Appendix B

Groundwater

Appendix B GROUNDWATER

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Appendix B GROUNDWATER

B.1 Groundwater Occurrence

There are the following five (5) types of the groundwater occurrence in the country as shown in Figure B.1:

1) Groundwater in unconsolidated Quaternary and Neogene sediments
   - i) High to medium yielding aquifers
   - ii) Low yielding aquifers
2) Groundwater in fault and fractured zones
   - i) Practically without aquifers
   - ii) Local aquifers
3) Groundwater in the karst

Quaternary and Neogene sediments, which are composed of unconsolidated sand and gravel layers, form high to medium yielding groundwater aquifers and are distributed in the following twelve (12) areas as mentioned in detail in Section B.6:

1) The Polog valley (Tetovo – Gostivar),
2) The Debar valley
3) The Kichevo valley
4) The Struga-Ohrid valley
5) The Prespa valley
6) The Pelagonija valley (Bitola – Prilep)
7) The Skopje valley
8) The Veles valley
9) The lower part of the Vardar (Gevgelija valley)
10) The Pcinja Basin
11) The Bregalnica Basin
12) The Strumica valley

The Quaternary and Neogene sediments, which are composed of sand and gravel layers, form good-yield and artesian aquifers in the central and lower parts of these areas. The groundwater in the West Macedonian block and Serbo-Macedonian block except for the above-mentioned valleys may be locally stored in the fractured fault zones and the basement rocks are considered to be practically impermeable aquifers. The karst aquifers occur in the caves of the karst limestone, which spreads in the Pelagonija block. It appears that the groundwater in the karst aquifers is highly transmissive.

B.2 Groundwater Information

B.2.1 Well Inventory and Database

Well data prior to 1982 for the whole country is compiled as a well inventory, but the well data have not yet encoded on the computers. For the JICA Study, the well data prior to 1982 as well as after 1982 were encoded on the new database system, PC computers, for data management.

The information for each well/borehole is stored according to 25 codes:

- Well reference number
- Type of well/borehole
- Purpose of well use
- Location (village; old and new municipalities; basin; longitude; latitude; elevation)
- Well dimension (depth; diameter)
- Water level
- Yield
- Pumping test (drawdown; radius of influence)
- Water quality (pH, water temperature; presence of chemical & bacteriological analyses)

The most relevant data of groundwater and aquifers are encoded on the PC computers. The chemical properties except for pH are indicated as codes of presence of chemical and bacteriological analyses. Monitoring of groundwater level and actual groundwater abstraction have seldom been carried out and the data of groundwater levels after the well drilling only are indicated on the new well database.

B.2.2 Characteristics of Groundwater

B.2.2.1 Wells by Well Type

Wells and boreholes by well type are classified to be drilled and artesian boreholes, dug wells, radial wells, observation wells and thermo-mineral drilled boreholes in order as shown in Table B.1. The major types of boreholes/wells are drilled boreholes, artesian boreholes, observation wells, dug wells, and radial wells as shown in Figure B.2. The well depth of the artesian boreholes is the deepest in comparison with other wells and about 100 m except for thermo-mineral wells and the observation wells and drilled boreholes are arranged in order as shown in Figure B.3. The diameter and yield of the radial wells are the largest in comparison with other wells, about 3 m and 150 l/sec, respectively as shown in Figure B.3. The water levels are below the ground surface, less than -7 m in average except for the artesian boreholes of about 5 m as shown in Figure B.3. The water temperature of the thermo-mineral wells is the highest in comparison with other wells, about 50 °C and other boreholes/wells range from 12 to 14.3 °C. The pH values are slightly alkaline and 7.2 in average as shown in Figure B.3. The major well types of boreholes/wells are summarized as follows;

Well type / Statistics	Artesian boreholes	Drilled bore-holes	Dug wells	Radial wells	Obser-vation wells	Thermo-mineral	Average (number of samples)
Number	102	321	70	9	85	18	(605)
Well depth(m)	98.8	48.7	7.6	19.2	70.4	336.4	63.2 (578)
Diameter(mm)	129.1	403.7	1259	2989	61.7	375.5	484 (438)
Water level(m)	4.8	-7.4	-5.1	-6.2	-16.3	-11.0	-6.6 (480)
Yield(l/sec)	3.1	23.9	8.1	150.6	-	35.0	18.9 (387)
Aquifer thickness(m)	17.8	15.2	4.4	-	18.7	-	15.6 (415)
Water temperature(°C)	14.3	12.2	12.7	12.0	12.1	47.3	15.5 (206)
PH	7.2	7.3	7.3	7.3	7.1	7.1	7.2 (188)

B.2.2.2 Wells by Use

Although forty-two (42) % of all wells has no classification of well use, the major uses of boreholes/wells are water supply (21%), industry (14%), observation (14%), agriculture (6%) and thermo-mineral (3%) in order as shown in the following table, Table B.2 and Figure B.4;

Well use	Number of boreholes/wells	Percentage (%)
Water supply	127	21
Industry	86	14
Observation	86	14
Agriculture	36	6
Thermo-mineral	18	3
No classification	252	42
Total	605	100

B.2.2.3 Wells by Aquifer Geology

Wells and boreholes by aquifer geology are classified to be alluvial, Pliocene, Neogene, Quaternary, karst and Pleistocene in order as shown in Table B.3. The major geological types of boreholes/wells are alluvial, Pliocene, Neogene, Quaternary, karst and Pleistocene in order as shown in Figure B.5. The well depth of the karst boreholes is deepest, about 109 m, except for others mainly the thermo-mineral boreholes and the Pliocene is arranged in order. The diameter of the alluvial wells is the largest, about 700 mm and the Quaternary and Pleistocene arranged in order. The yield of the Neogene well is largest, about

33 l/sec and the alluvial is arranged in order. The water levels are below the ground surface, less than -7 m in average except for the Pliocene boreholes of 0.3 m which are artesian aquifers and the alluvial and Pleistocene are arranged in order. The major geological types of boreholes/wells are summarized as follows;

Geology / Statistics	Alluvial	Pleisto-cene	Quater-nary	Plio-cene	Neo-gene	Karst	Others	Average (number of samples)
Number	174	24	85	139	104	43	36	(605)
Well depth(m)	45.1	37.4	41.3	87.1	46.6	108.7	215.8	63.2(578)
Diameter(mm)	698	459.9	661.7	199.9	473.3	258.5	374.0	484(438)
Water level(m)	-5.6	-6.3	-3.1	0.3	-8.9	-52.2	-7.8	-6.6(480)
Yield(l/sec)	28.7	4.1	7.6	4.8	33.3	19.6	26.6	18.9(387)
Aquifer thickness(m)	16.6	11.0	10.6	16.5	11.9	51.8	11.1	15.6(415)
Water tem-perature (℃)	11.7	11.9	13.8	14.1	17.6	15.6	31.6	15.5(206)
pH	7.2	7.3	7.5	7.3	7.2	7.1	7.1	7.2(188)

B.2.2.4 Wells by Former Municipality

Characteristics of wells and boreholes by former municipality are described in detail in Table B.4. In the case of the numbers of boreholes/wells by former municipality, the Skopje municipality, the Tetovo municipality, the Bitola municipality, and the Ohrid municipality are arranged in order and the number of the Skopje municipality is largest and 130 wells as shown in Figure B.6. The well depth of the Valandovo municipality is deepest, about 252.5 m, and the Kochani, Strumica, Vinica, and Prilep municipalities are arranged in order. The diameter of the Delchevo municipality is largest, about 2 m and the Probishtip, Shtip, T. Veles, and Vinica municipalities are arranged in order. The yield of the municipality is the largest, about 3 m and 150 l/sec, respectively. The water levels are generally below the ground surface, less than -7 m in average and the water level of the Kavadarci municipality is lowest and Tetovo, Gostivar, and Skopje municipalities are arranged in order. The water levels of the Bitola and Strumica municipalities are over the ground surface, 2.0 and 1.9 m. The water temperature of the Kochani municipality is highest, and the Vinica and Gevgelija municipalities, which the thermo-mineral wells are distributed, are arranged in order. The pH values are slightly alkaline, 7.2. The characteristics of boreholes/wells by municipality are summarized as follows;

Former municipality	No. of wells	Well depth (m)	Diameter (mm)	Water level (m)	Yield (l/sec)	Aquifer thickness (m)	Water temperature (°C)	pH
Berovo	4	33.6	650.0	-2.9	4.8	3.5	9.6	6.7
Bitola	40	67.8	221.3	2.0	12.0	17.8	14.6	7.0
M. Brod	5	16.4	196.7	-3.4	2.9	4.5	-	-
Valandovo	2	252.5	-	-4.3	1.4	20.9	-	-
Vinica	8	107.1	1095.0	-3.9	13.8	-	37.5	7.2
Gevgelija	23	71.0	647.2	-4.8	37.0	19.6	28.5	7.2
Gostivar	20	47.5	274.8	-12.2	4.1	26.9	11.6	6.9
Debar	8	28.1	685.7	-6.0	15.7	14.5	11.8	9.4
Delchevo	10	13.1	1978.9	-2.4	24.4	4.2	12.9	6.9
Demir Hisar	3	35.7	800.0	-1.9	17.7	13.7	11.8	6.6
Kavadarci	5	99.3	495.2	-63.1	1.7	4.0	15.7	7.3
Kichevo	12	20.8	267.0	-5.0	1.1	9.7	10.1	7.1
Kocani	8	172.7	535.3	-3.7	72.9	18.1	38.0	7.2
Kratovo	2	7.0	-	-3.0	5.0	3.5	-	-
Kriva Palanka	11	64.5	441.5	-2.6	6.5	8.9	9.5	7.0
Krushevo	4	18.5	253.6	-1.4	9.5	23.0	10.0	7.2
Kumanovo	28	35.7	621.4	-6.1	5.8	7.8	11.4	6.8
Negotino	12	29.4	630.9	-1.3	21.4	7.8	14.5	7.5
Ohrid	37	27.7	544.0	-4.5	14.9	17.9	13.2	7.6
Prilep	29	107.3	124.0	-0.7	4.0	15.9	13.9	6.9
Probishtip	4	50.0	1600.0	-2.6	22.7	3.6	8.0	7.2
Radovish	12	36.2	341.2	-3.3	22.4	15.3	12.3	7.2
Resen	33	55.3	556.7	-3.9	7.5	29.2	12.9	7.0
Sveti Nikole	26	47.9	480.8	-2.5	8.7	17.0	13.4	7.3
Skopje	130	64.6	316.5	-10.1	46.1	16.3	14.4	7.3
Struga	15	34.2	454.6	-1.2	1.0	30.0	12.2	7.2
Strumica	34	146.1	217.9	1.9	8.9	22.0	18.3	7.3
Tetovo	48	81.1	237.6	-18.8	7.0	19.6	11.5	7.1
T. Veles	18	43.2	1286.9	-5.3	16.3	5.9	18.0	7.1
Shtip	12	15.3	1301.9	-2.0	32.3	8.3	14.3	7.3
Others	2	14.0	865.0	-3.4	3.5	5.0	-	7.2
Total	605	63.2	484.0	-6.6	18.9	15.6	15.5	7.2

B.3 SPRING INFORMATION

B.3.1 Spring Inventory and Database

Springs are a special type of surface water and groundwater, which emerges from the ground surface through cracks and fissured zones. According to the study of The Water Economy Basis of Macedonia, there are 4,414 registered springs with various yields observed by the nationwide spring surveys in the summer seasons (mainly July & August) of 1975 and 1976 as shown in Figure B.7. The information on the springs is composed of 17 items including spring name, location, geology, present condition, yield, etc. The information on the springs was encoded on the computer in this Study stage and a database of 4,414 registered springs was formed.

