabwe Underground Water Supply & Sewerage Treatment Plant	6.0	0.0	0.0	0.0	0.0	0.0	MLGH
Mongu Water Supply Scheme	0.8	0.0	0.0	0.0	0.0	0.0	MLGH
Total	6.8	2.4	3.4	20.3	336.3	5,042.8	

Most of the projects shown in Table 7.1 were funded by foreign donors and have the main purpose of improving rural water supply.

7.1.2 Budget for Groundwater Development

Investment for groundwater development is included in water and sanitation sector. Actual investment for groundwater development projects in 1993 was 1.52 usmil$, and 95% of the actual investment came from foreign donors. Of this investment, 1.46 usmil$ was occupied by budget for well construction projects, and 88% of this budget were occupied by assistance rendered by foreign donors. Investment program of water and sanitation sector shown in " Public Investment Programme (1993-1995) " is as follows;

Table 7-2 Public Investment Programme: Water Sanitation Sector

(Exch.rate Kw/US$: 400.00)

1993			1994			1995			1993-95			%
Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	Foreign	Local	Total	
21.91	1,179.5	9,9943.5	10.51	950	5,154	7.31	1,265	4189	39.73	3,394.5	19,286.5	2.3

Table 7-3 Public Investment Programme: Water & Sanitation Sector: FundsSought

(US$ Millions)

Year	1993	1994	1995	Total 1993-95	%
Investment	24.25	14.79	13.83	52.87	3.64

7.2 Safe Yield of Borehole

Safe yield is defined as maximum yield of a borehole without groundwater hazard. Therefore, estimation of safe yield is most important in groundwater development plan. The importance of safe yield is as follows

Maximum groundwater development potential was discussed in Chapter D5. However, making use of all the potential is impossible, because available groundwater depends on method to abstract groundwater apart from the recharge rate. For example, yield from a borehole is related to diameter and depth of a borehole, aquifer thickness and capacity. Furthermore, groundwater storage disappears within 1 year regardless of the degree of groundwater use, because groundwater storage is renewable. On the other hand, if pumping exceeds renewable groundwater storage, effect to the groundwater may occur. In the end, safe yield is the most desirable yield which satisfies all conditions mentioned above.

Groundwater development is carried out by drilling boreholes and digging shallow wells. Though shallow wells are easier to dig and cheaper than boreholes, shallow wells have problems with water quality and quantity. Therefore, use of boreholes should be considered the best way for groundwater development.

Safe yield of borehole is dominated by the following:

1) Aquifer characteristics
2) Recharge and discharge around borehole
3) Diameter and length of borehole
4) Static groundwater level and pumping groundwater level.

Based on items listed above, the safe yield of borehole has been analyzed by the procedure explained below and shown in Figure 7-1.

7.2.1 Making Standard Model of Borehole and Aquifer

Simulation Model

Simulation model used in this analysis is the same as that used in groundwater simulation for kafue basin. The differential equation defining groundwater flow in this model is as follows:

$$\frac{\partial}{\partial x}(kh\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(kh\frac{\partial h}{\partial y})=S\frac{\partial h}{\partial t}+q$$

Where

h : Groundwater level (m)
k : Coefficient of permeability (m/day)
S : Specific yield (no unit)

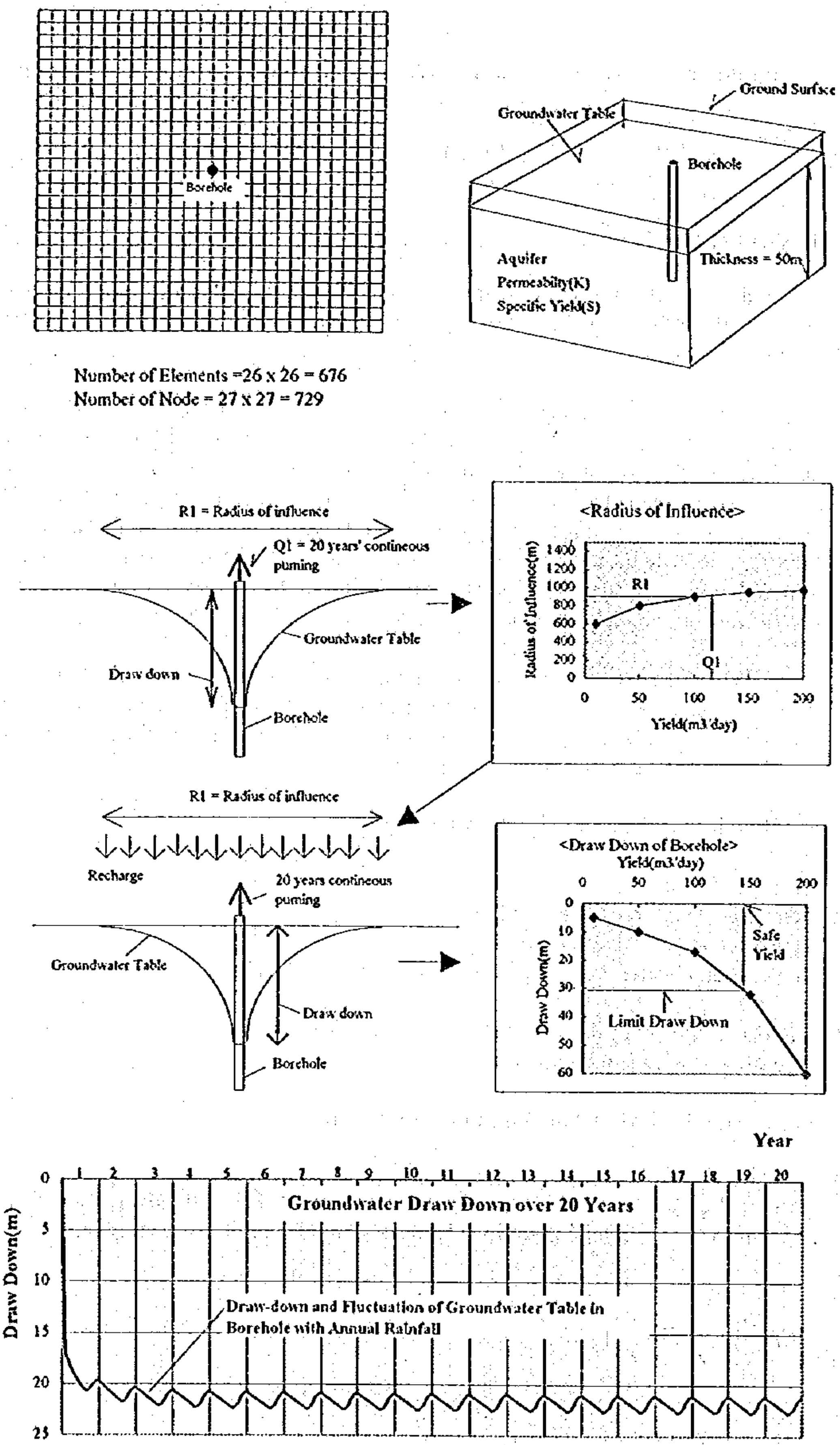


Figure 7-1 Method of Safe Yield Analysis

q : Recharge from rainfall and discharge from borehole (m/day)
x, y : Co-ordinates (m)
t : Time (day)

The aquifer model is shown in Figure 7-1.

Aquifer Characteristics

Aquifer characteristics are assumed as follows based on Table 4-6, 4-7.

Table 7-4 Aquifer Characteristics

Lithology	Representative Aquifer Parameters		
	Coefficient of permeability	Specific Yield	Thickness of Aquifer
Gneiss	0.06	0.02	50
Shale	0.05	0.02	50
Quartzite	0.16	0.05	50
Sandstone	0.27	0.04	50
Granite	0.15	0.03	50
Sand & Gravel	0.68	0.05	50
Limestone & Dolomite	1.31	0.05	50
Schist	0.68	0.05	50
Others	0.05	0.05	50

Diameter and Length of Borehole

Standard Diameter is assumed as 15 cm for rural water supply and 30cm for urban water supply. Standard length of borehole is assumed to be 50m.

