

Chapter 3

Water Resources Potential

3 Water Resources Potential

3.1 General

For the purpose of water supply planning, the water resources in the study area are examined. The water resources can be divided into two categories which are: Surface water and Groundwater. In any event, the main concept of selecting the suitable water resources for the provision of water should satisfy the following items:

- 1) Sustainability for water use, 2) Availability throughout the year, and 3) Safety as potable water source

3.2 Potential and prospects of usage of surface water

3.2.1 River water

Most rivers in the study area are categorized as non-perennial rivers. Even though some large rivers can be classified as perennial rivers, the amount of discharge in the dry season is quite limited. Therefore, stable provision of water volume and supply as drinking water from the river is out of consideration. Most of the flow rates are less than 2m³/s in the dry season, except Katar, Bilate, Kuflo and Weyto rivers. The flow rate of these rivers also decreases in the dry season. Even if an intake facility is constructed, a stable supply of drinking water throughout the year is not possible.

The water quality analysis results are shown in Table 3.1. The river water in the dry season shows some concentration of toxic parameters such as fluoride, but it reduces in the wet season to drinkable levels in terms of Ethiopian guideline of water quality. However the turbidity of the river water is very high, so the filtration system is very large and expensive, and it is difficult to maintain the facility.

Table 3.1: Water Quality of Major Rivers (Major parameters only)

Parameters	Katar		Meki		Bulbula		TikurWiha		Bilate		Gidabo		Gelana		Kulfo		Sile		Weyto	
	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug
pH	7.84	7.29	7.94	7.25	7.8	7.9	7.21	6.91	8.69	8.28	7.45	7.86	8.15	7.94	8.0	7.9	8.04	8.03		
TDS(mg/l)	94	39	142	43	231	211	175	109	1014	64	39	67	52	60	69	74	98	91		
DO(mg/l)	197	83.3	294	90.4	6.2	6.8	2.4	3.2	4.7	6.8	6.0	5.8	6.0	6.7	5.6	6.7	4.1	6.8		
EC(SS/cm)	4.9	6.6	5.6	6.4	482	442	368	229	2120	135	83	140	110	128	145	156	206	193		
TSS(mg/l)	94	312	530	3,600	96	122	196	68	168	1390	501	348	649	1480	450	542	1474	1036		
TurbidityNTU	40	255	470	-	35	83	104	36	109	1242	256	306	321	1353	148	388	546	720		
Na(mg/l)	16	5.2	29	15	54	60	57.5	35.0	450.0	12.0	6.6	7.0	5.2	6.0	7.9	7.7	11.6	13		
K(mg/l)	5.1	3.5	10.1	5.9	12.3	10.6	13.5	6.0	21.5	8.1	2.9	1.9	1.2	1.3	1.5	1.5	3.1	2.0		
Ca(mg/l)	15.2	8.0	25.6	4.8	25.6	20.8	8.8	9.6	16.8	15.2	4.8	14.4	14.4	13.6	14.4	15.2	19.2	19.2		
Mg(mg/l)	4.86	1.944	6.804	0.486	8.75	6.8	4.86	2.92	2.43	2.43	1.94	4.37	1.94	4.86	5.35	4.86	6.8	5.83		
HCO3(mg/l)	82	12.2	108	29.28	202	190	124	75.6	568	58.56	30	61	46	48.8	56	68.32	68	78.1		
Cl(mg/l)	1.5	2.5	5.5	2.0	14	12.5	13.0	13.5	65.5	4.5	2.0	6.0	1.3	2.0	2.0	7.5	5.5	8.5		
F(mg/l)	0.5	0.28	1.34	0.22	1.49	1.72	1.7	1.25	16.0	0.97	0.35	0.91	Trace	0.22	0.79	0.48	0.53	0.65		
SO4(mg/l)	1.27	3.04	18.62	2.4	6.14	0.4	40.73	2.2	44.65	0.18	14.18	0.6	3.6	5.1	0.85	0.62	2.33	0.09		
SAR	0.92	0.43	1.3	1.74	2.47	2.93	2.7	2.11	59.2	0.87	0.32	0.29	0.18	0.25	0.30	0.30				

The rivers in the study area do not have capacity to provide the stable potable water supply, and the treatment facility for turbidity is very large, expensive and difficult to maintain. Therefore the potential of river water as a drinking water source is low.

3.2.2 Lake water

As above, the main eight lakes exist in the study area of RVLB. Out of eight lakes, Lake Chew Bahir is located in the southernmost part of RVLB, and Lake Chew Bahir is not considered as it is a salt lake and it has poor water quality and quantity (volume) for potable water. The water level of the major seven lakes has been recorded since the early 1970s. The variations by year and by lake are obvious; however, the water level change of the lakes is not large in the long term. The water balance of the lakes, recharge and outflow (evaporation, groundwater outflow) seems to be well balanced. Therefore, securing a sufficient volume of drinking water seems to be possible. However, the problem is not the quantity of water but the quality.

Table 3.2: Water Quality of Major Lakes

Parameters	ZiwayLake		LakeAbiyata		LakeShala		LakeLangano		LakeAwasa		Abaya		Chamo	
	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug	Apr	Aug
pH	8.7	8.0	10.1	10.0	9.8	9.8	8.9	9.2	9.0	9.0	9.1	9.1	9.6	9.4
TDS(mg/l)	220.0	214.0	41.5	41600.0	23160.0	21300.0	923.0	959.0	424.0	408.0	628.0	540.0	1004.0	899.0
DO(mg/l)	460.0	445.0	2.9	2.3	2.8	2.7	1932.0	1941.0	6.7	6.7	6.1	6.8	6.3	6.8
EC(SS/cm)	6.0	6.7	83.6	84250.0	48150.0	44000.0	6.7	6.8	886.0	848.0	1319.0	1116.0	2104.0	1827.0
TurbidityNTU	46.0	54.0	22.0	26.0	22.0	26.0	77.0	97.0	13.0	16.0	112.0	89.0	59.0	66.0
Na(mg/l)	63.5	59.0	12940.0	13100.0	6000.0	6950.0	405.0	375.0	162.0	168.0	246.0	222.0	430.0	425.0
K(mg/l)	11.9	11.2	6284.0	6300.0	240.0	244.0	23.5	23.0	26.0	30.0	19.0	16.0	20.5	20.0
Ca(mg/l)	22.4	20.8	3.2	4.0	0.0	6.4	4.8	4.8	11.2	10.4	15.2	14.4	6.4	8.0
Mg(mg/l)	7.3	6.3	0.0	0.0	3.9	0.0	1.5	0.5	4.9	5.4	1.9	2.9	7.8	7.8
HCO3(mg/l)	166.0	185.0	6286.0	6344.0	4652.0	244.0	426.0	505.0	194.0	310.0	354.0	395.0	566.0	568.0
Cl(mg/l)	12.5	12.0	10778.0	10900.0	3250.0	6300.0	182.0	200.0	27.0	51.0	63.5	107.5	130.0	300.0
F(mg/l)	1.5	1.6	370.0	370.0	156.0	220.0	7.9	10.2	7.7	9.6	8.2	8.0	9.3	8.9
SO4(mg/l)	1.4	25.4	17.3	15.8	5.2	12.6	2.1	1.2	0.1	4.8	3.4	9.7	1.2	5.2
SAR	3.0		653.0	267.0			41.5		10.2		15.7	27.0		

Figure exceeds the Ethiopian Standard

(Sampled in 2007, refer to Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project (June 2008, MOWR, Halcrow, GIRD Consultants))

The major substances and parameter values of these lakes are indicated in Table 3.2. Most of the lakes have problems in the substances and parameters of pH, TDS, turbidity, Na, and Cl and savor and the lakes except the Lake Ziway, Awassa and Abaya are not suitable for drinking water in terms of the high salinity. Furthermore, Fluoride exceeds the limit of both Ethiopian and WHO standards. Only Lake Ziway exceeds WHO standards, but is lower than Ethiopian standards. The overall review of the water quality of the major lakes is poor. Lakes Abijata and Shalla have an extremely high fluoride content of more than 100mg/l throughout the year. The water is rather harmful to human health.

The review indicates that the total volume of the lakes in the study area has huge a potential to be used as a water resource in terms of its volume, but the consideration of the water quality shows them to be inadequate for domestic drinking water

3.3 Groundwater potential

The result shows the potential drinking water source may be limited to the groundwater resources in accordance with the review of surface water potential as a potable water source. The advantage of the groundwater, in particular deep groundwater, usage as a potential potable water source is summarized as follows;

- 1) Basically the water is clean for the drinking water in terms of water quality, and the quality is not largely affected by seasonal fluctuations.
- 2) The amount of water is steady throughout the year, and necessary volume of water can be extracted by type of water supply facility
- 3) Knowing that good aquifers exist below allows for flexibility in the point of source extraction. Therefore, the water supply facility can be provided within the vicinity of the community.

From the past, more than ten thousand wells and springs have been used as potable water sources in the Study area. It should be noted that not all of the point sources have the above mentioned characteristics of a potable water source. Hand dug wells and shallow wells which target the shallow aquifer in the Alluvium can be easily affected not only by the surface pollution such as cattle disposal and fertilizer, but also seasonal fluctuation of the water level. This means that these will not provide a stable water supply. Therefore, the identification of a good aquifer which satisfies the above mentioned criteria shall be put in first priority. The investigation of groundwater potential was clarified by the distribution of good aquifers, as well as its quality and quantity as an aquifer unit.

3.3.1 Classification of aquifer units

Aquifer can be subdivided into the following three lithofacies depending on the aquifer units.

- 1) Alluvium and lacustrine deposits
- 2) Pleistocene tuff, tuff breccia and basaltic rock units
- 3) Plio-Pleistocene tuff and basalt

In the description of aquifer in the existing wells, basalt and ignimbrites are common. It can be assumed that fracture and fissures are well developed in the volcanic rocks (such as rhyolite, basalt) by the tectonic movement. Moreover, in between those rock units, tuff with pumice and scoria is abundant. These tuffaceous units have good permeability, however the unit itself cannot be a good aquifer if an aquiclude exists below this formation. The relation between lithofacies and its potential as an aquifer is presented in Table 3.4 in reference with the aquifer classification of Hydrogeological Map of Ethiopia (2002, GSE) (see Table 3.3). The aquifer classification in Table 3.4 is expressed using the combination both the aspects of aquifer (No & description) and the productivity classes in Table 3.3.

Table 3.3: 1:2,000,000 Hydrogeological Map - Aquifer Classification and Definitions

No.	Description	Lithology	Productivity Classes	
1	Extensive aquifers with intergranular permeability	Unconsolidated sediments, alluvium, elluvium, colluvium, lacustrine sediments, poorly cemented sandstone	A	High
			B	Moderate
			C	Low
2	Extensive aquifers with fracture and/or karstic permeability	Consolidated sediments and metamorphosed carbonate: Limestone, sandstone, shale, marl, evaporite marble	Not distributed in the Study area	
3	Extensive aquifers with fracture permeability	Volcanic rocks, basalts, rhyolites, trachytes , ignimbrites	A	High
			B	Moderate
			C	Low
4	Localized aquifers with fracture and intergranular permeability	Non carbonate metamorphic rocks, granitic intrusives, dolerites	C	Low
			D	Poor
5	Main geothermal areas	Common occurrence of thermal groundwater in fractured volcanic rocks and subordinate unconsolidated sediments	Not distributed in the Study area	

Table 3.4: Aquifer Classification of RVLB

Period/Epoch	Stratigraphy	Name of strata	Major Lithology	Aquifer Code	Nature of Aquifer	Remarks
Holocene	AI / Q	Alluvium, unclassified fluvial deposits	Fine sand - mud	1B	Aquifers with intergranular permeability	Good permeability at the sand layer and aquiclude at clay
	lac 2	Bulbula Lacustrine Deposits	Lake deposits such as gravel, sand and mud	1C	Aquifers with intergranular permeability	Permeability is high at sand and gravel. Clayey layer may become aquicard
	Pm volcan rb	Corbetti Pumice Flow & Fall Deposits/ Corbetti Rhyolitic Deposits	Rhyolite lava flows, pumice falls, pumice flow deposits and Obsidian lava flows	3C	Aquifers with fracture permeability	It may be good aquifer if the lower layer become aquicard
	lac 1	Butajira Recent Basalt	Basalt lavas and reddish brown basaltic scoria	3C	Aquifers with fracture permeability	Low permeability at the massive basalt. It may be good aquifer if the lower layer become aquicard
	Y	Meki Lacustrine Deposits	Lake deposits such as poorly-sorted gravel, sand, pumice, tuff, and volcanic sand	1B	Aquifers with intergranular permeability	It may be good aquifer if the lower layer become aquicard
	ob	Langano Poorly Welded Pumiceous Pyroclastics	Yellowish white rhyolitic pumice tuff	1B	Aquifers with intergranular permeability	Partially good aquifer at the existance of lower aquicard
	W	Kulmusu Highly Welded Tuff	Rhyolitic to andesitic welded tuff	3B	Aquifers with fracture permeability	The lower aquicard is essential, however it has good potential aquifer
	G	Ketar River Acidic Volcanic Sedimentary Rocks	Rhyolitic tuffs and pumice tuffs	1B	Aquifers with intergranular permeability	The permeability is high knowing that the massive aquicard exists at lower layer
	tb	Gonde Strongly Green Welded Tuff	Rhyolitic to andesitic welded tuff	3A	Aquifers with fracture permeability	The fractures and fissures are well developed and form good aquifer in the area
	ba	Adami Tulu Basaltic Pyroclastics	Basaltic tuff breccias and lapilli tuffs	3A	Aquifers with fracture permeability	The fractures and fissures are well developed and form good aquifer in the area
Pleistocene	ba	Ogolche Pleistocene Basalt	Massive basalt lavas	3B	Aquifers with fracture permeability	Even massive basalt, fracture and fissures are partially developed. The fissure zones are recognized as good aquifer
	lak e	Lekansho Lacustrine Deposits	Lake deposits such as gravel, sand and mud	1C	Aquifers with intergranular permeability	Semi consolidated formation. Partially good aquifer has been formed
	rh	Gademotta Rhyolite	Rhyolite lava flows and rhyolitic tuffs	3A-3C	Aquifers with fracture permeability	The layer is defined as the upper portion of hydrogeological basement. Fracture basalt, ethyolite and permeable pumice layer has capacity of good aquifer
	NQs	N2b Basal NQs	Basalt lavas and basaltic pyroclastics	3A	Aquifers with fracture permeability	
	P I ocene	N1_2n Rhylolite	Plagioclase rhyolite tuff	3C	Localized aquifers with fracture and intergranular permeability	
Tertiary	N1n	N1n Basalt	Andchar Basalt	3B	Localized aquifers with fracture and intergranular permeability	
	N1ar	N1ar Rhylolite	Rhyolite			
	Ngs	Sharengela Rhylolite	Rhyolite piles and necks			
	Ngu	Upper Basalt	Porous basalt lavas	3C	Localized aquifers with fracture and intergranular permeability	
	Ngb	Beyana Tuff	Lapilli tuff with minor laminated tuff			
Miocene	Ngm	Middle Basalt	Porphyritic basalt lavas			
	Pgs	Shole Welded Tuff	Densely-welded rhyolitic welded tuff	3C	Localized aquifers with fracture and intergranular permeability	
	Pgl	Lower Basalt	Porphyritic basalt lavas			
Eocene- Orogenic	Mes	Adigrat Sandstone, Antaro Limestone	Sandstone, Shale and Limestone	4D	Localized aquifers with fracture and intergranular permeability	
	Pre	Biotite Gneiss, Pegmatite	Biotite Gneiss, Granite, Biotite Metagranite			
Mesozoic						References: (1) Laury and Abritton 1975, (2) Mihot et al. 1980, (3) EIGS-GIE 1985, (4) Woldegabriel et al. 1990, (5) GSE 1994, (6) GSE 2002, (7) EWTEC 2008
Pre-Cambrian						

3.3.2 Character of aquifer units and wells

The aquifers determined in the Study were compared to the description of aquifers in the existing well inventory. The distribution and classification is presented in Table 3.5. Description of existing well inventory is not accurate to correlate respective lithological description of aquifer. Therefore, the typical key composition (such as pumice, scoria, ignimbrite) of each description was referred to as the major aquifer units. Ignimbrite is most common lithology in the existing wells and corresponds to the Pleistocene rhyolite – andesitic welded tuff (from the comparison between JICA wells and existing wells). The major aquifer of Pleistocene basaltic tuff breccia – volcanic breccia can be referred to as scorriaceous tuff.

Most common groundwater source is extracted from Pleistocene tuff, tuff breccia and basaltic rock units (81% of total borehole water source). The members of this aquifer are, pumice tuff, welded tuff, tuff breccia and basalts (from upper formation). This aquifer is distributed from east of Lake Abaya to north of Lake Ziway.

Aquifer of Quaternary Sediments and lacustrine mainly consist of sand, gravel and silts. It is distributed throughout the entire study area (lacustrine is distributed chiefly in the area north of Lake Awassa). The Study referred to the water source mainly from boreholes and springs. However, most of hand dug wells are utilizing this shallow aquifer.

Tertiary rhyolitic rocks are supposed to be in a hydrogeological basement of the entire area. The older formations are commonly distributed in the southern part of the Study area. This old formation (Precambrian – Tertiary) has some potential as aquifer but is only distributed in a limited area, and utilized only 6% of total existing boreholes.

Table 3.5: Major Aquifer and Correlation with Existing Borehole

	Aquifer	Symbol	Major Lithology	Well No* Description of Existing We	Distribution
1	Quaternary Sediments and Lacustrine	Al/Q	Alluvium	25 sand, gravel, alluvium, clay	distributed in entire RVLB
		Lac1	Lake deposits such as gravel, sand and mud	4 clay, sand, lacustrine	locally distributed in northern part of RVLB and surrounding Lake Awassa area
2	Pleistocene Tuff, Welded Tuff, Basalt	W	Rhyolitic tuffs and pumice tuffs	56 tuff, pumice tuff, pumice, sandy tuff	continuously distributed from Ziway to Dila area
		G	Rhyolitic to andesitic welded tuff	35 ignimbrite, welded tuff	continuously distributed from Ziway to Dila area
		tb	Basaltic tuff breccias and lapilli tuffs	30 tuff breccia, scoricious basalt, scoria	locally distributed in entire RVLB
		ba	Massive basalt lavas	71 basalt, fractured basalt	locally distributed in entire RVLB
3	Tertiary Tuff and Basalt	rh, N2b	Rhyolite lava flows and rhyolitic tuffs	11 rholite, rholidic tuff, pyroclastics, trachyte	distributed in entire RVLB
		Nin, Ntar	Rhyolitic tuffs, basalt	4 fractured basalt, basalt	continuously distributed in the south of Dila

* Some existing wells described Sand, Gravel, clay are not considered if not evidence to correlate the Aquifer

It is concluded that satisfactory water source shall be Pleistocene tuff, welded tuff, basaltic rock units which are largely distributed in the northern part of Lake Abaya of the Study area. This aquifer satisfies the requirement of quality, quantity and location of extraction. The extraordinary event of rift valley formation and followed by the creation of faults made enough fissures and pore zones in these volcanic rocks for the storage of huge amounts of

groundwater.

3.3.3 Aquifer potential evaluation

Three (3) aquifers were identified by the study of existing well inventory, new borehole data and the geological survey. The aquifers are classified into the following criteria.

Aquifer 1 [Alluvium and lacustrine deposits] = 1B – 1C

Aquifer 2 [Pleistocene tuff, tuff breccia and basaltic rock units] = 3A – 3B (tuff = 1B)

Aquifer 3 [Plio-Pleistocene tuff and basalt] = 3A – 3C

Discharge (Q, l/sec), Specific Capacity (l/min/m) and Transmissivity (m²/day) are shown by each layer of 3 aquifers (refer to Table 3.6). Aquifer 2 gave highest score in discharge, specific capacity and transmissivity. Basaltic tuff breccia – volcanic breccia scored mean discharge of 6.3 l/min, mean specific capacity of 134 l/min/m and mean transmissivity of 242 m²/day. Note that some minimum figures fall below 1 as the Aquifer 2 classified as extensive aquifer with fracture permeability. However, at least 3-7 l/sec discharge (with maximum of more than 50 l/sec) can be expected if the bore hole hits the good fissure zone.

Aquifer 1 is also a good aquifer according to its nature of formation (sand, gravel). Most of this aquifer is shallow and unconfined. It should be noted that this aquifer is easily affected by surface pollution as well as seasonally affected by the water table.

Aquifer 3 is mainly distributed at the northern portion of entire study area. This aquifer is also stored in fissure in the volcanic rock. The distribution of this rock unit is said to be very limited. The aquifer mainly occupies at the northern part of the study area, and it may become potential aquifer in those remote areas in the north.

In conclusion, the most potential aquifer in the area is Aquifer 2 in the entire study area

Table 3.6: Aquifer Parameters

	Aquifer	Symbol	Major Lithology	Q(l/sec)			Specific Capacity (l/min/m)			Transmissivity (m ² /day)		
				AVE	MAX	MIN	AVE	MAX	MIN	AVE	MAX	MIN
1	Quaternary Sediments and Lacustrine	Al/Q	Alluvium	2.8	6.5	0.2	31.9	72.6	3.9	75.3	92.6	43.0
		Lac1	Lake deposits such as gravel, sand and mud	4.6	7.3	1.5	20.8	40.9	0.6	69.0	137.0	1.0
2	Pleistocene Tuff, Welded Tuff, Basalt	W	Rhyolitic tuffs and pumice tuffs	5.5	47.0	0.2	42.4	106.6	1.0	42.5	84.8	0.2
		G	Rhyolitic to andestic welded tuff	4.6	18.5	0.2	31.2	91.2	0.3	65.3	173.9	0.0
		tb	Basaltic tuff breccias and lapilli tuffs	6.3	22.0	0.1	134.6	414.6	2.5	242.0	914.4	12.5
		ba	Massive basalt lavas	2.9	7.7	0.2	19.3	55.1	2.9	77.7	211.7	2.7
3	Tertiary Tuff and Basalt	rh, N2b	Rhyolite lava flows and rhyolitic tuffs	4.9	19.6	0.6	11.6	25.6	3.8	9.3	24.8	0.1
		N1n, N1ar	Rhyolitic tuffs, basalt	3.9	6.0	2.0	13.5	13.5	13.5	12.6	12.6	12.6

Figure 3.1 shows the discharge of the well and springs. In general, high production (yield) water sources can be found at the area between slope along the rift ridge and flat lowland. High groundwater gradient can be expected at the escarpment. High discharge cannot be expected at the escarpment both located at the eastern and western ridge of the valley.

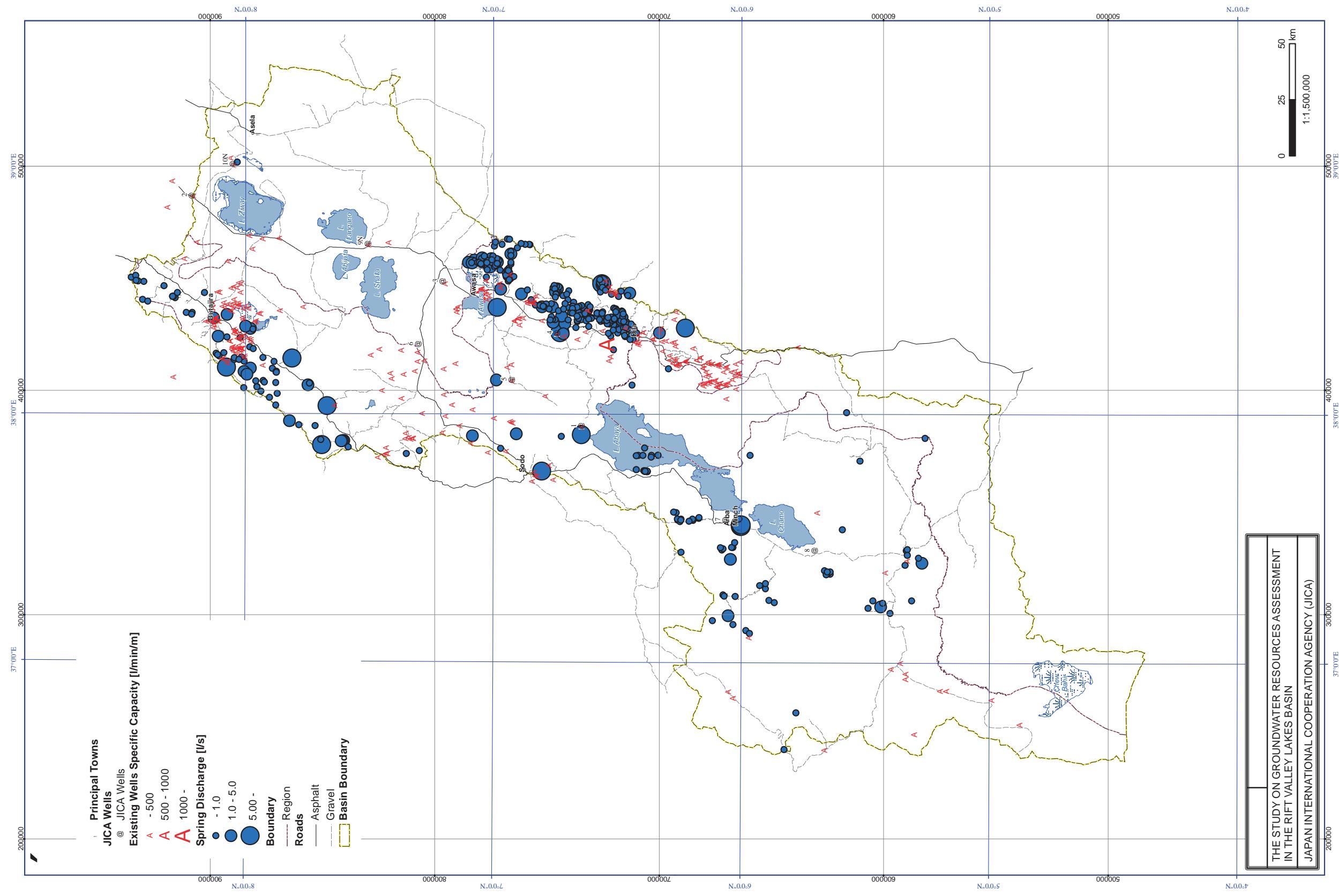


Figure 3.1: Discharge of Water Resource

3.3.4 Groundwater recharge

For the evaluation of the groundwater potential in the study area, it is very important to grasp the amount of groundwater recharge. As there are neither lysimeter measurement data nor long term groundwater level records that can be used for the analysis for the calculation of groundwater recharge, the recharge amount can be estimated by the calculation of groundwater discharge amount using equality of the recharge and discharge amounts in a long hydrological cycle.

The river water is formed by surface runoff from the precipitation and groundwater discharge to the river. The former is the surface runoff and interflow, the latter is discharge into rivers, discharge into lakes, and discharge to outside the basin, and so on. The most important component is considered to be the discharge into river streams. The two methods (programs: PART (USGS,2007) , RAT (Monash University, 2006)) in this study were selected since both are considered to be reliable and used to separate the groundwater (base flow) component and direct runoff component from daily river flow data. Finally, the average values of BFI (Base Flow Index) by two above programs were calculated in each lake. The Table 3.7 was shown as the groundwater recharge (= Base flow) calculated using the evaporation in each lake that the rainfall was subtracted multiplied by BFI. The portion of groundwater recharge out of the total water resources amount is 1965.7Mm³. As described herein, the proportion of groundwater discharge to recharge is about 20% at the most and about 0.13% at the least in each sub-basin.

Table 3.7: Groundwater Recharge Amount in Major Lake Basins in RVLB

Name	Evapo _{net}	BFI	GWR	Others	Total
Abaya	585.1	0.62	362.8	14.6	377.4
Abijata	106.5	0.60	63.9	2.7	66.6
Awassa	91.6	0.45	40.8	2.3	43.1
Chamo	282.2	0.68	191.9	7.1	199.0
Chew Bahir	412.7	0.74	305.4	10.3	315.7
Langano	423.0	0.65	275.0	10.6	285.5
Shalla	185.9	0.27	50.2	4.6	54.8
Ziway	977.7	0.60	586.6	24.4	611.1
Others	19.5	--	12.1	0.5	12.6
Total	3084.3	--	1888.6	77.1	1965.7

Evapo_{net}: Net Evaporation amount from lakes in rift valley area (Mm³).

BFI: Base flow index.

GWR: Groundwater recharge amount (Mm³).

Others: Groundwater recharge amount used by all other water consumption (Mm³).

Total: Total groundwater recharge amount for the lakes (Mm³).

3.4 Hydrogeological map and groundwater flow

3.4.1 Hydrogeological map

The hydrogeological map is established based on the hydrogeological features and characteristics of strata in reference with existing well inventory and survey results. The map of all areas is shown in Figure 3.2 as the hydrogeological map of A3 size and one set of four papers (scale: 1/250,000) in all RVLB are attached in the Main Report. The hydrogeological characteristics will be described based on the hydrogeological map.