B.3.2 Characteristics of Springs

B.3.2.1 Springs by Use

The number and yields of springs are categorized by present usage as shown in the following table. The total number and amount of free flowing spring water are summed to be 2,347 and 435 million m^3 annually, respectively as shown in Figure B.8. Tapped springs are located along various roads and are used for micro-scale water supply because of low yield (mainly less than 1 l/sec). Captured springs are utilized for large-scale water supply of cities and villages. The total number and amount of tapped and captured springs are summed to be 1,918 and 195 million m^3 annually, respectively.

Present use		Total number of springs	No. of springs with yield data	Total yield ($x10^6m^3$/year)	
Free-flowing*		2389	2347(55%)		435 (69%)
Captured	Tapped	1645	1630(38%)	22 (3.5%)	195 (31%)
	Captued	380	288 (7%)	173(27.5%)	
Total*		4414	4265(100%)		630(100%)

* The spring of Sveti Naum is excluded from the calculation because of a kind of river flow.

B.3.2.2 Springs by Geology

Wells and boreholes by aquifer geology are classified to be alluvial, Dilluvial, Neogene, Paleocene, Paleozoic, granite, gneiss, schist, volcanics and karst as shown in the following table. The major geological types of springs are Paleozoic, gneiss, karst, schist, alluvial, dilluvial, volcanics and Paleocene in order as shown in Figure B.9. The spring yield of the karst is largest, about 320 and 0.89 million m^3/year in total and average, respectively and the alluvial, Paleozoic and schist are arranged in order as shown in Figure B.10. The capturing yield of the karst is the largest and the Paleozoic and alluvial are arranged in order. The major geological types of springs are summarized as follows;

Geology	Number	Spring Yield (10^6m^3/year)				
		Average	Total	Free flowing	Capturing	Maximum
Alluvial	317	0.21	66.53	31.43	35.10	30.13
Dilluvial	303	0.04	12.87	10.03	2.84	2.20
Neogene	403	0.02	7.70	5.52	2.17	1.53
Paleocene	230	0.04	9.65	7.91	1.74	3.37
Paleozoic	753	0.17	127.05	116.78	10.27	23.50
Granite	203	0.03	6.27	3.71	2.57	0.68
Gneiss	720	0.02	17.62	14.60	3.02	1.34
Schist	490	0.12	58.24	52.52	5.72	8.04
Volcanics	300	0.02	4.56	2.15	2.40	0.90
Karst*	546	0.89	319.58	190.10	129.48	168.94
Total	4265		630.0	434.8	195.2	

* The spring of Sveti Naum is excluded from the calculation except for the maximum because of a kind of river flow.

B.3.2.3 Springs by Municipality

The number of springs in the Skopje municipality is largest, 450, and the Bitola, Kumanovo, Gostivar, and Prilep municipalities are arranged in order as shown in Figure B.11. The number of springs in the Vinica municipality is smallest, 52, and the Valandovo, Kratovo, Probishtip, and Ohrid municipalities are arranged in inverse order. The average yield of springs in the Ohrid municipality is highest, 0.739 million m^3/year and the Struga, M. Brod, Demir Hisar, and Kichevo municipalities are arranged in order. The total yield of springs in the Skopje municipality is highest, about 121 million m^3/year, and the Gostivar, Valandovo, Kichevo, and Demir Hisar municipalities are arranged in order as shown in Figure B.12. The free-flowing yield of springs in the M. Brod municipality is highest, about 87 million m^3/year, and the Kichevo, Gostivar, Demir Hisar, and Struga municipalities are arranged in order as shown in Figure B.13. The capturing yield of springs in the Skopje municipality is highest, about 108 million m^3/year, and the Gostivar, Struga, Kichevo, and Ohrid municipalities are arranged in order.

(Unit: $10^6 m^3$/year)

Municipality	Number	Average	Total	Free flowing	Captured	Maximum
Berovo	113	0.019	2.18	1.86	0.32	1.00
Bitola	335	0.010	3.25	1.91	1.35	0.24
M. Brod	159	0.559	88.90	86.88	2.02	40.18
Valandovo	62	0.116	7.22	6.02	1.20	4.64
Vinica	52	0.016	0.82	0.63	0.19	0.10
Gevgelija	96	0.019	1.79	1.00	0.79	0.28
Gostivar	228	0.416	94.87	59.07	35.81	30.13
Debar	74	0.124	9.20	7.67	1.54	1.34
Delchevo	126	0.030	3.76	2.69	1.08	0.56
Demir Hisar	98	0.513	50.31	47.29	3.02	23.50
Kavadarci	161	0.105	16.95	12.98	3.97	3.37
Kichevo	195	0.440	85.87	78.92	6.94	16.07
Kocani	85	0.022	1.84	1.09	0.74	0.18
Kratovo	63	0.006	0.39	0.17	0.22	0.04
Kriva Palanka	187	0.010	1.82	0.93	0.89	0.44
Krushevo	65	0.018	1.16	0.86	0.30	0.30
Kumanovo	308	0.010	2.94	1.99	0.95	0.36
Negotino	70	0.019	1.31	0.99	0.32	0.48
Ohrid*	64	0.739	29.66	23.19	6.46	168.94
Prilep	201	0.038	7.56	6.44	1.12	1.00
Probishtip	63	0.009	0.57	0.34	0.23	0.18
Radovish	147	0.010	1.47	1.03	0.44	0.41
Resen	107	0.041	4.36	3.99	0.37	1.21
Sveti Nikole	77	0.010	0.80	0.06	0.74	0.20
Skopje	450	0.268	120.78	13.11	107.67	104.26
Struga	64	0.698	44.64	36.82	7.82	10.04
Strumica	164	0.029	4.70	3.22	1.48	0.86
Tetovo	140	0.252	35.32	30.11	5.21	8.04
T. Veles	193	0.021	4.14	2.75	1.39	0.35
Shtip	118	0.012	1.42	0.70	0.72	0.33
Total	4265		630.0	434.8	195.2	

* The spring of Sveti Naum is excluded from the calculation except for the maximum because of a kind of river flow.

B.4 Groundwater and Spring Water Resources

B.4.1 Groundwater

B.4.1.1 Nationwide Groundwater Resources

The total amount of groundwater including karst limestone and marble amount to 30.47 m^3/sec, i.e. 961 x 10^6 m^3/year, which is equivalent to 18.7 % of that of river water resources (5,147 x 10^6 m^3/year).

- The total exploited amount of groundwater in unconsolidated sands and gravels amount to 1.99 m^3/sec, i.e. 62.8x 10^6 m^3/year and the total potential amount of groundwater in unconsolidated sands and gravels amount to 6.32 m^3/sec, i.e. 199x 10^6 m^3/year.
- The total exploited amount of groundwater in karst limestone and marble amount to 7.73 m^3/sec, i.e. 244x 10^6 m^3/year and the total potential amount of groundwater in karst limestone and marble amount to 23.99 m^3/sec, i.e. 757x 10^6 m^3/year. The amount of groundwater in the karst limestone and marble is estimated to be almost the yield of springs.
- The total exploited amount of groundwater amount to 9.77 m^3/sec, i.e. 308 x 10^6 m^3/year, which is equivalent to 32.0 % of the total groundwater.
- The amount of the groundwater, which complete explorations and studies have been already finished and evaluated properly, is calculated to be 1.98 m^3/sec, i.e. 62 x 10^6 m^3/year, which is equivalent to 6.5 % of the total groundwater.
- The amount of the groundwater, which some explorations has been done but not yet evaluated properly, is calculated to be 18.72 m^3/sec, i.e. 590 x 10^6 m^3/year, which is equivalent to 61.5 % of the total amount groundwater.

Aquifer	Amount				
	Exploited (under use) (m^3/sec)	Exploration finished (m^3/sec)	Exploration level (m^3/sec)	Total (m^3/sec)	Annual total (10^6m^3/year)
Unconsolidated sands & gravels (10^6m^3/year)	1.99 (62.8)	0.79 (24.9)	3.54 (111.6)	6.32 (199)	199
Faults & fractured zones (10^6m^3/year)	0.05 (1.6)	-	0.11 (3.5)	0.16 (5.1)	5.1
Karst limestone* (10^6m^3/year)	7.73 (243.8)	1.19 (37.5)	15.07 (475.2)	23.99 (757)	757
Total (m^3/sec) (10^6m^3/year) (%)	9.77 308.3 (32.0%)	1.98 62.4 (6.5%)	18.72 590.3 (61.5%)	30.47 961 (100%)	- 961 (100%)

* : The groundwater in karst limestone is counted as spring water.

According to the National Development Strategy, the total amount of groundwater in Macedonia is estimated to be approximately 940 x 10^6 m^3/year, which is equivalent to 18.3 % of that of river water resources (5,147 x 10^6 m^3/year).

B.4.1.2 Regional Groundwater Resources

(1) Groundwater Resources by Valley/River Basin

As mentioned in detail in Section B.2.2, the amounts of exploited and potential groundwater by valley/river basin are calculated and categorized as shown in the following table and Figure B.14.

(Unit: 10^6m^3/year)

Valley	Exploited	Potential
Polog valley	6.31	25.23
Skopje valley(Upper)	7.88	25.23
Skopje valley(Lower)	7.88	26.81
Kichevo valley	0.32	3.78
Pchinja river	2.84	8.20
Kriva Reka	0.32	4.10
Pchinja to Veles with Babuna & Topolka	2.52	5.68
Berovo-Delchevo	2.21	4.73
Kochani-Shtip	6.31	16.71
Zletovo river	0.95	1.89
Kriva Lakavica river	0.63	0.95
Ovce Pole valley	1.26	3.78
Upper part of Crna River, Pelagonia	3.78	15.77
Low part of Crna river	3.15	9.46
Lower Vardar	9.78	18.92
Radovish	0.63	4.73
Strumica	1.58	6.31
Crn Drim	4.42	17.03
Grand Total	62.8	199.3

(2) Groundwater Resources by Former Municipality

The amounts of exploited and potential groundwater by former municipality are calculated and categorized as shown in the following table and Figures B.15 to B.17.

(Unit: $10^6 m^3$/year)

Former Municipality	Well collecting (under use)	Total
Berovo	0.13	0.27
Bitola	3.76	11.78
M. Brod	0.00	0.00
Valandovo	0.02	0.04
Vinica	1.26	3.34
Gevgelija	6.48	12.55
Gostivar	0.82	3.28
Debar	0.63	2.42
Delchevo	2.08	4.46
Demir Hisar	0.54	1.68
Kavadarci	0.19	0.95
Kichevo	0.32	3.78
Kochani	3.72	9.86
Kratovo	0.47	1.84
Kriva Palanka	0.47	1.84
Krushevo	0.29	0.90
Kumanovo	1.58	6.15
Negotino	3.28	6.34
Ohrid	2.60	10.01
Prilep	2.17	9.97
Probishtip	0.95	1.89
Radovish	1.00	5.29
Resen	1.12	4.31
Sveti Nikole	1.26	3.78
Skopje	16.40	54.49
Struga	0.08	0.30
Strumica	1.58	6.31
Tetovo	5.49	21.95
T. Veles	2.52	5.68
Shtip	1.58	3.90
Total	62.8	199.3

B.4.2 Spring Water

B.4.2.1 Nationwide Spring Water Resources

Seasonal fluctuation of the yields is generally recognized more or less. In order to clarify the fluctuation, the regional (basin level) spring surveys have been carried out 2 times per year since 1982. The number of springs observed amounts to 1,379 springs in total. The yields obtained by the regional surveys were encoded on the computer in this Study stage and the fluctuation of spring yields was clarified. The ratio of the amount in autumn (Sept. to Dec.) to in spring-summer (April to July) is calculated to be 0.637.