Static Groundwater Level

Static groundwater level of boreholes ranges from 0m to 79m from borehole data-base. The average is assumed to be 7.1 m. Therefore, static groundwater level is assumed 10m from surface for this simulation.

7.2.2 Determination of Radius of Influence

The pumping effect is felt within the radius of influence. It means that the borehole collects groundwater within the radius of influence. In this calculation, radius of influence was assumed to be the distance from the borehole to where the groundwater draw-down is 0.01m. Generally speaking the radius of influence is not fixed but expands in proportion to yield of a borehole. Therefore the radius of influence was determined by the yield and lithology. The result is shown in Table 7-5 and Figure 7-2.

7.2.3 Determination of Relationship between Yield and Draw down of Borehole

After deciding the radius of influence by yield and lithology, relationship between draw-down of borehole and yields is calculated. Conditions for this calculation are as follows:

- Borehole collects groundwater from inside the radius of influence.
- Recharge from rainfall was given to inside the radius of influence and recharge rate is 8% of annual rainfall. Annual rainfall was assumed as 1,000mm and rainfall pattern was the same as used for Kafue basin groundwater simulation.

Table 7-5 Radius of Influence by Yield and Lithology

Sandstone		Shale		Granite		Schist	
Q(m3/day)	R(m)	Q(m3/day)	R(m)	Q(m3/day)	R(m)	Q(m3/day)	R(m)
50	960	20	720	50	920	40	940
100	1,040	30	740	100	1,000	50	980
150	1,140	40	760	150	1,060	100	1,120
200	1,180	50	800	200	1,100	150	1,160
250	1,200	100	900	250	1,140	200	1,200
300	1,220	150	960	300	1,180	250	1,240
		200	960	350	1,180	350	1,320
		250	960				
Limestone		**Sand & Gravel**		**Quartzite**		**Gneiss**	
Q(m3/day)	R(m)	Q(m3/day)	R(m)	Q(m3/day)	R(m)	Q(m3/day)	R(m)
50	1,295	50	1,120	50	1,120	20	720
100	1,505	100	1,290	100	1,220	30	780
150	1,680	150	1,400	150	1,340	40	800
200	1,750	200	1,470	200	1,360	50	840
250	1,855	250	1,540	250	1,390	100	940
300	1,925	300	1,610	300	1,420	150	980
350	1,960	350	1,645	350	1,440	200	1,000
400	1,995	400	1,680			250	1,020
450	2,030	450	1,680				
500	2,065						
550	2,100						
600	2,100						
650	2,135						
700	2,170						
750	2,205						

- Groundwater discharge from inside the radius of influence was modeled as:
  Groundwater discharge (m^3/day)
  = [Annual rainfall(m^3/year) - Annual pumping rate(m^3/year)] / 365 (days)

Relationship between draw-down and yields during 1 year were calculated for the conditions listed above.

7.2.4 Revision of 1 Year Draw Down to 20 Years Draw Down

From the yield and draw down during 1 year, the draw down over 20 years of pumping was analyzed. The draw down over 20 years was calculated for several cases and the ratios of (20 years draw down / 1 year draw down) were obtained. Using the ratios, draw down of 1 year was revised to that of 20 years. The result is shown in Table 7-6 and Figure 7-3.

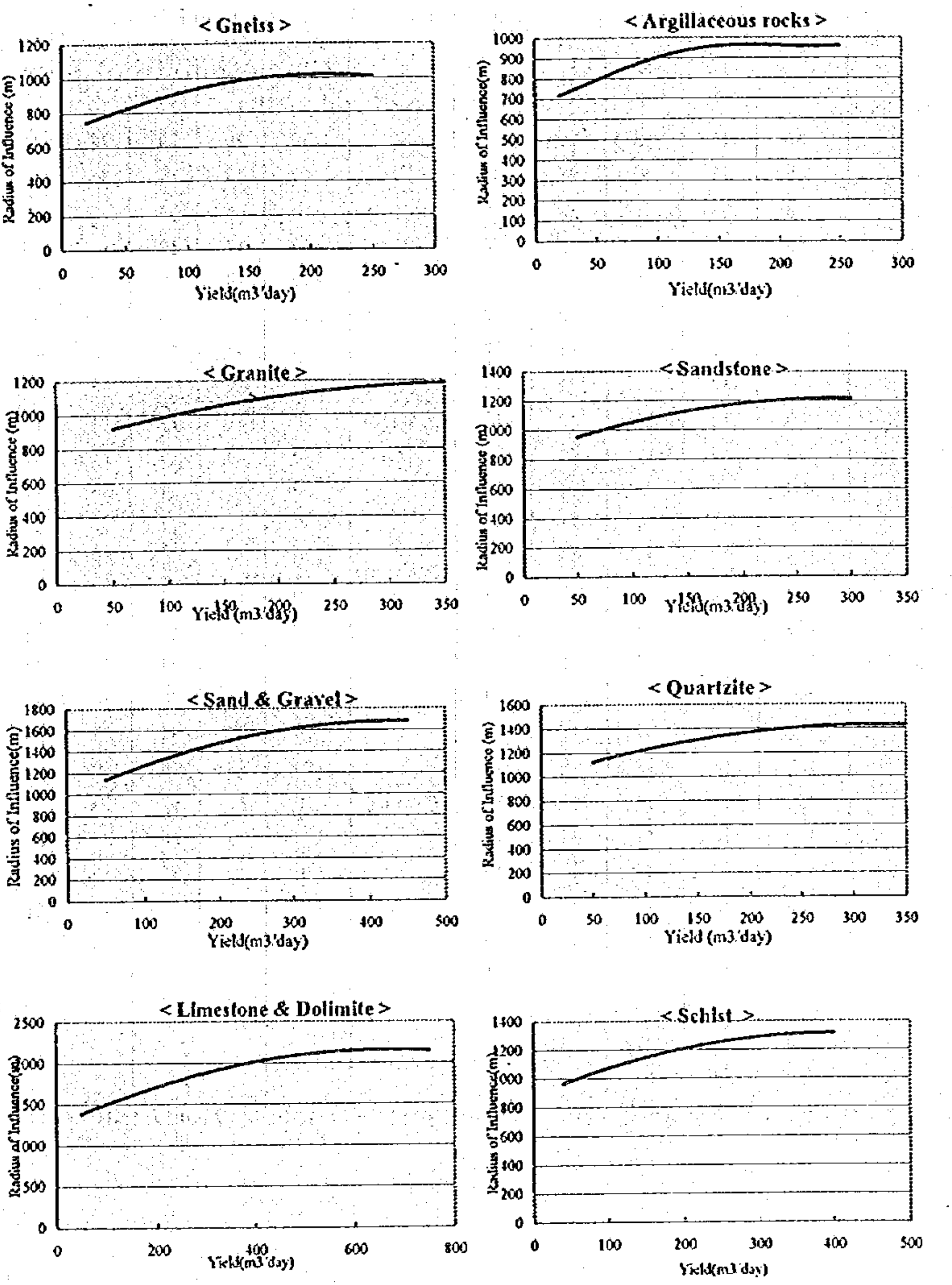
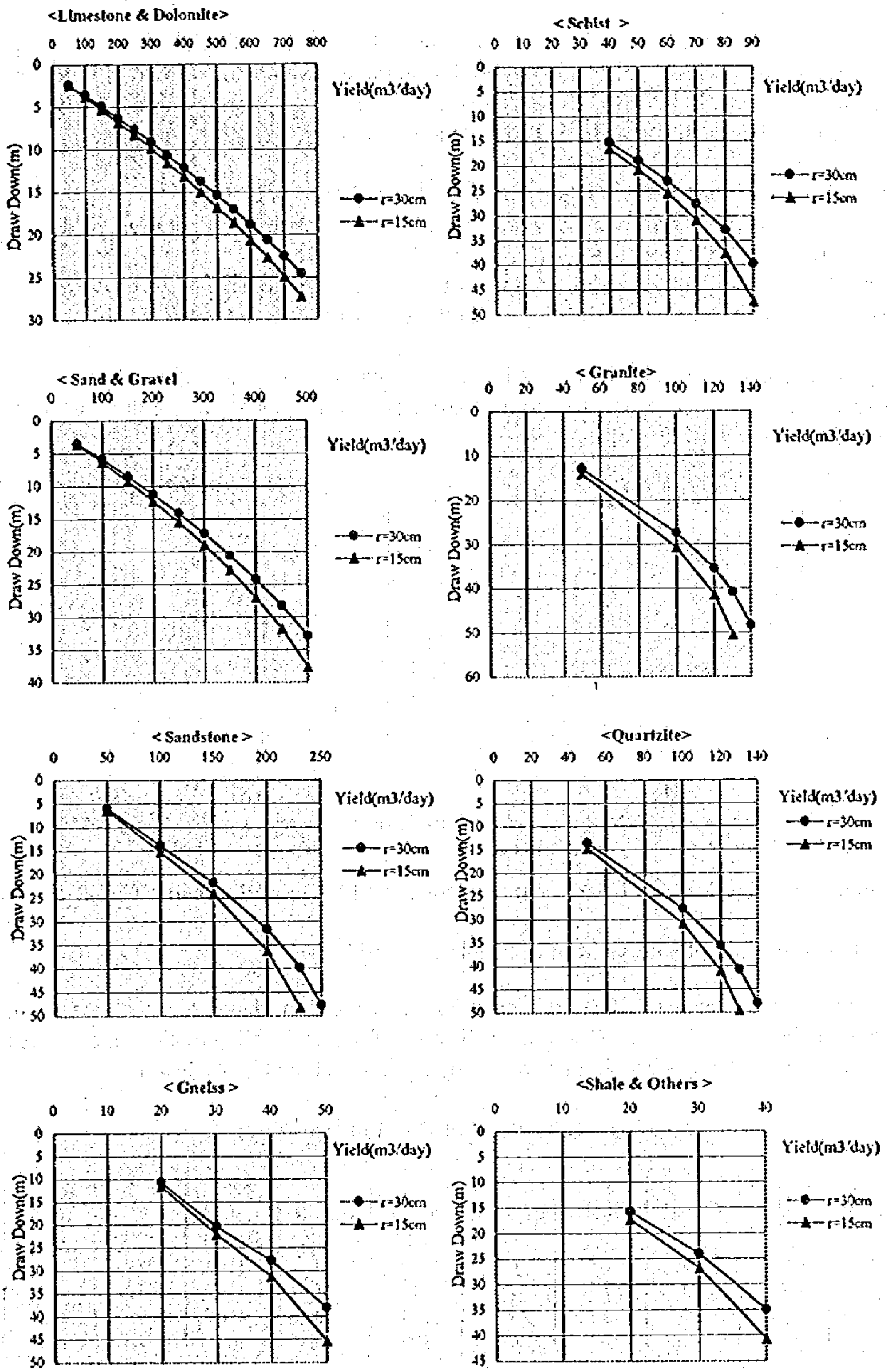