The hydrogeological feature of RVLB can be divided into two major areas, that is;

1. Northern Pleistocene volcanic zone from Ziway to Dila
2. Older volcanic zone and basement rocks at the southern region of Lake Abaya

Both areas have the feature of alternation of volcanic rocks (such as tuff, tuff breccia, pyroclastics, welded tuff and basaltic or rhyolitic lava) by several volcanic activities. However, the hydrological conditions are quite different.

a. Unconsolidated Quaternary sediments surrounding Rift Valley Lakes

Lacustrine deposits (lac2, lac1) are represented by sand, gravel, mud layers which are distributed in the areas surrounding Lake Ziway to Lake Awassa, Lake Abaya, Lake Chomo and Chew Bahir (with some salt lakes). Quaternary sediments (Al, Q = sand, mud and gravel) are distributed around the lakes and rivers. In general, lacustrine deposits are relatively more consolidated than Quaternary sediments. The lacustrine deposit may have lower production capacity than Quaternary deposits as it includes some impermeable clay layers. However, as above, the mean discharge rate of lacustrine is higher than Quaternary deposits comparing the aquifer coefficient. In general these deposits occupy a lower land of the rift valley with the scaling of lakes and mainly contain shallow aquifers. The aquifer is mainly used for the hand dug well and ring wells with depths up to 8 -12 m. However, shallow wells at north western flat of Lake Ziway – Shalla, and lake itself produces high fluoride water (above Ethiopian drinking water standard). The circumstance of the aquifer in this category is also highly affected by the surface water condition such as rainfall and heat. Therefore this aquifer does not satisfy the domestic standards for potable water sources.

The high groundwater potential areas in this type of deposits are distributed at relatively highland area of north eastern to eastern of Lake Ziway and low land of western Lake Ziway, in particular, alluvial and Lacustrine deposits were recognized widely and thickly in western area of Lake Ziway with high groundwater potential, and the areas of flat along the Bilate river and northern Lake Abaya also have high groundwater potential.

b. Hydrogeological condition of northern Pleistocene volcanic zone

The main aquifer in this area is Aquifer 2 [Pleistocene tuff, tuff breccia and basaltic rock units] which printed as light blue color in the Hydrogeological map. Late volcanic activities of late Pleistocene – early Holocene produced a lot of members of volcanic rocks. These members are basaltic pyroclastics with scoria (rb), pumice tuff (Pm), tuff, volcanic breccia, Basalt (volcan) of which (rb) and (Pm) has extensive permeability with high porosity. The condition to be an aquifer is the existence of impermeable layer below this formation. The rock units in this category are abundant in Ziway area. Most of these units do not contain

aquifers, with some exceptions of very local storage of water.

Early Pleistocene volcanic deposits, rhyolitic tuff – tuff (W), rhyolite – andesitic welded tuff (G), basaltic tuff breccia – volcanic breccia (tb), basalt (ba), are the most promising potential aquifers in the entire Study area. Lake deposits will be an aquiclude consist of well consolidated conglomerate and mud stone. Therefore, the upper formations, if the certain conditions allow storage of water, can become a good aquifer. The condition is the degree of developing fissures and cracks by the mass movement of the crust during the formation of rift. The upper tuff (W) is also potential aquifer knowing that aquiclude exists at lower formation. About 80% of boreholes (drilling hole) extract water from this early Pleistocene volcanics.

Hydrogeological map seems to be covered with the rhyolitic tuff – tuff (W) layer, but it should be noted that the other volcanic members exist underneath. The topographical features of high yielding aquifers are distributed in the emerging point of escarpment and flat of the valley. The fissure developed in the volcanic rocks at the escarpment by the rift activity and the permeability became higher. The emerging point provides favorable water pool between fissure rich rock units and those without fissures.

This aquifer has developed parallel to the original valley shape. Direction of water flow is also parallel to the valley which means it has a steep flow down below the escarpment and runs into the middle of the valley. The final destination of the groundwater is not lakes but the subsurface groundwater valley existing between Lake Abaya and Lake Awassa.

High potential area for water extraction are northern Lake Abaya where chiefly occupied by this type of volcanic rocks in general. Specific areas are at the intersection of eastern escarpment to central plane the valley of eastern Lake Ziway to eastern Bilate River, and at the intersection of western escarpment to central plane of rift valley of Awassa to Dila.

c. Hydrogeological condition of southern Tertiary volcanic and basement

The light brown and khaki colored portion on hydrological map is this formation. Major lithology of this rock unit is alteration of Tertiary basalt and rhyolite and its members. Mesozoic sandstone, limestone (Mes) and Precambrian biotite gneiss, granite (Pre) are also observed in limited area. These formations considered to be the hydrological basement rocks in the entire basin. However, very limited but some formations contain a local aquifer. Plio Pleistocene fissure rich rhyolite lava and tuff (rh) are potential storage for groundwater. Basalt lava and basaltic pyroclastics (N2b) are also considered as potential aquifers. There are some other potential aquifers such as tuff and basalt (N1n) and rhyolite and basaltic lava (N1ar), and the JICA observation wells obtained the high productivity as the results of pumping test in the distributed area of old basalts (Pgl) at Arba Minch and its surrounding area. But the continuity of these layers is unclear and not well understood. The potential of the aquifer is limited in the means of its production. The well information in this area is very limited, therefore the qualitative feature and the flow direction of aquifer is not known. The Mesozoic and Precambrian deposits are formulated by hydrogeological basement.

In general, the groundwater potential of extracting water is relatively low in these geologic formations. However, the lack of drilling data at this area prevents further analysis for the groundwater distribution and its nature. It shall be noted that further investigation required by adding more drilling and its inventory.

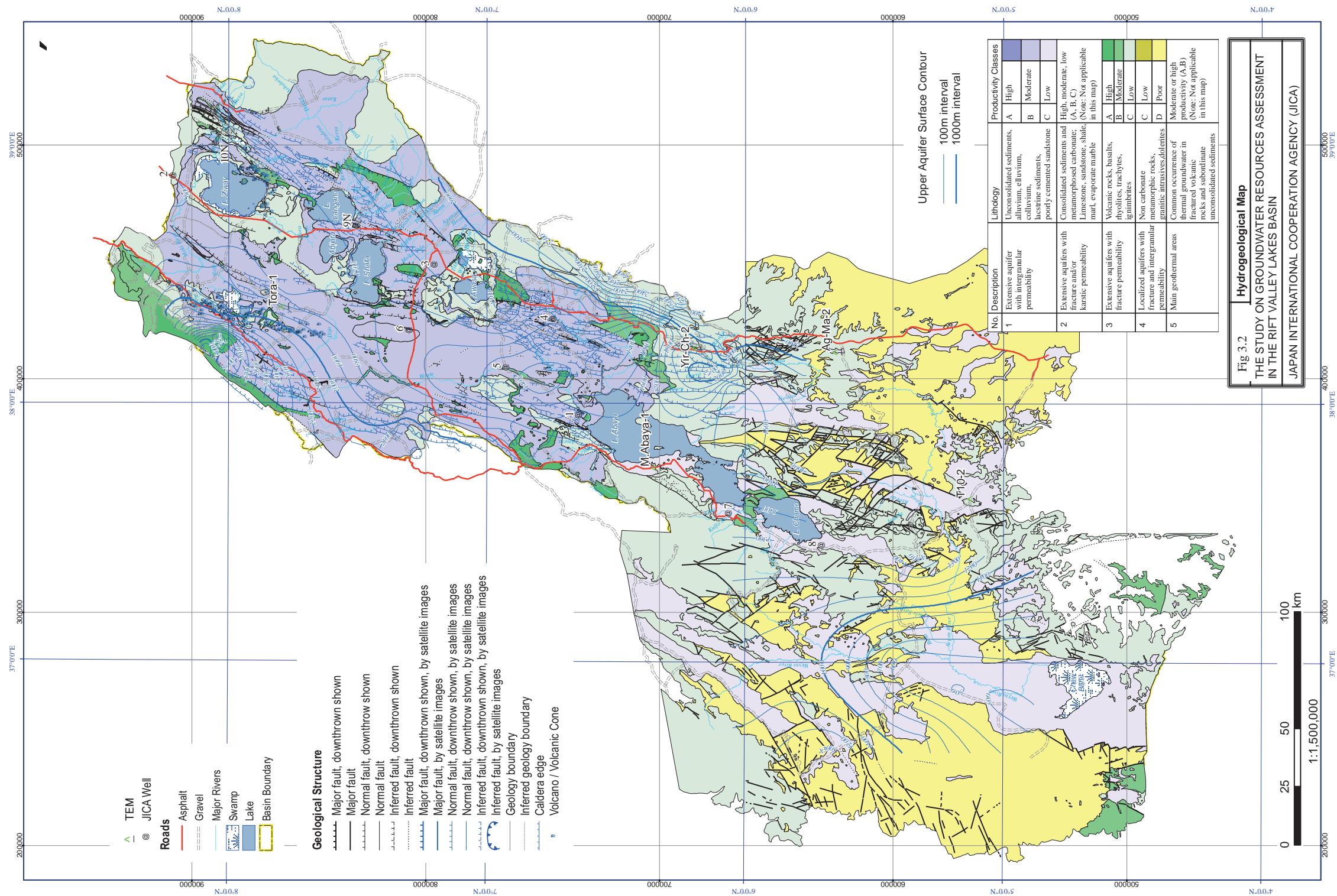


Figure 3.2: Hydrogeological Map in RVLB

3.4.2 Groundwater flow

a. Hydrogeological profiles

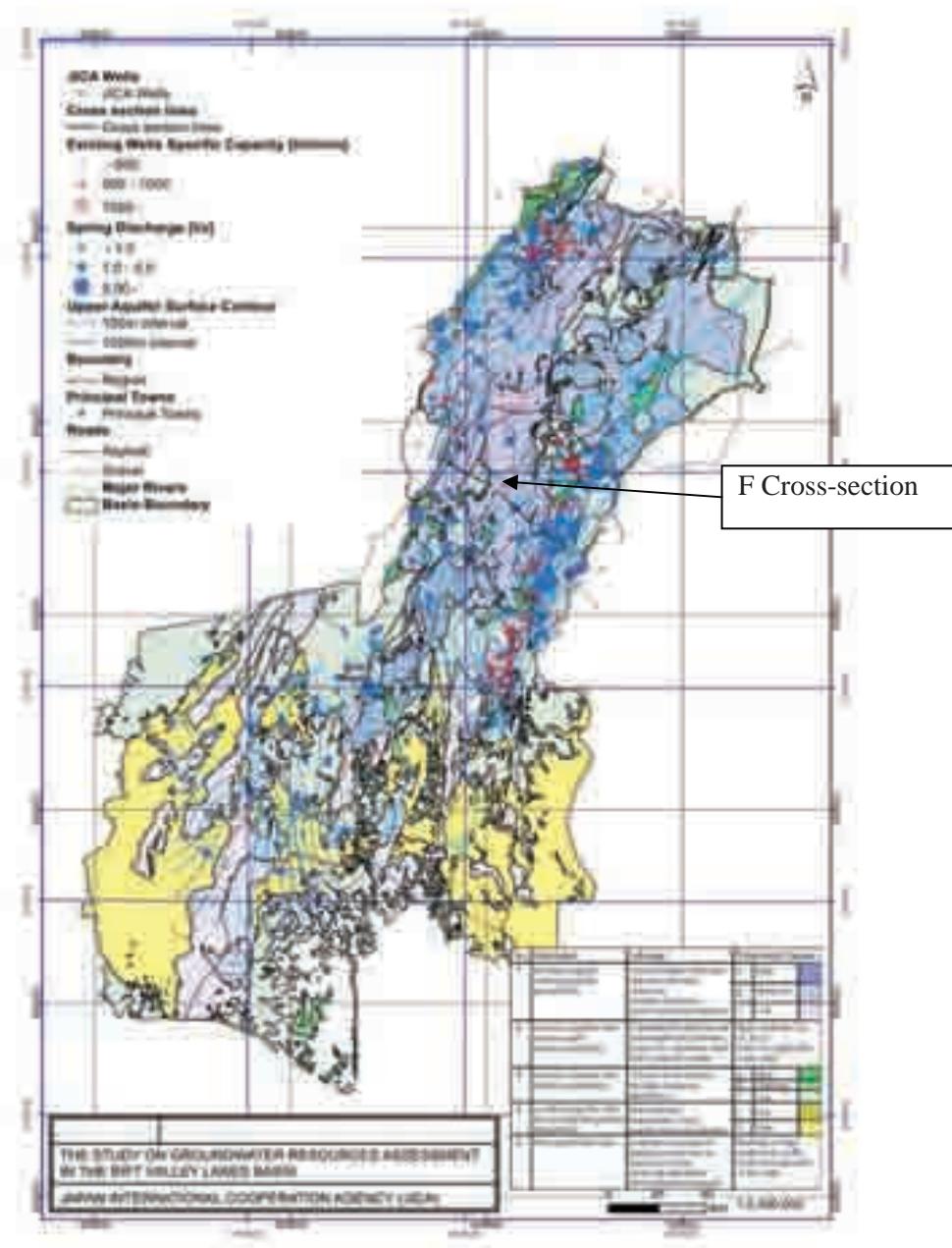
The major aquifer in the entire study area is early Pleistocene volcanic formations. The upper surface and lower surface of the aquifer has been tracked and its cross sectional trend is shown (refer to Figure 3.3: cross section of the southern of Lake Awassa through the JICA wells of No4 and No5N as sample). It was pointed out at the Hydrogeological map section, the hydraulic gradient is high at the escarpment of the rift valley (there are some cases; the hydraulic gradient of groundwater is low in order to be dammed up by the fault) and forms a concave concentration point at the rift center. It should be noted that this concave shape is not affected by uplifting in the valley, mostly made up with recent volcanic cones and hills. The maximum thickness of the aquifer is almost 100m, but it shall be more realistic to consider it as a thick and wide fissure developed zone. Even though it belongs to the same aquifer, the capacity of aquifer may differ horizontally or vertically. However, consideration of the 3D distribution of the aquifer for the exploration of the target water source will be useful to exploit the good quantity and quality groundwater with good accuracy, by avoiding the fluoride concentration zone.

b. Groundwater flow

The important parameter for the consideration of the groundwater flow is static water level of existing borehole. Therefore, the density of the borehole position and its distribution largely affects the result. Initially the study focused on the database provided by ENGWIS and HALCROW to extract whole static water data of entire borehole. Alteration of tuff, tuff breccia, welded tuff and basaltic rocks are widely distributed by the repeated volcanic activity. Furthermore, the formations of volcanics are segmented by the active mass movement of the rift. The lakes are distributed at the bottom of the valley and accumulation of Alluvium at the floor of the valley is active. This complex distribution of several formations made both confined and unconfined aquifer randomly. The existing well inventory provided by above database does not include the description of confined and unconfined layers.

In case of indicating the groundwater contour from the original database (SWL), there are several ups and downs, such as cones and concaves, randomly observed. Therefore, the upper and lower surface of the aquifer is defined as simulated water level contour to avoid the affect of unconfined state of groundwater. The groundwater flow was considered on the basis of this simulated water level contour. Although Figure 3.3 shows the contour of upper surface of aquifer, the lack of bore hole at sub basins of Galana, Segen-Amessa Guracha, Kulfo Gina and Eastern Ziway, Lake Langano. There is no indication of groundwater flow in these areas. The contouring of upper (or lower) surface of the aquifer indirectly suggests the distribution of available groundwater level.

The groundwater gradient is high at the escarpment of sub-basins of Western Ziway, Bilate, Awassa, Gidabo and Galena (Partly, groundwater will be dammed up by the fault and the hydraulic gradient of groundwater is low). The groundwater rapidly flows down and becomes gentle at the valley floor. The gradient is almost parallel to the original shape of the valley (not considering undulation of volcanic cones and hills). The end point is not necessarily the lakes but seems to be gathered into the depression of groundwater between Lake Abaya and Lake Awassa. At the far north of the study area, groundwater runs down along the Weto River and ends its flow into Chew Bahir.



F Cross-section

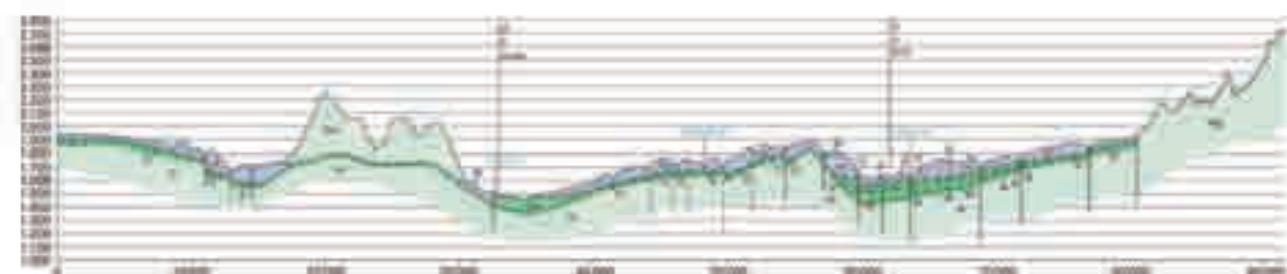


Figure 3.3: Hydrogeological Condition of F Cross Section

3.5 Water Quality

3.5.1 Methodology and water quality analysis items

a. Sampling points selection

In order to grasp the difference of water quality by aquifer and by water basin in the RVLB, the sampling sites are selected by the following procedure.

1. Divide the water basin into 14 characteristic basins
2. From the respective 14 sub-basins, 6 or 7 samples were taken from the different geological (aquifer) conditions and type of source.

If the site is not possible to sample, the sample site will be shifted to the same aquifer upon consultation with a Regional Water Engineer

Ninety sampling points of existing water resources and ten points of new drilling points for water quality analysis were selected based on the above selection procedure. Total sampling numbers are one hundred points.

b. Parameters and methodology of water quality analysis

b.1 Site analysis

The analysis items of water quality on sites are: basics items (temperature, electric conductivity, pH, ORP), items which may affect human health (Fe, Mn, F, NO₂, As, NH₄), and bacteria (Coliform, general bacteria). It was intended to grasp the summary of the quality of the water before the laboratory analysis will be completed. Three analysis experts measured each item promptly using the simple measurement equipment, pack test and simple test papers after having gathered water with a water level sampler from the existing well.

b.2 Laboratory analysis

The parameters for the water quality analysis were selected for examination of whether the groundwater quality (including spring water) could be classified by sub-basins or by geology (of aquifer). Elements harmful to the human body were also selected, however parameters were contained that specify the origin of water, such as Ca, Cl, Mg, Na, K, HCO₃, SO₄, NO₃ which are more useful for making Trilinear and Hexa Diagrams. The laboratory analysis was conducted with 22 items containing the necessary items which may affect human health (Mn, Cl, NO₃, NO₂, F).

b.3 Isotopic analysis

The ratio of stable isotopes in water will be analyzed to estimate the origin of the sampled groundwater.

Stable isotopes of hydrogen (D) and Oxygen (¹⁸O) will be analyzed and the results will be plotted on a diagram presented below. The diagram will help discern chemical proximity of waters within each of different groundwater basins by knowing their origins.

3.5.2 Characteristic of water quality and isotopic analysis

a. Results of water quality analysis

The site measurements give a general idea of the water quality, which shows some high fluoride content compared to the standard value (3.0mg/l). Four samples out of seven indicate a fluoride value of 3.0mg/l in Awassa sub-basin. Some samples from the northern area of Awassa sub-basin (between Lake Ziway and Awassa) also show higher values of fluoride content. The aquifers in this area are mainly lacustrine, welded tuff, tuff and pyroclastics. On the other hand, the southern area of Lake Abaya has relatively small fluoride concentration, except the samples from lacustrine. Despite the fact that no bacteria have been detected in the laboratory analysis, most of the site samples show the existence of coliform and general bacteria. Probably it is affected by artificial reasons such as careless treatment of litmus paper, and/or human saliva etc.

There are few results showing values high above the Standard, but some of them certainly exceed the limit of guideline values in the laboratory analysis results. High values of fluoride, iron, and nitrate are harmful to human health, and turbidity, total dissolved solids, ammonia, hardness and sulfates may give rise to complaints from consumers. The fluoride content of groundwater originated from the lacustrine aquifer in the East Ziway sub-basin (7.4mg/l) and the spring from volcanic rocks in Awassa sub-basin (10.33mg/l) display high values. Iron content mostly falls under the guideline value of 0.5mg/l, but some values exceed the limit with the maximum of 0.8mg/l. However, most high values of iron are found in basement rock areas (58.8mg/l). This iron concentration may be a result of hydrothermal activity in the area. Some samples show relatively high turbidity, total dissolved solids, ammonia, hardness and sulfate which may give rise to complaints from consumers. However, these sources are presently used as drinking water for long years. With some exceptions, the water quality analysis in this Study suggests the water is generally acceptable for drinking water.

b. Aspect of water quality

The characteristics of the water quality in terms of each sub-basin were discussed based on the projection onto the trilinear diagram (refer to Figure 3.4). Low in chloride ions, the pattern is classified into NaHCO_3 type and $\text{Ca}(\text{HCO}_3)_2$ type, in general. Chew-Bahir sub-basin and Abaya-Chamo sub-basin are classified as the origin of water comes from shallow groundwater and river water type. The $\text{Ca}(\text{HCO}_3)_2$ type groundwater is mainly occurring in circulating groundwater. In contrast, Awassa sub-basin tends to have a pattern of NaHCO_3 type where the water is originated in deep groundwater mainly occurring in stagnant groundwater environments. Ziway-Shalla sub-basin has both patterns of NaHCO_3 and $\text{Ca}(\text{HCO}_3)_2$ type. Overall groundwater pattern indicates the groundwater environment is circulating in the south, while the northern part has stagnant conditions by sub-basin. And the groundwater quality of edge of Rift Valley indicates more trend of circulating groundwater.

On the other hand, the characteristics of water quality on trilinear diagram by geology of aquifer are Groundwater in sandstone, limestone, basalt, pyroclastics, granite and gneiss are categorized as $\text{Ca}(\text{HCO}_3)_2$ type, and groundwater in tuff, tuff breccia, lacustrine and alluvium is classified into NaHCO_3 type and $\text{NaHCO}_3 + \text{Ca}(\text{HCO}_3)_2$ type. This pattern suggests the fissure and fracture groundwater exists under the circulation environment, and the layered water has nature of stagnant environment. It suggests that the groundwater exists in the alluvium and lacustrine in the central lower part of the Rift Valley is in a stagnant condition, and the fissure groundwater in the volcanic and gneiss is circulatory by nature.

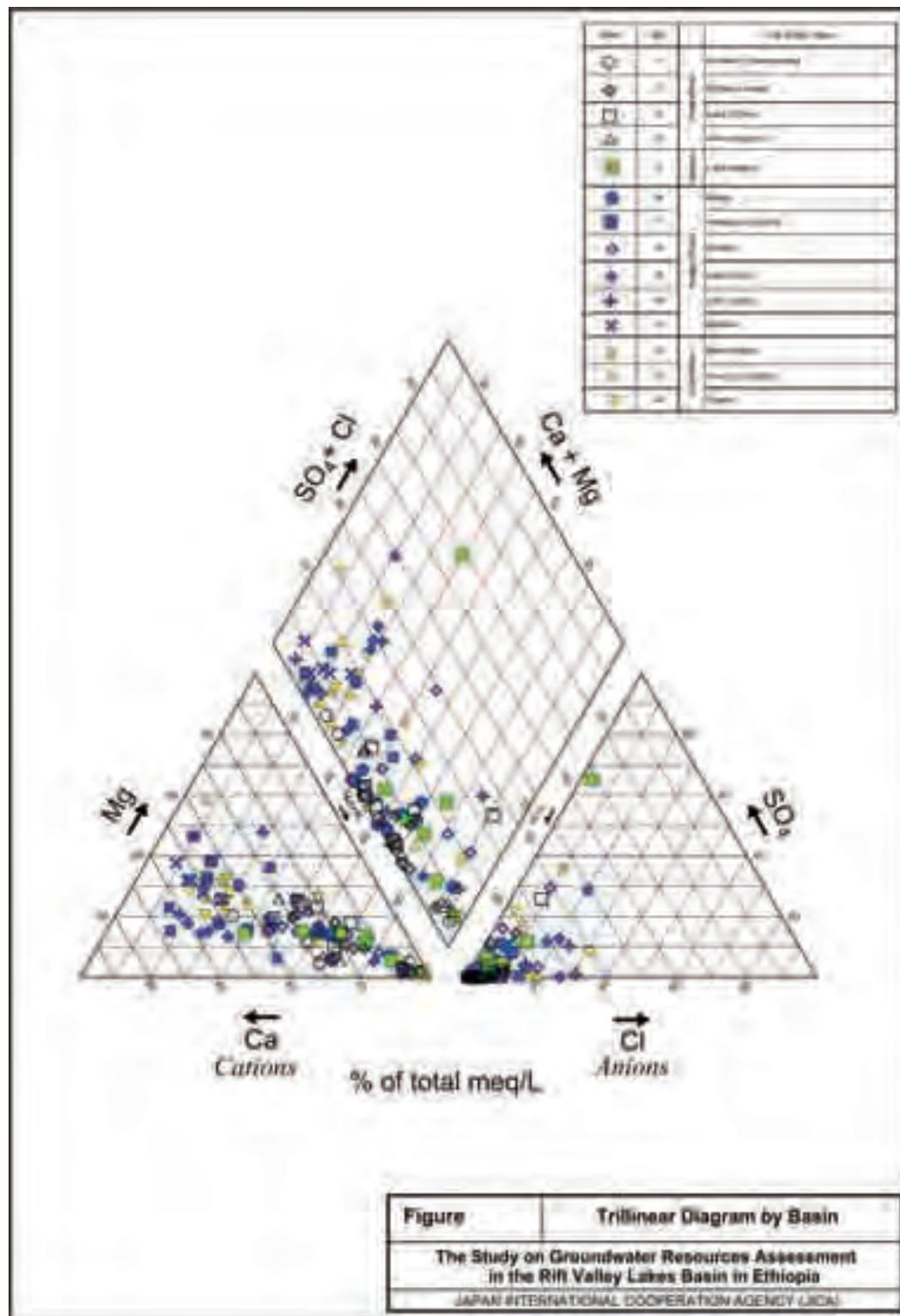


Figure 3.4: Trilinear Diagram by Basin

c. Isotopic analysis

The isotopic analysis results in the Rift Valley Lakes Basin by sub-basins and geology of aquifer are compiled. Regression line of the plotted isotope value is represented by the following formula.

$$\delta D = 7.12 \delta^{18}O + 12.3$$

This line is near to the meteoric line presented by Craig, 1961. Majority of $\delta^{18}O$ values are in the negative territory. Contrary, the values of δD are in the ranges from -10 to 10, and the plot of the value concentrated below SMOW (0, 0 = sea water value). However, in principle, the values are in the proximity of the meteoric line, which indicates that the majority of groundwater in the Study area originates from rainfall. As for the results of analysis, in particular the plot points which come close to the meteoric line were mainly contained in the circulating groundwater (shallow groundwater). Probably, the low value of δ presents the altitude effect of the origin, which most of the rainwater is infiltrated in the west-eastern high altitude ridge of the margin of the Rift Valley in western parts of Ziway area (refer to Figure 3.5).

The values close to the trend of $\delta D = 5 \delta^{18}O + \alpha$ are mainly from the sub-basins of Ziway-Shalla, Bilate, and Chew Bahir. The geology of aquifer of the area is mainly composed of alluvium, lacustrine, and pyroclastics. It can be assumed that the water affected by the hydrothermal activity and salty lake water may have different values than others.

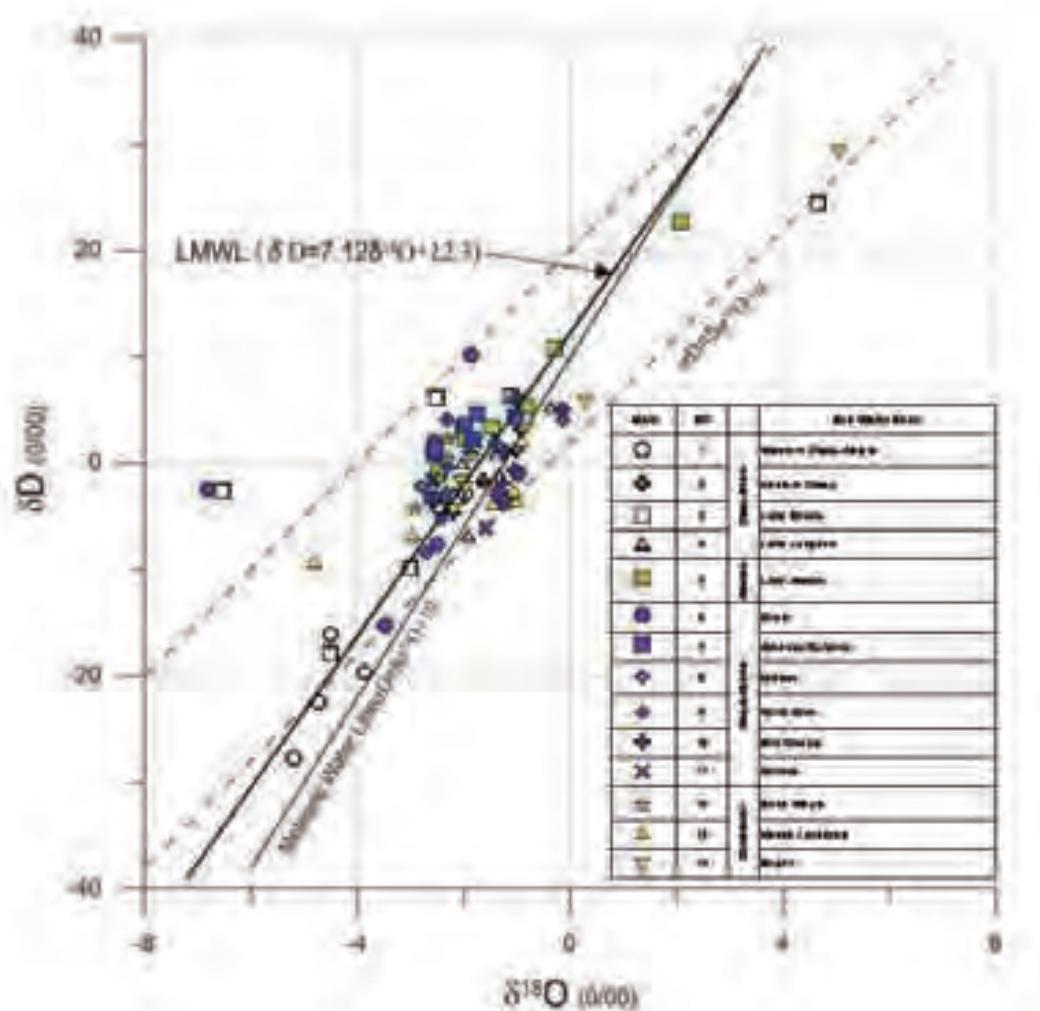


Figure 3.5: Distribution of Hydrogen & Oxygen Isotope Ratio (by sub-basin)

d. Distribution and trend of fluoride

The tendency fluoride value by the surface distribution and by the difference of depth was examined using the database in the Study area. High fluoride concentrations (more than 3 mg/l in reference with Ethiopian drinking water quality guidelines, 2002) are distributed in the north-western portion from Lake Ziway to Lake Shalla, especially at the inflection point at the slope and plane area. High concentrations can also be observed in the northeastern area of the Bilate River, and surrounding area of Lake Awassa (refer to Figure 3.6). The Figure 3.7 shows all fluoride data collected in this Study by the depth of bore hole. The characteristic of fluoride concentration is summarized as follows in regard to the data shown in these figures.