Annex 1 shows annual fluctuation of spring yield of Rashche.

Out of total number of springs, 3,000 springs with a discharge of less than 1 l/sec occupy seventy (70) %. Only fifty-nine springs (1.4 %) has a discharge of greater than 100 l/sec. The springs with a discharge of greater than 10 l/sec are 326 in number and are mostly distributed in the Shara Mountains of the Vardar

River basin, the Treska River basin and the Crn Drim River basin.

The total amount of free flowing spring water is summed to be 435 million m^3 annually. The total amounts of tapping and capturing spring water are summed to be 195 million m^3 annually.

B.4.2.2 Regional Spring Water Resources

(1) Spring Water Resources by Basin

The numbers and yields of springs by river basin as shown in the following table. The number of springs in the Crna River (upper) is largest, 645 and the Crn Drim, Pchina, Gevgelija, and Skopje (lower) basins are arranged in order as shown in Figure B.18. The average yield of springs in the Skopje (upper) basin is highest, about 0.9 million m^3/year, and the Kichevo, Polog, Treska, Crn Drim, and Crna (upper) basins are arranged in order. The total yield in the Crn Drim basin is highest, about 122 million m^3/year, and the Skopje (upper), Kichevo, Polog, Treska, and Crna (upper) basins are arranged in order as shown in Figure B.19. The capturing yield in the Skopje (upper) is highest, about 110 million m^3/year, and the Polog and Crn Drim basins are arranged in order. The free-flowing yield in the Crn Drim basin is highest, about 101 million m^3/year, and the Kichevo, Treska, Crna (upper), and Polog basins are arranged in order as shown in Figure B.20.

(Unit: $10^6 m^3$/year)

River basin	Number	Average	Total	Free-flowing	Capturing	Maximum
Polog	180	0.467	84.06	51.45	32.62	30.13
Treska	183	0.390	71.38	67.92	3.46	40.18
Kichevo	220	0.478	105.10	98.20	6.90	16.07
Skopje(upper)	132	0.918	121.15	11.77	109.38	104.26
Skopje(lower)	273	0.034	9.23	8.45	0.79	0.70
Veles	147	0.025	3.68	2.64	1.04	0.35
Pchinya	379	0.010	3.76	2.64	1.12	0.36
Kriva Reka	221	0.009	2.04	0.93	1.11	0.44
Ovce Pole	83	0.010	0.84	0.06	0.78	0.20
Kriva Lakavica	129	0.009	1.18	0.79	0.39	0.41
Zletovo	81	0.009	0.70	0.45	0.25	0.18
Shtip-Kochani	240	0.026	6.22	4.11	2.11	0.56
Delchevo	168	0.014	2.43	1.82	0.61	0.28
Crna(upper)	645	0.094	60.64	54.98	5.66	23.50
Crna(lower)	183	0.025	4.54	3.39	1.15	0.82
Gevgelija	319	0.078	24.80	19.19	5.61	4.64
Radovish	80	0.008	0.61	0.47	0.14	0.07
Strumica	145	0.039	5.59	4.16	1.43	1.00
Doiransko	18	0.013	0.23	0.08	0.15	0.04
Cironska	12	0.002	0.03	0.01	0.02	0.01
Crn Drim*	427	0.285	121.78	101.30	20.48	168.94
Total	4265		630.0	434.8	195.2	

* The spring of Sveti Naum is excluded from the calculation except for the maximum because of a kind of river flow.

(2) Spring Water Resources by Municipality

As mentioned in Sub-section B.3.2.3, the numbers and yields of springs by municipality as shown in the following table. The free-flowing yield is equivalent to the potential yield for future development.

(Unit: $10^6 m^3$/year)

Municipality	Free-flowing	Capturing	Total
Berovo	1.86	0.32	2.18
Bitola	1.91	1.35	3.25
Brod	86.88	2.02	88.90
Valandovo	6.02	1.20	7.22
Vinica	0.63	0.19	0.82
Gevgelija	1.00	0.79	1.79
Gostivar	59.07	35.81	94.87
Debar	7.67	1.54	9.20
Delchevo	2.69	1.08	3.76
Demir Hisar	47.29	3.02	50.31
Kavadarci	12.98	3.97	16.95
Kichevo	78.92	6.94	85.87
Kochani	1.09	0.74	1.84
Kratovo	0.17	0.22	0.39
Kriva Palanka	0.93	0.89	1.82
Krushevo	0.86	0.30	1.16
Kumanovo	1.99	0.95	2.94
Negotino	0.99	0.32	1.31
Ohrid*	23.19	6.46	29.66
Prilep	6.44	1.12	7.56
Probishtip	0.34	0.23	0.57
Radovish	1.03	0.44	1.47
Resen	3.99	0.37	4.36
Sveti Nikole	0.06	0.74	0.80
Skopje	13.11	107.67	120.78
Struga	36.82	7.82	44.64
Strumica	3.22	1.48	4.70
Tetovo	30.11	5.21	35.32
T. Veles	2.75	1.39	4.14
Shtip	0.70	0.72	1.42
Total	434.8	195.2	630.0

* The spring of Sveti Naum is excluded from the calculation except for the maximum because of a kind of river flow.

B.4.3 Groundwater and Spring Water Resources

The potential amount of spring water can be estimated by two different methods. The first method is calculated using the database of the spring inventory and the seasonal fluctuation of spring yields as mentioned in Sub-section B.4.2. The second method is calculated using the estimation of the static and dynamic groundwater resources and the results of the various groundwater explorations as mentioned in Section B.6. The potential amount of springs calculated by the second method is a little bit larger than that by the first method. Therefore, the potential amount of springs calculated by the first method should be available and used for future development.

B.4.3.1 Nationwide Potential for Future Development

The exploited, potential and total amounts of groundwater and spring water are summarized as shown in the following table and Figures B.21 and B.23;

(Unit: $10^6 m^3$/year)

Situation	Groundwater (wells)	Spring water	Total
Exploited (under use)	64.4(=62.8+1.6)	195.2 to 243.8	259.6 to 308.2
Potential (available for future development)	140.0(=136.5+3.5)	434.8 to 512.7	574.8 to 652.7
Total	204.4(=199.3+5.1)	630.0 to 756.6	834.4 to 960.9
National Development Strategy, 1997	520	420	940

B.4.3.2 Regional Potential for Future Development by Former Municipality

The potential amounts of groundwater and spring water by municipality are summarized as follows;

(Unit: $10^6 m^3$/year)

Municipality	Spring	Well
Berovo	1.86	0.15
Bitola	1.91	8.02
Brod	86.88	0
Valandovo	6.02	0.02
Vinica	0.63	2.08
Gevgelija	1.00	6.07
Gostivar	59.07	2.46
Debar	7.67	1.79
Delchevo	2.69	2.38
Demir Hisar	47.29	1.14
Kavadarci	12.98	0.76
Kichevo	78.92	3.47
Kochani	1.09	6.14
Kratovo	0.17	1.37
Kriva Palanka	0.93	1.37
Krushevo	0.86	0.61
Kumanovo	1.99	4.57
Negotino	0.99	3.07
Ohrid	23.19	7.42
Prilep	6.44	7.80
Probishtip	0.34	0.95
Radovish	1.03	4.29
Resen	3.99	3.19
Sveti Nikole	0.06	2.52
Skopje	13.11	38.10
Struga	36.82	0.22
Strumica	3.22	4.73
Tetovo	30.11	16.46
T. Veles	2.75	3.15
Shtip	0.70	2.31
Total	434.8	136.5

B.5 Groundwater Quality

Groundwater constitutes portions of the earth's water circulation system as the hydrological cycle. Groundwater dissolves parts of the soil and rocks as it infiltrates and percolates through them. The cations occurring in groundwater are commonly calcium, magnesium, sodium, iron, manganese, and potassium. The anions are mostly carbonate, hydrogen-carbonate (bicarbonate), sulfate, chloride, and nitrate.

B.5.1 Guidelines of Water Quality for Various Purposes

Whether water of a given quality is suitable for a particular purpose depends on the criteria or standards of acceptable quality for that use. Water quality standards or quality limits of water supplies are applied for drinking, irrigation, livestock, industry and etc.

B.5.1.1 Drinking Water for Human Consumption

The guidelines for drinking water most accepted are set out by the World Health Organization (1993) as shown in Tables B.5 to B.8. Table B.5 defines bacteriological quality of drinking water. Table B.6 presents chemicals of health significance in drinking water. Table B.7 expresses radioactive constituents of drinking water. Table B.8 defines substances and parameters in drinking water that may give rise to complaints from consumers.

A guideline value represents the concentration of a constituent that does not result in any significant risk to the health of the consumer over a lifetime and is suitable for human consumption and for all usual domestic purposes, including personal hygiene. When a guideline value is exceeded, this should be a signal: 1) to investigate the cause with a view to taking remedial action; 2) to consult with, and seek advice from the authority responsible for public health. Short-term deviations above the guideline values do not necessarily mean that the water is not suitable for consumption. It will be necessary to take account of a variety of geographical, socioeconomic, dietary and other conditions, in the case of development of national drinking water standards.

The basic requirements for drinking water are as follows;

- Free from disease causing microscopic organisms
- No compounds that affect human health
- Fairly clear (low turbidity and little color)
- Not saline
- No compounds that cause offensive taste or smell
- No compounds that cause corrosion of supply system
- No compounds that cause strain of clothes washed

The Macedonian drinking water quality guidelines are summarized as shown in the following table, compared with the WHO guidelines.

Constituent	Unit	Macedonian	WHO
(1) pH		6.5–9.5	6.5–8.5
(2) Turbidity	NTU	2.4	5
(3) Ammonium as N (N-NH_3)	mg/l	0.1	1.5 (as NH_3)
(4) Nitrate as N (N-NO_3)	mg/l	10.0	50.0 (as NO_3)
(5) Nitrite as N (N-NO_2)	mg/l	0.005	3.0 (as NO_2)
(6) Sulfate (SO_4)	mg/l	200.0	250.0
(7) Chloride (Cl)	mg/l	200.0	250.0
(8) Iron (Fe)	mg/l	0.3	0.3
(9) Manganese (Mn)	mg/l	0.05	0.1
(10) Chromium (Cr)	mg/l	0.05	0.05
(11) Arsenic (As)	mg/l	0.05	0.01
(12) Lead (Pb)	mg/l	0.05	0.01
(13) Mercury (Hg)	mg/l	0.001	0.001
(14) Cadmium (Cd)	mg/l	0.005	0.003
(15) Selenium (Se)	mg/l	0.01	0.01
(16) Fluoride (F)	mg/l	1.5	1.5
(17) Phenols (C_6H_5OH)	μg/l	1.0	1–10
(18) Tri-chlorophenols	μg/l	1.0	2–300
(19) Di-chlorophenols	μg/l	-	0.3–40
(20) Chloroform ($CHCl_3$)	μg/l	30.0	200
(21) Tri-chloroethylene (CCl_2=CHCl)	μg/l	30.0	70
(22) Tetra-chloroethylene (CCl_2=CCl_2)	μg/l	10.0	40
(23) DDT	μg/l	1.0	2
(24) Aldrin & Dieldrin	μg/l	0.03	0.03
(25) Lindane	μg/l	3	2
(26) 2,4D	μg/l	40.0	30
(27) Chlordane ($C_{10}H_6Cl_8$)	μg/l	0.03	0.02
(28) Gross alpha radio-activity	Bq/l	0.11	0.1
(29) Gross beta radio-activity	Bq/l	1.0	1.0

B.5.1.2 Irrigation Water

The suitability of irrigation water is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems arise as the total salt increases and then special management practices may be required to maintain acceptable crop yields. The problems are modified by soil, climate and crop, as well as by the skill and knowledge of the water users

The water-quality related problems that are most commonly encountered and used as a basis to evaluate water quality are those related to;

1) Salinity,
2) Water infiltration rate,
3) Toxicity, and
4) Other miscellaneous problems

The salts in soils and water reduce water availability to the crop to such an extent that yield is affected. Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water can not be infiltrated to supply the crop adequately from one irrigation to the next. The ions of sodium, chloride, or boron from soils or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields. Excessive nutrients reduce yield or quality.