Figure 7-2 Radius of Influence by Yield and Lithology

Table 7-6 Relation between Yield and Draw Down over 1 and 20 Years

Lithology	Yield	After 1 year (m)		After 20 years (m)		Lithology	Yield	After 1 year (m)		After 20 years (m)	
	Q(m3/day)	r=30cm	r=15cm	r=30cm	r=15cm		Q(m3/day)	r=30cm	r=15cm	r=30cm	r=15cm
Gneiss	20	9	10	11	12	Shale	20	13	14	16	17
	30	17	18	20	22		30	20	22	24	27
	40	23	26	28	31		40	29	34	35	41
	50	32	38	38	45	Sandstone	50	6	7	6	7
Sand & Gravel	50	3	3	3	4		100	12	13	14	15
	100	5	5	6	6		150	18	20	22	24
	150	7	8	9	9		200	26	30	32	36
	200	9	10	11	12		230	33	40	40	48
	250	12	13	14	15		250	40	-	48	-
	300	14	16	17	19	Quartzite	50	11	12	14	15
	350	17	19	21	23		100	23	26	28	31
	400	20	23	24	27		120	30	34	36	41
	450	24	27	28	32		130	34	41	41	50
	500	27	31	33	38		140	40	-	48	-
Limestone and Dolomite	50	2	2	2	2	Schist	40	13	14	15	17
	100	3	3	4	4		50	16	17	19	21
	150	4	4	5	5		60	19	21	23	25
	200	5	6	6	7		70	23	26	28	31
	250	6	7	8	8		80	27	31	33	38
	300	8	8	9	10		90	33	40	40	47
	350	9	10	11	12	Granite	50	11	12	13	14
	400	10	11	12	13		100	23	26	27	31
	450	12	13	14	15		120	30	35	36	42
	500	13	14	15	17		130	34	42	41	51
	550	14	16	17	19		140	40	-	48	-
	600	16	17	19	21						
	650	17	19	21	23						
	700	19	21	23	25						
	750	21	23	25	27						

Note; r is diameter of borehole (cm). r=15 (cm) for rural water supply, r=30 (cm) for urban water supply.



Note; r = Diameter of Borehole

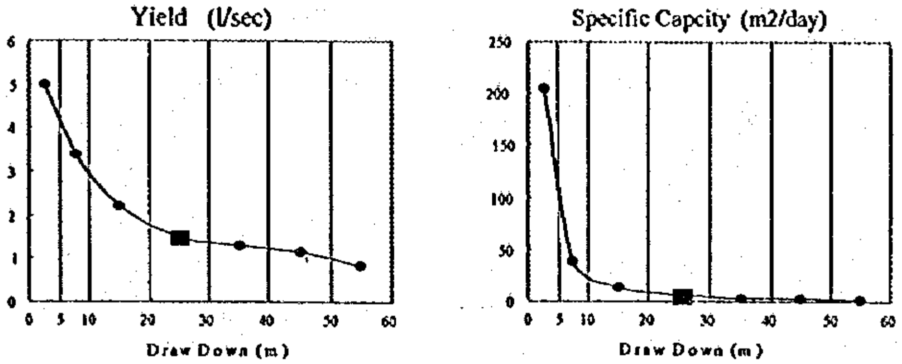
Figure 7-3 Relation between Yield and Draw down after 20 years Pumping

7.2.5 Allowable Draw Down of Borehole

Based on the relation between yield and draw down of borehole, safe yield over long term pumping should be decided. It is necessary to decide the allowable draw down of borehole. Allowable draw down is assumed to be 20m - 30m. This assumption is based on the facts derived from the Borehole Data-Base. The facts are as follows;

- The depth from groundwater table to main aquifer is about 20m - 30m.
- There is a turning point around draw down of 20-30m in relationship between yield and draw down as shown in Figure 7-4 (a).
- There is a turning point around draw down of 10-20m in relationship between draw down and specific capacity indicating well efficiency as shown in Figure 7-4 (b).

Judging from the facts listed above, well efficiency with draw down of more than 30m seems to be very low. Therefore, to adopt 20-30m draw down as allowable draw down is considered to be reasonable.



(a) (b)

Note; These figures show relationship between final draw down and the representative final yield and specific capacity of boreholes at pumping test respectively. Data number is 4,500.

Figure 7-4 Relationship between Draw Down and Yield and Specific Capacity

7.2.6 Determination of safe yield of borehole by aquifer

Yields with a draw-down of 20 - 30m over 20 years are considered to be a safe yield, because pumping draw down of 20 - 30m is allowable for sustainable pumping as explained in previous section . The safe yield of borehole by aquifer is shown in Table 7-7.

Table 7-7 Safe Yield of Borehole (m^3/day)

Allowable Draw Down	Diameter of Borehole	Lithology							
		Gneiss	Shale	Quartzite	Sand-stone	Granite	Sand & Gravel	Limestone & Dolomite	Schist
20m	15cm	28	23	66	126	68	314	584	48
	30cm	30	25	73	138	75	340	632	53
30m	15cm	39	32	97	174	98	430	-	68
	30cm	42	35	106	192	106	468	-	75

The safe yields shown in Table 7-7 depend on the permeability of the aquifer. Safe yields have been calculated by using representative parameters of each aquifer. However, values of permeability of each aquifer have a wide range as shown in Figure 4-8. Therefore, the safe yield shown in Table 7-7 should be considered to be an average value and the actual safe yield will vary for each site.