1. The concentration is high at the vicinity of recent volcanic cones surrounding Butajira
 2. High concentration zone can be observed at the area surrounding Lake Awassa

3. It is not quite clear, but the fluoride value decreases by the depth of water source

It is more realistic to consider high concentration is related to the recent volcanic activity occurs at the shallower sub surface rather than it was brought from the deep ground. However, further study is required to justify the origin of fluoride concentration.

The researchers are actively analyzing the reason and origin of the fluoride content in this area, and are divided into two scenarios. One is the fluoride concentration occurs from the obsidian of recent volcanic activity, and the other is provided by the hydrothermal activity of the area. The Study is not intended to clarify the origin of fluoride concentration. However, it may be more realistic to consider the fluoride concentration is related to recent shallow volcanic activity. No5N point shows the high concentration of fluoride because of the faces of rhyolitic rocks in hot spring area.

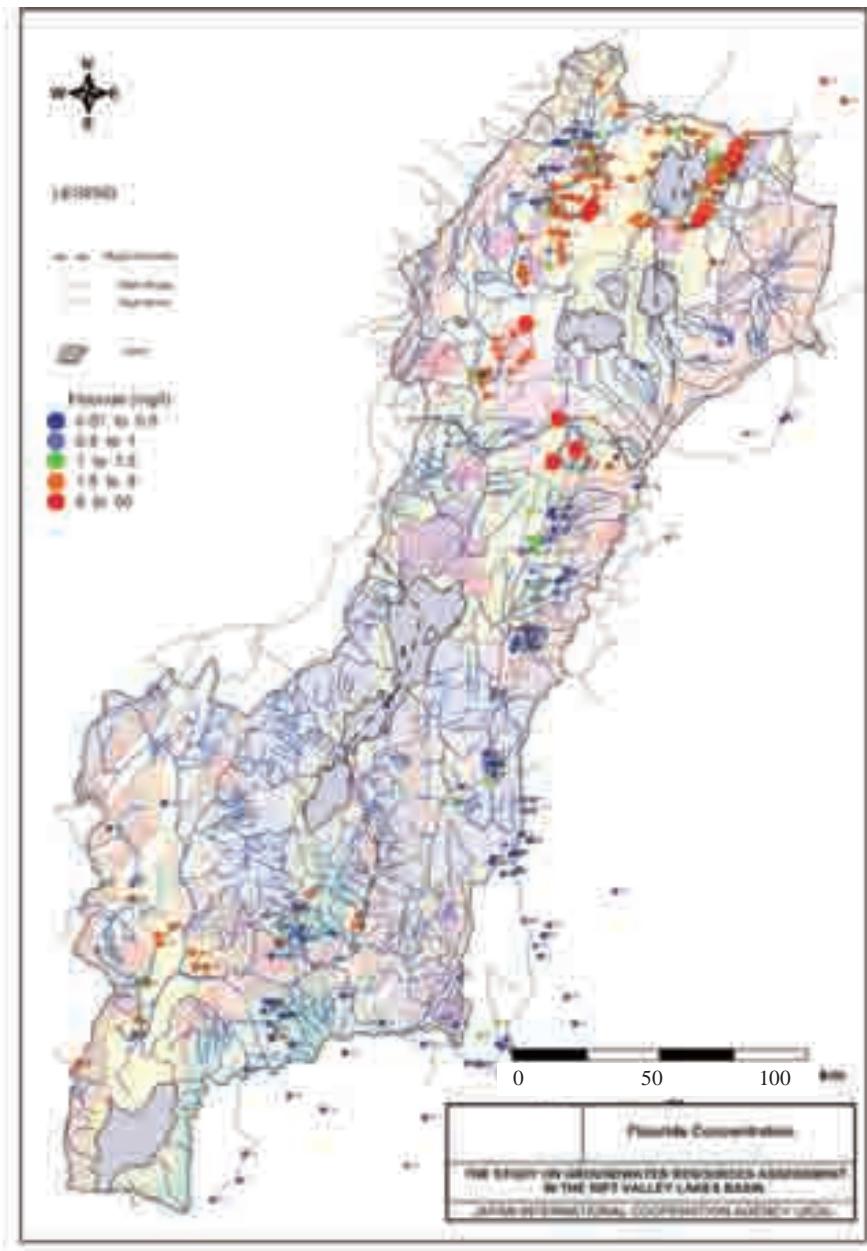


Figure 3.6: Fluoride Concentration

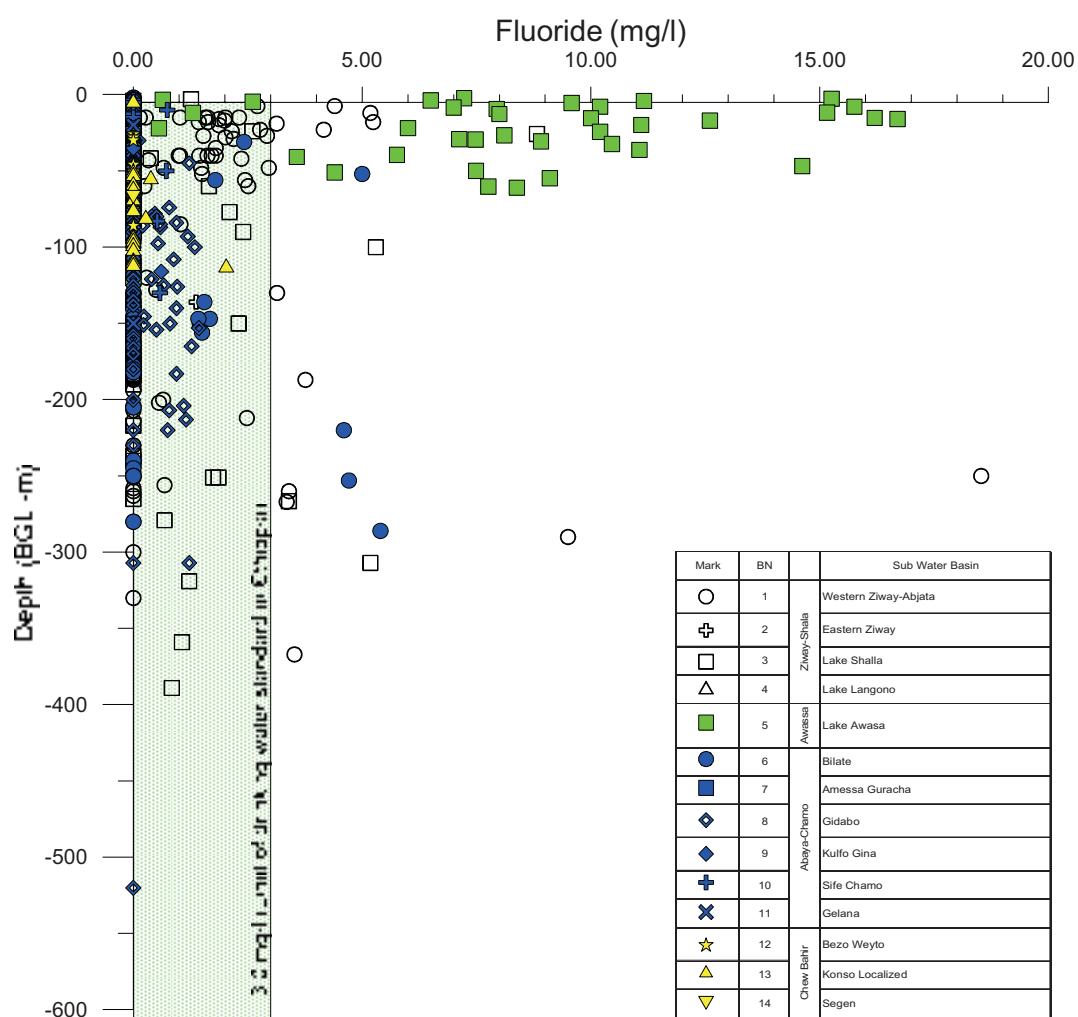


Figure 3.7: Relation between Well Depth and Fluoride Value of the Study Area

Chapter 4

Water Supply Plan

4 Water Supply Plan

4.1 Water supply plan for requested small towns

4.1.1 General conditions of requested small towns

The requested regions in the RVLB of this project are the SNNPRs and Oromia Region. As a result of confirmation of the final list of requested small towns, 82 small towns (SNNPRS=52, Oromia region=30) were selected. These 82 small towns comprise the majority of small towns in these two regions. The average population of requested towns is 5,800 people (as of 2010), the average water supply coverage is about 24%, and the population growth rate is 3.3% (2011-2015). 87% of small towns have existing water supply facilities, however there are many old and non-function facilities (45% of facilities have an output of less than 50%). The remaining facilities are the traditional sources (usage of the surface water of small rivers). There are many water borne diseases in the requested towns, including many cases of typhoid, dysentery, and diarrhea. The location map of 82 small towns is as follows;

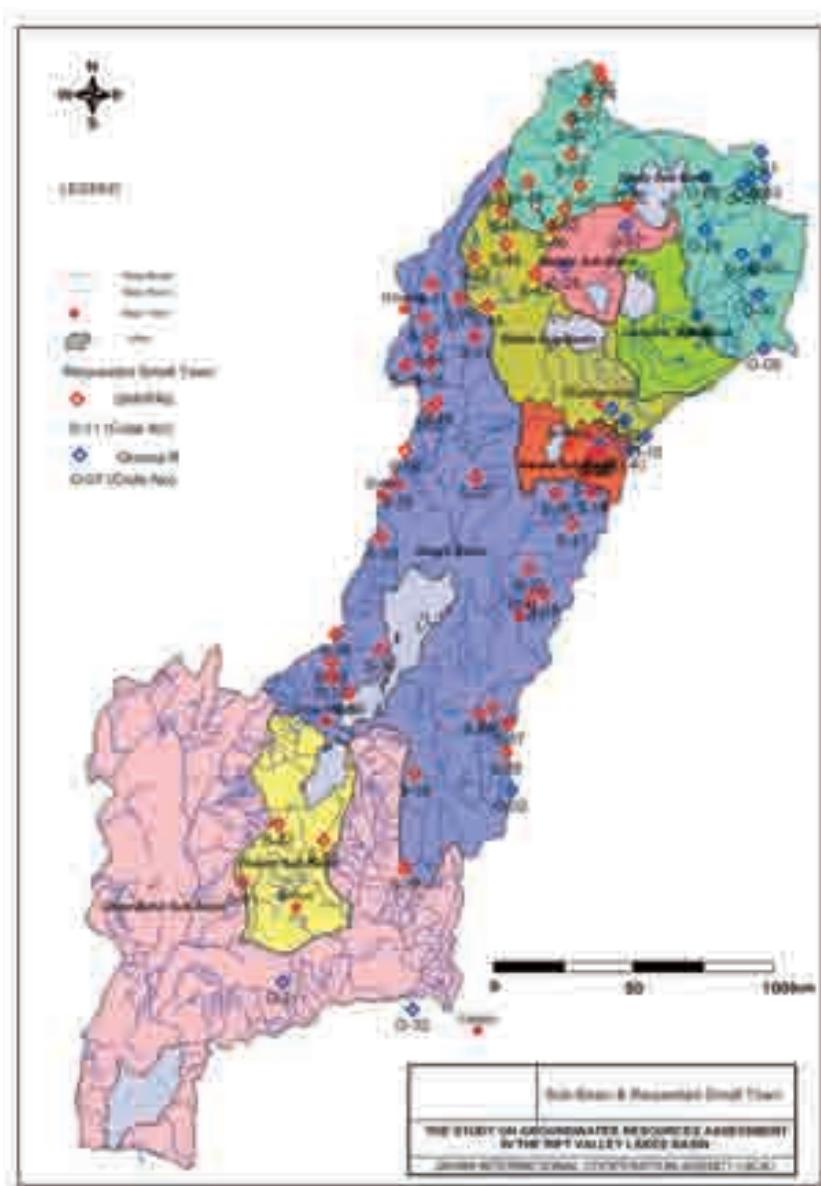


Figure 4.1: Sub Basin and Requested Small Towns

4.1.2 Possibility of groundwater development for requested small towns

The groundwater potential of the northern part of Lake Abaya and its surrounding area will be able to expect a moderate to high production capacity except the northeast-east side of Lake Awassa in accordance with the hydrogeological map. The point is quality, not quantity; the areas that exceed the water quality standard are recognized in Lake Ziway and its surrounding area of Oromia Region, southeast of Butajira, and Lake Awassa and its surrounding area of SNNPRS. On the other hand, the basalt and tuff of Miocene of Pre-Tertiary and the gneiss and granite of Pre-Cambrian is mainly distributed in the southern part from Lake Abaya and its surrounding area, so the capacity of the aquifer is predicted to be poor to moderate in these areas. The Quaternary deposits distributed in the lowland of above areas and the water potential is estimated as the moderate productivity in those areas.

The high priority small towns are located in the area of northern Lake Abaya and its surrounds, which consists of Pleistocene deposits, and has a moderate to high productivity of water resources. The aquifer depths of wells (screen depth) estimated by the hydrogeological map is mainly 130m-150m, 50-70m in depth. Well drilling depth is estimated to be from 100m to 200m. The yield predicted is 3L/sec~7L/sec. The remaining high priority small towns are located in the area south of Lake Abaya and its surrounds, and the aquifer capacity shows a low to moderate productivity. The aquifer of wells assumed by the hydrogeological map is 80m-100m in depth and well drilling depth is probably 150m. The yield is estimated to be about 2L/sec~5L/sec. All small towns targeted for the priority project in Oromia Region are located in the area north of Lake Awassa and its surrounds, and moreover, most are also east of Lake Ziway. The groundwater potential has a low to moderate production capacity, and aquifer depth is extensively about 30m-100m and 130m-150m. The well depth is assumed to be 150m-200m in depth.

The small towns requested except the high priority small town in SNNPRS are all within the RVLB, and in Oromia Region most of the small towns are located in the area north of Lake Abaya. The groundwater potential in SNNPRS for the requested small towns is mainly of moderate productivity; however, in the small towns in the area south of Lake Awassa and its surrounding area, the aquifer capacity indicates poor to low productivity. The groundwater potential in Oromia Region for the requested small towns is low to moderate productivity.

4.1.3 Policy and outline of design for Water Supply Plan

The water supply plan for the requested small towns was planned based on the following policy below; and the model of water supply facilities is shown in Figure 4.2:

a. Basic items

- Target year of water supply plan is 2015.
- Unit water demand is considered 20 L/c/day in accordance with “Urban Water Supply Design Criteria 2006”.
- The facilities and water sources for the water supply plan was planned in accordance with the 100% target water supply coverage.
- The latest data are adopted for the population data of each small town.

- The basic water sources of facilities are deep wells because they are not significantly influenced by drought. However, in case of existence of the stable spring water sources which produce sufficient quantity and good quality of drinking water for the candidate small towns, these spring water sources to be adopted as a new water source of water supply facility.
- To keep the cost of operation & maintenance to a minimum, the water supply plan will avoid as much as possible using items that require large amounts of power.
- In order to suppress initial investment (construction cost), a plan is made with as much local materials and equipment as possible while also being able to be constructed locally.
- Structure of pipeline does not apply the pipe network system in terms of degree of difficulty for construction and operation & maintenance. Hence, each pipeline is basically to be separate, for conveyance, transmission and distribution.

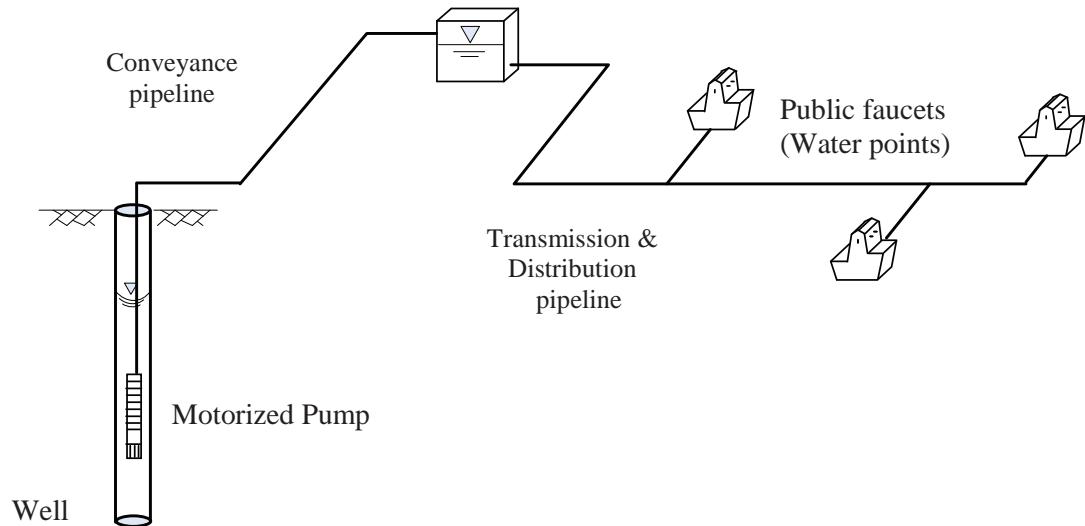


Figure 4.2: Model of water supply facility

b. Outline of design

b.1 New wells

The number of new wells is to be calculated by necessary water supply quantity based on the population and unit water demand of each selected small town which is as a prospect based on the results of capability by the groundwater potential evaluation. In case it is difficult to evaluate the potential of water usage in small towns, the number of wells is to be calculated by the standard yield in Ethiopia.

b.2 Motorized pump

Electric power suitable for such motorized pump systems is commercial electric power and/or diesel engine generator as a standby power source. The high-output motorized pump is needed in the water supply facility which performs pumping with motorized pump among the water supply scheme for the reason the groundwater level is low or the vertical interval of groundwater level is high. Duration of pump operation is planned as 8 hours/day. In terms of protection of pump and operation & maintenance: air valve / pressure meter / sluice valve / follow meter / check valve / tee for drainage shall be equipped on the well top (well mouth). And straight pipes shall be installed, as a rule, on either side of a flow meter to avoid water turbulence, which is important for maintaining accuracy of the flow meter.

b.3 Type and capacity of reservoir tank

Types of reservoir tank to be considered are Ground Reservoir or Elevated Reservoir according to the topographical conditions and the size of the small town. Ground reservoir tank is to be a rectangle RC (reinforced concrete) with waterproof coating and/or circle piling-stone (masonry) structure with waterproofing core wall which is standard type in Ethiopia. Capacity of reservoir tank is to be approximately 30% of daily maximum water supply volume.

b.4 Water treatment facility

The water supply facility of this plan will not adopt a treatment facility basically because the water source to be used is groundwater from wells.

b.5 Method of water distribution and pipe

The gravity mains are to be adopted for water distribution line in order to ease for O&M. A closed distribution pipe network is not to be adopted. Gravity mains are to be installed parallel and independently from the reservoir tank to each pipe end. Steel pipes have generally been used (e.g. Galvanized Iron Pipe, GIP). And besides PVC pipe, PE pipe (Polyethylene Pipe) has become popular recently, which is easy to handle. Therefore, these new materials are to be examined for use in the water supply plan in terms of construction, maintenance and economical matters.

b.6 Method of water supply

The method of water supply to be adopted is Public Faucets (PF), the structure of which is to be based on Ethiopian standards. Quantity and distribution of public faucets in towns are to be based on the conditions of the Design Criteria of MoWE, SNNPR and Oromia Region and UAP. Other considerations are avoiding overlaps, duplication and interference with existing water services.

b.7 Management of water consumption

For accurate management of water facilities and consumption, water flow meters are to be installed at well top, the outlet pipe (transmission, distribution pipe) of reservoir tank, and on the water supply pipe of public faucets and house connections

The water supply plan of requested small towns based on the general design above is as shown in Table 4.1and Table 4.2.

Table 4.1: Facility Size and Approximate Project Expense

Requested number	Small Town	Population 2015	Well nos.	Pump nos.	Total Pipes km	Tank nos.	Tap nos.	Project Expense USD
SNNPRS	52	323,204	108	108	494.3	56	923	65,011,594
Oromia R.	30	227,695	62	62	394.5	33	651	49,084,101

1USD=75.85Yen (November 2011JICA Exchange Rate)

Table 4.2: Water Supply Plan of Requested Small Towns

No.	Zone	Woreda	SNNPRS		Population		Well	Pump	Generator	Generator room	C pipe	Tank	T pipe	D pipe	Tap	
			Small Town	2010	2015	nos.	nos.	nos.	nos.	m	nos.	m	m	m	nos.	
1	SZ-01	Gurage	SW-01 Sodo	S-01	Buei	6,961	8,188	1	1	1	1	1,140	1	3,800	11,400	23
2	SZ-01	Gurage	SW-01 Sodo	S-02	Kela	3,519	4,139	1	1	1	1	690	1	2,300	6,900	12
3	SZ-01	Gurage	SW-01 Sodo	S-03	Tiya	1,937	2,278	1	1	1	1	450	1	1,500	4,500	7
4	SZ-01	Gurage	SW-01 Sodo	S-04	Suten	1,298	1,527	2	2	2	2	1,080	1	1,800	5,400	4
5	SZ-01	Gurage	SW-03 Mareqo	S-06	Koshe	6,858	8,067	2	2	2	2	900	1	1,500	4,500	23
6	SZ-02	Hadiya	SW-04 Lemmo	S-07	Lisana	1,711	2,013	1	1	1	1	450	1	1,500	4,500	6
7	SZ-02	Hadiya	SW-05 Shashago	S-09	Dosha	1,881	2,213	1	1	1	1	450	1	1,500	4,500	6
8	SZ-02	Hadiya	SW-07 Analemmo	S-11	Fonko	2,380	2,799	1	1	1	1	600	1	2,000	6,000	8
9	SZ-02	Hadiya	SW-08 Mirab Badawocho	S-12	Wada	2,113	2,485	1	1	1	1	510	1	1,700	5,100	7
10	SZ-03	Kembata Timbaro	SW-09 Anigacha	S-13	Anigacha	6811	8,011	1	1	1	1	1,050	1	3,500	10,500	23
11	SZ-03	Kembata Timbaro	SW-10 Kedia Gamela	S-14	Adilo	4,659	5,480	1	1	1	1	450	1	1,500	4,500	16
12	SZ-03	Kembata Timbaro	SW-11 Dayiboya	S-15	Daniboya	8,111	9,541	2	2	2	2	1,200	2	2,000	6,000	27
13	SZ-04	Sidama	SW-12 Shebedio	S-16	Leku	11,810	13,892	1	1	1	1	1,200	1	4,000	12,000	40
14	SZ-04	Sidama	SW-13 Dara	S-17	Kebado	8,365	9,839	2	2	2	2	1,200	1	2,000	6,000	28
15	SZ-04	Sidama	SW-13 Dara	S-18	Teferi Kela	4,178	4,914	1	1	1	1	900	1	3,000	9,000	14
16	SZ-04	Sidama	SW-14 Gorche	S-19	Goreche	2,986	3,512	1	1	1	1	450	1	1,500	4,500	10
17	SZ-04	Sidama	SW-15 Malga	S-20	Manicho	4,017	4,725	1	1	1	1	450	1	1,500	4,500	14
18	SZ-04	Sidama	SW-16 Wenso	S-21	Bokasa (Bokaso)	2,039	2,398	4	4	4	4	1,200	1	1,000	3,000	7
19	SZ-04	Sidama	SW-41 Alta Chuko	S-22	Chuko	8,884	10,450	2	2	2	2	3,000	1	5,000	15,000	30
20	SZ-04	Sidama	SW-18 Wendo Genet	S-23	Chuko	14,626	17,204	4	4	4	4	4,200	1	3,500	10,500	49
21	SZ-04	Sidama	SW-18 Wendo Genet	S-24	Ela (Kela)	5,259	6,186	2	2	2	2	600	1	1,000	3,000	18
22	SZ-05	Gedeo	SW-20 Kochore	S-27	Fiseha Genet	4,189	4,927	4	4	4	4	3,600	1	3,000	9,000	14
23	SZ-05	Gedeo	SW-21 Gedeb	S-28	Gedeb	10,021	11,787	4	4	4	4	3,600	1	3,000	9,000	34
24	SZ-06	Wolayita	SW-23 Humbo	S-30	Tabela (Humbo)	6,246	7,347	2	2	2	2	2,100	1	3,500	10,500	21
25	SZ-06	Wolayita	SW-24 Deguna Fanigo	S-32	Dimtu	1,702	2,002	2	2	2	2	600	1	1,000	3,000	6
26	SZ-07	Gamo Gofa	SW-26 Mirab Abaya	S-34	Birbir	5,831	6,859	2	2	2	2	1,500	1	2,500	7,500	20
27	SZ-07	Gamo Gofa	SW-27 Chencha	S-35	Chenicha	10,223	12,025	2	2	2	2	2,040	1	3,400	10,200	34
28	SZ-07	Gamo Gofa	SW-27 Chencha	S-36	Ezo	1,822	2,143	4	4	4	4	960	1	800	2,400	6
29	SZ-07	Gamo Gofa	SW-27 Chencha	S-37	Dorze	1,256	1,477	2	2	2	2	360	1	600	1,800	4
30	SZ-07	Gamo Gofa	SW-28 Amaro Special	S-38	Kele	8,632	10,153	4	4	4	4	1,800	1	1,500	4,500	29
31	SZ-07	Gamo Gofa	SW-29 Burji Special	S-39	Soyama	6,268	7,373	2	2	2	2	1,500	1	2,500	7,500	21
32	SZ-07	Gamo Gofa	SW-30 Konso Special	S-41	Segen	3,626	4,265	2	2	2	2	900	1	1,500	4,500	12
33	SZ-07	Gamo Gofa	SW-31 Darashe Special	S-42	Gidole	13,176	15,498	4	4	4	4	3,000	1	2,500	7,500	44
34	SZ-08	Silite	SW-32 Siliti	S-43	Kibat	5,676	6,676	4	4	4	4	3,000	2	2,500	7,500	19
35	SZ-08	Silite	SW-32 Siliti	S-44	Alkeso	1,028	1,209	1	1	1	1	750	1	2,500	7,500	3
36	SZ-08	Silite	SW-33 Lanifaro (Lanfur)	S-46	Tora	9,163	10,778	4	4	4	4	3,360	1	2,800	8,400	31
37	SZ-08	Silite	SW-33 Lanifaro (Lanfur)	S-47	Mito	3,277	3,855	2	2	2	2	1,200	1	2,000	6,000	11
38	SZ-08	Silite	SW-34 Dalocha	S-48	Dalocha	7,024	8,262	1	1	1	1	810	1	2,700	8,100	24
39	SZ-08	Silite	SW-35 Sankura	S-49	Alem Gebeya	3,656	4,300	2	2	2	2	1,500	1	2,500	7,500	12
40	SZ-08	Silite	SW-35 Sankura	S-51	Mazoria	2,730	3,211	1	1	1	1	360	1	1,200	3,600	9
41	SZ-08	Silite	SW-36 Wilbareg	S-52	Wilbareg (Bilbareg)	2,197	2,584	2	2	2	2	1,200	1	2,000	6,000	7
42	SZ-01	Gurage	SW-02 Meskan	S-53	Hamus-Gabeya(Barno)	4,152	4,884	2	2	2	2	480	1	800	2,400	14
43	SZ-02	Hadiya	SW-05 Shashago	S-54	Hirkofofa	2,590	3,047	2	2	2	2	300	1	500	1,500	9
44	SZ-02	Hadiya	SW-06 Misrik Badawoch	S-55	Weyira Mazoria	8,346	9,817	2	2	2	2	900	2	1,500	4,500	28
45	SZ-05	Gedeo	SW-20 Kochore	S-56	Biloya	4,484	5,274	4	4	4	4	1,560	1	1,300	3,900	15
46	SZ-05	Gedeo	SW-21 Gedeb	S-57	Chorso-Mazoria	8500	9,998	2	2	2	2	1,200	1	2,000	6,000	29
47	SZ-06	Wolayita	SW-37 Damot Pulasa	S-58	Shento	5,345	6,287	1	1	1	1	540	1	1,800	5,400	18
48	SZ-06	Wolayita	SW-38 Sodo Zuria	S-59	Dalbo Atowa	4,772	5,613	2	2	2	2	900	1	1,500	4,500	16
49	SZ-07	Gamo Gofa	SW-39 Arba Minch Zuria	S-60	Latite	7,221	8,494	2	2	2	2	1,080	1	1,800	5,400	24
50	SZ-07	Gamo Gofa	SW-30 Konso Special	S-61	Gewada	5,967	7,019	5	5	5	5	1,500	2	1,000	3,000	20
51	SZ-08	Silite	SW-32 Siliti	S-62	Udasa	4,470	5,258	1	1	1	1	600	1	2,000	6,000	15
52	SZ-08	Silite	SW-40 Alichu wuriro	S-63	Kawakoto	783	921	1	1	1	1	540	1	1,800	5,400	3
SNNPRS Average				5,284	6,215	2	2	2	2	2	2	1,268	1	2,060	6,179	18
SNNPRS Total				274,776	323,204	108	108	108	108	65,910	56	107,100	321,300	923		