The FAO guidelines on classification of irrigation water are shown in Tables B.9 and B.10 (1985). Good water for irrigation has the potential to allow maximum economic returns. In general, poor water causes soil and cropping problems that reduce yields. Water considered "unsuitable" under the prior concept of quality might really be "unable" under certain conditions.

B.5.1.3 Livestock Water

No generalized criteria or guidelines exist for livestock use. In general, there is a wide range of ions, bacteria, and viruses affecting water quality. However, guidelines of water quality for livestock drinking water as shown in the following table are often discussed especially in arid and semi-arid areas. A high level of magnesium is known to cause source of diarrhea.

Parameter	Threshold	Limit
TDS	2500	5000
Calcium (mg/l)	500	1000
Magnesium (mg/l)	250	500
Sodium (mg/l)	1000	2000
Hydrogen-carbonate (mg/l)	500	1500
Chloride (mg/l)	1500	3000
Fluoride (mg/l)	1	6
Nitrate (mg/l)	200	400
Sulfate (mg/l)	500	1000
pH	6.0 - 8.5	5.6 - 9.0

The toxicity problems are amplified when the forage is also irrigated with the same potentially toxic water. The plants take up the salts and raise the toxicity risk to the animal when both the sources of feed and water combine to exceed the critical levels. This problem may also happen with an element such as selenium.

The FAO guidelines of water quality for levels of toxic substances in livestock drinking water (1985) are shown in the following table.

Toxic substance	Upper limit
Aluminum (Al)	5.0
Arsenic (As)	0.2
Beryllium (Be)	0.1
Boron (B)	5.0
Cadmium (Cd)	0.05
Chromium (Cr)	1.0
Cobalt (Co)	1.0
Copper (Cu)	0.5
Fluoride (F)	2.0
Iron (Fe)	-
Lead (Pb)	0.1
Manganese (Mn)	0.05
Mercury (Hg)	0.01
Nitrate + Nitrite (NO_3-N + NO_2-N)	100.0
Nitrite (NO_2-N)	10.0
Selenium (Se)	0.05
Vanadium (V)	0.10
Zinc (Zn)	24.0

B.5.2 Sampling of Groundwater

In this Study, groundwater samplings for water quality analyses including chemical, microbiological and radiological aspects were conducted two times from the viewpoints of geology, hydrology, and accessibility to the sites as shown in the following table. The following table shows itemization of groundwater sampled.

Season in 1998	Drilled well	Dug well	Radial well	Thermo-mineral	Spring	Total
Dry season, Feb.	40	14	1	1	27	83
Wet season, June	40	14	1	1	-	56
Dry season, Sept.	40	14	1	1	1	57

The water sampling points were determined as shown in Figure B.24 in consideration of the criteria that representative wells with existing data of lithology, hydrogeology and water quality for aquifers in 12 valleys should be selected.

The amounts of water samplings were taken in 3 liters for general analysis, 10 liters for radioactivity, and 0.25 liters for coliform. The water samples were brought to the laboratory within the same day after sampling.

The water quality analyses for the water samples were entrusted to a Macedonian laboratory through the subcontractor under the contract with the JICA Study Team.

B.5.3 Result of Groundwater Quality Analyses

B.5.3.1 Dry Season (Feb.) of 1998

(1) Water samplings and chemical analyses

The Groundwater quality survey (2) is composed of 50 groundwater samplings and water quality analyses of forty (20) chemical components and 27 spring water samplings and water quality analyses of twenty (20) chemical components. The groundwater samples were taken at 12 locations in alluvium/dilluvium of valley/river basins as shown in the following table. Regarding six (6) groundwater samples, the 40 chemical components, the chemical components of Macedonian standards for drinking water testing and geo-chemical components of groundwater, were selected and analyzed as shown in the following table.

Location(Valley/River Basin)	No. of Sampling
1) Polog	6
2) Debar	1
3) Treska	1
4) Struga	3
5) Prespa	3
6) Pelagonija	7
7) Skopje	7
8) Veles	4
9) Gevgelija	3
10) Pchinja	6
11) Bregalnica	11
12) Strumica	4
Total	56

Chemical component	Chemical component
(1) Water temperature	(21) Chromium (Cr)
(2) Electrical conductivity	(22) Arsenic (As)
(3) pH	(23) Lead (Pb)
(4) Turbidity	(24) Mercury (Hg)
(5) Bicarbonate (HCO_3)	(25) Cadmium (Cd)
(6) Carbonate (CO_3)	(26) Selenium (Se)
(7) Sodium (Na)	(27) Fluoride (F)
(8) Potassium (K)	(28) Phenols (C_6H_5OH)
(9) Calcium (Ca)	(29) Tri-chlorophenols
(10) Magnesium (Mg)	(30) Chloroform ($CHCl_3$)
(11) Copper (Cu)	(31) Tri-chloroethylene
(12) Silica (SiO_2)	(32) Tetra-chloroethylene
(13) Total hardness	(33) DDT
(14) Ammonium as N (N-NH_4)	(34) Aldrin & Dieldrin
(15) Nitrate as N (N-NO_3)	(35) Lindane
(16) Nitrite as N (N-NO_2)	(36) 2,4D
(17) Sulfate (SO_4)	(37) Chlordane($C_{10}H_6Cl_8$)
(18) Chloride (Cl)	(38) Gross alpha radio-activity
(19) Iron (Fe)	(39) Gross beta radio-activity
(20) Manganese (Mn)	(40) Total coliform MPN

The water samples of springs were taken at 12 locations in alluvium/dilluvium of valley/river basins as shown in the following table.

Location (valley/river basin)	No. of Sampling
1) Polog	3
2) Debar	1
3) Treska	3
4) Struga	2
5) Prespa	2
6) Pelagonija	4
7) Skopje	3
8) Veles	1
9) Gevgelija	1
10) Pchinja	3
11) Bregalnica	2
12) Strumica	2
Total	27

The 20 chemical component, for consideration of geo-chemical characteristics of spring water, were selected and analyzed as shown in the following table.

	Chemical component		Chemical component
(1)	Water temperature	(11)	Calcium (Ca)
(2)	Electrical conductivity	(12)	Magnesium (Mg)
(3)	pH	(13)	Nitrate (NO_3)
(4)	Bicarbonate (HCO_3)	(14)	Nitrite (NO_2)
(5)	Carbonate (CO_3)	(15)	Iron (Fe)
(6)	Chloride (Cl)	(16)	Manganese (Mn)
(7)	Sulfate (SO_4)	(17)	Silica (SiO_2)
(8)	Potassium (K)	(18)	Ammonium (NH_4)
(9)	Manganese (Mn)	(19)	Fluoride (F)
(10)	Sodium (Na)	(20)	Total Hard

The water sampling points were determined as shown in Figure B.24 in consideration of the criteria that representative wells with existing data of lithology, hydrogeology and water quality for aquifers in 12 valleys should be selected.

The amounts of water samplings were taken in 3 liters for general analysis, 10 liters for radioactivity, and 0.25 liters for coliform. The water samples were brought to the laboratory within the same day after sampling.

(2) Geo-chemical characteristics of groundwater

Each ion value is converted to milli-equivalent/liter (meq/l) and ion balance analyses between the sums of all the converted cations and anions are calculated. According to the ion balance analyses, the accuracy of three (3) samples (A16, A26 and A59) is not satisfactory.

i) Water of wells and boreholes

In the case of the waters of wells and boreholes analyzed, the bicarbonate and carbonate concentrations of its anion prevail as shown in Table B.11. The calcium concentrations of its cation for forty-four (44) samples out of forty-nine samples analyzed are predominant and the sodium concentrations for only five (5) samples are predominant. Therefore, the groundwaters of wells and boreholes analyzed belong to a calcium-bicarbonate water type predominantly.

ii) Spring water

The bicarbonate and carbonate concentrations of its anion prevail. The calcium concentrations of its cation for twenty-first (21) samples out of twenty-seven samples analyzed are predominant and the sodium concentrations for only five (6) samples are predominant. The spring waters analyzed belong to a calcium-bicarbonate water type and a sodium-bicarbonate water type. There are two types of the spring waters and the origin of the spring waters is affected separately by some natural factors such as geology.

(3) Hygienic characteristics of groundwater

i) Nitrate and nitrite

As shown in Table B.12, the nitrate concentrations of 13 samples out of 84 samples are higher than the Macedonian standards for drinking water and it would be an indicator of environmental pollution. Although nitrate is not a concern in older children and adults, infants less than three (3) months of age have nitrate reducing bacteria in their digestive systems and these bacteria convert nitrate to nitrite, which bind strongly with blood hemoglobin and prevent sufficient oxygen transport in the baby. Regarding the spring waters analyzed in the first phase of this Study, the concentrations of nitrate and nitrite are very low and it shows no indicator of environmental pollution.

ii) Iron and manganese

The concentrations of iron for 5 samples out of 84 samples are detected and large manganese concentrations of 8 samples out of 84 samples are detected higher than the Macedonian standards for drinking water. Although no health-based guideline value for iron in drinking water is proposed by WHO, there is usually noticeable taste at iron concentrations over 0.3 mg/l, which turbidity and color may develop. Although manganese concentrations below 0.1 mg/l are usually acceptable to consumers, manganese concentration exceeding 0.1 mg/l in water supplies stains ware and laundry and causes an undesirable taste in beverages. The provisional health-based guideline value for manganese is 5 times higher than the acceptability threshold of 0.1 mg/l.

iii) Hardness

The hardness values of 12 samples out of 84 samples are very higher than the Macedonian standards for drinking water. No health-based guideline value is proposed for hardness by WHO. However, the degree of hardness may affect its acceptability to the consumer in terms of taste and scale deposition. The maximum acceptable concentrations of hardness of EC and Japan are 50 and 300 mg/l as $CaCO_3$, respectively. The ratio between hardness as $CaCO_3$ and German (Macedonian) hardness is 17.9 and the above-mentioned concentrations of EC and Japan are 2.79 and 16.8, respectively.

iv) Radioactivity and pesticides

There is no indicator of radiological pollution and pesticides.

(4) Agricultural characteristics of groundwater

As shown in Table B.13, adjusted sodium absorption rate (SAR) and electrical conductivity were calculated using concentrations of sodium, calcium, magnesium, bicarbonate and carbonate in order to classify irrigation waters. Fifty (50) samples out of all (82) samples are classified to be a medium-salinity and low-sodium type of water (C2-S1). Sixteen (16) samples out of all samples are classified to be a low-salinity and low-sodium type of water (Cl-S1). Fourteen (14) samples out of all samples are classified to be a high-salinity and low-sodium type of water (C3-S1). Therefore, with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

(5) Livestock characteristics of groundwater

There is no indicator of pollution for livestock use.