7.3 Water Supply for Rural Area

7.3.1 Water Supply Facilities

Point water supply by borehole equipped with hand pump is suitable for rural water supply. Facilities for rural water supply should meet the conditions listed below:

1) Yield of a borehole is 7.5m^3/day under the condition of 10 hours' operation.
2) Consumption rate for domestic use is 35 (lit/cap./day) and water loss is 3.5(lit/cap./day), so total demand is 38.5(lit/cap./day).
3) Standard borehole structure is 60m in depth and 10-15 cm in diameter. The diameter of 10cm is sufficient for installation of hand pump
4) Borehole is located within 500m from the villager in terms of reducing haul distance of water

Standard borehole structure is shown in Figure 7-5.

7.3.2 Water Supply Project for Rural Areas

The number of new boreholes for rural water supply by district is estimated as follows:

The number of new boreholes needed
= [(Projected population in 2015) x (per capita consumption rate + loss rate)
x (Water supply ratio in 2015) - Total existing capacity] / (Yield of a Borehole)

Population by district in 2015 was projected by socio-economic analysis. Total of per capita consumption and loss rate is 38.5(lit/cap./day). Water supply percentage in rural area is proposed to be 75% in target year of 2015. Yield of borehole should be determined to be 7.5 m^3/day using a hand pump, because the yield of 7.5m^3/day is lower than the smallest safe yield obtained in Chapter D5. Based on these results, the number of new boreholes needed was calculated by province. The results are shown in Table 7-8. These results are summarized as follows:

Table 7-8 Water Supply Project for Rural Areas (Base demand)

Province	New Production (m^3/day)	Total New Borehole Number
Lusaka	8,176	1,090
Copperbelt	12,780	1,704
Central	21,256	2,834
North-western	13,066	1,742
Western	7,936	1,058
Southern	26,372	3,516
Luapula	15,512	2,068
Northern	26,596	3,546
Eastern	37,276	4,970
Zambia Total	168,970	22,528

1) To attain the water supply plan, more than 22,000 new boreholes must be drilled over the whole of Zambia by 2015.

2) It follows that more than 1,100 new boreholes must be drilled every year.
3) The number of new boreholes is different by province as shown in Table 7-8. The number of new boreholes is higher in Northern province where existing boreholes are few, and in Eastern and Southern province where increase of population is high.

Groundwater development plan to 2015 in rural areas is proposed as shown in Table 7-9.

7.4 Water supply for Small Urban Area

Generally speaking, surface water is more suitable for urban water supply than groundwater, because they need a great deal of water. However, groundwater is more suitable for the water supply of urban areas where it is difficult to convey water from rivers economically. Such urban areas have been selected and new groundwater supply projects are proposed in this master plan.

7.4.1 Water Supply Facilities

Water supply for small urban areas should be carried out by boreholes equipped with power pumps. Facilities for water supply require the conditions listed below:

1) Yield of a borehole should be less than the safe yield of the area.
2) Consumption rate for domestic use is 50 (lit/cap./day) and water loss is 5.0 (lit/cap./day). So total demand is 55.0(lit/cap./day).
3) Standard borehole structure is 60m in depth and 30cm in diameter(see Figure 7-5). Diameter of 30cm is needed for installation of power pump.
4) Boreholes should be arranged in a well field. But it should be noted that safe yield of a borehole in a well field is less than yield of a single borehole. However, in this study, yield of a single borehole is used as that of a well field for an approximate estimation.
5) Piped water supply system with storage reservoir is suitable for water supply of small urban areas. Large water treatment facilities are not necessary in principle for groundwater.

Groundwater development plan to 2015 in small urban areas is proposed as shown in Table 7-9.