No.	Zone	Oromia region			Population		Well	Pump	Generator	Generator room	C pipe	Tank	T pipe	D pipe	Tap
		Woreda	Small Town		2010	2015	nos.	nos.	nos.	nos.	m	nos.	m	m	nos.
1	OZ-01 Arsi	OW-01 Hitosa	O-01	Iteya	14,239	16,749	1	1	1	1	1,650	1	5,500	16,500	48
2	OZ-01 Arsi	OW-02 Ziway Dugda	O-02	Ogolcha (Agolcho)	4,759	5,598	1	1	1	1	1,050	1	3,500	10,500	16
3	OZ-01 Arsi	OW-03 Tiyo	O-03	Gonde	4,350	5,117	1	1	1	1	1,200	1	4,000	12,000	15
4	OZ-01 Arsi	OW-04 Digaluna Tijo	O-05	Kidame Digelu	1,780	2,094	1	1	1	1	540	1	1,800	5,400	6
5	OZ-01 Arsi	OW-04 Digaluna Tijo	O-06	Sagure	10,926	12,852	2	2	2	2	1,200	2	2,000	6,000	37
6	OZ-01 Arsi	OW-05 Munesa	O-07	Kersa	9,916	11,664	4	4	4	4	5,400	1	4,500	13,500	33
7	OZ-04 West Arsi	OW-20 Limana Bibilo	O-09	Meraro	4,725	5,558	1	1	1	1	960	1	3,200	9,600	16
8	OZ-04 West Arsi	OW-08 Kofele	O-10	Kofele	14,401	16,939	5	5	5	5	7,500	2	5,000	15,000	48
9	OZ-01 Arsi	OW-03 Tiyo	O-11	Kulumsa	3,472	4,084	1	1	1	1	600	1	2,000	6,000	12
10	OZ-01 Arsi	OW-01 Hitosa	O-12	Boru Jawi	4,446	5,230	2	2	2	2	1,200	1	2,000	6,000	15
11	OZ-03 East Shewa	OW-16 Adami Tulu & Jido Kombolcha	O-20	Abosa	3,578	4,209	1	1	1	1	330	1	1,100	3,300	12
12	OZ-03 East Shewa	OW-16 Adami Tulu & Jido Kombolcha	O-22	Adami Tulu	8,166	9,605	4	4	4	4	4,200	1	3,500	10,500	27
13	OZ-03 East Shewa	OW-16 Adami Tulu & Jido Kombolcha	O-28	Jido	2,659	3,128	1	1	1	1	540	1	1,800	5,400	9
14	OZ-01 Arsi	OW-03 Tiyo	O-29	Katar Genet	3,953	4,650	1	1	1	1	960	1	3,200	9,600	13
15	OZ-01 Arsi	OW-20 Limana Bibilo	O-30	Lemo Sirba	5,590	6,575	2	2	2	2	1,500	1	2,500	7,500	19
16	OZ-02 Borena	OW-09 Teltele	O-31	Milami	4,510	5,305	2	2	2	2	1,260	1	2,100	6,300	15
17	OZ-02 Borena	OW-21 Bure Hara	O-32	Garaba	7,500	8,822	2	2	2	2	1,800	1	3,000	9,000	25
18	OZ-02 Borena	OW-10 Yabelo	O-33	Ei Woyya(Wayya)	4,090	4,811	1	1	1	1	300	1	1,000	3,000	14
19	OZ-04 West Arsi	OW-22 Wondo	O-34	Bura (Busa)	5,112	6,013	2	2	2	2	1,500	1	2,500	7,500	17
20	OZ-03 East Shewa	OW-19 Adama	O-35	Awash Mercasa	10,200	11,998	2	2	2	2	1,800	1	3,000	9,000	34
21	OZ-03 East Shewa	OW-23 Bosat	O-36	Walanciti	11,260	13,245	5	5	5	5	9,750	2	6,500	19,500	38
22	OZ-03 East Shewa	OW-23 Bosat	O-37	Doni	4,164	4,898	1	1	1	1	600	1	2,000	6,000	14
23	OZ-03 East Shewa	OW-23 Bosat	O-38	Befa (Bofa)	7,040	8,281	2	2	2	2	1,620	1	2,700	8,100	24
24	OZ-04 West Arsi	OW-22 Wondo	O-39	Intaye	8,500	9,998	2	2	2	2	1,680	1	2,800	8,400	29
25	OZ-04 West Arsi	OW-08 Kofele	O-40	Kabate	4,146	4,877	2	2	2	2	1,080	1	1,800	5,400	14
26	OZ-04 West Arsi	OW-14 Sheshemane	O-41	Awasho-Dhanku	7,040	8,281	4	4	4	4	2,880	1	2,400	7,200	24
27	OZ-04 West Arsi	OW-14 Sheshemane	O-42	Hursa	5,700	6,705	4	4	4	4	2,400	1	2,000	6,000	19
28	OZ-02 Borena	OW-12 Mijo (Miyo)	O-43	Hidi-Lola	6,550	7,704	2	2	2	2	1,500	1	2,500	7,500	22
29	OZ-02 Borena	OW-13 Dugda dawa	O-44	Fincadaa (Fincawaa)	7,200	8,469	2	2	2	2	1,500	1	2,500	7,500	24
30	OZ-03 East Shewa	OW-24 Liben	O-45	Adulala	3,601	4,236	1	1	1	1	450	1	1,500	4,500	12
Oromia Region Average					6,452	7,590	2	2	2	2	1,965	1	2,797	8,390	22
Oromia Region Total					193,573	227,695	62	62	62	62	58,950	33	83,900	251,700	651
2 Regions Avarega (SNNPRS+Oromia)					5,868	6,903	2	2	2	2	1,616	1	2,428	7,284	20
2 Regions Total (SNNPRS+Oromia)					468,349	550,899	170	170	170	170	124,860	89	191,000	573,000	1,574

4.1.4 Current status, issues of the Operation and maintenance plan for water supply facility

a. Current status

a.1 Existing organization

Among 82 small towns, there is an organization for operation & maintenance in most of the small towns which have an existing water supply facility. Type of the organizations varies such as enterprise (self-supporting accounting system), water committee, and water office under the administration of Woreda. Activities of the organizations are comprised of the technical squad and administrative squad. Number of office personnel and their duties are different from one to more than ten persons by the scale of organization and the existing water supply facility.

a.2 Administration

At public faucets, generally staff collect water fees (82%) according to the size of the water tank (fee per 20L poly-tank) of water users. And there are also systems of monthly contract (12%) between the organization and each user or water salesperson of public faucet such as a fixed amount per month. Small towns that supply houses and businesses with groundwater by motorized pump or spring water, charge a tariff as set by the town, zone or regional water office. This is based on a contract format made by the regional office. The unit price is prescribed in cost charged by quantity in cubic meters, and is sorted from $1m^3 \sim 30m^3$ /month such as $0\sim 5m^3$: 3.25 Birr/ m^3 , $6\sim 10m^3$: 3.5Birr/ m^3 , $11\sim 30m^3$: 3.75Birr/ m^3 , more than $30m^3$: 4Birr/ m^3 . The fee of the water meter is often charged as a monthly lease. The hand pump and on-spot facilities are charged a fixed rate (1~3 Birr) per month for each household.

b. Issues

b.1 Shortage of basic information for management of water facility

Data of water sources (well specifications, water yields, pump specifications, etc.) information, data of water sources (well specifications, water yields, pump specifications, etc.) and data of existing water supply facilities (information of pipe network, etc.) are totally lacking because no information or records are kept in written form (document, drawing). This information is dependant on the memory of the staff. Hence, it is not accurate.

b.2 Shortage of availability of O&M

Necessary expense for the business operation and the trends of expenditure items and expenses cannot be grasped. Water tariff based on the budget balance is not examined. Facilities have limitation of operation time, water leakage, shortage of water supply amount due to deterioration of the facilities. Water demand cannot be met due to deterioration of pumps and/or generators. Water leakages occur due to deterioration of pipes, poor construction. The existing water supply facilities do not have enough water reserves or supply capacity due to faulty design.

4.2 Water supply plan for high priority small towns

4.2.1 Details of requested small town profiles

The detailed information of requested small towns is arranged in the small town profiles of Data book of final report. The small town profiles were compiled to include information about the following items necessary to categorize the water supply plan by field survey and data collection.

- Administrative organization
- Town location, whether in RVLB or not (GPS coordinates)
- Accessibility to the town (distance from the principal town, road conditions).
- Water coverage (calculated by water consumption and/or products)
- Existing water sources (numbers, quintiles, borehole specifications, system of water collection, duration of operation, etc)
- Existing water supply facilities (specifications of the principal structures, water consumption, etc)
- Operation & maintenance (organization of water supply management, water fee and collection, method of operation & maintenance, etc)
- Problems of water supply for small towns (technical, accounting, Management , etc)

Selection of high priority small towns is selected based on the detailed information above.

4.2.2 Selection and size of high priority small towns

The classification and prioritization of small towns were conducted to decide on the priority of implementation in regard to the water supply plan of requested small towns. Prioritized small towns are extracted by the next categories such as ground water potential, water quality, water coverage, beneficiary population & ratio. Small towns are selected finally are 11 towns in SNNPR and 9 towns in Oromia Region. The water supply plan for the high priority small towns is shown in Table 4.3 and Table 4.4:

Table 4.3: Facility Size and Approximate Project Expense

High Priority	Small Town	Population	Well	Pump	Total Pipes	Tank	Tap	Project Expense
	number	2015	nos.	nos.	km	nos.	nos.	USD
SNNPRS	11	71,770	21	21	86.9	13	205	162,229
Oromia R.	9	63,354	23	23	113.2	10	181	143,205

1USD=75.85Yen (November 2011JICA Exchange Rate)

Table 4.4: Water Supply Plan of High Priority Small Towns

SNNPRS				Population		Well	Pump	Generator	Generator room	C pipe	Tank	T pipe	D pipe	Tap		
No.	Zone	Woreda	Small Town	2010	2015	nos.	nos.	nos.	nos.	m	nos.	m	m	nos.		
7	SZ-02	Hadiya	SW-05 Shashago	S-09	Dosha	1,881	2,213	1	1	1	1	450	1	1,500	4,500	6
11	SZ-03	Kembata Timbaro	SW-10 Kedia Gamela	S-14	Adilo	4,659	5,480	1	1	1	1	450	1	1,500	4,500	16
12	SZ-03	Kembata Timbaro	SW-11 Dayiboya	S-15	Daniboya	8,111	9,541	2	2	2	2	1,200	2	2,000	6,000	27
14	SZ-04	Sidama	SW-13 Dara	S-17	Kebado	8,365	9,839	2	2	2	2	1,200	1	2,000	6,000	28
24	SZ-06	Wolayita	SW-23 Humbo	S-30	Tabela (Humbo)	6,246	7,347	2	2	2	2	2,100	1	3,500	10,500	21
36	SZ-08	Silite	SW-33 Lanfaro (Lanfuro)	S-46	Tora	9,163	10,778	4	4	4	4	3,360	1	2,800	8,400	31
40	SZ-08	Silite	SW-35 Sankura	S-51	Mazorria	2,730	3,211	1	1	1	1	360	1	1,200	3,600	9
42	SZ-01	Gurage	SW-02 Meskan	S-53	Hamus-Gabeya(Bamo)	4,152	4,884	2	2	2	2	480	1	800	2,400	14
43	SZ-02	Hadiya	SW-05 Shashago	S-54	Hirkofoto	2,590	3,047	2	2	2	2	300	1	500	1,500	9
44	SZ-02	Hadiya	SW-06 Misrak Badawoch	S-55	Weyira Mazoria	8,346	9,817	2	2	2	2	900	2	1,500	4,500	28
48	SZ-06	Wolayita	SW-38 Sodo Zuria	S-59	Dalbo Atowa	4,772	5,613	2	2	2	2	900	1	1,500	4,500	16
SNNPRS Average				5,547	6,525	2	2	2	2	1,064	1	1,709	5,127	19		
SNNPRS Total				61,015	71,770	21	21	21	21	11,700	13	18,800	56,400	205		
Oromia region				Population	Well	Pump	Generator	Generator room	C pipe	Tank	T pipe	D pipe	Tap			
No.	Zone	Woreda	Small Town	2010	2015	nos.	nos.	nos.	nos.	m	nos.	m	m	nos.		
8	OZ-04	West Arsi	OW-08 Kofele	O-10	Kofele	14,401	16,939	5	5	5	5	7,500	2	5,000	15,000	48
9	OZ-01	Arsi	OW-03 Tiyo	O-11	Kulumsa	3,472	4,084	1	1	1	1	600	1	2,000	6,000	12
10	OZ-01	Arsi	OW-01 Hitosa	O-12	Boru Jawi	4,446	5,230	2	2	2	2	1,200	1	2,000	6,000	15
14	OZ-01	Arsi	OW-03 Tiyo	O-29	Katar Genet	3,953	4,650	1	1	1	1	960	1	3,200	9,600	13
15	OZ-01	Arsi	OW-20 Limana Bibilo	O-30	Lemo Sirba	5,590	6,575	2	2	2	2	1,500	1	2,500	7,500	19
19	OZ-04	West Arsi	OW-22 Wondo	O-34	Bura (Busa)	5,112	6,013	2	2	2	2	1,500	1	2,500	7,500	17
25	OZ-04	West Arsi	OW-08 Kofele	O-40	Kabate	4,146	4,877	2	2	2	2	1,080	1	1,800	5,400	14
26	OZ-04	West Arsi	OW-14 Sheshemane	O-41	Awasho-Dhanku	7,040	8,281	4	4	4	4	2,880	1	2,400	7,200	24
27	OZ-04	West Arsi	OW-14 Sheshemane	O-42	Hursa	5,700	6,705	4	4	4	4	2,400	1	2,000	6,000	19
Oromia Region Average				5,984	7,039	3	3	3	3	2,180	1	2,600	7,800	20		
Oromia Region Total				53,860	63,354	23	23	23	23	19,620	10	23,400	70,200	181		
2 Regions Avarega (SNNPRS+Oromia)				5,766	6,782	2	2	2	2	1,622	1	2,155	6,464	19		
2 Regions Total (SNNPRS+Oromia)				114,875	135,124	44	44	44	44	31,320	23	42,200	126,600	386		

4.2.3 Financial analysis of O&M on water supply for high priority small towns

This project compares the ATP (5% of household income, 100% collecting) in target year of 2015 with the operation & maintenance cost by the construction fee. The annual household income for the ATP that resulted from the Socioeconomic and Water Usage Survey was 12,357 Birr in SNNP Regional State, and 18,891 Birr in Oromia Regional State. Consequently, ability to pay in SNNP Regional State was estimated to be 51.49Birr per month and in Oromia Regional State was assumed to be 78.71 Birr per month. The total O & M cost is 90.7 million Yen. As the amount of the annual ability to pay is 91.3 million Yen, about 7% is going over the budget finally.

4.2.4 Comparing Groundwater Recharge with Yield

The ratio of yield to the groundwater recharge is about less than 5% in each sub-basin, except Awassa sub-basin, in cases where the existing well yield is unchangeable, even after the estimated yield for 2025 is added (refer to Table 4.5). In any event, the groundwater in RVLB is sufficiently able to use for the quantity at least for the time being in terms of the relation between the amount of yield and the groundwater recharge.

Table 4.5: Ratio of yield to groundwater recharge

Sub-basin	Yield (existing wells)			Planned Yield (2025)		Ammount of Yield	Groundwater Recharge	Ratio to Groundwater Recharge(%)
	L/sec	m3/year	Mm3/year	m3/year	Mm3/year			
Ziway	Western Ziway	216.08	238.72	7528273.92	7.53	1317650	1.32	8.85
	Eastern Ziway	22.64						611.1
Langano		6.8	6.8	214444.8	0.21	152570	0.15	0.36
Abijata		17.66	17.66	556925.76	0.56	213160	0.21	0.77
Shalla		22.63	22.63	713659.68	0.71	734745	0.73	54.8
Awasa		272.93	272.93	8607120.48	8.61	508445	0.51	2.63
Abaya	Bilate	190.15						
	Gidabo	198.15						
	Galana	129.85						
	Kulfo Gina	5.5						
Chamo	Sife Chamo	6		441504	0.44	295285	0.3	0.74
	Konso Localized	8						199
Chew Bahir		29	29	914544	0.91	206225	0.21	1.12
								315.7
								0.35

4.2.5 Advantages expected by implementation of water supply plan

The following advantages are expected by the implementation of water supply plan.

a. Quantitative advantages

The following items are expected by the construction of water supply facilities;

- ① Water supply population will increase from 274,000 people (2010) to 323,000 people (2015) and water coverage also increase to 17.9% from 2010 to 2015 in SNNPRS.
- ② Water supply population will increase from 193,000 people (2010) to 227,000 people (2015) and water coverage also increase to 17.6% from 2010 to 2015 in Oromia Region.

b. Qualitative advantages

The following items will be expected by the water supply plan of safe and stable water;

- ① The health conditions are improved and the water borne diseases are decreased.
- ② The school enrollment and employment ratio are increased by decreasing the water fetching labor of children and women.
- ③ That increased economic opportunities and employment will be created as a result of higher productivity of beneficiaries.

Chapter 5

*Future Simulation by Groundwater
Models*

5 Future Simulation by Groundwater Models

5.1 General

4 groundwater simulation models have been created to evaluate the practicability of the water supply plan formulated in this study. For the model creation, the only way to make the models fit the groundwater environment in the study area is using all available data and survey results for model parameter and package specification in the condition of insufficient of necessary data about aquifer parameters and groundwater monitoring.

5.2 Groundwater modelling

The modeling of groundwater was executed in four sub-basins (refer to Figure 5.1). Each sub-basin is as follows;

- 1) Bilate sub-basin
- 2) Ziway-Shalla sub-basin
- 3) Gidabo-Galana sub-basin of the Abaya-Chamo sub-basin (Collective term : East Abaya sub-basin)

Amessa Guraoha-Kulfo Gina of the Abaya-Chamo sub-basin (Collective term : West Abaya sub-basin)

The groundwater environment that comes close to the actual conditions is established by groundwater modeling using hydrogeological situations, aquifer units, and aquifer coefficient in the target sub-basin. The groundwater model plays a role in groundwater management by the predicting groundwater fluctuations when usage of groundwater increases or decreases.

The basic information for the modeling in each sub-basin carrying out the simulation is shown in Table 5.1. In addition, the model is created using the world famous groundwater simulation program, MODFLOW. It was developed by the U. S. Geological Survey (USGS) and the source code can be freely downloaded from the USGS website.

Table 5.1: Basic Information of Model

Sub-basin	Area of model (km ²)	Cell number (E-W × N-S)	Mesh distance (km)	Layer division
Ziway-Shalla	24,300	10,800 (100 × 108)	1.5	4 layers
Bilate	13,616	13,616 (74 × 184)	1.0	4 layers
Abaya East	18,870	18,870 (111 × 170)	1.0	4 layers
Abaya West	5,184	5,184 (108 × 48)	1.0	4 layers



Figure 5.1: Sub-basin of Groundwater Modeling

The analyses in four sub-basins were executed using the same data of the others criteria, parameter and so on. The contents of each parameter are as follow:

a. **Boundary condition**

The outside of the each model sub-basin were specified as inactive boundary cell. All rivers and lakes in the model area are taken into consideration, majority cells in layer 1 will be specified as constant head boundary. Layer 1 is separated into 2 layers, layer 1 and layer 2 because the thickness of upper part of layers 1 is kept into thin layer for constant head boundary specification in the groundwater simulation model.

b. Parameter specification

The layer property (aquifer type) divided into the four layers is that the first layer is unconfined aquifer and second-fourth layers are confined aquifers.

All available aquifer data has been summarized to get values of the hydraulic conductivity for different lithofacies in Rift Valley as shown in Table 5.2. The vertical hydraulic conductivity is uniformly specified as 0.00001 m/day for all 4 layers. And also effective porosity is set as 0.1 uniformly to all layers.

Table 5.2: Specification of Aquifer Parameter in the Model

Symbol	Main Lithofacies	Transmissibility (m ² /day)	Average (m ² /day)
AL/Q	Fine sand or mud	90.2 - 388	248
Lac	Lacustrine sediment	10 - 2080	1,081
N1_2n	Rhyolite	2.5 - 376.5	190
Volcano	Volcanics	1980 - 3801	2,891
rb	Basalt	64 - 79	72
W	Volcanics & sedimentary rocks	2 - 3801	1,907
Tb	Scoria	158.7	158.7
Ba	Basalt	64 - 79	72
Ngs	Rhyolite	64 - 79	72
Pgl	Basalt	64 - 79	72
G	Welded tuff	12.5 - 914	52
Rh	Rhyolite	2.5 - 376.5	190

c. Model package

The groundwater recharge per day is calculated by the product of the evaporation from lakes and BFI (Basic Flow Index) of river flow in each sub-basin. Assign the total daily groundwater recharge to each cell in the model according to the criterion that the groundwater recharge amount in cell is proportional to the elevation of the cell. The groundwater recharge can only occur in the top layer that is an unconfined aquifer as revealed by the water level observation results, so all the groundwater recharge is specified on layer1.

Two kinds of variables are needed to use the well package: locatable well depth and yield amount. To which layer a well should be assigned is based on the well depth and layer thickness. The withdrawal amount is needed to specify the groundwater use in those well cells. As there are few data concerning yield data of the existing wells, the standard yield per capita per day in each well was applied for the yield data of well package.

d. Results of calibration

The calculation method of steady flow is used for model calibration this time, because the steady flow method is generally used for the first time calibration to check or to ensure the convergence or stability of the model. Steady state flow method is compared to a macroscopic calculation method effective to check the model fitting to a certain degree. Simulation time span for this method is set as infinite to check if water level can stabilize

under the conditions of given parameters and specified variables in the model. As for the model calibration, the most important issue is to check if the model can converge under all specified parameters and variables in different packages. In most cases, if the model does not converge, some problems exist in parameters or variables specification, errors would occur when steady state flow method is used. The steady flow method is generally used for the first time calibration to check or to ensure the convergence or stability of the model. A supplementary program is needed and has been created. Even though the calibration can be supported by the supplementary program, still a long time was taken for iterative calibration. Model calibration result, as shown in Figure 5.2 does not only ensure the convergence of the model but also ensures the groundwater level distribution in the model area fit the characteristic of relief and other conditions. (Sample: Results of calibration of first layer in Ziway-Shalla sub-basin).

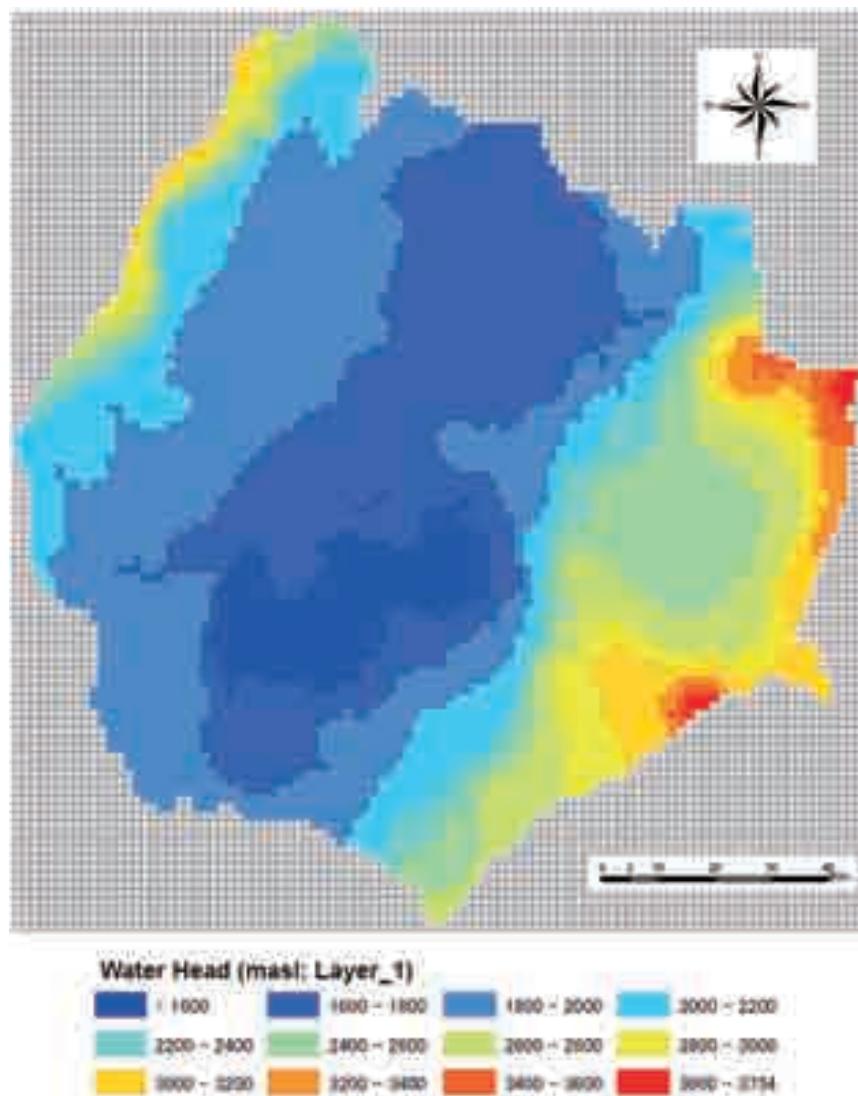


Figure 5.2: Results of Calibration of First Layer in Ziway-Shalla Sub-Basin (unit: m)

5.3 Model modification and results of calibration

When interim report was created as mentioned above, the boundary conditions of the models were specified following the GIS database, which captures not only information on groundwater but also all kinds of information on natural conditions. However, the incompleteness of some information has been confirmed later in the discussion with the counterpart, Professor Tenalem. And then, the model was modified before the predictions were made.

The modification is conducted in the Ziway model, which has the most vast model domain and includes most numerous wells in the water supply plan. The modification is mainly conducted in the specification of model boundary and hydraulic conductivities.

Some lake and rivers cells specified as constant head boundary before have been modified as shown in Figure 5.3.

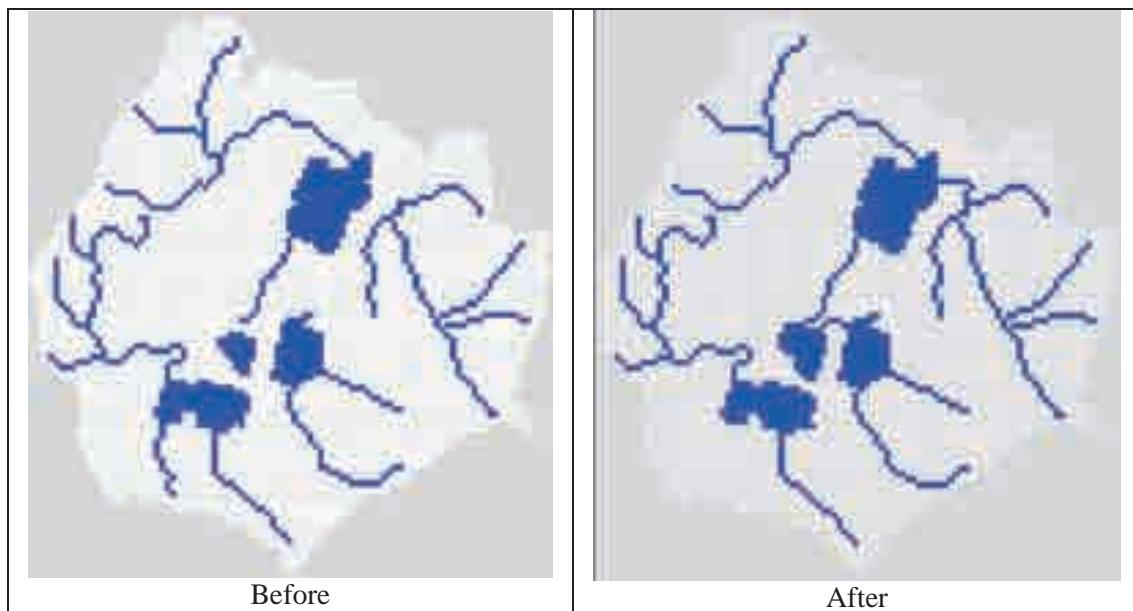


Figure 5.3: Modification of Boundary Condition in Ziway Groundwater Model

A river specified as constant head boundary following the GIS database is not a perennial river, but an ephemeral stream. Therefore the river cells have been changed from constant boundary cell to calculation boundary cell. In some other areas, several constant boundary cells have been newly specified, because there are several perennial rivers located between lakes. When comparing the lake area between the GIS database and the book of "The Hydrogeological System of the Lake District Basin – Central Main Ethiopian Rift", several differences were found in lake areas and then the lake area was modified following the book.