B.5.3.2 Wet Season (June) of 1998

(1) Water samplings and chemical analyses

The Groundwater quality survey (2) is composed of 56 groundwater samplings and water quality analyses of 40 chemical components. The water samples were taken at 12 locations in alluvium/dilluvium of valley/river basins as shown in the following table.

Location(Valley/River Basin)	No. of Sampling
1) Polog	6
2) Debar	1
3) Treska	1
4) Struga	3
5) Prespa	3
6) Pelagonija	7
7) Skopje	7
8) Veles	4
9) Gevgelija	3
10) Pchinja	6
11) Bregalnica	11
12) Strumica	4
Total	56

The 40 chemical components, the chemical components of Macedonian standards for drinking water and geo-chemical components of groundwater, were selected and analyzed as shown in the following table.

Chemical component	Chemical component
(1) Water temperature	(21) Chromium (Cr)
(2) Electrical conductivity	(22) Arsenic (As)
(3) pH	(23) Lead (Pb)
(4) Turbidity	(24) Mercury (Hg)
(5) Bicarbonate (HCO_3)	(25) Cadmium (Cd)
(6) Carbonate (CO_3)	(26) Selenium (Se)
(7) Sodium (Na)	(27) Fluoride (F)
(8) Potassium (K)	(28) Phenols (C_6H_5OH)
(9) Calcium (Ca)	(29) Tri-chlorophenols
(10) Magnesium (Mg)	(30) Chloroform ($CHCl_3$)
(11) Copper (Cu)	(31) Tri-chloroethylene
(12) Silica (SiO_2)	(32) Tetra-chloroethylene
(13) Total hardness	(33) DDT
(14) Ammonium as N (N-NH_4)	(34) Aldrin & Dieldrin
(15) Nitrate as N (N-NO_3)	(35) Lindane
(16) Nitrite as N (N-NO_2)	(36) 2,4D
(17) Sulfate (SO_4)	(37) Chlordane($C_{10}H_6Cl_8$)
(18) Chloride (Cl)	(38) Gross alpha radio-activity
(19) Iron (Fe)	(39) Gross beta radio-activity
(20) Manganese (Mn)	(40) Total coliform MPN

The water sampling points were determined as shown in Figure B.24 in consideration of the criteria that representative wells with existing data of lithology, hydrogeology and water quality for aquifers in 12 valleys should be selected.

The amounts of water samplings were taken in 3 liters for general analysis, 10 liters for radioactivity, and 0.25 liters for coliform. The water samples were brought to the laboratory within the same day after sampling.

(2) Geo-chemical characteristics of groundwater

According to the ion balance analyses, the accuracy of all samples is satisfactory.

The Stiff diagrams are shown in Figures B.25 to B.30 as a typical example for 6 valleys and the Piper diagrams are also shown in Figures B.31 to B.36.

i) Water of wells and boreholes

In the case of the waters of wells and boreholes analyzed, the bicarbonate and carbonate concentrations of its anion prevail as shown in Table B.14. The calcium, magnesium and sodium concentrations of its cation are predominant for thirty-seven (37), ten (10), and nine (9) samples out of fifty-six (56) samples analyzed, respectively. The waters of wells and boreholes analyzed belong to a calcium-bicarbonate water type predominantly. It is geo-chemically recognized that bicarbonate in groundwater is generally the dominant anion, and that sodium and bicarbonate are the major cation and anion, respectively, in the granite and rhyolite, and that magnesium and bicarbonate are the major cation and anion in the gneiss.

The groundwater of the A29, which is thermo-mineral water taken from the very deep well of 350 m in depth at Gevgelija, shows a sodium-sulfate type of water. It is geo-chemically recognized that sulfate is normally the dominant anion in the lower zone of large sedimentary basins.

ii) Spring water

In the case of the spring waters analyzed in the first phase of this Study, the bicarbonate and carbonate concentrations of its anion prevail and the calcium concentration of its cation is predominant. The spring waters analyzed belong to a calcium-bicarbonate water type and a sodium-bicarbonate water type. Two types of the spring waters are separately affected by some natural factors such as geology.

(3) Hygienic characteristics of groundwater

i) Nitrate and nitrite

As shown in Table B.15, the nitrate concentrations of 11 wells out of 56 wells are higher than the Macedonian standards for drinking water and it would be an indicator of environmental pollution. Regarding the spring waters analyzed in the first phase of this Study, the concentrations of nitrate and nitrite are very low and it shows no indicator of environmental pollution.

ii) Iron and manganese

The concentrations of iron for 9 wells out of 56 wells are detected and large manganese concentrations of 12 wells out of 56 wells are detected higher than the Macedonian standards for drinking water. The lead concentrations of 7 wells out of 56 wells are detected higher than the Macedonian standards for drinking water.

iii) Hardness

The hardness values of 11 wells out of 56 wells are very higher than the Macedonian standards for drinking water.

iv) Coliform bacteria

The total coliform numbers (MPN) of 11 wells out of 56 wells are higher than the Macedonian standards for drinking water. According to the WHO guideline value of total coliform bacteria, total coliform bacteria must not be detectable in any 0.1 liter sample. In the case of large water supplies, must not be present in 95% of samples taken throughout any 12-month period.

iv) Radioactivity and pesticides

There is no indicator of radiological pollution and pesticides.

(4) Agricultural characteristics of groundwater

As shown in Table B.16, adjusted sodium absorption rate (SAR) and electrical conductivity were calculated using concentrations of sodium, calcium, magnesium, bicarbonate and carbonate in order to classify irrigation waters. Thirty-three (33) samples out of all (56) samples are classified to be a medium-salinity and low-sodium type of water (C2-S1). Three (3) samples out of all samples are classified to be a low-salinity and low-sodium type of water (C1-S1). Twenty (20) samples out of all samples are classified to be a high-salinity and low-sodium type of water (C3-S1). Therefore, with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

(5) Livestock characteristics of groundwater

There is no indicator of pollution for livestock use.

B.5.3.3 Dry Season (Sept.) of 1998

(1) Water samplings and chemical analyses

The Groundwater quality survey (3) is composed of 56 groundwater samplings and water quality analyses of 40 chemical components. The water samples were taken at 12 locations in alluvium/dilluvium of valley/river basins and the 40 chemical components, the chemical components of Macedonian standards for drinking water and geo-chemical components of groundwater, were selected and analyzed, as shown in the tables discussed in Sub-section B.3.2.

(2) Geo-chemical characteristics of groundwater

i) Water of wells and boreholes

In the case of the waters of wells and boreholes analyzed, bicarbonate and carbonate concentrations of its anion prevail and calcium concentration of its cation is predominant as shown in Table B.17. Therefore, the waters of wells and boreholes analyzed belong to a calcium-bicarbonate water type predominantly. The calcium-bicarbonate water type of water can be formed by dilution of limestones with carbonate (CO_2) in the water.

ii) Spring water

In the case of the spring waters analyzed in the first phase of this Study, bicarbonate and carbonate concentrations of its anion prevail and calcium concentration of its cation is predominant. The spring waters analyzed belong to a calcium-bicarbonate water type and a sodium-bicarbonate water type. Two types of the spring waters can be separately affected by some natural factors such as geology.

(3) Hygienic characteristics of groundwater

i) Nitrate (NO_3) and nitrite (NO_2)

As shown in Table B.18, the nitrate concentrations of 25 wells out of 56 wells are higher than the Macedonian standards for drinking water and it would be an indicator of environmental pollution. Regarding the spring waters analyzed in the first phase of this Study, the concentrations of nitrate and nitrite are very low and it shows no indicator of environmental pollution. Although nitrate is not a concern in older children and adults, infants less than three (3) months of age have nitrate reducing bacteria in their digestive systems and these bacteria convert nitrate to nitrite, which bind strongly with blood hemoglobin and prevent sufficient oxygen transport in the baby.

The nitrite concentrations of 11 wells out of 56 wells are higher than the Macedonian standards for drinking water.

ii) Iron (Fe) and manganese (Mn)

The concentrations of iron for 6 wells out of 56 wells are detected and large manganese concentrations of 11 wells out of 56 wells are detected higher than the Macedonian standards for drinking water. Although no health-based guideline value for iron in drinking water is proposed by WHO, there is usually noticeable taste at iron concentrations over 0.3 mg/l, which turbidity and color may develop. Although manganese concentrations below 0.1 mg/l are usually acceptable to consumers, manganese concentration exceeding 0.1 mg/l in water supplies stains ware and laundry and causes an undesirable taste in beverages. The provisional health-based guideline value for manganese is 5 times higher than the acceptability threshold of 0.1 mg/l.

iii) Lead (Pb)

The lead concentrations of 2 wells out of 56 wells are detected higher than the Macedonian standards for drinking water. Lead deposits as well as the smelts might affect the lead concentration of groundwater.

iv) Hardness

The hardness values of 16 wells out of 56 wells are very higher than the Macedonian standards for drinking water defined in German unit. No health-based guideline value is proposed for hardness by WHO. However, the degree of hardness may affect its acceptability to the consumer in terms of taste and scale deposition. The maximum acceptable concentrations of hardness of EEC and Japan are 50 and 300 mg/l as $CaCO_3$, respectively. The ratio between hardness as $CaCO_3$ and German (Macedonian) hardness is 17.9 and the above-mentioned concentrations of EEC and Japan are 2.79 and 16.8, respectively.

v) Total coliform numbers (MPN)

The total coliform numbers (MPN) of 26 wells out of 56 wells are higher than the Macedonian standards for drinking water.

vi) Radio-activity and pesticides

There is no indicator of radiological pollution and pesticides.

(4) Agricultural characteristics of groundwater

As shown in Table B.19, adjusted sodium absorption rate (SAR) and electrical conductivity were calculated using concentrations of sodium, calcium, magnesium, bicarbonate and carbonate in order to classify irrigation waters. Thirty-nine (39) samples out of all (57) samples are classified to be a medium-salinity and low-sodium type of water (C2-S1). Three (3) samples out of all samples are classified to be a low-salinity and low-sodium type of water (C1-S1). Fifteen (15) samples out of all samples are classified to be a high-salinity and low-sodium type of water (C3-S1). Therefore, with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

(5) Livestock characteristics of groundwater

There is no indicator of pollution for livestock use.

B.6 Regional Hydrogeology

B.6.1 Physical Environment

B.6.1.1 Topography

Macedonia is predominantly a mountainous country. There are 34 peaks over 2,000 m above sea level, the highest of which is Korab (2764 m). There are many valleys and plains between the mountains and mountain ranges.

Macedonia is a land-locked country surrounded by four (4) countries, i.e. Bulgaria on the east, New Yugoslav on the north, Albania on the west and Greece on the south, located in the southern part of the Balkan peninsular. The country lies between 20°27'32" and 23°02'12" of east longitude and 40°51'16" and 42°22'21" of north latitude, extending to east-west direction of 210 km and to south-north of 160 km with a border line of 850 km in total. The total surface area amounts to 25,713 km^2.

The topographic condition of the country is roughly classified into the followings:

- High mountainous area in the west,
- Eastern mountainous area with relatively lower area compared with the west
- Lowland and hilly regions in the middle between the east and the west

These areas range from an altitude of 50 m in the alluvial lowland of the Vardar River near the border with Greece to the high mountainous area extending to the border of the west Albania and the north west border of New Yugoslavia where the peaks range from 2, 200 to 2, 700 m in altitude. The country is occupied by plains with 19.1 % and by mountainous and hilly areas with 80.9 %.