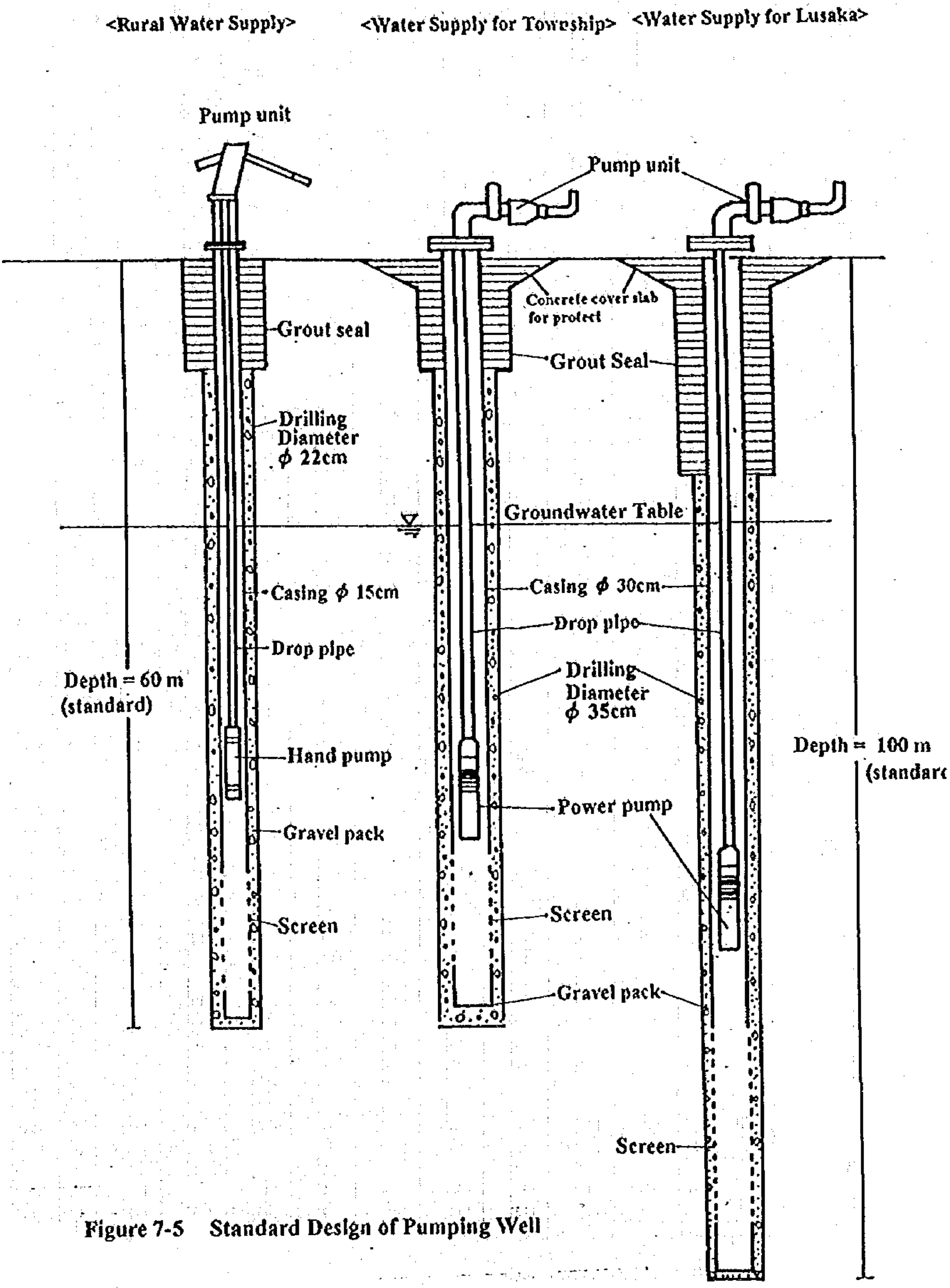


Figure 7-5 Standard Design of Pumping Well

Table 7-9 Groundwater Development Plan to 2015

Province	Area	1996		1997		1998		1999		2000		2001		2002		2003		2004		2005	
		Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.
Lusaka	Township										3										1
	Rural		49		49		49		49		49		49		49		49		49		49
	Total	(1)	49	(1)	49	(1)	49	(1)	49	(1)	52	(1)	49	(1)	49	(1)	49	(1)	49	(1)	50
Copperbelt	Township				2		2		2		2										5
	Rural				70		70		70		70		72		72		72		72		139
	Total			1	72	1	72	1	72	1	72	1	72	1	72	1	72	1	72	1	144
Central	Township		21		21		21		21		22		9		9		9		9		10
	Rural		123		195		195		195		122		135		135		135		135		134
	Total	(1)	144	(1)	216	(1)	216	(1)	216	(1)	144	(1)	144	(1)	144	(1)	144	(1)	144	(1)	144
Northern	Township				37		37		37		37		7		7		7		7		8
	Rural				107		107		107		107		137		137		137		137		208
	Total			2	144	2	144	2	144	2	144	2	144	2	144	2	144	2	144	2	216
Northwester	Township				17		17		17		16		2		2		2		2		2
	Rural				55		55		55		56		70		70		70		70		142
	Total			1	72	1	72	1	72	1	72	1	72	1	72	1	72	1	72	2	144
Western	Township		4		4		5		5		5										7
	Rural		68		68		68		67		66		71		71		71		70		70
	Total	(1)	72	(1)	72	(1)	73	(1)	72	(1)	71	(1)	71	(1)	71	(1)	71	(1)	70	(1)	77
Eastern	Township				65		65		65		65		14		14		14		14		14
	Rural				223		223		223		223		274		274		274		274		274
	Total			4	288	4	288	4	288	4	288	4	288	4	288	4	288	4	288	4	288
Southern	Township		23		23		23		23		23		15		15		15		15		15
	Rural		49		121		121		121		121		201		201		201		201		201
	Total	(1)	72	(2)	144	(2)	144	(2)	144	(2)	144	(3)	216	(3)	216	(3)	216	(3)	216	(3)	216
Luapula	Township				12		11		11		11		3		3		2		2		3
	Rural				60		61		61		61		69		69		70		70		141
	Total			1	72	1	72	1	72	1	72	1	72	1	72	1	72	1	72	2	144

Province	Area	2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		Total
		Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	Rig	B.H.	
Lusaka	Township										1											5
	Rural		60		60		60		60		60		60		60		60		60		60	1090
	Total	(1)	60	(1)	60	(1)	60	(1)	60	(1)	61	(1)	60	(1)	60	(1)	60	(1)	60	(1)	60	1095
Copperbelt	Township										5											18
	Rural		100		100		100		99		99		100		100		100		100		99	1704
	Total	2	100	2	100	2	100	2	99	2	104	2	100	2	100	2	100	2	100	2	99	1722
Central	Township		8		8		8		8		10		7		7		7		7		7	229
	Rural		133		133		133		133		133		133		133		133		133		133	2834
	Total	(2)	141	(2)	141	(2)	141	(2)	141	(2)	143	(2)	140	(2)	140	(2)	140	(2)	140	(2)	140	3063
Northern	Township		4		4		4		4		6		2		2		2		3		3	218
	Rural		237		236		236		236		236		237		236		236		236		236	3546
	Total	3	241	3	240	3	240	3	240	3	242	3	239	3	238	3	238	3	239	3	239	3764
Northwester	Township		2		2		2		2		2		2		2		2		2		2	97
	Rural		110		110		110		110		110		110		110		110		110		109	1742
	Total	2	112	2	112	2	112	2	112	2	112	2	112	2	112	2	112	2	112	2	111	1839
Western	Township										6											36
	Rural		37		37		37		37		36		37		37		37		37		36	1058
	Total	(1)	37	(1)	37	(1)	37	(1)	37	(1)	42	(1)	37	(1)	37	(1)	37	(1)	37	(1)	36	1094
Eastern	Township		11		11		11		10		11		10		10		10		10		10	434
	Rural		271		271		271		271		270		271		271		271		271		270	4970
	Total	4	282	4	282	4	282	4	281	4	281	4	281	4	281	4	281	4	281	4	280	5404
Southern	Township		14		14		15		15		15		10		10		11		11		11	316
	Rural		198		198		198		198		197		198		198		198		198		197	3516
	Total	(3)	212	(3)	212	(3)	213	(3)	213	(3)	212	(3)	208	(3)	208	(3)	209	(3)	209	(3)	208	3832
Luapula	Township		2		2		2		2		3		2		2		2		2		2	79
	Rural		141		141		141		140		140		141		141		141		140		140	2068
	Total	2	143	2	143	2	143	2	142	2	143	2	143	2	143	2	143	2	142	2	142	2147

(Note), Rig : Number of drilling rigs required.
( ) means using existing drilling rig
B.H. : Number of new boreholes

7.4.2 Water supply Project for Small Urban Areas

The number of new boreholes for water supply of small urban areas by district is estimated as follows:

The number of new boreholes
= [(Projected population in 2015) x (per capita consumption rate + loss rate)
x (Water supply ratio in 2015) - Total existing Capacity] / (Yield of a borehole)

Population by district in 2015 was projected by socio-economic analysis. Total of per capita consumption and loss rate is 55(lit/cap./day). Water supply ratio in small urban areas is proposed to be 100% in target year of 2015. Yield of borehole is determined by safe yield by lithology obtained in Chapter D5. Based on these results, the number of boreholes was calculated by small urban area. The results are shown in Table 7-10 and 7-11. These results are summarized as follows:

Table 7-10 Water Supply Project For Small Urban Area by Province (Base Demand)

Province	Total Town ship Number	New Production (m^3/day)	Total New Borehole Number
Lusaka	1	960	5
Copperbelt	3	6,324	18
Central	7	13,084	229
North-western	2	3,395	97
Western	9	16,878	36
Southern	18	25,216	316
Luapula	2	8,374	70
Northern	9	19,373	218
Eastern	7	27,956	434
Zambia Total	58	121,560	1423

1) Water supply from groundwater is necessary for 80 townships. The number of such townships is the highest in Southern province and the lowest in Copperbelt province.
2) The number of new boreholes is different by township according to safe yield of the aquifer. The average yield of boreholes shown in Table 7-10 is 85m^3/day. The average yield by province is highst in Western province(470m^3/day), on the other hand lowest in North-western province(35m^3/day).

Table 7-11 Water Supply Project For Small Urban Area by Toemship (Base Demand)

Ptovince	Township	Number of New Boreholes	Water Production Rate (m3/day)
Lusaka	Rufunsa	5	960
Copperbelt	Masaiti	6	252
	Mpongwe	6	3,040
	Chambishi	5	2,530
Central	Chbombo	4	2,020
	Chisamba	1	510
	Kapri Mposhi	55	2,310
	Mumbwa	90	3,150
	Namupundwe	12	1,270
	Mukushi	23	2,440
	Serenje	45	1,890
Northwestern	Mfumbwe	60	2,100
	Kasempa	32	1,120
Western	Mongu	14	6,550
	Limulunga	4	1,870
	Namushakande	2	940
	Lukulu	3	1,400
	Sikongo	1	470
	Kaoma	9	4,210
	Shangombo	1	470
	Mulobezi	1	470
	Katima-Mulilo	1	460
Southern	Namwala	3	1,400
	Itezhi-Tezhi	45	1,580
	Mazabuka	14	6,550
	Magoye	14	490
	Nkambala	4	1,870
	Nega-nega	2	940
	Kafue-gorge	12	590
	Chikankata	25	880
	Monze	20	2,120
	Chisekesi	9	380
	Choma	60	2,520
	Batoka	9	380
	Pemba	10	420
	Mbabala	4	420
	Kalomo	25	2,650
	Zimba	6	250
	Gwembe	13	550
	Maamba	40	1,680
Luapula	Mansa	72	7,630
	Mwansabombwe	7	740
Northern	Kaputa	31	1,070
	Mbala	42	1,470
	Mporokoso	15	1,580
	Luwingu	7	740
	Chilubi	5	180
	Isoka	26	2,760
	Nakonde	12	1,270
	Chinsali	4	1,870
	Mpika	79	8,370
Eastern	Chama	42	1770
	Lundazi	50	2,100
	Chadiza	8	850
	Katete	75	3,150
	Petauke	90	3,780
	Nyimba	17	710
	Kacholola	4	420

7.5 Groundwater Development Plan in Lusaka

7.5.1 Current Situation of Water supply in Lusaka

The water supply schemes using groundwater were initiated in 1950 and more than 65 production wells with high abstraction rate have been completed to date. About 49 boreholes are now operating ,and the total current abstraction volume amounts to 111,500 m^3/day. This means that almost 40% of the water supply in Lusaka is provided from groundwater. However, construction of new boreholes is necessary to satisfy future water demand.