The modification of boundary specification is not only limited in the first layer, because one of the 4 main lakes in the model, Shalla Lake has been pointed out to have a depth of more than 250m. Therefore, the constant head boundaries have been specified until the layer4. The result of constant boundary modification for Shalla Lake is shown in Figure 5.4.



Figure 5.4: Modification of Boundary Condition in Ziway Groundwater Model (Shalla Lake)

When interim report was created, for the 4 main constant head boundary specified lakes the water level was specified according to the DEM data of SRTM (90 m mesh from the USNASA). Some minor differences between the SRTM data and the real lake's water level have been pointed out by Professor Tenalem. And then the water level specifications for the lakes have been modified on the base of the same book of "The Hydrogeological System of the Lake District Basin – Central Main Ethiopian Rift". The modification result is shown in the Table 5.3.

Table 5.3: Result of Lake Water Level Specification Modification

Lake	Level Before	Level After
Ziway	1639	1636
Abijata	1577	1578
Langano	1586	1585
Shalla	1555	1550

Water level unit: m

Moreover, 13 wells obtained from the GIS database were used for model calibration at the time of the interim report compilation. After that, 6 new observation wells data were collected from EWTEC increasing the number of available wells to 19.

The model calibration was conducted again after the modification of model boundaries and addition of head observation wells. The location of head observation wells and the result of calibration are shown in Figure 5.5.

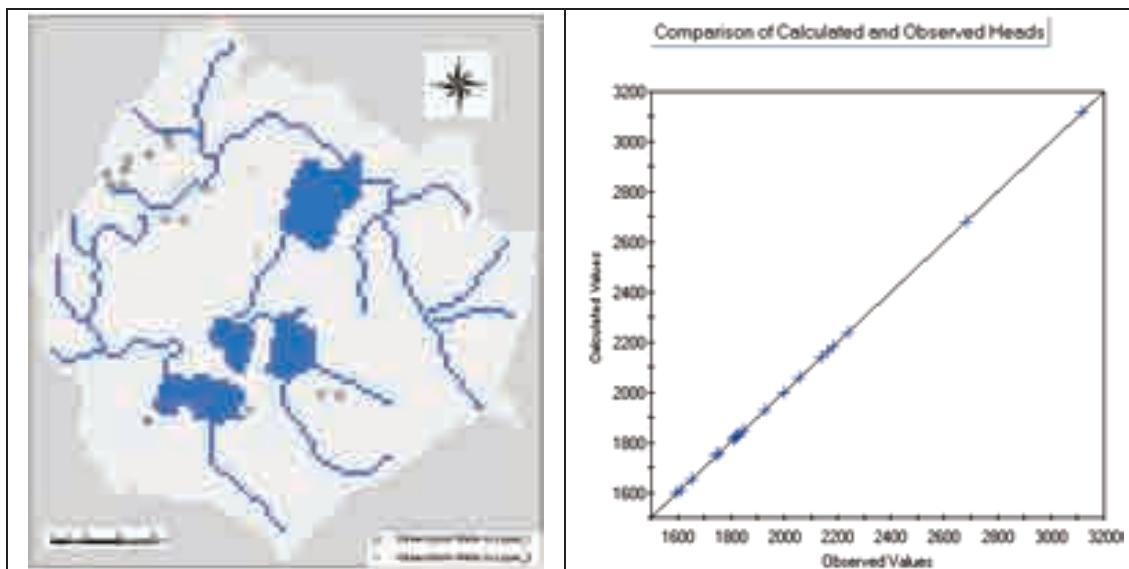


Figure 5.5: Location of Head Observation Wells and Result of Calibration in Ziway Model

As the result of model calibration, water head distributions in each layer of the Ziway model are extracted and shown in Figure 5.6 to Figure 5.8.

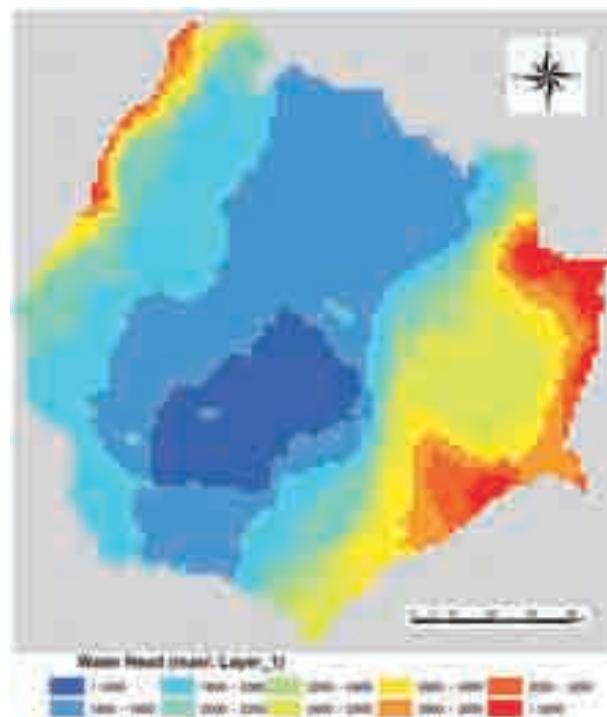


Figure 5.6: Result of Ziway Basin Model Simulation (Layer 1)(unit: m)

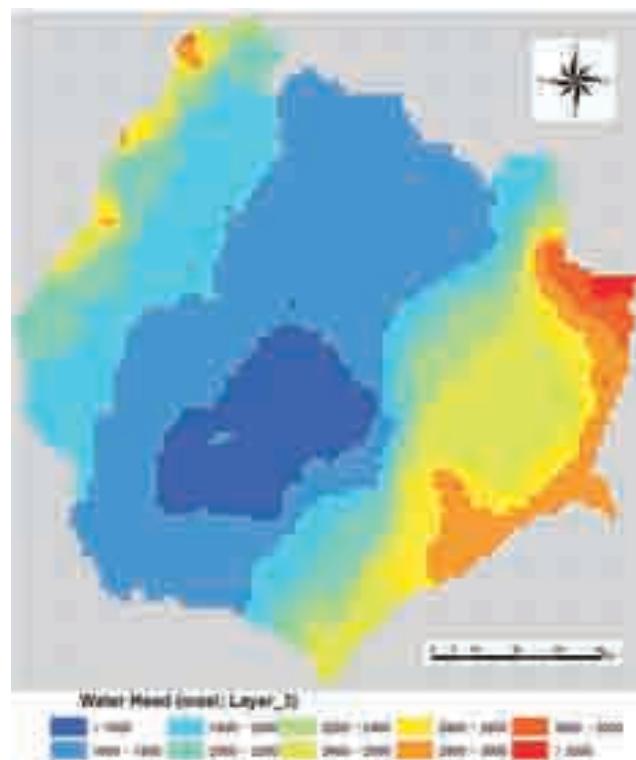


Figure 5.7: Result of Ziway Basin Model Simulation (Layer 3)(unit: m)

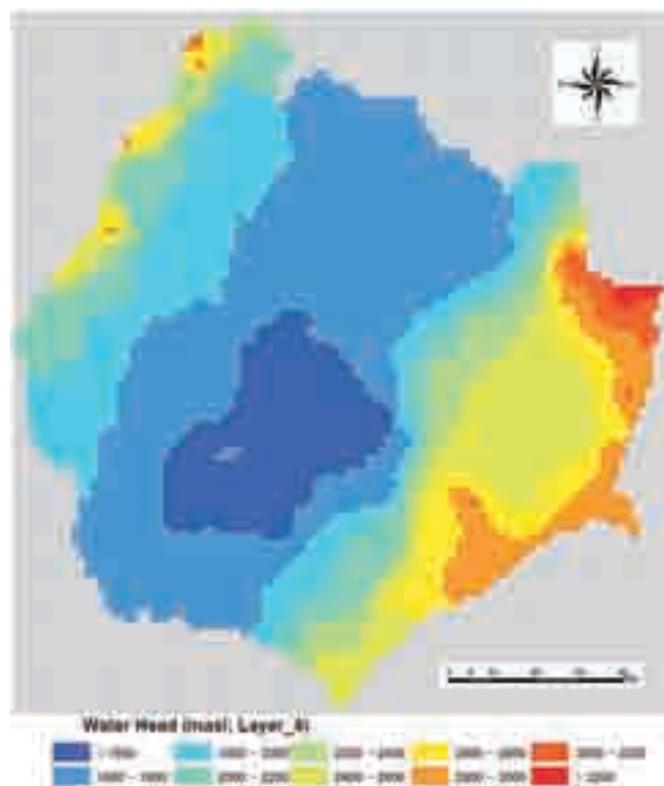


Figure 5.8: Result of Ziway Basin Model Simulation (Layer 4)(unit: m)

5.4 Future pumping scenarios and cases specification

4 scenarios were formulated to predict the effect of the newly planned wells on the groundwater environment.

a. Scenario 1 (Reference Scenario)

The withdrawal amounts from the new planned wells are designed to increase within the plan duration. Hence, the steady flow method is not suitable for the prediction, but the other method of transient flow should be used instead.

When new wells are drilled and used for groundwater withdrawal, groundwater drawdown is unavoidable. And then, whether this groundwater drawdown is within permissible levels or not becomes an important issue that should be seriously examined. This is because in cases whereby the drawdown level is over the permissible limit, some problems would happen such as insufficient water supply, high maintenance cost, land subsidence and so on. Therefore the main task of prediction by groundwater model is to make clear the possible groundwater drawdown amount. On the other hand, groundwater drawdown means the groundwater level becomes lower than the base level. Therefore, one thing that needs to be thought over is what base level to set for lower water level comparison.

To make clear water level fluctuation under natural conditions, a scenario is set as without new planned wells but has precipitation and / or groundwater recharge fluctuation following hydrologic cycle. This scenario will be used as the standard reference condition for groundwater level drawdown calculation in case the new planned wells are used.

b. Scenario 2 to Scenario 4

In the study area, the service population of new planned wells and the population increase ratio will change according to all kinds of natural and social conditions. The target year of new water supply plan is up to 2015 as the target of water supply plan of new UAP2. After that the next target year is set as 2025 in consideration with the extinguishment cost for ten years. And the population up to the target year of the water supply plan is set following a uniform population increase ratio based on the social analysis' result (2011-2015 : 3.3%、2016-2020 : 2.8%、2021-2025 : 2.5%). Taking this matter into consideration, not only one plan for water supply in the future, but another two plans have been formulated to correspond to relatively less and more population increase conditions, respectively. The total daily groundwater withdrawal amount (m^3/day) by using the 74 new wells in the three water supply plans are as follows:

- ❖ Scenario 1 (Plan 1) : 12,534 (In take amount of water in the small towns of daily average water)
- ❖ Scenario 2 (Plan 2) : 15,032 (In take amount of water in the small towns of daily maximum water)
- ❖ Scenario 3 (Plan 3) : 17,814 (Unit water demand can be increased to 25 l/c/d from 2016-2025 and daily maximum water can be kept)

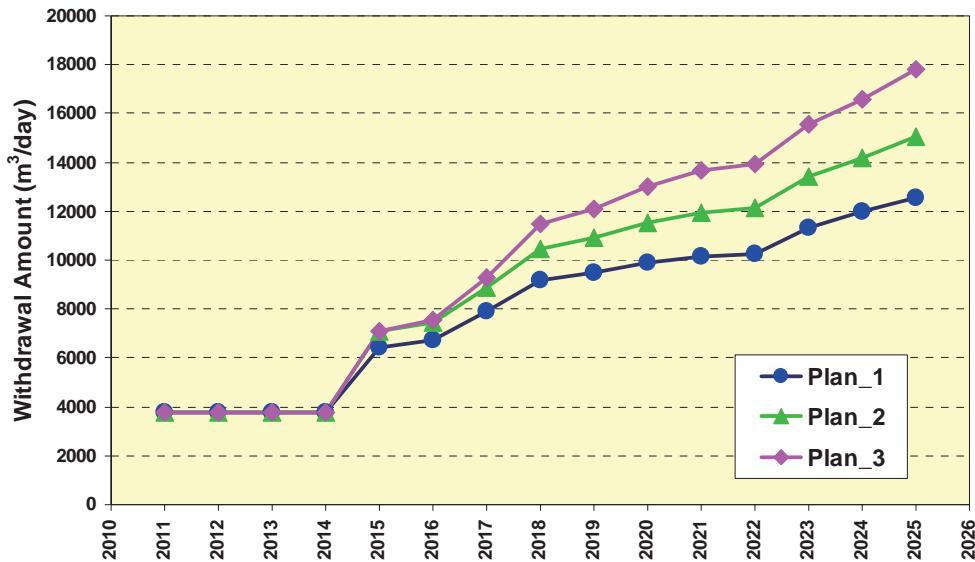


Figure 5.9: Withdrawal Amount for Each Water Supply Plan

After the Scenario 1, Scenario 2 to Scenario 4 are created following the three water service plans as shown in Figure 5.9.

5.5 Distribution of new wells

As mentioned above, 4 groundwater models have been created in the Rift Valley area, for the new water supply plan evaluation. However, the 4 models don't cover the whole Rift Valley area. 62 from 74, more than 80 percent of the newly planned wells have been involved into the 4 models.

The well's location, row and column number for the new planned wells specification is decided based on well's coordinates given in the well plan. And the well's layer specification is decided following the presumed well's strainer depth in the well's plan. The new well's ID, coordinates, drilling depth, presumed strainer depth and corresponding row, column and layer numbers are summarized in Table 5.4 to Table 5.7.

Table 5.4: Planned Wells in Ziway Model (32 wells)

Town_ID	Easting	Northing	Row	Col	Depth	Strainer	Layer
O-01	525789	898989	27	87	100	30-100	1
O-02	501151	888795	33	71	140	60-140	3
O-03	520879	888380	33	84	100	30-100	1
O-05	527753	858194	53	88	100	80-100	3
O-06	517142	857073	54	81	150	130-150	1
O-07	498043	831878	71	69	110	50-110	1
O-09	526870	818549	79	88	100	80-100	1
O-10	476343	782584	103	54	110	50-110	1
O-11	517670	886130	34	82	100	30-100	3
O-12	527151	889046	32	88	100	80-100	1
O-20	469693	886574	34	50	120	50-120	3
O-22	467669	869137	46	48	150	100-150	3
O-28	441606	852012	57	31	120	50-120	3

Town_ID	Easting	Northing	Row	Col	Depth	Strainer	Layer
O-29	501766	867164	47	71	150	130-150	1
O-30	524802	840806	65	86	150	130-150	1
O-41	461770	793962	96	44	110	50-110	1
O-42	467482	789539	99	48	110	50-110	3
S-01	450564	919685	12	37	100	80-100	1
S-02	444689	912633	17	33	120	80-120	1
S-03	456768	932196	4	41	100	80-100	1
S-04	457353	928959	6	41	100	80-100	1
S-06	448175	885173	35	35	150	80-150	1
S-43	426149	887107	34	21	150	130-150	1
S-44	415670	875249	42	14	100	50-100	1
S-46	436358	868558	46	27	100	80-100	1
S-47	429240	848987	59	23	150	80-150	3
S-48	416683	861330	51	14	180	130-180	3
S-49	409074	836119	68	9	250	200-250	3
S-52	403219	855693	55	5	100	50-100	1
S-53	444381	898358	26	33	150	80-150	3
S-62	441600	875629	41	31	100	80-100	1
S-63	413574	885422	35	12	100	30-100	1

Table 5.5: Planned Wells in Bilate Model (12 wells)

Town_ID	Easting	Northing	Row	Col	Depth	Strainer	Layer
S-07	382047	830873	68	18	200	130-170	1
S-09	397071	839228	59	33	150	80-120	3
S-11	385587	844936	54	21	200	130-150	1
S-13	374202	811859	87	10	200	130-150	1
S-14	387502	796712	102	23	200	130-150	1
S-15	383977	812084	86	19	200	130-150	3
S-32	403721	766084	132	39	200	130-150	3
S-51	403911	823298	75	39	150	30-80	3
S-54	384570	820680	78	20	200	130-150	3
S-55	384678	793963	105	20	200	130-150	1
S-58	373639	776639	122	11	200	130-150	1
S-59	370680	762721	136	6	100	50-70	1

Table 5.6: Planned Wells in Eastern Abaya Model (12 wells)

Town_ID	Easting	Northing	Row	Col	Depth	Strainer	Layer
O-32	419060	638333	130	69	100	80-100	1
S-16	438137	759326	9	89	70	50-70	1
S-17	427292	715624	53	78	100	80-100	1
S-18	432846	718356	50	83	100	80-100	1
S-19	453653	759991	9	104	70	50-70	1

S-21	445220	746447	22	96	100	80-100	1
S-22	426989	728189	40	77	150	100-150	1
S-27	411345	671729	97	62	100	80-100	1
S-28	416921	653784	115	67	100	80-100	1
S-38	377988	644892	124	28	100	80-100	1
S-56	405405	669769	99	56	100	80-100	3
S-57	418355	665767	103	69	100	80-100	1

Table 5.7: Planned Wells in Western Abaya Model (6 wells)

Town_ID	Easting	Northing	Row	Col	Depth	Strainer	Layer
S-30	364091	741131	24	16	70	50-70	1
S-34	363450	695658	64	38	100	80-100	3
S-35	342198	691040	78	22	100	80-100	1
S-36	344386	702079	68	18	100	80-100	1
S-37	342151	684810	84	25	100	80-100	1
S-60	350026	678098	86	35	110	80-120	3

5.6 Specification in analysis of transient flow

5.6.1 Parameter

The steady flow method is used for model calibration. However, another method, transient flow method needs to be used for model prediction. And the transient flow method needs some more parameters than steady flow method. Those parameters are specified as follows:

- Specific Storage : 0.000001 (uniformity)
- Specific Yield : 0.1 (uniformity)

5.6.2 Period specification

According to the discussion of the counterpart, Professor Tenalem, the periods are specified for different seasons. By this kind of setting, a year will be separated into 2 periods corresponding to a dry season from November of the previous year to March, and a rainy season from April to October.

In the target year of water service plan, 2025, there are three seasons of the first dry season, rainy season and the last dry season. Therefore the total number of periods in the 15 calculation years should be calculated as follows:

$$\text{Total Periods} = 15 \times 2 + 1 = 31 \text{ Periods}$$

To get relatively detailed water level fluctuation information, not only period's specification based of seasons, time steps is specified in month units. Therefore, in the 15 calculation years, the total time steps is:

$$\text{Total Steps} = 15 \times 12 = 180 \text{ Steps}$$

As common sense, water demand is not the same in rainy season and dry season, more water is generally used in dry season than rainy season. Therefore, the water service amount planned as yearly average should be separated into different amount for different seasons. The daily water service amount in the 7 months rainy season from April to October is set as 90 % of the yearly average amount, and then the daily water service amount for dry season can be calculated by the equation below.

Daily water service amount in dry season / yearly average amount

$$= (12 - 0.9 \times 7) / 5 = 1.14$$

5.6.3 Recharge specification

Average precipitation in long observation series is used for recharge amount specification in recharge package for each model's calculation by steady flow method. However, if the same specification is used for prediction by transient flow method, the result would become rough. Therefore, rather than the average amount of precipitation, the year and season fluctuated precipitation amount are used for the model prediction.

On the other hand, the precipitation amount up the last observation day can be obtained exactly, but the prediction of precipitation amount in the duration of the water supply plan from 2011 to 2025, is almost impossible. Then the precipitation fluctuation can only be specified following the existing observation result. It is common sense in hydrology, that even though the precipitation will change year by year, over a relative long duration the hydrological cycle makes precipitation fluctuations around the average amount. From this view point, the recharge amount for the 15-year water service plan is specified by extracting data for 15 continuous years from the existing precipitation observation results.

a. Selection of meteorological station

a.1 Location

In each model domain, there are several meteorological stations used for precipitation observation. Relatively large difference has been made clear in precipitation amount from different stations according to the topography and other factors. To prevent too large or too small precipitation specification, one way is to select a station around the central part of the model.

a.2 Observation year selection

Based on the 15 year duration of the water service plan, another criterion for station selection is that the station has a continuous observation series longer than 15 years. If the observation series is discontinuous, it is possible that the selected result is biased toward rainy or dry years.

a.3 Few missing days

All stations with an observation series of more than 15 continuous years have days missing from the precipitation record. In hydrological analysis, the missing data is complemented by self correlation method. This method can reduce somewhat the miss in data to enhance the precision and reliability of the analysis, but it is impossible to get real value of precipitation

for the missing days. Therefore, containing fewer missing data is considered a criterion for series selection to ensure the correctness of recharge specification.

The name and location of the 4 selected stations in each model according to the above 3 criteria are shown in Figure 5.10.

b. Precipitation series selection

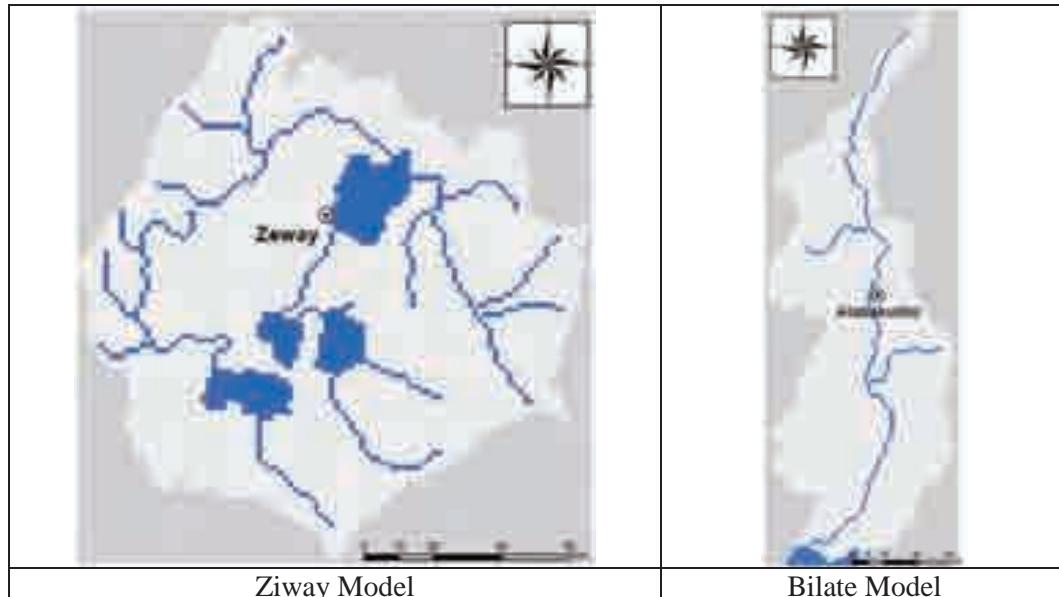
The hydrological cycle in Rift Valley area is known as around 10 years from the result of hydrological analysis. Hence, there would be not problem for the 15 year duration of water service plan to contain a complete hydrological circle. On the other hand, all the 4 stations shown in Figure 5.10 have much longer observation series than 15 years. Then the precipitation series selection is mainly based on the criterion of fewer missing days.

b.1 Monthly average precipitation in Ziway model

Ziway meteorological station has an observation series as long as 29 years from 1982 to 2010. The 15-year continuous series with the fewest missing day is from 1990 to 2004. This series contains 12 missing days, 5 days in 2001 and 7 days in 2002. The monthly average precipitation for rainy season (April to October) and dry season (last November to March) in the selected series is shown in Figure 5.11.

b.2 Monthly average precipitation in Bilate model

Alaba Kulito Station is used for precipitation series selection in Bilate Model. The station has a 22-year observation series from 1989 to 2010. The 15-year continuous series with the fewest missing day is from 1996 to 2010. This series contains only one missing day in 2000. The monthly average precipitation for rainy season and dry season in the selected series is shown in Figure 5.12.



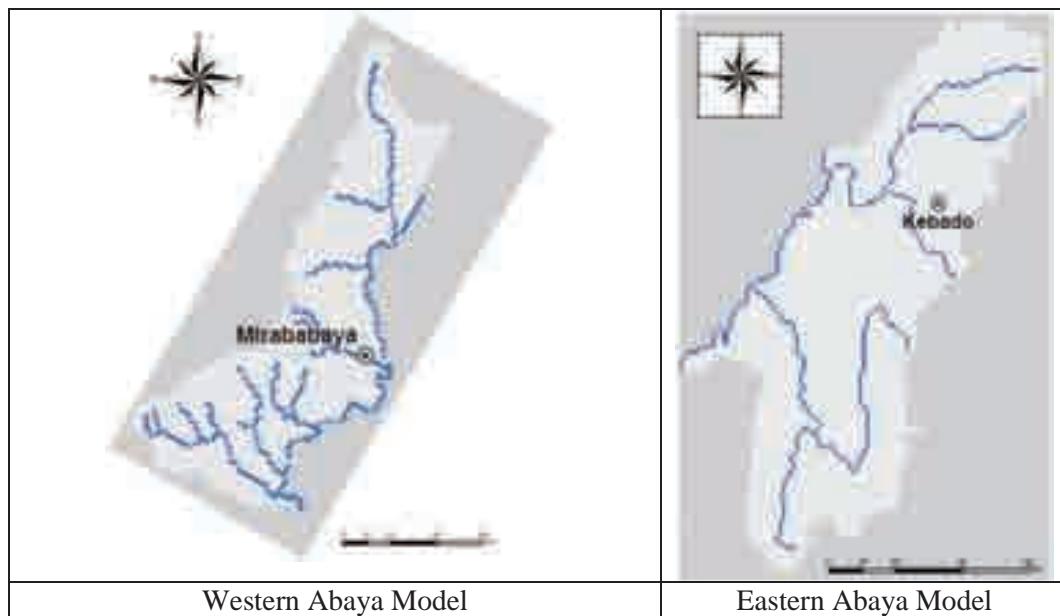


Figure 5.10: Location of Selected Meteorological Stations in the Models.

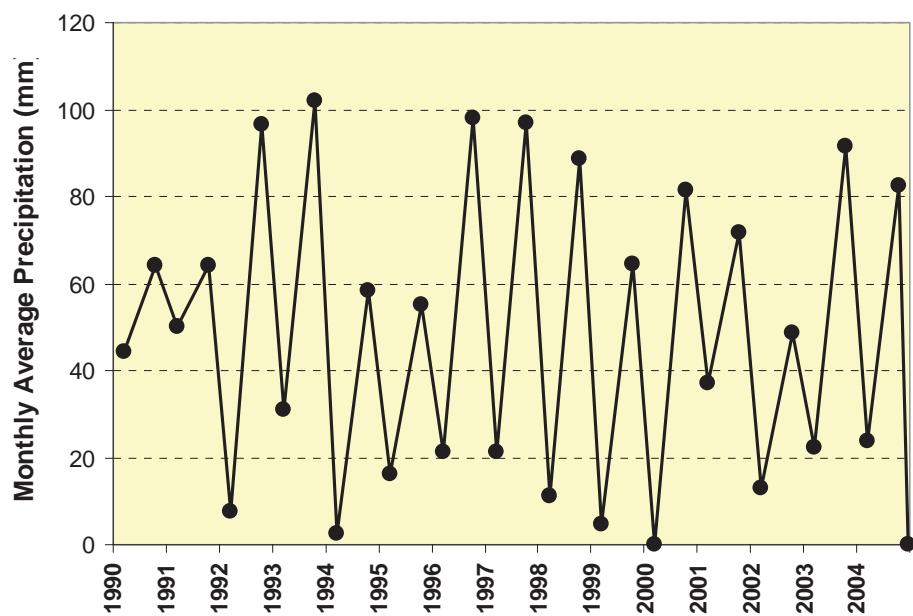


Figure 5.11: Monthly Average Precipitation in Dry and Wet Seasons at Ziway Station

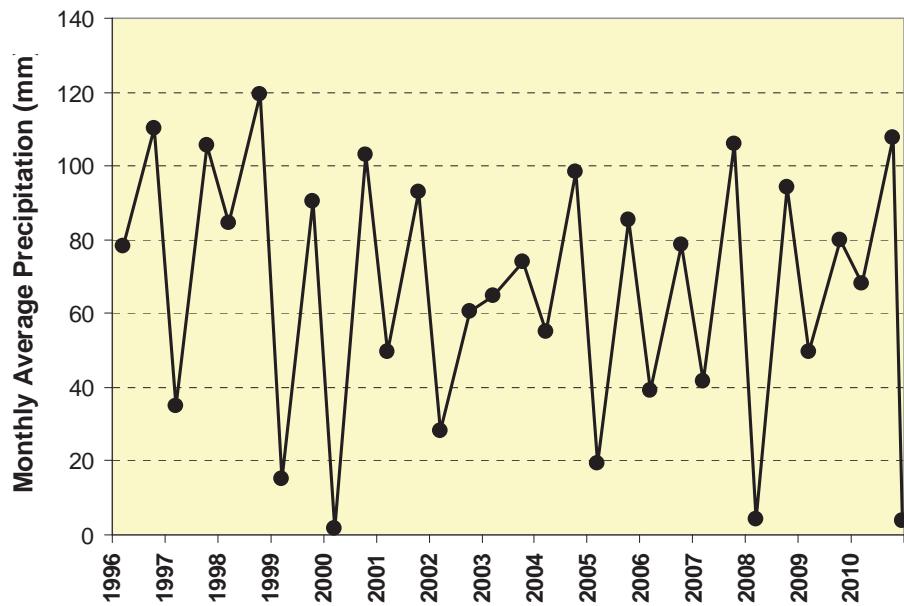


Figure 5.12: Monthly Average Precipitation in Wet and Dry Seasons at Alaba Kulito Station

b.3 Monthly average precipitation in Eastern Abaya model

Kebado Station is used for precipitation series selection in Eastern Abaya Model. The station has a 20-year observation series from 1991 to 2010. The 15-year continuous series with the fewest missing day is from 1995 to 2009. This series contains 6 missing days, 5 days in 2001 and 1 day in 2008. The monthly average precipitation for rainy and dry seasons in the selected series is shown in Figure 5.13.