Major watersheds in the country consist of three (3), the Vardar River, the Crn Drim River and the Strumica River. These rivers originate in the country and flow out to the neighboring countries. The watershed of the Vardar River is the largest of the three, and occupies more than 80 % wide of the country. The Vardar watershed is generally divided into seven (7) sub-watershed basins, namely (i) upper reach of the Vardar, (ii) the Treska, (iii) the Crna, (iv) middle reach of the Vardar, (v) the Pcina, (vi) the Bregalnica, and (vii) lower reach of the Vardar. The other three rivers are minor, which do not belong to the above and the area of them is too small to adopt for the Study.

Major lakes remarkable in the country are also three (3), Ohrid, Prespa, and Dojran. Lake Prespa and Lake Ohrid, where are located in the southwest of the country, were formed by the geotectonic movement more than 2 to 3 million years ago. Lake Ohrid is designated by UNESCO as a cultural heritage for its crystal water as well as scenic beauty. The altitude of the water surface of Lake Prespa is 853 m with a maximum depth of 54 m. The surface area is 274 km^2, of which 174 km^2 belongs to FYROM, while the remaining 100 km^2 does to Albania and Greece. Meanwhile, the altitude of the water surface of Lake Ohrid is 693 m with a maximum depth of 286 m. The surface area is 349 km^2, two thirds (2/3) of which belongs to FYROM, and the remaining does to Albania. The watershed area of Lake Ohrid is 1,129 km^2 by itself and it will be more than 2,000 km^2 when the water amount said to be supplied from Lake Prespa through underground is converted and added to the watershed area. The other lake of Dojran is located in the southeast of the country near the border with Greece. The altitude of the water surface of the lake is 148 m with a maximum depth of about 10 m, where the lake water level tends to descend in recent years.

B.6.1.2 Geology

The first and complete insight into geological and geomorphological structures of Macedonia was given by a geologist Cvijic in 1906. A review of the geological structure of the Balkan region and the tectonic zoning of Macedonia was given by a German geologist F. Kossmat in 1924 based on extensive study during World War I.

In the period after 1950s detailed geological investigations and studies were performed and numerous deposits profitable mineral resources were found. As results of the studies, the following geological maps were published:

- Geological Map of SFR Yugoslavia (1:500,000 and 3 sheets) in 1970
- Geological Map of Macedonia (1:200,000 and 2 sheets) in 1977
- Engineering Geological Map of Macedonia (1:200,000 and 2 sheets) in 1977

The lithological and stratigraphic characteristics of Macedonia point to the fact that Macedonia contains various sedimentary, metamorphic and magmatic formations ranging from the Precambrian to the present times as shown in Figure B.37.

The Tertiary Alpine tectonic movement affects the territory of Macedonia, which is located in the central part of the Balkan Peninsula. The movement is closely and directly related to the high level of seismicity.

The geology of the country is generally divided into two (2) geo-tectonic regions, namely Serbo-Macedonian Massif on the east and Dinarides on the west. The Dinarides is farther divided into three zones, i.e., Vardar Zone (VZ), Pelagonija Horst Anticlinorium (PHA) and West Macedonian (WM) zones from east to west as shown in Figure B.38.

Firstly, the Serbo-Macedonian Massif (SMM) in the eastern side of Macedonia consists mainly of crystalline schist, gneiss and other metamorphic rocks of Pre-Cambrian to Paleozoic eras with intrusions of diorite and other igneous rocks. The strata were folded by the Variscan Orogeny of the latest stage of the Paleozoic era.

Secondly, the Vardar Zone (VZ) occupies the wide zone along the Vardar River and mostly comprises Tertiary formations under the hilly areas and Quaternary deposits in the lowland. Outcrops of the basement rocks older than the Tertiary is scarce. Spring sites spread in the zone and surrounding lowlands. Presumably the zone was formed in the latest stage of the Alpine Orogeny. Karst was formed mainly in the southern part of the Vardar zone similarly with the Pelagonia block to be mentioned below.

Thirdly, the Pelagonija Horst Anticlinorium (PHA) zone occupies the western part of the country and consists mainly of the Paleozoic and Mesozoic formations including limestone, which form karst. Structurally the PHA zone is on the extension of the Ginaru Mountains range along the East Coast of the North Adriatic Sea and the strata were folded by the Alpine Orogeny in the Mesozoic to Cenozoic era. The PHA zone may be geologically divided into two areas, one is the Saruplani-Peristeru zone and the other is the Pelagonia geo-anticlinal horst.

Finally, the West Macedonian (WM) zone spreads in the western side of the country. The monotonous metamorphic shale complex was not affected by dislocation place in the pre-Alpine period and is characterized by transgressive relations with the Alpine formations.

Territory of the Republic of Macedonia is one of the most active seismic zones in the Balkan Peninsula. The oldest earthquake in the Balkan Peninsula is in 479 BC South of Thessaloniki. In the territory of Macedonia the oldest earthquakes is in 361 AD in Stobi (south of Veles, old antic city) all cities were destroyed. But the oldest earthquake written in some document was in 518 AD, when the ancient city of Skupi (Skopje) was destroyed.

According to the International Project (1970-1976), the earthquake of an epicenter at Berovo in 1904 was the strongest earthquake in the Balkan Peninsula with a magnitude of 7.8 and an intensity of X. There have been 10 big earthquakes with intensities of VIII to X in the territory of Macedonia since 1904. The most severe earthquakes occurred at Skopje with an intensity of IX in 1963 and at Debar with an intensity of IX in 1967. There were three (3) big earthquakes in 1920, 1958 and 1994 with intensities of VII to VIII in Bitola. Fourteen (14) main zones (epicenter areas) were detected, where big cities and industrial facilities are located.

B.6.1.3 Meteorology and Hydrology

(1) Rainfall

Macedonian climate and general rainfall characteristics can be represented as a result of the Mediterranean climate. Macedonia has its largest rainfall in the winter season (November and December) and smallest rainfall in the summer season (July and August).

The month of May has the highest magnitude of rainfalls, while the month of August has the lowest through the year.

The western part of the country has greater rainfall with an annual average of more than 1000 mm than in the eastern part with an average of less than 700 mm and in the central part with an average of around 500 mm. An isohyetal map of average annual rainfall is drawn, based on the rainfall data from all the 295-registered rainfall stations for the period of 1961 to 1996, as shown in Figure B.39. Tables B.20 to B.24 show monthly rainfalls from 1961 to 1996 at Tetovo, Skopje, Kochani, Strumica and Bitola. Averages, maximum and minimum of annual rainfalls for 36 years at these 5 stations are summarized as follows;

Station	Annual rainfall (mm/year)		
	Average	Maximum	Minimum
Tetovo	710	1,008	385
Skopje	508	741	301
Kochani	525	708	360
Strumica	545	762	286
Bitola	605	842	365

The worst drought occurred in 1993 within the period of 1961 to 1996, followed by 1973 and 1986. The years of the last decade since 1990 are within the worst 10 drought ranks. On the other hand, the wettest was recorded in 1962, followed by 1963, 1981 and 1995. The decade of 1961 to 1970 was the wettest decade and includes the higher rank numbers, higher than 20 (out of 36-years).

(2) Other Meteorological Elements

There are 35 meteorological stations for rainfall, temperature, humidity, wind speed, sunshine duration, cloudiness and etc. in Macedonia.

The meteorological records in Skopje are summarized as follows:

- Monthly averages of temperature range from 0.5 to 23.3 · C.
- Monthly averages of relative humidity are from 69 to 83 %.
- Monthly values of sunshine duration from 172 to 198 hours.
- Monthly averages of wind speed from 0.8 to 4.7 m/sec.
- Monthly averages of cloudiness from 3.9 to 6.

(3) Hydrology

Macro-scale or nationwide hydrological conditions are summarized as follows,

- An extremely dry period is noticed during the last 7-years (1990 to 1996).
- The driest year was 1990.
- The wettest year was the hydrological year 1962/63. Most of rivers over-spilled and flooded and the flood caused great damages.
- The second wettest year was 1979. High water levels were recorded and many rivers flooded.
- Most of rivers have two maximum flow records, in spring due to snow melting and in autumn due to heavy rainfall.

(4) Water balance by river basin

The annual rainfall depth in Macedonia is estimated at 595 mm based on the average for 36 years (1961 to 1996). The annual runoff depth is estimated at 187 mm, which is equivalent to 30.72 % of the annual rainfall depth. The annual loss depth, which includes evapotranspiration, groundwater recharge and river intakes, is calculated to be 407 mm.

The annual water balance for the major river basins is summarized as follows,

- The south-eastern part, especially Strumica, has low runoff and high loss.
- The upper part of Vardar river, especially Treska, has high runoff and low loss.

Basin	Rainfall (mm)	Runoff		Loss	
		(mm)	(%)	(mm)	(%)
Vardar	591	192	33	399	67
Treska	696	392	56	305	44
Pchinja	521	134	26	387	74
Bregalnica	538	123	23	415	77
Crna	554	156	28	398	72
Strumica	565	86	15	478	85
Crn Drim	801	229	29	572	71
Average	609	187	31	422	69

B.6.2 Methodology for Estimation of Groundwater Resources

General methodology for estimation of groundwater resources is to summarize hydrogeological results that have been carried out and obtained through three phases of explorations: 1) regional exploration, 2) local exploration and 3) specific exploration. Through the regional exploration, lithological and tectonic structures, geomorphological and hydrological features, and spatial position and size of aquifers can be determined at map scales of 1:100,000 and 1:200,000. Hydrogeological Map of Macedonia at a scale of 1:200,000 was published in 1977 after the regional explorations that were conducted during 1963 to 1975. Exploration-level hydrogeological maps of Macedonia were published in a scale of 1:100,000 and compiling of the well inventory was also conducted in 1982.

For the purpose of water supply of some towns as well as industry and agriculture, local and detailed hydrogeological explorations can be carried out at map scales of 1:25,000 and 1:50,000 and local hydrogeological characteristics can be determined. The geology & hydrogeology in Polog valley and origin of the water of Rasce spring in a scale of 1:50,000 was published in 1986 and the hydrogeological explorations in the Skopje valley and the urban area of Skopje were carried out during 1964-1965 and 1980-1981 in a map scale of 1:25,000.

The specific explorations of thermal, mineral and thermo-mineral water can be carried out and specific hydrogeological characteristics can be clarified at deeper layers. Hydrogeological map of Macedonia (1:200,000) for thermal, mineral and thermo-mineral water was in 1977.

In order to determine the amount of groundwater resources, the aquifers are classified into three different types according to the quality of porosity: 1) inter-granular and unconsolidated aquifer, 2) fissured aquifer, and 3) karst aquifer.

The groundwater is classified into three categories according to the level of exploration: the amount which has been already exploited for more than two years, and the amount which has not been examined and explored enough, but can be divided into two categories according to the level of exploration.

B.6.3 Polog Valley

This basin belongs to the West-Macedonian and Vardar tectonic zone as well as to the upper Vardar River basin. The Polog valley is formed in the Gostivar and Tetovo areas.

B.6.3.1 Geology

The geological structure of Polog Valley is composed of sedimentary, igneous and metamorphic rocks of Paleozoic and Mesozoic eras, and Tertiary and Quaternary periods as shown in Figure B.40.

The Paleozoic rocks are represented by albititic phyllitic mica-schist and green schist, meta-sandstone, meta-conglomerate, chloride-epidote sericite quartzite, schist, meta-diabase, carbonate schist and marble. The Paleozoic schists are intruded by granodiorite, granite, diorite, and diabase.