7.5.2 Geology and Aquifer in Lusaka

Outline of geology and aquifer is summarized in Table 7-12.

Table 7-12 Aquifer Capacity of Lusaka Dolomite and Cheta Limestone

Stratigraphic Unit	Formation	Symbol	Lithology
Quaternary to Recent	Alluvium and Colluvium	O	Clay, Silt, Sand
Katanga System	Lusaka Dolomite	N	Crystalline Dolomites
	Cheta	L	Schist
		K	Crystalline Dolomitic Limestone
	Chunga	G	Schist
Basement Complex		C	Gneiss

Geological Map (1: 200,000) is shown in Figure 7-6 and Geological section is shown in Figure 7-6. Lusaka dolomite has highest potential for groundwater development due to its porous nature. Lusaka dolomite is mainly distributed in the southern part of Lusaka, so most of the production wells used for water supply currently are located in the southern part of Lusaka as shown in Figure 7-6. However, the capacity of groundwater storage of Lusaka dolomite is limited. It appears to be difficult to abstract more groundwater from Lusaka dolomite in terms of water balance. The capacity of aquifer in the dolomite and limestone around Lusaka is shown in Table 7-13.

Table 7-13 Aquifer Characteristics of Lusaka Dolomites

Aquifer Lithology	Average Thickness of Main Aquifer	Average Yield at Pumping Test	Average Specific Capacity	Average Permeability	Average Trans-missivity	Average Specific Yield
Limestone and Dolomite	20.8 (m)	45 (m^3/hr)	24.5 (m^2/day)	8.0 (m/day)	39.0 (m^2/day)	0.068

7.5.3 Groundwater Development Plan in Lusaka

<u>Promising Development Site</u>

Dolomitic Limestone of Cheta formation is distributed in the northern part of Lusaka. This is a promising aquifer for new groundwater development, because it is separated from Lusaka dolomite by Chunga schist and has not yet been developed on a large scale. The main reason Cheta limestone has not been developed for water supply to date is that this