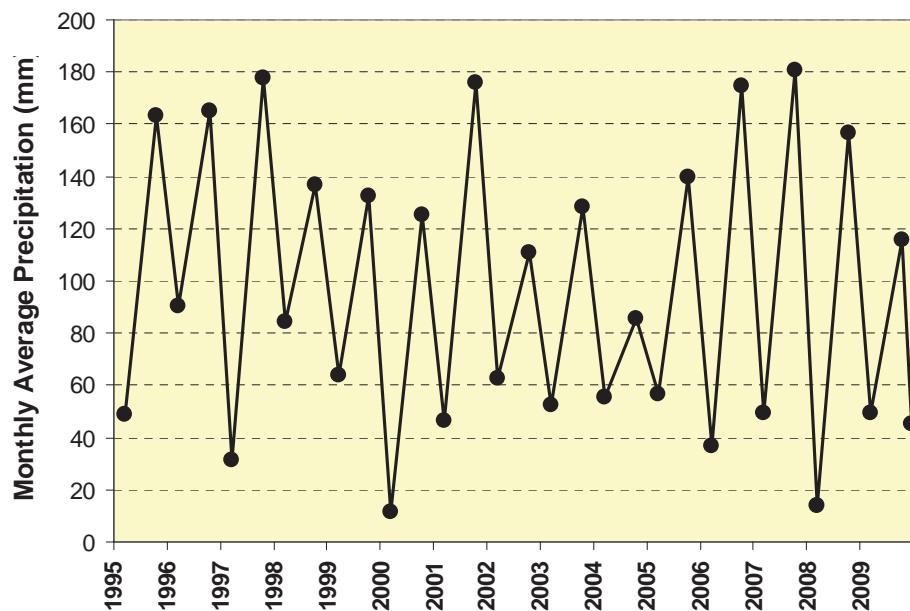


Figure 5.13: Monthly Average Precipitation in Wet and Dry Seasons at Kebado Station

b.4 Monthly average precipitation in Western Abaya model

Mirababaya Station is used for precipitation series selection in Western Abaya Model. The station has a 29-year observation series from 1982 to 2010. The 15-year continuous series with the fewest missing days is from 1995 to 2009. This series contains 2 missing days in 1998 and 2001, respectively. The monthly average precipitation for rainy and dry seasons in the selected series is shown in Figure 5.14.

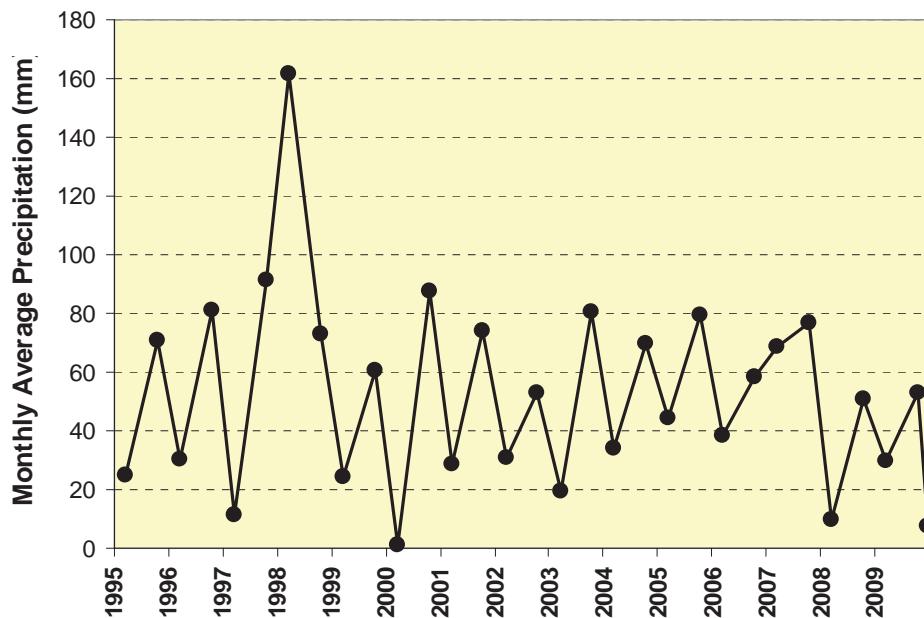


Figure 5.14: Monthly Average Precipitation in Wet and Dry Seasons in Mirababaya Station

5.6.4 Boundary condition specification

Groundwater level is affected by not only recharge amount, but also the water level of constant head boundary, which is specified in cells of main rivers and lakes. For this reason, simulation program Modflow prepared a package of “Time_Variant_Specific_Head”. On the other hand, the lake’s water level can be obtained from the water level observation result of lakes, but there is no river water level observation result available in the study area. Refer to the water level fluctuation of lakes in the study area, the river’s water level fluctuation is specified as flows:

a. River's water level fluctuation

a.1 The Highest water Level

The highest water level of constant head boundary for rivers generally appears in the rainy season of the year with the highest precipitation. And the water level for the year is specified as 0.7m over the average water level of the river. The other 14 year's water level in the rainy seasons is then specified according to the ratio of the precipitation in the rainy season to the highest precipitation year.

a.2 The Lowest water Level

Similar to the highest water level specification, the lowest water level of the constant head boundary is considered as appearing in the dry season of the year with lowest precipitation. And the water level for the year is specified as 0.5m under the average water level of the river. The other 14 year's water level in the dry seasons is then specified according to the ratio of the precipitation in the dry season to the lowest precipitation year.

The specification of water level fluctuation in lakes is specified based on the water level observation result.

b. Water Level Observation Result in Ziway Lake (Ziway Model)

As shown in Figure 5.15, water level observation record covers a 35-year time series from 1974 to 2008. Corresponding to the selection result of precipitation series for recharge package, water level series from 1990 to 2004 are selected for water level specification. The highest, lowest and average water levels in the selected time series are 2.3, 0.22 and 1.17m. According to this result, water levels in the 4 lakes shown in Table 5.1 are specified as 1.13 m for the highest water level over average value and 0.95 m for the lowest level under average value.

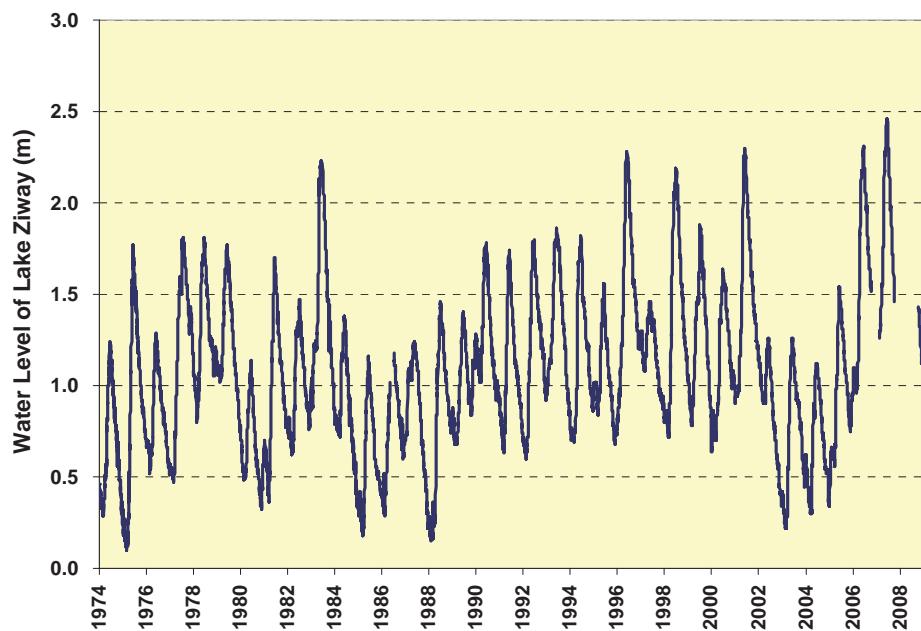


Figure 5.15: Water Level Observation Result of Lake Ziway

c. Water Level Observation Result in Abaya Lake (Bilate, Eastern Abaya and Western Abaya Models)

Abaya Lake concerns with the other 3 models of Bilate, Eastern Abaya and Western Abaya. The lake's water level observation records cover a 41-year series from 1969 to 2009, as shown in Figure 5.16. However the observation result in the last year of 2009 ends in March, meaning the lake's observation result could not exactly correspond to the selected precipitation series in the 3 models. And then, the lakes' water level fluctuations are specified as follows:

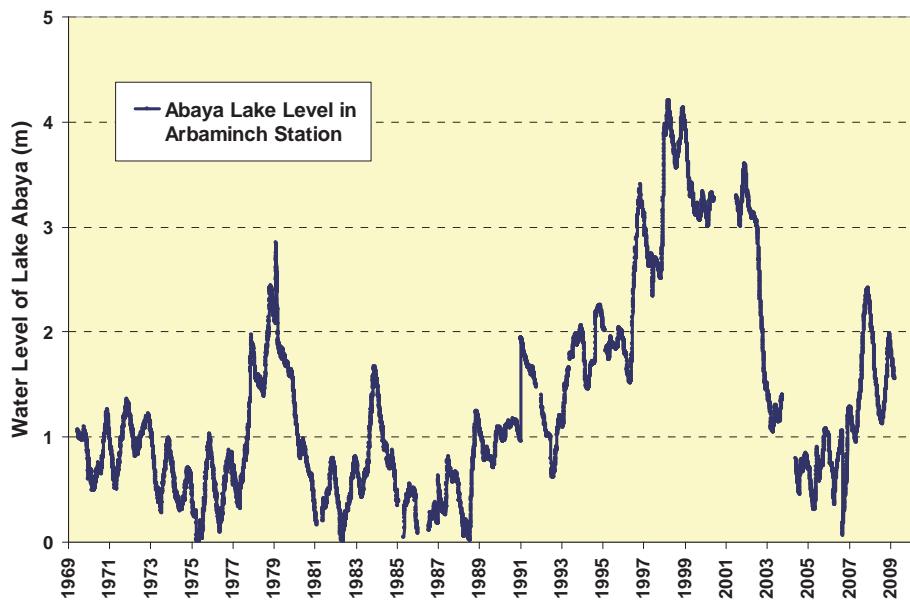


Figure 5.16: Water Level Observation Result of Lake Abaya

c.1 Lake water level series selection

According to 2 criteria of a) relatively few missing data and b) relatively better correspondence to the selected precipitation series, 15 years of water level observation results are selected in Lake Abaya from March 1994 to March 2009.

c.2 The Highest, lowest and average water level

The highest, lowest and average water level in selected series of Abaya Lake is as follows:

The highest level: 4.2m

The lowest level: .007m

The average level: 2.09m

Within the selected data series that corresponds to the selected precipitation series for the 3 models, Abaya Lake has the highest and the lowest water level to be over and under the average water level as 2.11m and 2.02m. The lake water level for each season and year in the model calculation duration is specified directly according to the lake water level observation result.

c.3 Missing data complement

For 2 models of Eastern Abaya and Western Abaya, the selected precipitation series is the same from January 1995 to December 2009. But the collected Abaya Lake observation data is up to March, 2009. There is no data of lake's water level available that corresponds to the precipitation series from April to December. Then the water level is specified according to the precipitation fluctuation in the two models, respectively.

5.7 Results of future simulation

After all the necessary parameters and package specification described above, 4 Scenarios are formulated for each model to conduct the prediction of groundwater level fluctuation. The prediction result of water level fluctuation for the 4 scenarios of all the 62 new planned wells are given in the Data book of final report.

5.7.1 Groundwater Level Drawdown in Ziway Model

Ziway model has the largest model domain and also has the most numerous (32) wells. The water level fluctuations of the 32 wells are summarized in Table 5.8.

Table 5.8: Groundwater Level Drawdown in Ziway Model

Well_Code	N_Min	N_Max	P_Min	P_Max	Down_Max
O_01	2145.7	2146.6	2145.7	2146.6	0.04
O_02	1699.0	1699.8	1699.0	1699.8	0.01
O_03	2241.6	2242.6	2241.3	2242.4	0.46
O_05	2652.3	2653.4	2652.3	2653.4	0.02
O_06	2499.3	2500.3	2498.7	2500.1	0.77
O_07	2708.9	2709.8	2708.1	2709.5	0.99
O_09	2962.1	2963.2	2961.8	2963.2	0.32
O_10	2597.2	2598.3	2594.2	2597.7	3.41
O_11	2156.0	2157.2	2156.0	2157.2	0.01
O_12	2389.3	2390.2	2388.7	2390.1	0.67
O_20	1641.4	1642.9	1641.0	1642.8	0.50
O_22	1629.6	1630.4	1626.8	1629.5	3.00
O_28	1625.6	1626.3	1625.6	1626.2	0.04
O_29	2138.6	2139.7	2138.5	2139.7	0.11
O_30	2483.7	2484.8	2483.5	2484.8	0.25
O_41	2090.1	2091.1	2090.0	2091.1	0.14
O_42	2397.8	2398.9	2397.7	2398.9	0.05
S_01	2001.7	2002.7	2001.6	2002.6	0.18
S_02	1902.3	1903.0	1902.2	1903.0	0.06
S_03	2273.0	2273.8	2272.8	2273.8	0.27
S_04	2194.7	2195.6	2194.5	2195.5	0.20
S_06	1802.9	1803.7	1802.3	1803.5	0.59
S_43	2099.5	2100.2	2099.3	2100.2	0.14
S_44	2170.9	2172.0	2170.9	2171.9	0.03
S_46	1833.8	1834.5	1833.0	1834.4	0.85
S_47	1728.7	1729.4	1728.6	1729.4	0.04
S_48	1945.0	1945.9	1944.8	1945.9	0.16
S_49	1875.7	1876.8	1875.7	1876.8	0.02
S_52	2011.6	2012.5	2011.5	2012.4	0.02
S_53	1838.7	1839.7	1838.7	1839.7	0.03
S_62	1844.8	1845.5	1844.1	1845.5	0.84
S_63	2879.1	2880.2	2878.9	2880.2	0.34

N_Min: Minimum value of water level in Scenario 1 (No new wells)

N_Max: Maximum value of water level in Scenario 1 (No new wells)

P_Min: Minimum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

P_Max: Maximum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

Down_Max: Maximum water level drawdown by comparing water levels between Scenario 1 and 4.

In locations of the 32 new planned well sites, the groundwater level fluctuation range in Scenario 1 is from 0.69m to 1.47 m. Scenario 1 is the reference scenario without utility of new planned wells, in which groundwater fluctuation depends on the changes of groundwater recharge amount. In planned well's scenarios (Scenario 2 to 4), groundwater level fluctuation range is getting larger according to the designed water withdrawal amount. Comparing to the reference scenario, the largest water withdrawal amount scenario (Scenario 4) has the average groundwater drawdown of 0.53m, and the maximum and minimum drawdown is 3.41m and 0.01m, respectively.

Figure 5.17 shows the results of the 4 scenarios in well site of O_10, which has the maximum groundwater drawdown in the Ziway model. Comparing to the reference scenario, the range of groundwater drawdown is getting larger following the withdrawal amount from planned wells. However, the groundwater levels in the 3 well withdrawal scenarios do not decrease consistently. In rainy years of 2018 and 2022 the recovery tendency can be found from the figure.

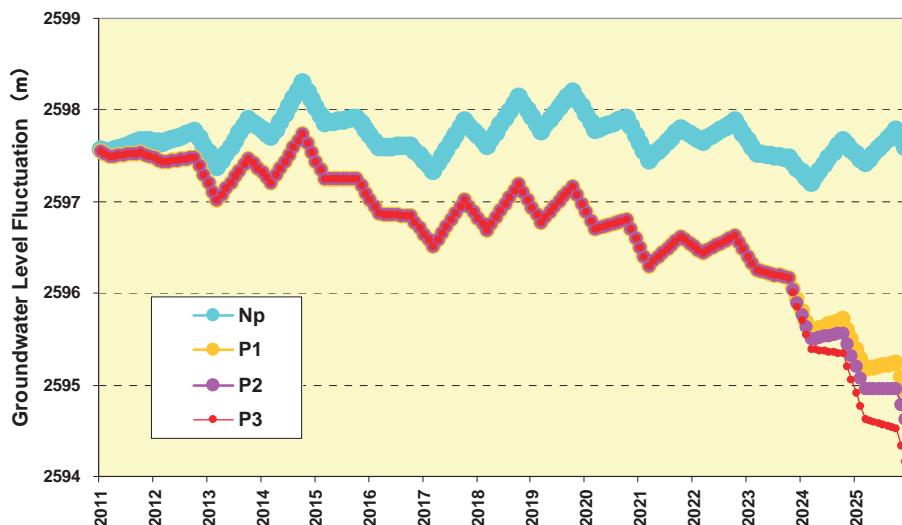


Figure 5.17: Groundwater Level Drawdown in Location of Planned Well O_10,
(Ziway model)

The relatively large groundwater drawdown can be seen from the Figure 5.17 in the last 3 years from 2003 to 2005. The reason of this drawdown can be explained from the recharge amount specification as shown in Figure 5.11. The precipitation in rainy season of the year 2003 has the smallest value to be the driest year in the precipitation series. The following year of 2004 is an ordinary year. The precipitation amount in dry season of the last year 2005 is zero, that is, groundwater is not recharged at all that season. By the way, the largest groundwater drawdown in well site of O_10 is 3.41m as shown in Figure 5.11 and Table 5.8. This groundwater drawdown amount can be considered generally as within permissible levels.

Figure 5.18 shows the results of the 4 scenarios in well site of O_02, which has the minimum groundwater drawdown in the Ziway model. In reference scenario of Scenario 1, the groundwater fluctuation range is 0.741m, and in all other 3 scenarios of Scenario 2 to 4, the range is 0.743m. Comparing to the reference scenario the groundwater drawdown is very small, only 0.01m. The reason of this very small groundwater drawdown in case of well withdrawal can be explained by Figure 5.19.

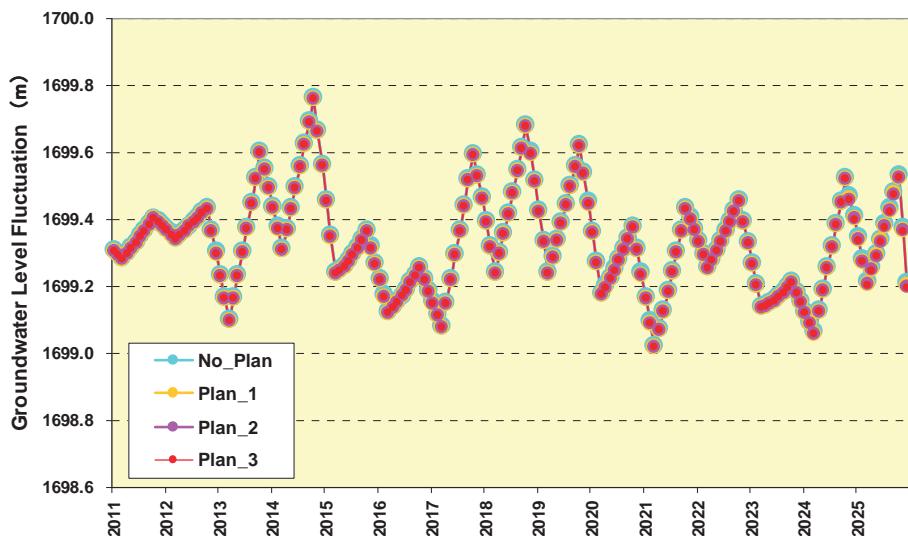


Figure 5.18: Groundwater Level Drawdown in Location of Planned Well O_02,
(Ziway model)

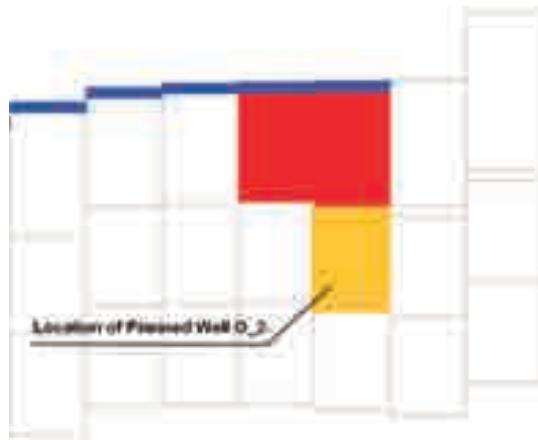


Figure 5.19: Location of Planned Well O_02, (Ziway Model).

As shown in Figure 5.19, the planned well O_02 is under a constant head boundary of river. The water level in the well site not only depends on the withdrawal amount, but is also affected by the constant head boundary. Therefore, even though the groundwater withdrawal amount is specified as 250m³/day to the target year of 2025, the water level drawdown is very small when comparing to the reference scenario.

Groundwater level drawdown for the whole 32 wells grids in layer_1 of Ziway model and the last day of the plan, 2005/12/31 have been extracted and shown in Figure 5.20. The effect of using the wells on the adjacent grids is limited to less than 3 grids. The small groundwater level drawdown well like O_02, affects not at all to the adjacent grids. As the grid size is specified as 1,500m, the affect of those well can be considered as less than 750m. On the other hand, the largest groundwater drawdown in the well site of O_10 is 3.43 m, a little larger than the value of 3.41m, which is extracted form the well coordinates location. Some other wells like O_01 and O_02 also have relatively large groundwater drawdown in the grid central points, and also clearly have affect to the adjacent grids. That is, the effect of groundwater withdrawal from those wells might extend to as much as several km.

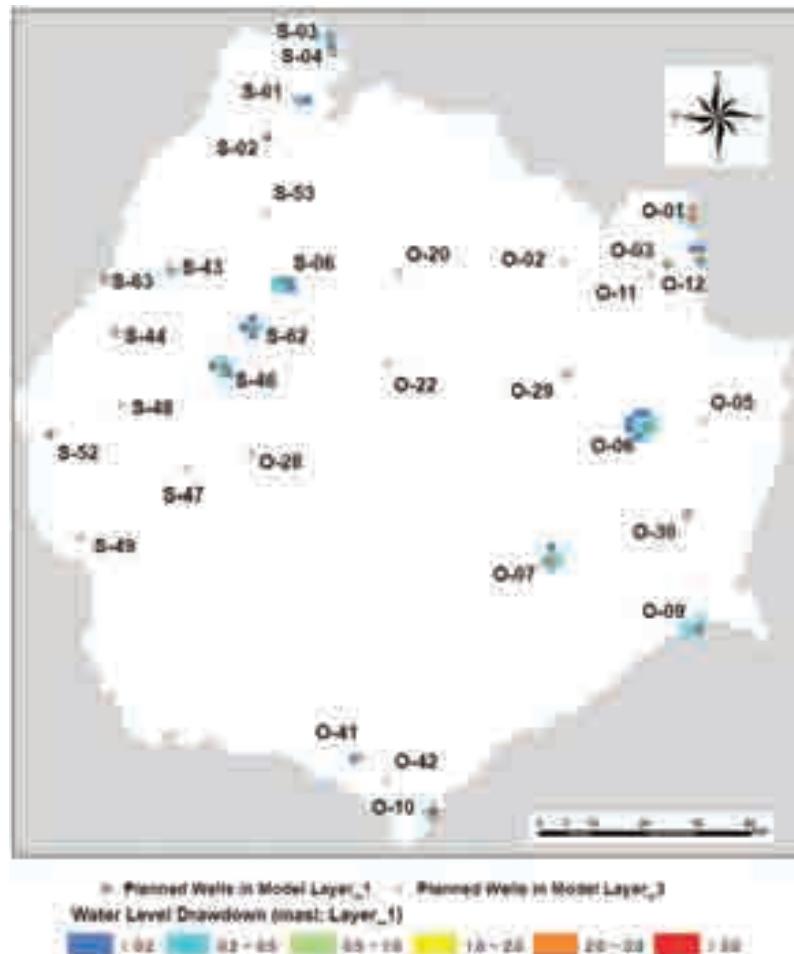


Figure 5.20: Planned Well Locations and Groundwater Level Drawdown in Layer_1,
Ziyaway Model (unit: m)

The layer classification of planned wells is following the depth of well strainer as described above. And then not only layer_1, but also layer_3 has some wells specified there. The groundwater level drawdown distribution in layer_3 has been extracted from grid central points and shown in Figure 5.21. In layer_3, the maximum groundwater drawdown appears in grid of well O_22, to be 5.56m. Attention should be paid for this amount of groundwater drawdown, even though it still can be considered as within a permissible level. By the way, as the coordinate's location of well O_22 is relatively far from the grid central point, the maximum groundwater drawdown extracted from well site is 3.0m, about 54% of the value in the grid central point.

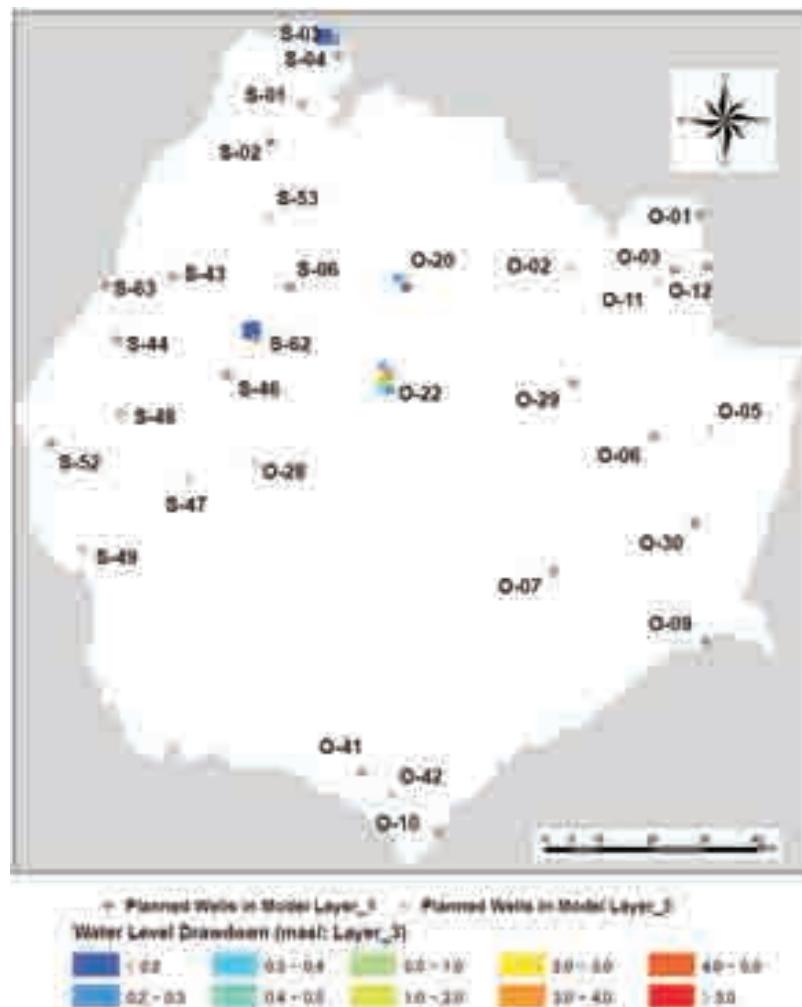


Figure 5.21: Planned Well Locations and Groundwater Level Drawdown in Layer_3, Ziway Model (unit: m)

5.7.2 Groundwater Level Drawdown in Bilate Model

There are 12 planned wells distributed in the Bilate model. The water level fluctuations of the 12 wells are summarized in Table 5.9.

Table 5.9: Groundwater Level Drawdown in Bilate Model

Well_Code	N_Min	N_Max	P_Min	P_Max	Down_Max
S_07	2002.0	2002.8	2001.5	2002.6	0.65
S_09	1945.8	1946.7	1945.8	1946.7	0.02
S_11	2221.4	2222.2	2219.3	2221.8	2.34
S_13	2059.5	2060.3	2057.7	2059.8	1.89
S_14	1855.0	1855.6	1852.6	1855.5	2.47
S_15	1950.7	1951.4	1948.6	1951.0	2.14
S_32	1476.2	1477.1	1476.2	1477.1	0.01
S_51	1843.9	1844.7	1843.9	1844.7	0.02
S_54	1894.7	1895.5	1894.6	1895.5	0.05
S_55	1688.6	1689.3	1686.2	1689.3	2.51

Well_Code	N_Min	N_Max	P_Min	P_Max	Down_Max
S_58	1500.8	1501.4	1500.4	1501.4	0.39
S_59	1440.9	1441.6	1439.9	1441.6	1.06

N_Min: Minimum value of water level in Scenario 1 (No new wells)

N_Max: Maximum value of water level in Scenario 1 (No new wells)

P_Min: Minimum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

P_Max: Maximum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

Down_Max: Maximum water level drawdown by comparing water levels between Scenario 1 and 4.

Similar to the Ziway model, the groundwater level fluctuation in the reference scenario depends on the groundwater recharge amount. In the 12 well's location, the largest, smallest and average groundwater fluctuation range for the whole 180 calculation time steps is 0.94m, 0.60m and 0.77m. In planned well withdrawal scenarios the largest, smallest and average groundwater fluctuation range becomes 3.1m, 0.81m and 1.72m.

In the well withdrawal plan, when comparing the water levels between scenario_4 and reference scenario, the maximum groundwater drawdown, 2.51m appears at location of well S_55. In contrast, the minimum groundwater drawdown appears in well site of S_32, the same as the minimum drawdown in Ziway model to be 0.01m. Groundwater level fluctuations in the two wells are shown in the Figure 5.22 and Figure 5.23.