Permian-Triassic, Lower and Middle Triassic sediments and pegmatites lie unconformably over a Paleozoic base. Triassic formations in the Suva Gora are composed of dolomitic and bituminous marbles and gray-white marbled limestone and unconformably over the Paleozoic base.

Jurassic formations are developed in the area between the Radika River and Korab Mountains. The Upper Cretaceous is recognized on the Korab Mountains in the form of dark-gray clayey-sandy sediments. The Mesozoic rocks are granite, granodiorite, massive marbled limestone, diabase, spilite, harzburgite and dunite.

The Tertiary rocks are represented by Pliocene lacustrine sandy clay, sand with a thickness of 250 m and marl and are generally developed in the southern part of the Polog depression.

The Quaternary rocks are widely distributed and are alluvial sediments, slope breccia, proluvial terrace deposits, fluvio-glacial sediments and morainic materials.

During the Hercynian orogeny, this basin was folded into large-size plicate structures with strikes in NW-SE, N-S or SW-NE directions. The large ruptured structures are marginal faults of the Polog depression.

B.6.3.2 Hydrogeology

Phreatic and artesian aquifers were formed in the inter-granular and unconsolidated sediments as shown in Figure B.41 and Figure B.42.

The phreatic aquifers are formed in alluvial and proluvial sediments, marble debris and in the Upper Pliocene deposits that are situated in the foothill of the Shar Planina Mountains, from Dobri Dol village to Odri village. The wells in Tetovo ("gas station" and "Fershped"), Miletino and Gostivar-Proshevachka Jurija, belong to this aquifers. The phreatic aquifers belong to the group with a good yield of Q = 1 - 10 l/sec and of Q > 10 l/sec.

The artesian aquifer is represented in Dolen Polog, in Zilche village, Janchishte village, Jegunovce village and Raotince and occurs in upper Pliocene lacustrine sediments with an aquifer of about 40 m in thickness. The yield of the artesian aquifer ranges from 1 - 10 l/sec.

Karst aquifers occur in the karst presented by marble, marbled limestone and dolomite, located in Suva Gora and Zeden Mountains. The karst type springs are the Toplice spring at Vrapchishte village, the spring at Rogachevo village and the springs at Gostivar with a yield of Q = 0.5 - 1 m^3/sec. The most significant springs within the Suva Gora karst aquifer are the springs in Forino, Chegrane and Volkovija and the yield varies from Q = 0.5 -1 m^3/sec.

There are large springs in the slope of the Shara Mountains: the Vrutok spring with a yield of about Q = 1 m^3/sec which is used for water supply to Gostivar, the Vakuvski spring at Urvic Village, and the Popova Shapka spring which is used for water supply to Tetovo.

B.6.3.3 Groundwater Resources

(1) Quaternary and Pliocene Aquifers

In the Polog valley, the surface area and the average thickness of the Quaternary and Pliocene sediments are estimated to be 47.3 m and 300 km^2, and the porosity of the aquifer is assumed to be 0.2. The static amount of groundwater resources in the Quaternary and Pliocene sediments of the Polog valley is calculated to be 2838 million m^3. The average hydraulic conductivity is assumed to be $9.8x10^{-3}$ cm/sec. The hydraulic gradient is estimated to be 0.007 along the flowpath of 40 km. Therefore, the dynamic amount of groundwater resources in the Quaternary and Pliocene sediments of the Polog valley is calculated to be 1.298 m^3/sec.

(2) Karst Aquifer

Regarding determination of the amount of karst groundwater resources in the Suva Gora aquifer of the Polog valley, the infiltration area is estimated to be 150 km^2 and the average coefficient of infiltration and hydraulic head gradient are 1.18 m/sec and 0.75, respectively. Therefore, the amount of karst groundwater resources in the Suva Gora is calculated to be 4.2 m^3/sec.

B.6.4 Debar Valley

This basin belongs to the river basin Crn Drim and the West-Macedonian tectonic zone.

B.6.4.1 Geology

The geology of this basin is composed of Paleozoic, Mesozoic, Tertiary and Quaternary rocks. The Paleozoic rocks are phullitoide and marbled limestone. The Mesozoic rocks are limestone, claystone, argillo-schist, limestone and sandstone, marl, marly limestone, gabbro, diabase and flysch sediments with gypsum and anhydrite occurrences. The Tertiary rocks are represented by Eocene marly sandstone and Pliocene marls. The Quaternary rocks are alluvial sediments, and dilluvial and proluvial deposits, moraine and talus.

B.6.4.2 Hydrogeology

Inter-granular and unconsolidated aquifers were formed in the rocks with inter-granular porosity, which are formed in the alluvial, dilluvial and proluvial sediments. This aquifer in Piskupshtina village (the well A7) is formed in the alluvial sediments and is classified to be a good yield aquifer.

The karst rocks with caverns and fissures are presented by Triassic limestone and form karst aquifers. The karst aquifers have an important role for solving the problem of water supply for Debar Town and within the valley. The spring St. Jovan Bigorski originates from the karst aquifer. The springs at Rosoki, Selce, Lazaropole, Mavrovo, Vrben, Belicica and Brodec Villages are distributed within this area.

B.6.4.3 Groundwater Resources

(1) Quaternary and Neogene Aquifers

Regarding the Quaternary and Neogene sediments in the Debar valley, the surface area and the average thickness of the Quaternary and Neogene sediments are estimated to be 15 m and 12 km^2, and the porosity of the aquifer is assumed to be 0.194. The static amount of groundwater resources in the Quaternary and Neogene sediments of the Debar valley is calculated to be 35 million m^3. The average hydraulic conductivity is assumed to be 6.98×10^{-3} cm/sec. The hydraulic gradient is estimated to be 0.03 along the flowpath of 3.5 km. Therefore, the dynamic amount of groundwater resources in the Quaternary and Neogene sediments of the Debar valley is calculated to be 0.11 m^3/sec.

(2) Karst Aquifer

Regarding determination of the amount of karst groundwater resources in the karst aquifer of the Ilina Mountains, the infiltration area is estimated to be 65 km^2 and the average coefficient of infiltration and hydraulic head gradient are 0.81 m/sec and 0.78, respectively. Therefore, the amount of karst groundwater resources in the Ilina Mountains is calculated to be 1.3 m^3/sec.

Regarding determination of the amount of karst groundwater resources in the karst aquifer of the Mavrovo-Radika, the infiltration area is estimated to be 20 km^2 and the average coefficient of infiltration and hydraulic head gradient are 0.788 m/sec and 1.0, respectively. Therefore, the amount of karst groundwater resources in the Mavrovo-Radika is calculated to be 0.5 m^3/sec.

B.6.5 Kichevo-Treska Valley

B.6.5.1 Geology

The Kichevo-Treska River basin is composed of Paleozoic metamorphic and magmatic rocks, Mesozoic sediments and magmatic rocks, Tertiary sediments and effusive rocks, and Quaternary sediments.

The Cambrian-Ordovician metamorphic rocks are the oldest rocks in the Kichevo Valley. These rocks are very represented and presented by phyllitoide, quartz meta-sandstone, marble, green schist and quartzite.

The Devonian rocks are presented by phyllitoide, conglomerate, meta-sandstone, carbonate schist, massive marble, diabase and rhyolite.

The Triassic rocks lie over the Paleozoic complex and are mostly distributed in the west. The rocks are presented by platy limestone and thick-bedded and massive limestone.

The Pliocene sediments are represented in the valley parts of the terrain and lie uncomformably over the Cambrian-Ordovician and Devonian rocks. The Pliocene rocks are represented by marl, clay, sand and graver.

The Quaternary rocks are represented by alluvial sediments, and dilluvial and proluvial deposits.

The West Macedonian zone actually presents the inner Dinara belt which is characterized by large structural formations and intensive compressive structures (thrusts, overthrusts etc). The tectonic development of the terrain refers to two large orogenies: Hercynian and Alpine orogenies. By the Hercynian orogeny, the Paleozoic sediments were regionally metamorphosed and folded in mild syncline and anticline structures. The strong dynamo-metamorphism, intensive folding of the terrain and alteration of the Hercynian structures resulted from the Alpine orogeny. The strike structures in West-Macedonian zone have mostly NW-SE to NNW-SSE directions.

B.6.5.2 Hydrogeology

Within the Kichevo-Treska River basin, the following types of aquifers are distinguished: 1) inter-granular and unconsolidated aquifer, 2) fissured aquifer, and 3) karst aquifer.

1) Inter-granular and unconsolidated aquifer

The aquifers are developed within the Quaternary and Pliocene sediments. In the Quaternary sediments, the aquifers are developed in the alluvial sediments and proluvial-dilluvial deposits. The thickness of these sediments is about 20 m. The wells in the alluvial sediments of Kichevo-Treska River have good yield of 10 - 15 l/sec, which the alluvium of Treska River is characterized by good filtration.

Within the proluvial-dilluvial deposits, the aquifers are characterized by low water bearing. From hydrogeological point of view, the Pliocene sediments have no special importance for practical use. The groundwater occurs in the layers that are composed of sand and gravel. They are characterized by poor water-bearing and sub-artesian groundwater.

2) Fissured aquifer

The aquifers have no special importance for practical use from hydrogeological point of view. The aquifers are developed in the granodiorite and metamorphic rocks that were tectonically altered and are characterized by a spring yield of 0.1 - 1.0 l/sec and the maximum yield of 1.0 l/sec.

3) Karst aquifer

The karst aquifers prevail in this terrain and are developed mostly in the limestone and marble. The karst aquifers are characterized by a spring yield of 0.05 - 2.0 m^3/sec. The Studencica spring at Javorec has an important role for solving the problem of water supply for Kichevo, M. Brod, Krucevo and Prilep Towns. The springs at Popolzani, Belica, and Staroec Villages are distributed within this area.

B.6.5.3 Groundwater Resources

(1) Quaternary Aquifer

In the Kichevo valley, the surface area and the average thickness of the Quaternary sediments are estimated to be 12.9 m and 72 km^2, and the porosity of the aquifer is assumed to be 0.17. The static amount of groundwater resources in the Quaternary sediments is calculated to be 158 million m^3. The average hydraulic conductivity is assumed to be 8.07×10^{-3} cm/sec. The hydraulic gradient is estimated to be 0.03 along the flowpath of 6.4 km. Therefore, the dynamic amount of groundwater resources in the Quaternary sediments of the Kicevo valley is calculated to be 0.2 m^3/sec.

(2) Karst Aquifer

Regarding determination of the amount of karst groundwater resources at the Studencica spring in the southeast slope of the Bistra Mountains, the infiltration area is estimated to be 60 km^2 and the average coefficient of infiltration and hydraulic head gradient are 0.8 m/sec and 1.1, respectively. Therefore, the amount of karst groundwater resources at the Studencica spring in the southeast slope of the Bistra Mountains is calculated to be 1.67 m^3/sec.

The amount of karst groundwater resources from other parts in the Treska valley can be estimated as shown in the following procedure. The infiltration area is estimated to be 1250 km^2 and the average coefficient of infiltration and hydraulic head gradient are 0.75 m/sec and 0.71, respectively. Therefore, the amount of karst groundwater resources from other parts in the Treska valley is calculated to be 21.1 m^3/sec.

B.6.6 Struga Valley

This valley consists of the Ohrid and Struga valleys. This valley belongs to the West-Macedonian tectonic zone and to the basin of the Lake Ohrid.

B.6.6.1 Geology

The geological structure of the valley is composed of Precambrian, Paleozoic, Tertiary and Quaternary rocks.