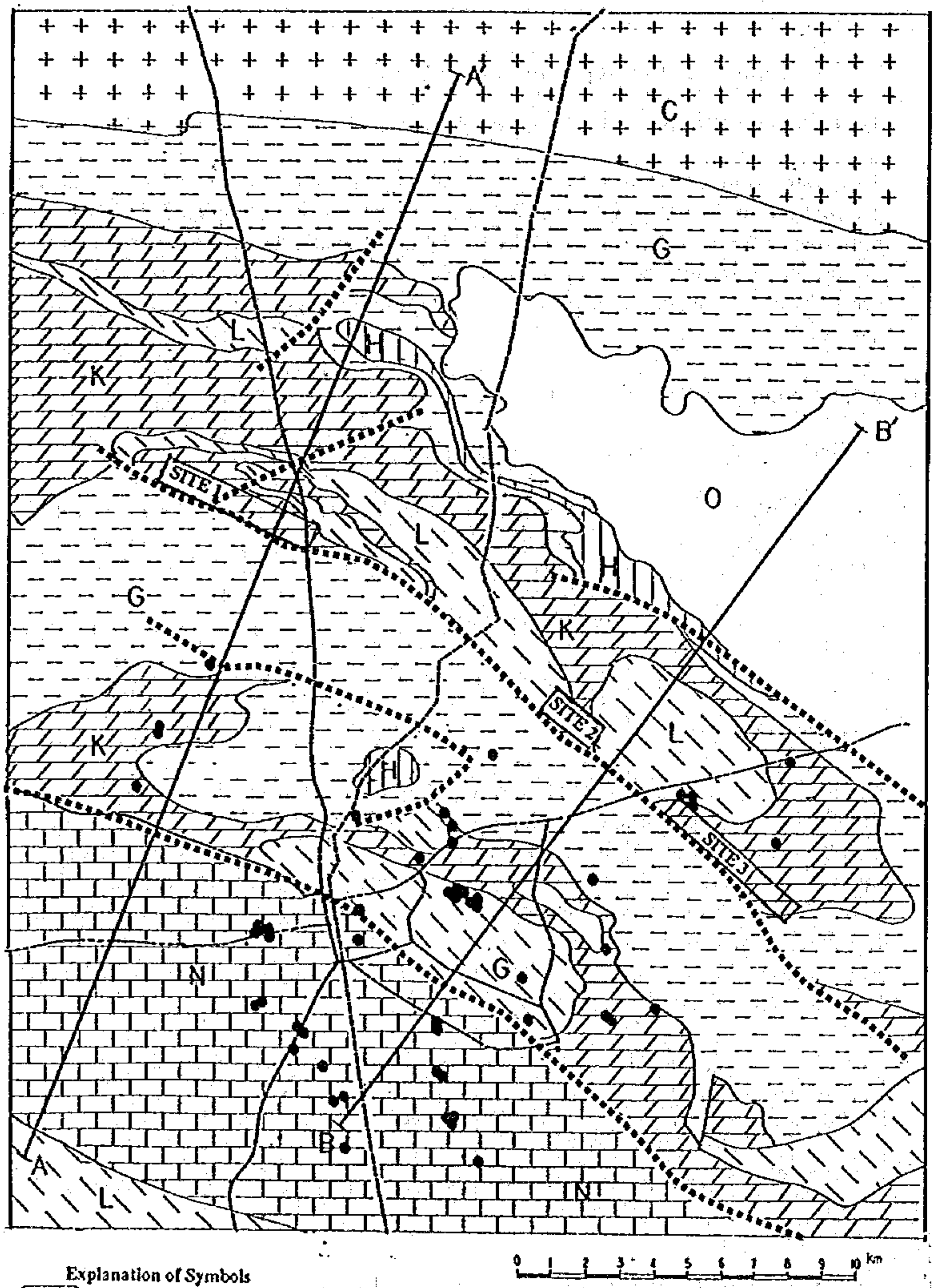


Figure 7-6

Geological Map around Lusaka

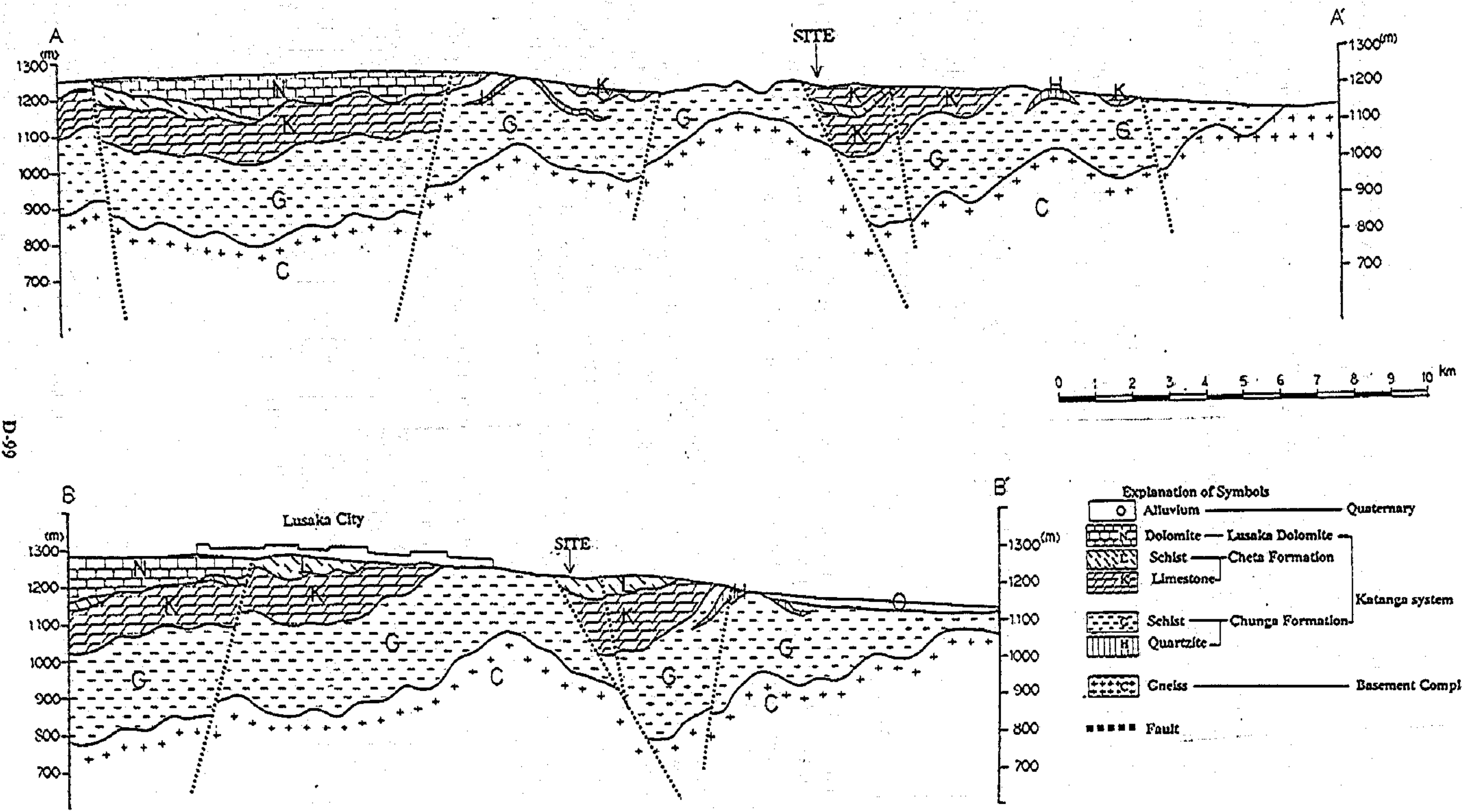


Figure 7-7 Geological Section around Lusaka

limestone is located far from the center of Lusaka. However, Lusaka city has recently expanded northward toward the Cheta formation area.

The limestone contacts the schist along a fault in the southern end as shown in Figure 7-6 and 7-7. This fault has a total length of 34 km and the probability of its existence is high. Usually many fractures developed in a fault zone and these fractures are expected to contain much groundwater. Therefore, new boreholes should be arranged along the fault line as shown in Figure 7-6.

Water Demand and Groundwater Potential of Cheta Limestone

From the future water demand, 20,000(m^3/day) = 7.3x10^6(m^3/year) of groundwater is required. On the other hand, groundwater potential of Cheta Limestone is estimated as follows;

Table 7-14 Groundwater Potential of Cheta Limestone

Area of Cheta Limestone	Average Annual Rain fall	Recharge Rate	Groundwater Recharge	Future Demand	Ratio of Demand / Potential
210 (km2)	840 (mm)	0.08	14.1x10^6 (m^3/year)	7.3x10^6 (m^3/year)	0.52

From Table 7-14, ground water development potential of Cheta limestone is estimated to be 14.1x10^6 (m^3/year). Therefore, the ratio of water demand / groundwater potential is only 52 %. Groundwater potential of Cheta Limestone is considered to be sufficient to meet new water demand

Potential Yield and Number of New Boreholes

Yield of new boreholes should be decided based on the capacity of Cheta limestone and current yield of existing boreholes in the aquifer. There is little data on Cheta limestone because most of boreholes in Lusaka are located in Lusaka dolomite. However, the capacity of Cheta limestone is considered to be almost the same as that of Lusaka dolomite. Therefore, the capacity of Lusaka dolomite including current yield can be used in place of Cheta limestone. The current yield of production wells being operated by Lusaka Water and Sewerage Company is shown in Table 7-15.

Table 7-15 Outline of Production Well of Lusaka Water & Sewerage Company

Number of Borehole	Date of completion	Depth		Diameter		Abstraction Rate*				Water Level			
						Wet Season		Dry Season		Rainy Season		Dry Season	
		Average (m)	Range (m)	Average (cm)	Range (cm)	Average (m^3/day)	Range (m^3/day)	Average (m^3/day)	Range (m^3/day)	Average (GL-m)	Range (GL-m)	Average (GL-m)	Range (GL-m)
49	1954 -1992	63	38 - 92	30	15 - 330	2,350	100 -5,000	2,200	100 -6,400	13.6	3.7 - 39.1	23.3	12.0 - 44.9

(Note) : Abstraction rate is calculated as 24 hours operation.

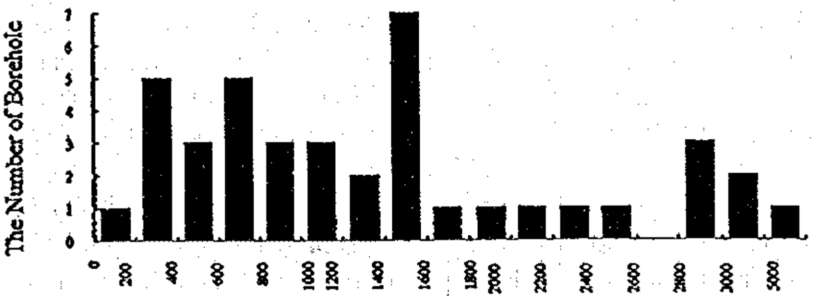


Figure 7-8 Histogram of Yield Operated by L.W.S.C

According to Figure 7-8, it seems possible to abstract 200-600 (m^3/hr) of groundwater. Assuming that a suitable abstraction rate is 400 (m^3/hr), the total number of boreholes to satisfy the water demand of 20,000(m^3/day) is 20,000/400 = 50. Actual safe yield of each borehole should be decided from step draw down test. Boreholes should be located at sufficient distances from each other for effective pumping. Therefore, they should be grouped in 3 well fields as shown in Figure 7-6 and also be adequately scattered within each well field.

Borehole design

The diameter of borehole should be 30cm, because this is the most common size for production wells which belong to Lusaka Water and Sewerage Company. Average length of borehole should be about 100m. Cheta schists are interbedded irregularly between Cheta limestones as shown in Figure 7-7. Therefore, the borehole needs sufficient length to penetrate the schist. Moreover, the deeper borehole, the greater the chance to encounter the fault fracture zone.

Geological Sounding

Geological survey is necessary to locate well fields. Electric resistivity prospecting and electromagnetic prospecting are effective for finding the fracture zone along the fault line. Test drilling is important to estimate safe yield and aquifer capacity.

7.6 Provincial Drilling Centre

From now on, a considerable number of boreholes and water supply facilities are needed in order to achieve the plan described in the Master Plan by year 2015. For this purpose, many materials and much equipment such as drilling rigs, support vehicles, pipe casing are required. Especially the construction of drilling centres in every provincial town is important. There are only 4 drilling centres in Zambia at present and this situation impedes the promotion of nation-wide groundwater development. The plan for introducing new drilling rigs and proposed drilling schedule by year are shown in Table 7-9.

7.7 Construction of Drilling Training Institute

In Zambia the techniques related to groundwater development and maintenance of facilities are still progressing and their levels are insufficient. Execution of the Master Plan is difficult without technical experts in hydrogeology, drilling, mechanical engineering and construction. On the other hand, groundwater supply facilities are often not in use because of insufficient maintenance as shown in Figure 7-9 and 7-10 (by CMMU). Under the Master

Plan, about twenty-four thousand boreholes should be completed before 2015. Training of engineers and technicians required to take a siting, operating machines and maintaining facilities, is a urgent requirement. In addition , local maintenance and management system for facilities should be established from the view point of achieving sustainable water supply. This involves training of hand pump repair workers, those in charge of sanitary education for villagers and persons to organize a users' community for rural water supply. As mentioned above, construction of the Groundwater Development Training Institute is an urgent and necessary project. Principles of training at the institute are as follows:

1) To train engineers and technicians in charge of siting, drilling boreholes, maintaining drilling rigs and water supply facilities.
2) To train staff who educate pump-repair workers, organise village committees and institute sanitary education for villagers.
3) To aim at groundwater development carried out by provincial staff.
4) To establish a training institute in Lusaka and accept trainees from provinces.
5) Training comprises both on the job training and lectures.
6) The training institute should have adequate facilities to carry out the above mentioned training.