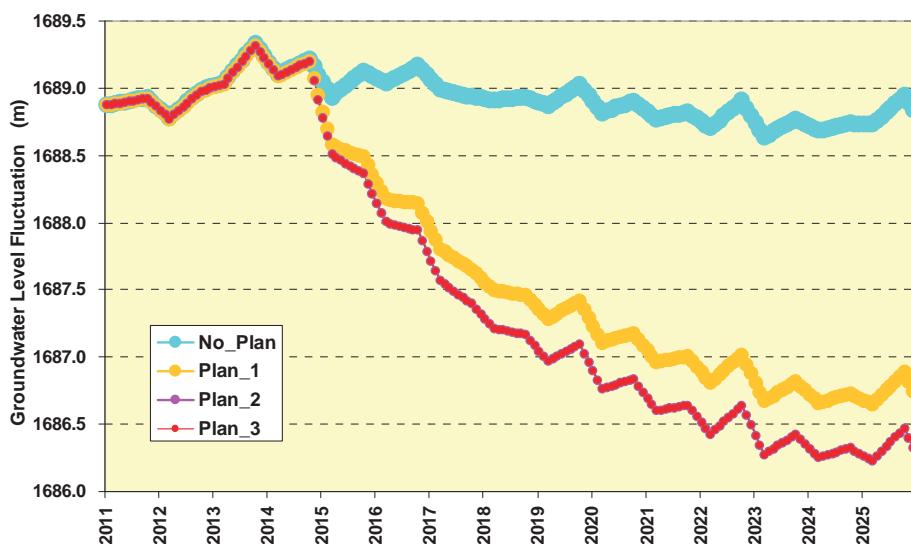


Figure 5.22: Groundwater Level Drawdown in Location of Planned Well S_55, (Bilate model)

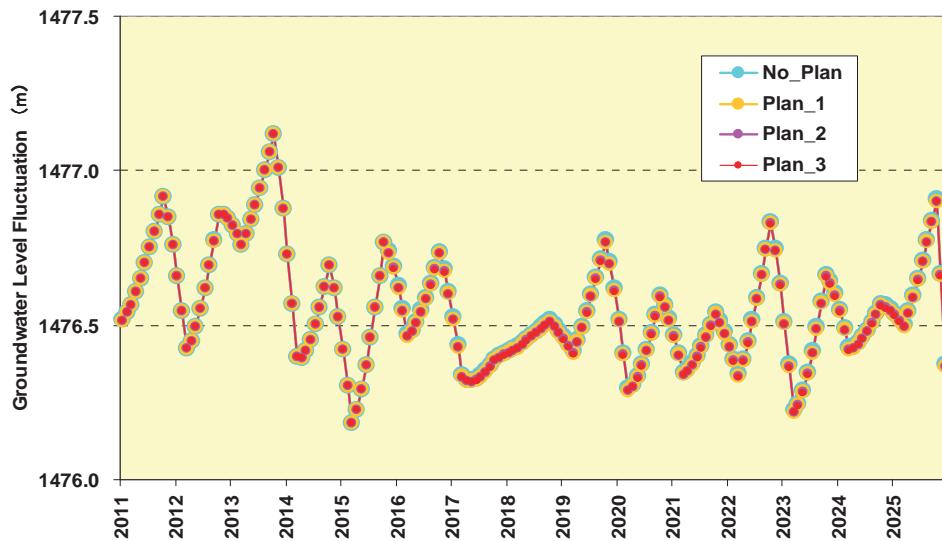


Figure 5.23: Groundwater Level Drawdown in Location of Planned Well S_32, (Bilate model)

Similar to the Ziway model, the planned wells are specified in layer_1 and layer_3, according to the well strainer depth. And not only groundwater level fluctuation in the well sites, but also groundwater drawdown in the grid central points are extracted and shown in Figure 5.24 and Figure 5.25.

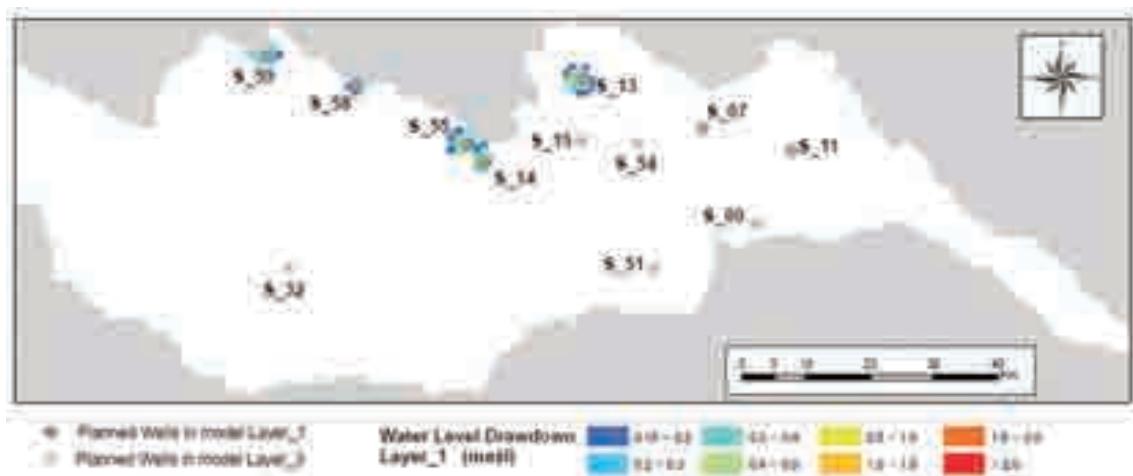


Figure 5.24: Planned Well Locations and Groundwater Level Drawdown in Layer_1, Bilate Model (unit: m)

Figure 5.25 shows the groundwater drawdown distribution in layer_1 of Bilate model on the last day of the plan, 2005/12/31. The maximum groundwater drawdown, 2.51m appears in the well site of S_55.

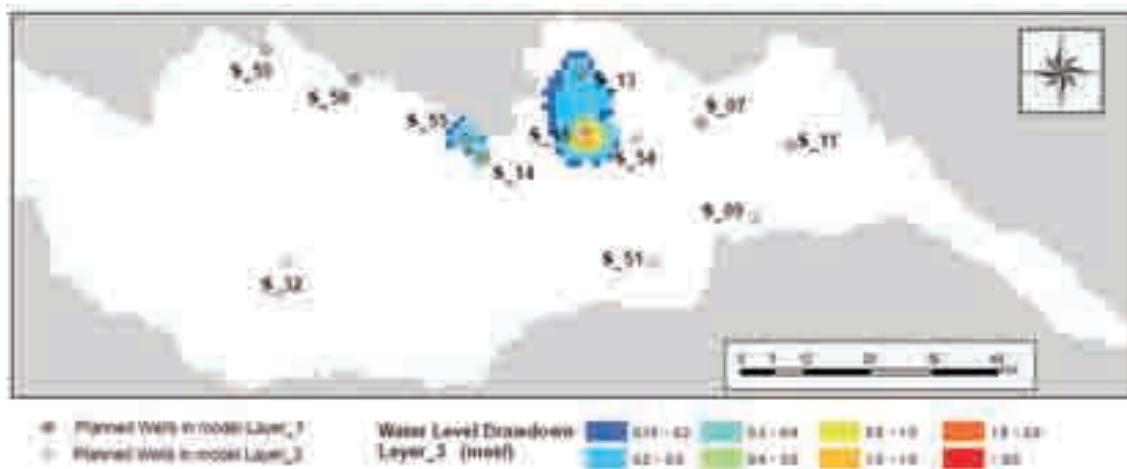


Figure 5.25: Planned Well Locations and Groundwater Level Drawdown in Layer_3, Bilate Model (unit: m)

Figure 5.25 shows the groundwater drawdown distribution in layer_3 in the same day. The maximum groundwater drawdown, 2.12m appears in well site of S_15. This value is smaller than the maximum groundwater drawdown of 2.14m in the same well site as shown in Table 5.9. The maximum groundwater drawdown in the well site appears at the end of dry season of 2024 (April, 2025). This result can be explained from Figure 5.12. Within the 15-year precipitation amount specification, 2009 corresponds to the planned year of 2024. The precipitation in rainy season of this year is ranked as 26% in the 15 years, to be a dry year. The relative smaller groundwater recharges together with relative larger groundwater withdrawal amount cause the occurrence of the maximum groundwater level drawdown.

Moreover, in case of groundwater use, different aquifers can affect each other. An example has been explained in Ziway model, in which the well specified in layer_3 was affected by the constant head boundary in layer_1. In Bilate model, the wells specified in layer_1 affects the groundwater level in layer_3, for example the wells of S_55 and S_14.

5.7.3 Groundwater Level Drawdown in Eastern Abaya Model

There are 12 planned wells distributed in Eastern Abaya model. The water level fluctuations of the 12 wells are summarized in Table 5.10.

Table 5.10: Groundwater Level Drawdown in Eastern Abaya Model

Well_Code	N_Min	N_Max	P_Min	P_Max	Down_Max
O_32	2150.0	2150.5	2147.0	2150.0	3.26
S_16	1813.0	1813.4	1812.6	1813.3	0.43
S_17	1781.1	1781.5	1778.1	1781.3	3.15
S_18	1837.4	1837.8	1837.3	1837.8	0.20
S_19	2280.7	2281.2	2280.2	2281.1	0.53
S_21	1920.2	1920.7	1919.4	1920.7	1.01
S_22	1805.1	1805.5	1802.6	1805.1	2.64
S_27	2133.7	2134.2	2130.6	2134.0	3.28
S_28	2247.6	2248.1	2247.4	2248.1	0.38
S_38	1643.3	1643.6	1641.0	1643.3	2.44
S_56	1732.0	1733.2	1732.0	1733.2	0.02

Well_Code	N_Min	N_Max	P_Min	P_Max	Down_Max
S_57	2383.1	2383.7	2380.4	2383.5	2.96

N_Min: Minimum value of water level in Scenario 1 (No new wells)

N_Max: Maximum value of water level in Scenario 1 (No new wells)

P_Min: Minimum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

P_Max: Maximum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

Down_Max: Maximum water level drawdown by comparing water levels between Scenario 1 and 4.

In case no new wells will be used for water service, the groundwater level fluctuation depends on the groundwater recharge amount. In the 12 well's location, the largest, smallest and average groundwater fluctuation range for the whole 180 calculation time steps is 1.19m, 0.38m and 0.57m. In planned well withdrawal scenarios the largest, smallest and average groundwater fluctuation range becomes 3.35m, 0.53m and 1.91m.

When comparing the largest withdrawal scenario with the reference scenario, the Scenario 4 and Scenario 1, the maximum groundwater drawdown, 3.28m can be found from well site of S_27. In contrast, the minimum groundwater drawdown, 0.02m appears in well site of S_56. The water level fluctuations in the two wells are shown in Figure 5.26 and Figure 5.27.

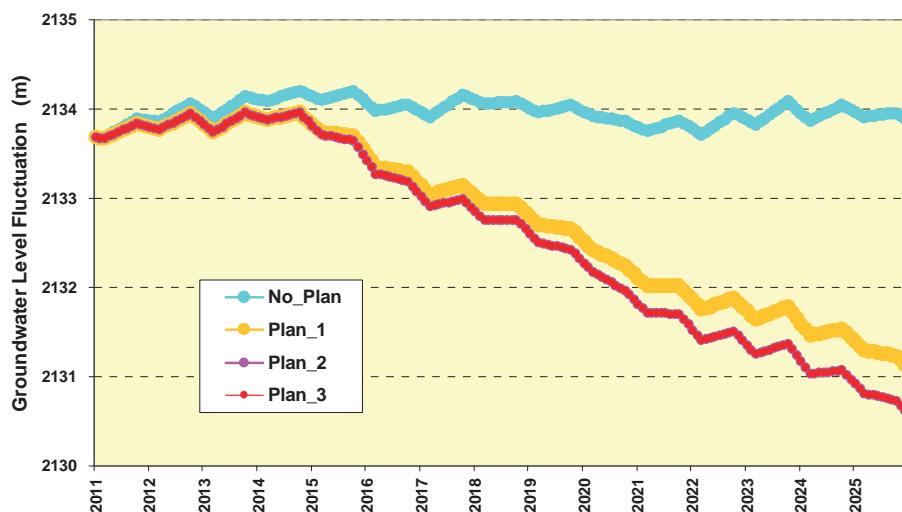


Figure 5.26: Groundwater Level Drawdown in Site of Planned Well S_27, (Eastern Abaya model)

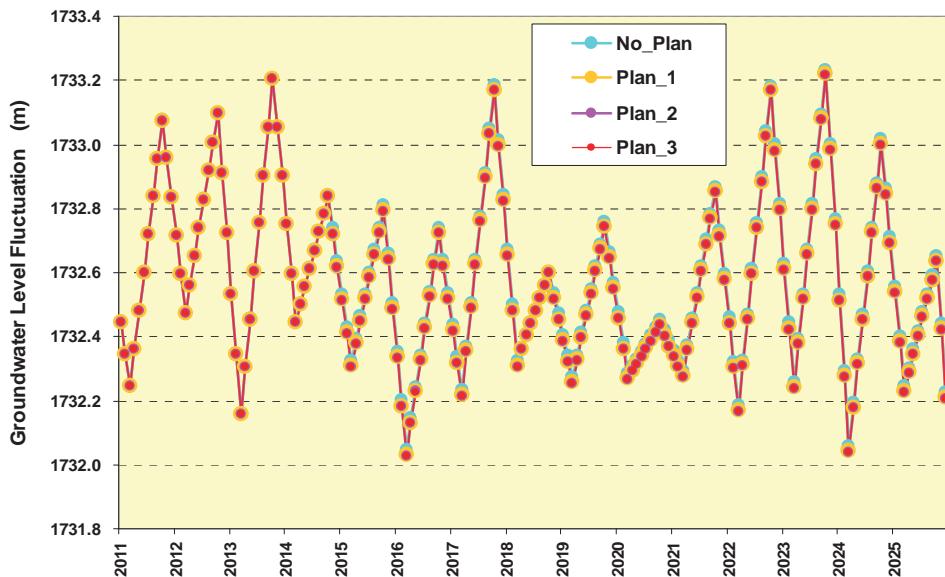


Figure 5.27: Groundwater Level Drawdown in Site of Planned Well S_56, (Eastern Abaya model)

The water level drawdown distribution on the last day of the plan, 2005/12/31 is shown in Figure 5.28 and Figure 5.29 for Layer_1 and Layer_3 in Eastern Abaya model.

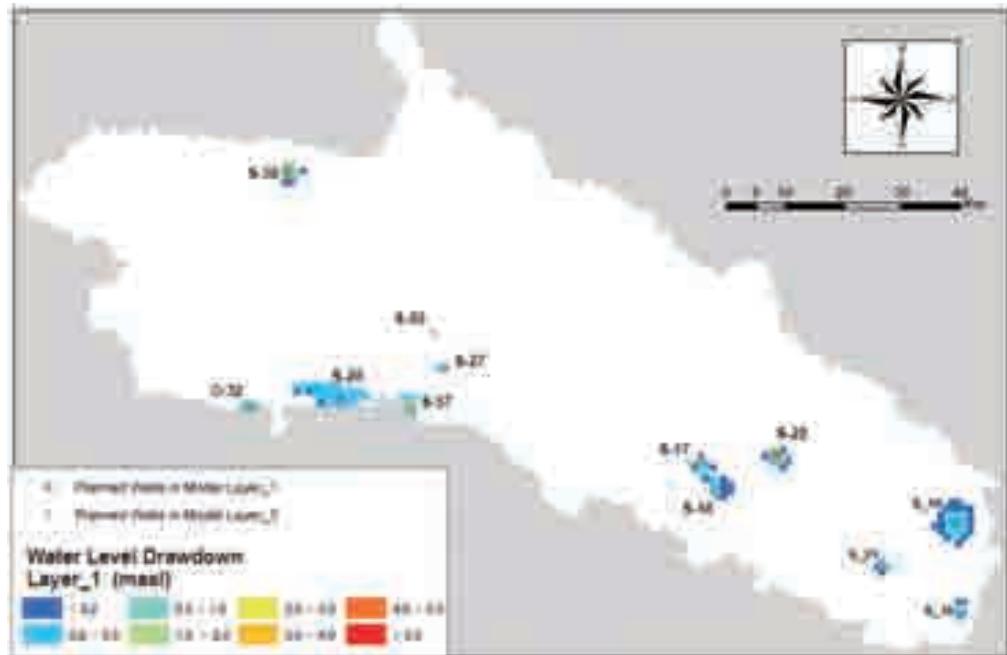


Figure 5.28: Planned Well Locations and Groundwater Level Drawdown in Layer_1, Eastern Abaya Model (unit: m)

The maximum water level drawdown in the well site over the entire 15 planned water service years is 3.28m in site of well S-27, as shown in Figure 5.8. However, as shown in Figure 5.26, the maximum water level drawdown is 5.59m in the central point of the grid holding the well S_22. Contrast to the water level drawdown in the central point, the maximum water level drawdown in site of well S_22 is 2.64m shown in the Table 5.10. The more than double difference of the drawdown between central point and well site can be explained by Figure 5.29.

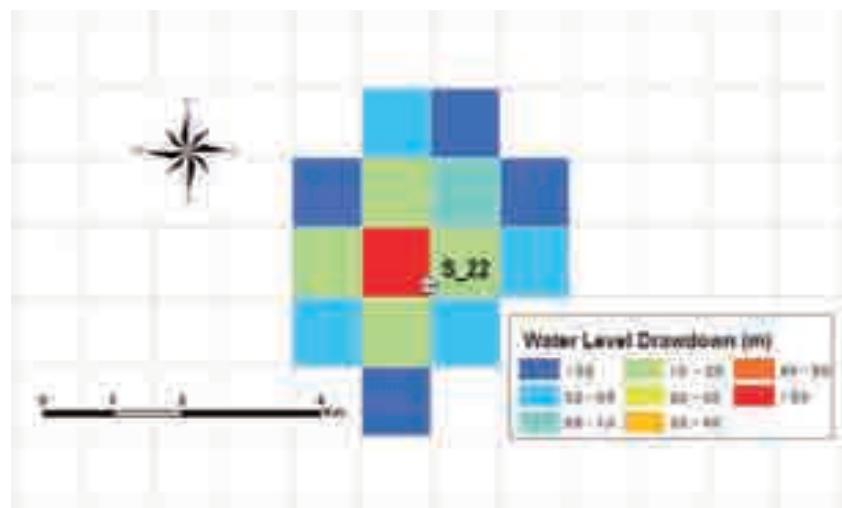


Figure 5.29: Location and Water Level Drawdown around the Well S_22 in Eastern Abaya Model

As shown in Figure 5.29, the well coordinates based well location is near the grid boundary, far from the grid central point. Because the well withdrawal is automatically specified at the central point of the grid by the grid system used in Modflow, the relatively larger difference occurred between the central point and well site.

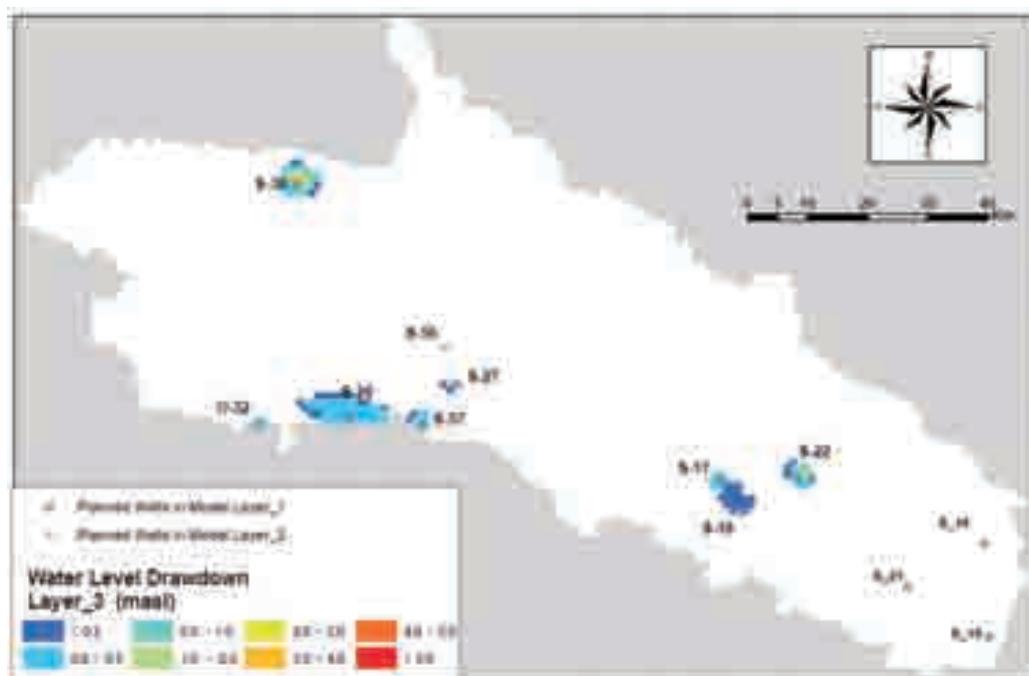


Figure 5.30: Planned Well Locations and Groundwater Level Drawdown in Layer_3, Eastern Abaya Model (unit: m)

Groundwater level drawdown distribution caused by new planned wells on the last day of the plan, 2005/12/31 is shown in Figure 5.30 for layer_3 of Eastern Abaya model. The maximum water level drawdown, 3.29m appears in the grid of well site S_38.

5.7.4 Groundwater Level Drawdown in Western Abaya Model

There are 6 planned wells within Western Abaya model. The water level fluctuations of the 6 wells are summarized in Table 5.11.

Table 5.11: Groundwater Level Drawdown in Western Abaya Model

Well_Code	N_Min	N_Max	P_Min	P_Max	Down_Max
S_30	1516.3	1516.9	1514.3	1516.6	2.38
S_34	1234.1	1234.7	1234.1	1234.7	0.02
S_35	2595.1	2595.9	2594.2	2595.7	1.26
S_36	2799.3	2800.9	2798.8	2800.6	1.76
S_37	2333.8	2334.6	2333.6	2334.5	0.62
S_60	1216.2	1216.8	1216.1	1216.8	0.07

N_Min: Minimum value of water level in Scenario 1 (No new wells)

N_Max: Maximum value of water level in Scenario 1 (No new wells)

P_Min: Minimum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

P_Max: Maximum value of water level in Scenario 4 (Plan 3 with largest withdrawal)

Down_Max: Maximum water level drawdown by comparing water levels between Scenario 1 and 4.

In case of no water withdrawal from the new wells (Scenario 1), groundwater fluctuation depends on the ups and downs of groundwater recharge. At the coordinate site of the 6 wells, the largest, lowest and average water level fluctuation range for the whole 180 calculation time steps is 1.11m, 0.60m and 0.79m. The largest, lowest and average water level fluctuation range in the scenarios of well use is 2.25m, 1.32m and 0.62m.

When comparing the largest water withdrawal scenario (Scenario 4) with the reference scenario, the largest water level drawdown, 2.38m can be found from well site of S_30. In contrast with the largest drawdown, the lowest drawdown, 0.02m appears in well site of S_34. Water level fluctuation of these two wells is shown in Figure 5.31 and Figure 5.32.

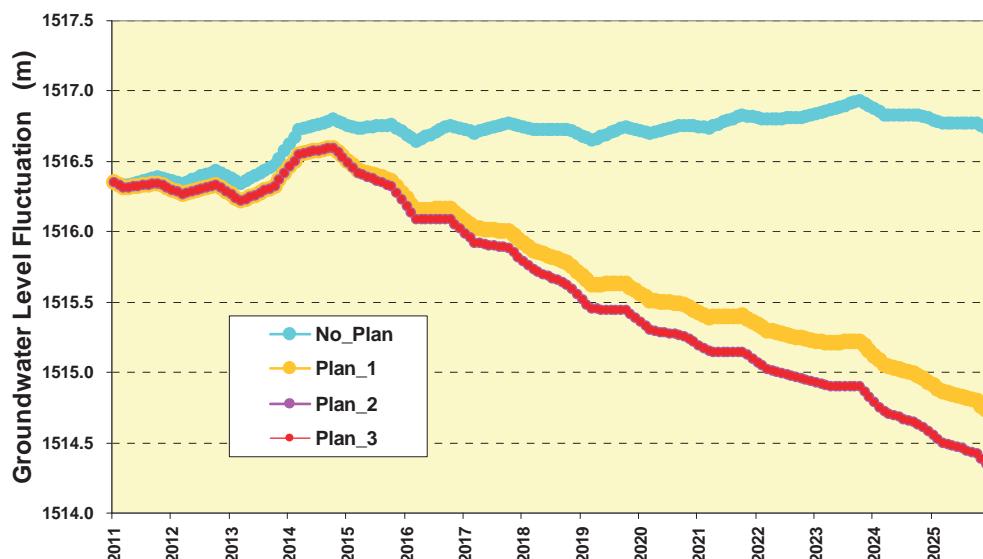


Figure 5.31: Groundwater Level Drawdown in Planned Well Site S_30, (Western Abaya model)

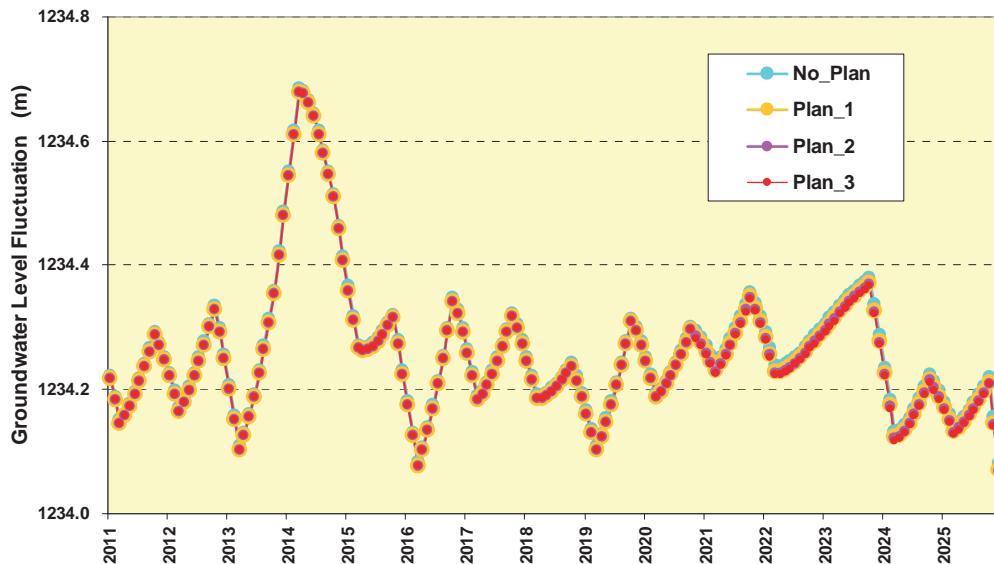


Figure 5.32: Groundwater Level Drawdown in Planned Well Site S_34, (Western Abaya model).

Groundwater level drawdown distributions on the last day of the plan, 2005/12/31 are shown in Figure 5.33 and Figure 5.34 for layer_1 and Layer_3 in Western Abaya model.

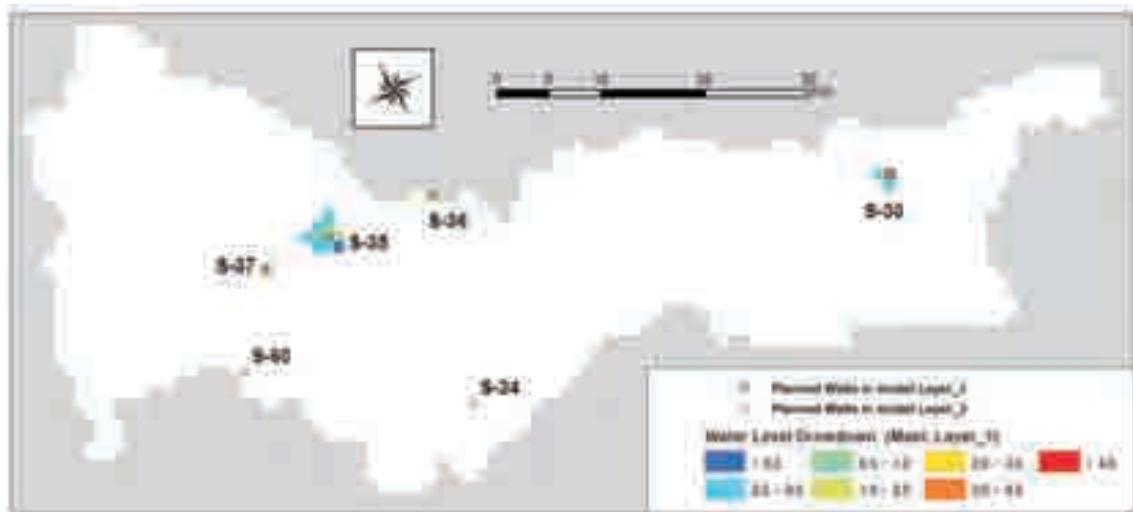


Figure 5.33: Planned Well Locations and Groundwater Level Drawdown in Layer_1, Western Abaya Model (unit: m)

In the 6 new planned wells in Western Abaya model, the maximum groundwater level drawdown appears in grid of well S_30, to be 4.5m. This value is nearly double of the maximum groundwater drawdown value of 2.38m, which is calculated in the site of well's coordinates according to the new well plan. The reason of this relatively large difference is the same as explained above, because a relatively large distance between the well coordinates site and grid central point.