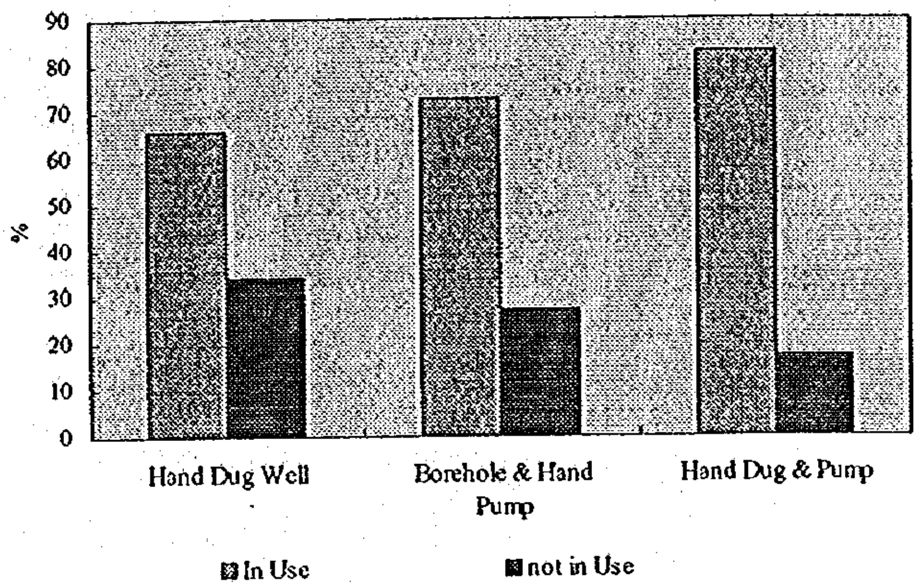


Figure 7-9 % in Use/not in Use of Water Supply Facilities in Rural Areas by CMMU

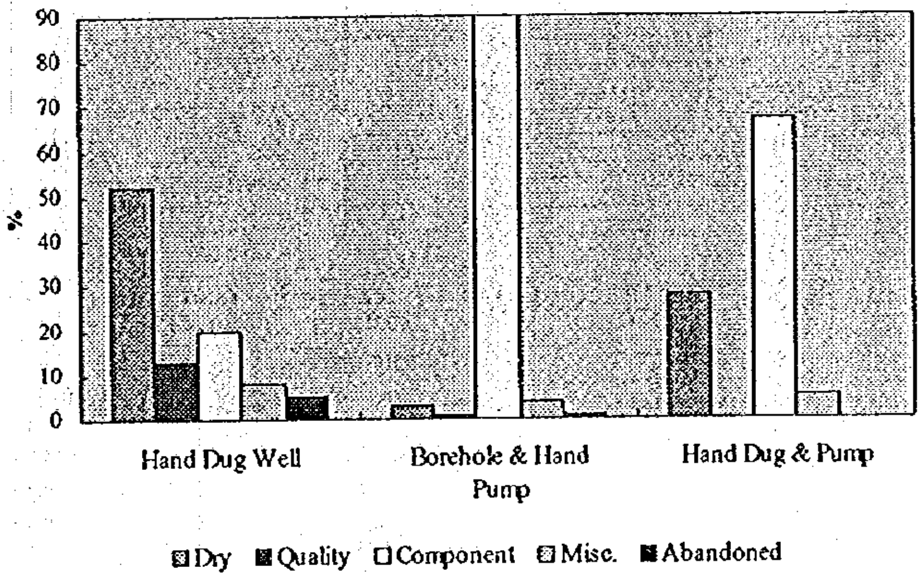


Figure 7-10 Reason Why Water Points are not in Use by CMMU

CHAPTER 8 COST OF GROUNDWATER DEVELOPMENT

8.1 Cost of Rural Water Supply

Cost of completion of a borehole for rural water supply is shown in Table 8-1 and total costs by province are shown in Table 8-2. The cost estimation includes assumption listed below:

Table 8-1 Borehole Cost for Rural Water Supply

Item	Specification	Unit Price	Quantity	Cost(K)	Cost(us$)
<Drilling and Hand pump>					
Mobilization		240,000		240,000	
Kilometer Charge		3,000		529,000	
Drilling	D=22cm	21,000	60m	1,260,000	
Casing Plain	D=15cm	22,000	45m	990,000	
Casing Perforated	D=15cm	24,000	15m	360,000	
Gravel Pack		3,000	55m	165,000	
Grouting		50,000	6m	300,000	
Pumping Test	8 hours	150,000		150,000	
Allowance		160,000	4 days	640,000	
Hand Pump		475,000	1 piece	475,000	
<Sub Total>		1,148,000		5,109,000	
Engineering Cost		10%		510,900	
< Total>				5,620,000	9,213
<Maintenance & Rehabilitation(once/10 years)>					
Mobilization		240,000		240,000	
Kilometer Charge		3,000		529,000	
Cleaning		510,000		510,000	
Hand Pump		475,000		475,000	
<Sub Total>				1,754,000	
Engineering Cost		10%		175,400	
< Total>				1,930,000	3,163
<Grand Total>				7,550,000	12,400

Table 8-2 Total Cost for Groundwater Development in Rural Areas

Province	Base Demand	
	Supply Volume (m^3/day)	Const. Cost (milUS$)
Lusaka	8,176	10.14
Copperbelt	12,780	15.85
Central	21,256	26.36
Northwestern	13,066	16.20
Western	7,936	9.84
Southern	26,372	32.70
Luapula	15,512	19.23
Northern	26,596	32.98
Eastern	37,276	46.22
<Total>	168,970	209.52

1) The cost includes drilling, installation of hand pump, maintenance of borehole and hand pump. Items of cost are the same as adopted by the DWA.
2) Size of borehole is 60m in length and 15cm in diameter.
3) The cost was estimated on the assumption that every province has a drilling centre in its provincial town. Therefore, costs of 'Distance from Centre' and 'Mobilisation' were estimated based on average distance from the provincial town to the drilling point.

4) Maintenance cost , i.e. cost of exchanging hand pump and borehole rehabilitation, was assumed to happen once every 10 years.
5) Exchange rate of US$ to Kwacha is, US$1=K610. Unit price of each item in the cost table follows that of DWA in 1995.

The cost for rural water supply is summarized as follows:

1) The difference in cost for drilling a borehole is small by province on condition that every province has a drilling centre in its provincial town. The average cost for drilling is US$9,300 per one borehole.
2) The difference in the cost for maintenance is small by province. The average cost for maintenance is US$3,200 per one borehole.
3) The average cost of one borehole including both drilling and maintenance is US$12,500 per one borehole.
4) The total cost per province is proportional to the total number of boreholes because rural water supply needs only boreholes not other facilities such as treatment facilities.

8.2 Cost of Water Supply for Small Urban Area

Cost of completion of one borehole is shown in Table 8-3 and the total costs by province is shown in Table 8-4 and by township in Table 8-5. The cost estimation involves almost the same assumptions as in the case of rural water supply, however, there are some differences as listed below:

Table 8-3 Borehole Cost for Small Urban Water Supply

Item	Specification	Unit Price	Quantity	Cost(K)	Cost(us$)
<Drilling and Power Pump>					
Mobilization		240,000		240,000	
Kilometer Charge		3,000		545,000	
Drilling	D=35cm	34,000	60m	2,040,000	
Casing Plain	D=30cm	44,000	45m	1,980,000	
Casing Perforated	D=30cm	48,000	15m	720,000	
Gravel Pack		3,000	55m	165,000	
Grouting		50,000	5m	250,000	
Pumping Test (8hr)		150,000		150,000	
Allowance		160,000	4 days	640,000	
Power Pump		7,320,000	1 piece	7,320,000	
<Sub Total>				14,050,000	
Engineering Cost		10%		1,405,000	
< Total>				15,455,000	25,336
<Maintenance & Rehabilitation(once/10 years)>					
Mobilization		240,000		240,000	
Kilometer Charge		3,000		545,000	
Cleaning		510,000		510,000	
Power Pump		7,320,000		7,320,000	
<Sub Total>				8,615,000	
Engineering Cost		10%		861,500	
< Total>				9,476,500	15,535
<Grand Total>				24,510,000	40,200