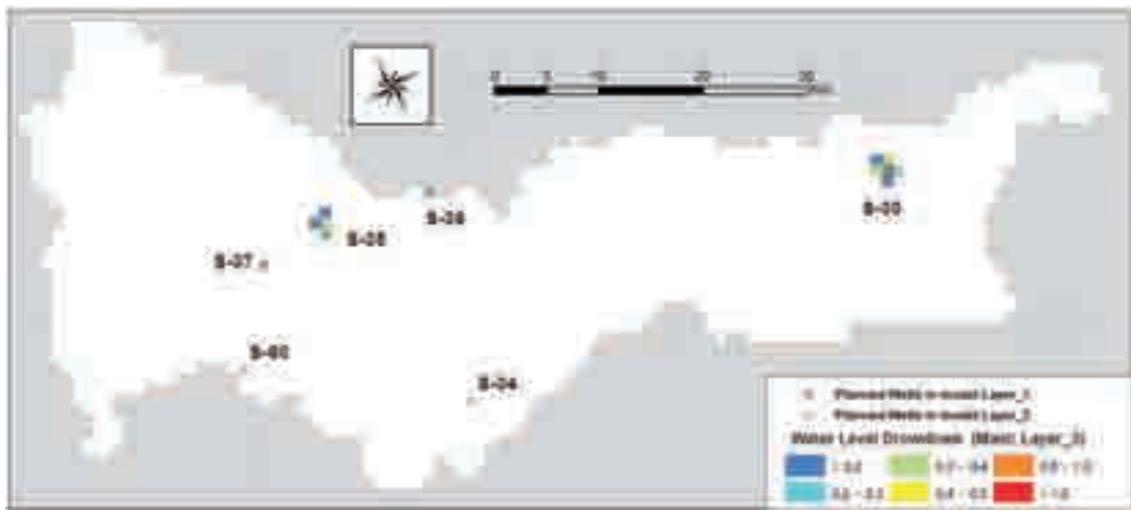


Figure 5.34: Planned Well Locations and Groundwater Level Drawdown in Layer_3,
Western Abaya Model (unit:m)

In layer_3 of Western Abaya model, the maximum groundwater drawdown value 1.71m appears in the grid of well S_30.

5.8 Evaluation of planned wells in small towns

4 groundwater simulation models have been created in the Rift Valley area for future groundwater utility evaluation. More than 80%, 62 from 74 wells involved in the new water supply plan by groundwater development are contained in the 4 models. The precipitation data used for the recharge amount specification cover a continuous 15-year time series. Therefore, at least the effect of a 15 return year's non-exceedance probability has been examined. Moreover, as shown from Figure 5.11 to Figure 5.14, dry year can be found near the end year of all the 4 precipitation series, corresponding to larger withdrawal amount in the water supply plan. Therefore, it can be considered that the effect of groundwater utility plan to the groundwater environment have been evaluated in the condition with relatively high risk. That is, the safety of groundwater utility has been confirmed in relatively large probability.

As the baseline for effect evaluation of groundwater development plan, the groundwater level fluctuation range in reference scenario (Scenario 1) is summarized below:

Maximum : 1.47m, Minimum : 0.38m, and Average : 0.82m

Groundwater level fluctuation range in the most withdrawal plan is as follows:

Maximum : 3.58m, Minimum : 0.53m, and Average : 1.48m

Compared to the baseline, the groundwater level drawdown range at well coordinate's sites in the most withdrawal plan is as follows:

Maximum : 3.41m, Minimum : 0.01m, Average : 0.95m

The groundwater drawdown in the central points of well grids can be summarized below:

Maximum : 5.59m, Minimum : 0.01m, Average : 1.32m

The following conclusion can be obtained from the above summary results. Not only in the rainy year or ordinary year of groundwater recharge, even in a 15 return year of dry season the largest withdrawal plan can be used without serious worries of effects to the water supply and groundwater environment. And the area of the largest drawdown is also limited.

Chapter 6

Technology Transfer Workshop

6 Technology Transfer Workshop

6.1 General

The workshop was performed as a part of technology transfer to the implementation agency, C/P of the EWTEC, GSE and AAU and private companies associated with the C/P personnel. The C/P personnel basically have a high level of attainment and knowledge, so the actual technical contents were transferred in collaboration with them. In fact, the TEM training was conducted with TEM machine, the field survey in RVLB for the volcanic geology workshop, the software training was held using the GIS and groundwater modeling, and the isotopic workshop actually used the isotopic analysis machine at AAU.

6.2 Workshop contents

The following five territories were conducted for the technology transfer workshop. The main works of workshop are shown in Table 6.1.

Table 6.1: Conditions of Each Workshop

Territories	Date performed	Participants	Main Groups
TEM Electromagnetic Prospecting	Dec.23 rd ,24 th of 2010	14 numbers +4 numbers (Japanese)	GSE, MoWE, AAU, EWTEC, Private consultant company (1 company)
Volcanic Geology	Jan.26 th ,27 th of 2011	10 numbers +4 numbers (Japanese)	MoWE, EWTEC, GSE, AAU, Oromia Region & SNNPRs Water Resources Bureau
GIS/Database	May 23 rd ,24 th of 2011	14 numbers +2 numbers (Japanese)	MoWE, AAU, GSE, Private consultant company (2 companies)
Water Quality/Isotope Analysis	May 23 rd of 2011	25 numbers +3 numbers (Japanese)	MoWE, AAU, GSE, Private consultant company (2 companies)
Groundwater Modeling	May 25 th of 2011	13 numbers +3 numbers (Japanese)	MoWE, AAU, GSE, Private consultant company (1 company)

6.2.1 Main objectives and contents of workshop

a. TEM electromagnetic survey

The purposes of the workshop were to understand the basic theory of electromagnetic prospecting, to learn measurement methods and acquire and analyze measurement data through practical training, and to learn how to interpret the data.

The lecture on the first day mainly consisted of explanations of the purposes of the study, an overview of the electric prospecting that was conducted in the 1st year and study results, and

comparisons between drilling results and relative festivity structure. On the 2nd day, practical training was given on the grounds of EWTEC in TEM prospecting, and participants were given hands-on instruction in the installation of everything from transmission loops to survey equipment, taking measurements, and removing equipment. Because the transmission loop used in the practical training at EWTEC was only 50 meters on each side, it appeared that resistivity data could be obtained from a maximum depth of -200m. It should be noted that the central loop method was used for the measurements. After that, the acquired data were analyzed, and a discussion was held using existing geological columnar sections to compare with the data.

b. Volcanic geology

The workshop on volcanic geology was conducted in order to share the survey results and volcanic point of view with the counterparts in the field. The contents and excursion location are shown in the next Table 6.2 and Figure 6.1. The discussions with C/P personnel and study team were executed in regard to the distribution, aspects and correlation of the welded tuff in the study area in the field.

Table 6.2: The Contents and Schedule of the Workshop

Location	Coordination (WGS 84)	Contents	
26th January 2011			
Koshe (East of Butajira)	8°00'55.3"N 38°31'32.8"E	Characteristics and distribution of Koshe highly welded tuff	
Gademotta (West of Ziway)	7°56'50.5"N 38°38'58.9"E	Distribution, formation and lithology of Gademotta caldera body.	
Adele (South of Lake Langano)	7°25'49.2"N 38°40'37.5"E	Characteristics and distribution of Kuyera highly welded tuff	
Kuyera (South of Lake Langano)	7°25'49.2"N 38°40'37.5"E	Characteristics, distribution and internal change of Kuyera highly welded tuff	
27th January 2011			
Mt.Chebi (West of Shashamene)	7°10'52.5"N 38°28'56.5"E	Pumice fall deposit overlying Obsidian lava	
Bura (Shashemene-Sodo road)	7°14'52.1"N 38°30'55.5"E	Basaltic Scoria cone and pumice fall deposit	
West side of Lake Langano (Sabena Lodge)	7°35'32.5"N 38°41'27.5"E	Characteristics and distribution of Langano poorly welded pumiceous pyroclastics	
		Observation of Welded tuff in Koshe (East of Butajira)	Observation of pyroclastic deposits in Gademotta(West of Ziway)

Figure 6.1: Workshop on Volcanic Geology

c. GIS/Database

The GIS/Database workshop was executed in order to know the survey results of RVLB project based on the works and analysis of GIS/Database in RVLB, and learn the basic knowledge of GIS. In workshop, personal computers were prepared with all participants and the following contents of GIS were carried out at a center of the practical exercise.

- ◆ Case study 1: Making project site location map: Start ArcMap and open a map document & add data to a map document, explanation of ArcGIS.
- ◆ Case study2: Making field survey map:
 - 2.1. Explore DEM (Digital Elevation Model) data
 - 2.2. What is ASTER/DEM (Digital Elevation Model)?
 - 2.3. Making contour lines
 - 2.4. Geo-referencing
 - 2.5. Plot drilling points location
 - 2.6. Add the attribute data to SHP (Database link)
 - 2.7. Thematic map
 - 2.8. Export a layer to SHP & coordinate (WGS <> UTM)
 - 2.9. Map Projection/Coordination
- ◆ Case study 3: Basic analysis:
 - 3.1. Cross section
 - 3.2. Make Watershed/Basin using DEM
 - 3.3. Making process of watershed boundary using Hydrology Modeling
 - 3.4. Calculation of catchment area
 - 3.5. Types of geographic datasets
- ◆ Case study 4: Converting data from hardcopy to softcopy (digitizing)
 - 4.1. Making SHP file (polygon)
 - 4.2. Digitizing
 - 4.3. Input the attribute data to the traced polygon

d. Water quality and isotope analysis

The main purposes of workshop were to know the basic theory of water quality and isotope analysis in conjunction with the survey results of water quality and isotope analysis in RVLB project. The major items of the technical transfer were the isotope analysis result of the Study and introduction of paper regarding the utilization of hydrogen and oxygen isotope in Japan. Major analysis and calibration were conducted in the AAU laboratory. Therefore the Professor Seifu Kebede (AAU) conducted the lecture of “Basic of Isotope” followed by discussions, and questions and answers. As a case study, hydrogen and oxygen results and relation with the groundwater flow (simulation) at the hill side of Mt. Fuji was introduced.

After the seminar, the participants receive the explanation of isotope analyzer and its

operation method followed by the explanation of extraction and analysis method of tritium by the person in charge of each laboratory.

The program of the seminar is shown as follows:

PROGRAM

1. Introduction: The aim of this seminar
By Mr. T Matsumoto (Team Leader)
2. The basics of isotope as a tracer (Hydrogen and Oxygen Isotope)
By Dr. Seifu Kebede (Professor AAU)
3. The Isotopic Analysis Results of the Rift Valley
By Mr. K. Ichikawa (JICA Expert)
4. Discussions & Comments
- Transfer to the Hydrochemistry laboratory -
Explanation of the Isotopic analysis machine – preparation of samples and mechanism
By Ato Adane (Laboratory Researcher AAU)

Actual analysis was conducted at AAU, therefore most presentations were given by persons from AAU.

e. Groundwater modeling

The main purposes of workshop were to know the basic theory and meaning of groundwater modeling with C/P personnel. The main contents are as follows;

- 1) Conception and theory about groundwater system
- 2) History of groundwater simulation
- 3) Methods and program of groundwater simulation
- 4) Function and main package in Modflow based programs
- 5) Basic process for groundwater model creation

About 260 slides were used for showing images and main contents of the workshop. All the slides were compiled to be handed over and allocated to the participants.

6.2.2 Importance and issues of technology transfer workshop

As a whole, the technology transfer in the development study is carried out in a short period of time, differ from technical cooperation project. Therefore it is effective that the technology transfer like this is performed with a variety of trainings in share with the survey results. As the technical ability of C/P is different among all C/P, it is slightly difficult to decide the contents of training. However it is easy to understand for C/P regarding the survey results and to explain the survey results for trainer. It is out of necessity that the C/P complains concerning the short time of training. However to understand the general contents of training is very significant by workshop. The main achievement degree and issues of each training are as follows;

- They have the basic knowledge on the method and operations of the TEM measurement, but have no application ability. They are not totally proficient in data analysis procedures.

The know-how on actual survey and data analysis has been transferred to the C/P personnel although the collaborative survey was limited by area and, thus, could not cover various types of geology. They are expected to acquire more survey experience in different geological settings (e.g. alluvial terrain, volcanic terrain, fault and fractured zones) to enhance their capacity of survey operation and data analysis. The survey was only done with the fixed size of transmission loop in the workshop. In the future, different sizes of transmission loop should be employed to get the survey data in order to analyze the relation between the survey depth and analytical resolution. Through this analysis, they should learn the limitation in survey depth and resolution for different frequency bands to be employed.

- C/P has a good understanding of basic volcanology principles. However, they lack experience in identifying strata, confirming distribution of strata and the correlation of layers. Therefore, the actual method of the geological survey was transferred for the technology based on the identification of the typical welded tuff distributed characteristically in the field and the correlation of welded tuff. The aspects of volcanic activity were recognized with the structure and lithology of the volcanic construction in association with the caldera distributed characteristically in the field, and the Holocene recent basalt lava was observed in consideration with its stratigraphic relation to other strata. The volcanic geology is basic works for making a hydrogeological map. Most participants said that they understood very well the characteristics of volcanology and the distribution in RVLB and the methodology of the correlation over a wide area. Overall, as the majority of participants were specialized in hydrogeology, they said that they would like to learn the relationship between geology and hydrogeology in the field workshop. This is the next issues of this workshop.
- C/P has the basic knowledge for the remaining three training courses, but has few chances to meet the actual works by themselves. Therefore the C/P questionnaire said it is very useful in this time to be able to learn the basic training and theory. The issues are to take a long time for the training, and to plan the contents in accordance with the ability of C/P. For example, C/P belonged to AAU Dr course have a several kind of the training experiences, in particular, it would need to carry out the practical exercise in a groundwater modeling. In any event, the participants of training are requesting the practical training in all territories.

Chapter 7

Conclusion and Recommendation

7 Conclusion and Recommendation

7.1 Conclusion

- ◆ Regarding meteorological factors, firstly precipitation, the average annual rainfall amounts range from 492mm for minimum value to 2,582mm for maximum value. The average of the 72 stations in the rift valley basin is 1,079mm. The rainy season is July to September for most of Ethiopia, but in RVLB the rainy season is unclear. The values of monthly Average Evaporation from four out of five stations are relatively close to each other, ranging between 1,395mm for minimum value and 1,963mm for maximum value. The average annual temperature for all 52 stations used for the analysis is 19.6 °C.
- ◆ Daily river flow data from 36 stations were collected, and the four patterns of flow rates variation were recognized from the data of seasonal fluctuation of river flow. The main patterns are characterized by high level of correlation with the precipitation pattern of rainy and dry seasons in the same area. Precipitation patterns with two peaks and one peak are observed in flow rates. The other two patterns are particular and the points are few in the study area.
- ◆ According to the existing data, the main lakes are Ziway, Langano, Abijata, Shalla, Awassa, Abaya, Chamo, and Chew Bahir in RVLB. Most lakes were formed by tectonic activities or by caldera. Lake Shalla has a maximum depth of 266m, and Lake Awassa has a minimum depth of 9m and also a minimum area of 130km². Lake Abaya has a maximum area of 1160km². The major basin will be divided into the following four major groups: 1. Ziway-Shalla Basin, 2. Awassa Basin, 3. Abaya-Chamo Basin, 4. Chew Bahir Basin. The four main basins were further divided into 14 (fourteen) sub-basins. RVLB is a closed basin independent from the surrounding basins. The evaporation from the lake surface accounts for about 95% of the annual average evaporation amount from the entire basin.
- ◆ The study area belongs to the **African Rift**. The area is topographically characterized by a depression zone with steep marginal faults along its edges. The area of the basin is about 53,000km². The Rift Valley Lakes Basin could be divided into two areas in a large sense. The northern portion of the area around the lakes of Ziway to Awassa is almost flat in the valley bed. The southern area, from Lake Abaya to Chew Bahir, has relatively precipitous terrain.
- ◆ The oldest volcanic activities are basalt and rhyolite flows in Oligocene, by middle Miocene, the rift was formed in some parts with containment basaltic flows. In Pliocene, a huge pyroclastic flow covered the northern part of the study area. The volcanic activities are mainly recognized in late Pliocene to early Pleistocene stage and in middle Pleistocene to recent stage. The history of volcanic activity in RVLB is that the large rhyolitic calderas and volcanic chains composed of separate basaltic lava domes are observed. Fault system in northern RVLB is characterized by the development of continuous major faults which has big displacement with minor parallel faults, and fault zones associated with volcanic activity in the rift floor. In Pleistocene, Wonji Fault Belt (WFB) is formed at the rift floor, and floor basalt and rhyolite are erupted along WFB. While, Pre-Cambrian and Neogene fault systems in southern RVLB is neither continuous nor regular.
- ◆ In the preliminary survey of geology in the field, the RVLB was divided into seven areas in accordance with the aspects of geology and distribution. The strata of each area were correlated based on the specific geology (a key bed), and the correlation chart was

described. Finally, the stratigraphy in RVLB was created and the geological map was completed in the RVLB.

- ◆ The main aquifer units based on the geology were a rhyolitic welded tuff (G) and basaltic tuff breccia-lapilli tuff (tb) of the Pleistocene in Quaternary. Those strata distributed in north area of Lake Abaya and the fracture zones were formulated in the strata. The basaltic rock of Tertiary (pgl) and rhyolitic lava are also the good aquifer in the southern area with fracture zone.
- ◆ Regarding the water resource potential in RVLB, the water resources can be divided into two categories which are: Surface water and Groundwater. However, the potential of surface water such as river and lake water is low when considering: 1) Sustainability for water use, 2) Availability throughout the year, and 3) Safety as a potable water source.
- ◆ Aquifers can be subdivided into the following three lithofacies depending on the aquifer units; 1) Alluvium and lacustrine deposits, 2) Pleistocene tuff, tuff breccia and basaltic rock units, 3) Plio-Pleistocene tuff and basalt. The groundwater potential of these aquifers can be divided into the following classes in accordance with the standard of Ethiopia in conjunction with the existing wells and JICA new wells. The hydrogeological map can be created in light of the geological map in consideration with the below classification of aquifer.

1) = 1 B~1 C, 2)= 3 A~3 B, 3)= 3 A~3 C (A: high, B: moderate, C: low, 1~3 : classification of strata)

The hydrogeological map was made in consideration with a classification of aquifer and distribution of geology.

- ◆ The groundwater flow shows that the groundwater gradient is high at the escarpment of sub-basins of Western Ziway, Bilate, Awassa, Gidabo and Galena. The groundwater rapidly flows down and becomes gentle at the valley floor. The end point is not necessarily the lakes but seems to be gathered into the depression of groundwater between Lake Abaya and Lake Awassa. At the far north of the study area, groundwater runs down along the Weto River and ends its flow into Chew Bahir.
- ◆ There are few results (about 10%) showing values high above the Ethiopian standard, but some of them certainly exceed the limit of guideline values in the laboratory analysis results of 93 samples for the existing wells and springs and 7 samples for JICA wells out of 100 samples. The characteristics of the water quality in terms of each sub-basin were discussed based on the projection onto the trilinear diagram. The fissure and fracture groundwater exists under the circulation environment, and the layered water has nature of stagnant environment. It suggests that the groundwater in the alluvium and lacustrine in the central lower part of the Rift Valley is in a stagnant condition, and the fissure groundwater in the volcanic and gneiss is circulatory by nature.

- ◆ The isotopic analysis results in RVLB indicated that in principle, the values are in the proximity of the meteoric line, which indicates that the majority of groundwater in the Study area originates from rainfall. As for the results of analysis, in particular the plot points which come close to the meteoric line were mainly contained in the circulating groundwater (shallow groundwater). Probably, the low value of δ presents the altitude effect of the origin, which most of the rainwater is infiltrated in the western high altitude

ridge along the margin of the Rift Valley in western parts of Ziway area.

- ◆ The tendency of distribution of Fluoride in RVLB is as follows;
 - ✚ The concentration is high at the vicinity of recent volcanic cones surrounding Butajira
 - ✚ High concentration zone can be observed at the area surrounding Lake Awassa
 - ✚ It is not quite clear, but the fluoride value decreases with the depth of water source

It is more realistic to consider high concentration is related to the recent volcanic activity occurs at the shallower sub surface rather than it was brought from the deep ground.

- ◆ The number of requested small towns is 82 (SNNPR: 52, Oromia Region: 30), and the water supply plan can be planned. The main necessity items are as follows: 1) Target year: 2015, 2) Water demand unit: 20L/c/d, 3) Water source: groundwater, 4) Models of water supply facilities: 10 types. The O&M issues of existing water organizations were arranged and ideas were indicated. Finally, the drinking water will be supplied in 2015 of target year for the 0.55 million peoples of 82 small towns by 170 wells.
- ◆ The water source is groundwater for the water supply plan in RVLB. Therefore, the groundwater development plan is discussed about the next items; possibility of development, comparing the recharge of groundwater with plan of water usage, possibility of groundwater development, plan of budget for development of water source. Consequently, it is concluded that the groundwater development is possible, for example the estimated yield of 2015 targeted year in Awassa sub-basin is 20% of groundwater recharge and also the other sub-basin is less than 5% of groundwater recharge.
- ◆ The classification and prioritization of small towns were conducted to decide on the priority of implementation in regard to the water supply plan of requested small towns. The evaluation for the high priority small towns was executed based on the socio-economic evaluation. The result was that the ATP (Ability to Pay) cost went over the O&M cost. Moreover, organization and institutional evaluation, natural/social environmental evaluation and technical aspects were also no problem for the water supply plan.
- ◆ The future simulation of groundwater modeling was carried out in four sub-basin areas (Ziway area, Bilate area, Abaya east area and Abaya west area). The calibration results reflected the actual conditions in each sub-basin. Also, the fluctuation calculation of groundwater level was executed in accordance with the usage of groundwater in future using the groundwater model. Consequently, the drawdown of groundwater is max. 5.6m (average 1.3m) and the area is limited in case of using the maximum yield of four scenarios. It means it has a very low impact on the groundwater environment.

7.2 Recommendation

7.2.1 Definite establishment of groundwater database system

Ethiopian Government has aimed to utilize the groundwater potential information for water resource development through the EGRAP (Ethiopian Groundwater Resources Assessment Program) of the national master plan in relation to groundwater investigation. The establishment of the ENGDA (Ethiopia National Groundwater Database) was one of the important enhancement measures, but the ENGDA could not be continued. Instead the ENGWIS (Ethiopian National Groundwater Information System) project was carried out as a new groundwater database and this project was finished in March 2010. ENGWIS has already been described in the progress report (1) and this interim report. In short, at this point the establishment of the software has been finished and the groundwater information of 30,000 points has been inputted. The study team confirmed the contents of ENGWIS for the utilization of the data. However the study team did not encounter a satisfactory arrangement, and could hardly find any accurate data. The main problem is that there is no coordinate data, no aquifer information, and no SWL and pumping test data, and so on. As ENGWIS has the plan to update the data by donation of UNICEF from now and to additionally input the information of 100,000 points, the system will be improved gradually. An important point is whether specific discussions are being held concerning the importance of the groundwater database for Ethiopia with regard to the operation and continuation of the ENGWIS project. It is difficult to make activities for the database system without the assistance of budget from donors and GOE. The main recommendations for these discussions at the moment are given below;

- As premises for the improvement of internet environment, it needs to perform basic maintenance for the technical and operational aspects so as to access the main server machine from the outside. Technically, the server should be improved by making simultaneous multiple user access possible; and operationally, it is necessary to establish rules and a system for its use, and a method of identifying users.
- The previous data will be updated; however the groundwater information from each region from now on must be obtained and information that should be inputted must be determined. Therefore, the format of data and items are determined in collaboration with AAU, MoWE and GSE.

When an implementation timeline of these technical, operational and information aspects has been settled upon, or an actual road map has been determined, the position of ENGWIS in the MoWE can be clarified and the budget and institutional aspects of ENGWIS established as a national project; it will then be able to contribute to achieving the national target for the UAP and so on. At first, it is necessary to allocate the members of MoWE immediately for the actual activities of the technical and operational aspects. Moreover, the staff of MoWE and regional water bureaus need to be given training in regard to the method of collection and contents of data.

7.2.2 Better map utilization and improved techniques for making hydrogeological maps

The groundwater potential survey and hydrogeological map creation are aspects to be strengthened with the establishment of the groundwater database in EGRAP. So far, there is no information to create hydrogeological maps (Scale: 1:250,000), including the compilation

of existing hydrogeological maps, except for RVLB (for example, exclusive of the Nazret area, for which a map has already been made). The highly reliable hydrogeological map cannot be created without the adequate existing database mentioned above. Therefore, the hydrogeological map and the existing groundwater point data are inextricably linked. In fact, the planar hydrogeological information will be obtained from the hydrogeological map, and the cross-sectional hydrogeological profile information will be collected from the existing well information. However, the information of groundwater contours and main aquifer surface contours is input on the hydrogeological map and well information is also recognized for the points on such maps. As the Regional Water Bureau staff has a high probability not to utilize the geological and hydrogeological maps including topographical maps in Ethiopia. In the meantime, the staff of MoWE recognizes the method of utilization of the hydrogeological map in RVLB, and after that the staff spread around the methodology of the hydrogeological map to the regional staff. The examples of utilization are as follows;

- In case of lack of existing well information, it is easy to select the well by the utilization of hydrogeological map because of the judgment of aquifer distribution in accordance with the hydrogeological map. The hydrogeological map will be utilized in such cases.
- As the geology and water quality aspects are shown in the attached hydrogeological map, the probability of groundwater development is comprehended comprehensively. And it is easy to select alternatives when utilizing water resources, because the location for springs is shown.
- It is significant to know the hydrogeological conditions of the places where the Regional Bureau staff live by getting them to identify these on optical and planar maps. At least, they can know which area has high potential on the planar maps. By taking advantage of such a map, it will contribute to planning of regional water supply plans.

From now, it is advisable that the MoWE and relevant staff assume the techniques for making hydrogeological maps and the actual works can be carried out. On this occasion, the minimum technology is to create the reliable geological map. The geological engineers have vast knowledge, some of whom work in the field, actually putting this knowledge to use. However, our study found there are very few such field engineers. Therefore, the MoWE needs to secure human resources which can do the field survey for making the geological map. In any event it is indispensable to create a reliable geological map for the enhancement of hydrogeological mapping techniques. Another important issue is how to make the existing data more reliable. The accurate existing data is very few such as the example of ENGWIS, so no effort should be spared to obtain the coordination data of wells independently.

7.2.3 Improvement of drilling technology, arrangement of results and pumping test

The most challenging job through our development study was the well drilling, and the drilling in RVLB was too late due to the machine trouble, geological conditions and lack of parts preparation and so on. And the geological information is few in regard to the existing wells, the information accuracy is low, and there were many samples for which pumping tests were not carried out. The two suggestions described previously cannot gain highly accurate outputs without the drilling technology. The companies tendered were very few or very expensive for the simple reason that the area is RVLB, the target depth is very deep and the purpose of drilling is investigation, not only well construction. For a fact, the drilling works are not so easy due to the complicated geological conditions, the hard and soft deposits

repeated in RVLB. However, areas of geological conditions like this exist in the drilling sites, and it is necessary to drill deep wells in RVLB from now on. The drilling technology is mainly the rotary method by mud water and DTH method by air hammer. There are very few drilling companies that are capable of both these methods in spite of existence of specification of works. In this drilling, there were no drilling companies that would try both drilling methods in response to the layer conditions (three companies, including a sub-contractor, were employed). The study team described the lithology by the chip sample with drilling, but the example of works like study team is very few in the existing well data. Errors were observed in the measurement of yield which is a basic job and affects the results of tests in regard to the pumping test, especially the step-draw down test. There are some examples that the yield of each step for the step-draw down test cannot quite be determined. As just described, some suggestions concerning the issues of the well drilling generally are as follows;

- It is necessary to carry out long-term training for private companies involved at the center of MoWE for the enhancement of the well drilling level. On the occasion of this training, the geological engineers from the private companies are to work in collaboration with the drilling engineers, and this training aspires for the high level drilling technology and pumping test for the available data of ENGWIS. The instructor should be an engineer of the enterprise, a private company or EWTEC with a high skill level. It is desirable to teach how to use old drilling machines of private companies in the training.
- It is necessary to input the unit price in consideration with the drilling in the difficult geology such as RVLB. As the more expensive price is a problem for drilling, it is advisable to secure the high budget in case of drilling in RVLB compared to drilling in Addis Ababa.

The drilling contractors needed to be ranked based on the qualification institution in reference to the training session intended for the private drilling companies. It is important to recognize the level of the drilling companies by rank.

7.2.4 Full utilization of project's water supply plan

The water supply plan was devised targeting all 82 small towns requested in SNNPR and Oromia Region. And also the high priority towns were selected from the 82 small towns. It is very important to survey each small town in detail. Therefore, a detailed profile was compiled on each of the small towns. However, it is difficult to obtain reliable water supply coverage data. It is vital that Regional Water Bureau or MoWE staff understand which data is important for grasping the condition of the water supply. The detailed town profiles were attached in the data book of the final report. These profiles utilized the contents of survey items. To make a water supply plan, it is very important to consistently obtain detailed data on each small town. Therefore, a groundwater development plan was made based on the hydrogeological map. Moreover, the water supply plan takes into consideration the findings of the groundwater development plan. Thereby the basic conditions are in place to make the water supply plan with collaboration among the staff of the Regional Water Bureaus, and water supply engineers of Zonal and Woreda Water and Energy Office. It is hoped that they can fully utilize the Project reports to do this.

The high priority small towns were selected by taking into account several criteria.

Consequently, the small towns which Japan can assist are limited by budget. So it is better to use our project report for water supply and to work on gaining support from other donors and the Ethiopia government.

And finally, these activities will contribute to increasing the number of people who have access to safe water.