The Precambrian rocks are composed of quartz-sericite schists.

The Paleozoic rocks are composed a complex of the metamorphic and magmatic rocks: phyllitic schist, meta-sandstone, meta-conglomerate, marbled limestone.

Triassic formations lie over the Paleozoic complex. The Middle Triassic is distinguished according to fossil remains and is composed of clastic and carbonate sediments. The Mesozoic rocks are characterized by platy limestone with hornstone, massive limestone, sandstone, claystone, peridotite, and diabase.

The Tertiary rocks have a fresh-water character and are presented by Pliocene sand, clay and gravel.

The Quaternary rocks are widely presented and consist of lacustrine-marsh sediments, dilluvial and proluvial deposits, fluvio-glacial deposits and alluvial sediments.

B.6.6.2 Hydrogeology

The hydrogeological characteristics of this terrain are rather complex and all types of rocks are represented. The most distinguished rocks are karst limestone with caverns and fissures and the rocks with intergranular porosity.

The rocks with inter-granular porosity are non-coherent sediments and the Ohrid valley includes the following geological formations: alluvial sediments, dilluvial and proluvial deposits, and lacustrine-marsh sediments. The Ohrid valley is mostly composed of lacustrine-marsh sediments with a thickness of 20 to 30 m. These unconsolidated sediments form phreatic aquifers with a medium yield of Q = 10 l/sec.

The karst rocks with caverns and fissures are presented by Triassic limestone and form karst aquifers. The karst aquifers have an important role for solving the problem of water supply to Struga and Ohrid and within the valley. The karst aquifers form the springs at St. Naum and Duvlo in the Galicica Mountains, at Vevcani, Oktisi and Arzanovo in the Jablanica Mountains and at Svinista in the Ilinska Mountains. The wells in St. Naum and in the factory "Bratstvo" in Ohrid are also situated in karst aquifer.

Because of the intensively developed processes of karstification in the Ohrid Valley, the surface water flows are very seasonal. Impermeable crystallines and silicate rocks are represented in the places besides the limestone. The watershed area is very small and the Crn Drim River has tributaries of the Ohrid Lake and the Sateska River.

B.6.6.3 Groundwater Resources

(1) Quaternary Aquifer

In the Ohrid valley, the surface area and the average thickness of the Quaternary sediments are estimated to be 10 m and 28.3 km^2, and the porosity of the aquifer is assumed to be 0.2. The static amount of groundwater resources is calculated to be 68 million m^3. The values of hydraulic conductivity range from $1x10^{-1}$ to $1x10^{-3}$ cm/sec and the average is assumed to be $9.92x10^{-3}$ cm/sec. The hydraulic gradient is estimated to be 0.03 along the flowpath of 4.2 km. Therefore, the dynamic amount of groundwater resources in the Quaternary sediments of the Ohrid valley is calculated to be 0.15 m^3/sec.

Regarding the Neogene sediments in the Ohrid valley, the surface area and the average thickness of the Neogene sediments are estimated to be 10 m and 15 km^2, and the porosity of the aquifer is assumed to be 0.2. The static amount of groundwater resources is calculated to be 30 million m^3. The values of hydraulic conductivity range from $3x10^{-3}$ to $3.6x10^{-2}$ cm/sec and the average is assumed to be $8.58x10^{-3}$ cm/sec. The hydraulic gradient is estimated to be 0.006 along the flowpath of 3.74 km. Therefore, the dynamic amount of groundwater resources in the Neogene sediments of the Ohrid valley is calculated to be 0.019 m^3/sec.

In the Struga valley, the surface area and the average thickness of the Quaternary sediments are estimated to be 13 m and 34 km^2, and the porosity of the aquifer is assumed to be 0.21. The static amount of groundwater resources is calculated to be 93 million m^3. The average hydraulic conductivity is assumed to be $1.1x10^{-2}$ cm/sec. The hydraulic gradient is estimated to be 0.025 along the flowpath of 5.6 km. Therefore, the dynamic amount of groundwater resources in the Quaternary sediments of the Struga valley is calculated to be 0.2 m^3/sec.

Regarding the Neogene sediments in the Struga valley, the surface area and the average thickness of the Neogene sediments are estimated to be 15 m and 18 km^2, and the porosity of the aquifer is assumed to be 0.17. The static amount of groundwater resources is calculated to be 46 million m^3. The average hydraulic conductivity is assumed to be $9.8x10^{-3}$ cm/sec. The hydraulic gradient is estimated to be 0.01 along the flowpath of 9.5 km. Therefore, the dynamic amount of groundwater resources in the Neogene sediments of the Struga valley is calculated to be 0.14 m^3/sec.

(2) Karst Aquifer

The amount of karst groundwater resources in the karst aquifer of the Galicica Mountains can be determined as follows. The infiltration area is estimated to be 268 km^2 and the average coefficient of infiltration and hydraulic head gradient are 1.47 m/sec and 0.8, respectively. Therefore, the amount of karst groundwater resources in the Polog valley is calculated to be 10 m^3/sec.

Regarding determination of the amount of karst groundwater resources in the karst aquifer of the Jablanica Mountains, the infiltration area is estimated to be 100 km^2 and the average coefficient of infiltration and hydraulic head gradient are 1.69 m/sec and 0.8, respectively. Therefore, the amount of karst groundwater resources in the Jablanica Mountains is calculated to be 4.3 m^3/sec.

Regarding determination of the amount of karst groundwater resources in the Suva Gora aquifer of the Polog valley, the infiltration area is estimated to be 150 km^2 and the average coefficient of infiltration and hydraulic head gradient are 1.18 m/sec and 0.75, respectively. Therefore, the amount of karst groundwater resources in the Suva Gora aquifer of the Polog valley is calculated to be 4.2 m^3/sec.

B.6.7 Prespa Valley

B.6.7.1 Geology

Devonian rocks are represented by quartz-sericite schist, phyllite schist, meta-sandstone, green schist, conglomerate, granodiorite and syenite.

Triassic rocks are presented by sandstone, claystone, conglomerate, rhyolite, diabase, and massive and platy limestone. The Triassic limestone is rather represented in the west and northwest parts of the basin.

Jurassic rocks are represented by gabbro, diabase and leucocratic (light-colored) granite.

Tertiary sediments are presented by Pliocene gravel, sand, clay and marl (Pl_2) and gravel, sand and clay (Pl_3).

The sediments of Quaternary age are presented by lacustrine marsh sediments (j), moraine sediments (gl), fluvio-glacial sediments (fgl), terra rossa (ts), slope deposits (d), and proluvial (Pr) and alluvial (al) sediments. They are mostly represented in the peripheral parts of the valleys.

The tectonic development of the terrain refers to two large orogenies: Hercynian and Alpine. By the Hercynian orogenesis, the Paleozoic sediments were regionally metamorphosed and folded in moderate syncline and anticline structures. The Alpine orogeny yielded strong dynamo-metamorphism, intensive folding of the terrain and in the most pat, and alteration of the

Hercynian structures. In the latter phases of the Alpine orogeny at the end of the late Pliocene or at the beginning of the middle Pliocene, the terrain was influenced by rather intensive radial tectonics, where many tectonic rift valleys were formed. The predominant strike structures of the alpine orogeny have N-S to NW-SE directions and W-E and NE-SW directions.

B.6.7.2 Hydrogeology

Within this basin, the following types of aquifers have been represented: 1) inter-granular and unconsolidated aquifer, 2) fissured aquifer, 3) karst aquifer and 4) waterless aquifer.

(1) Inter-granular and unconsolidated aquifer

This aquifer is developed within the Quaternary sediments. Within the alluvial sediments, the aquifers are characterized by good waterbearing and have a yield of 5.0-10.0 l/sec. The Pliocene sediments of the aquifers are characterized by variable waterbearing: the wells in the vicinity of Carev Dvor have a yield of 10-15 l/sec and those in the region of Pretor-Asamati have 3.0-5.0 l/sec.

(2) Fissured aquifer

The aquifers are developed in the granite, granodiorite, rhyolite and rocks that have been tectonically altered. They are characterized by a well yield of 0.1-0.5 l/sec and have no important role for practical use in this area.

(3) Karst aquifer

The karst aquifers are developed within the Tertiary limestone and are characterized by good waterbearing. A typical example is the spring at Krushje with a yield of 35-160 l/sec. As a whole, the aquifers form good waterbearing body. The yields of the springs are variable, ranging from 1-2 l/s. to 20-30 l/sec.

(4) Waterless terrain

The waterless terrain is presented by schists and has a yield of about 0.1 l/sec or less.

B.6.7.3 Groundwater Resources

(1) Quaternary and Neogene Aquifers

Regarding the Neogene sediments in the Prespa valley, the surface area and the average thickness of the Neogene sediments are estimated to be 16 m and 49 km^2, and the porosity of the aquifer is assumed to be 0.19. The static amount of groundwater resources in the Neogene sediments of the Prespa valley is calculated to be 149 million m^3. The average hydraulic conductivity is assumed to be $5.71x10^{-3}$ cm/sec. The hydraulic gradient is estimated to be 0.025 along the flowpath of 7 km. Therefore, the dynamic amount of groundwater resources in the Neogene sediments of the Prespa valley is calculated to be 0.16 m^3/sec.

In the Prespa valley, the dynamic amount of groundwater resources in the Quaternary sediments of the Prespa valley is calculated to be 0.047 m^3/sec.

B.6.8 Pelagonija Valley

This valley belongs to the Pelagonia massif and the river basin of Crna River.

B.6.8.1 Geology

The Pelagonia basin is equivalent to the Bitola and Prilep Valleys. The geology of the valleys is composed of the Precambrian, Paleozoic, Mesozoic, Tertiary and Quaternary rocks as shown in Figure B.43.

The Precambrian rocks are composed of gneiss, mica-schist and dolomite.

The Paleozoic rocks are represented by graphite and quartz muscovite schist, graphite mica-schist, mica-schist, amphibole and amphibole schist, quartz and quartz-sericite schist, biotite schist, green schist, quartzite, metamorphic rhyolite, phyllite, argillo-schist and sandstone, hornstone, dolomite marble, granodiorite syenite and alkaline granite.

The Mesozoic rocks are muscovite granite, granite-porphyry, gabbro, diabase and dolomitized limestone and conglomerate.

The Quaternary rocks are represented by alluvial sediments, proluvial and dilluvial deposits, organic-marsh sediments, river terrace deposits and fluvio-glacial deposits. The Pelagonia valley was formed in Neogene age and has been filled with the Quaternary deposits.

B.6.8.2 Hydrogeology

The Pelagonia valley is composed of rocks with inter-granular porosity and karst limestone with caverns and fissures as shown in Figures B.44 and B.45.

(1) Inter-granular and unconsolidated aquifer

The rocks with inter-granular porosity are non-coherent sediments, which fill the Pelagonia valley. The aquifers are formed in alluvial sediments, dilluvial and proluvial deposits, organic marsh, river terrace deposits, fluvio-glacial deposits and Pliocene sediments. The alluvial and Pliocene sediments out of these sediments form good yield aquifers and the remaining sediments have poor aquifers. The good aquifers are represented by the wells at Sopotnica, Bucin, Krusheani and Pivara in Prilep and at Aglarci, Kvasara and Egri in Bitola. The inter-granular and unconsolidated rocks form artesian aquifers and the wells at Egri in Bitola and Krusheani and Pivara in Prilep belong to artesian aquifers.

(2) Karst aquifer

This group of rocks is presented by dolomitized limestone that is rather kartificated. In these rocks karst aquifers are formed and are classified to be the aquifer group with a good yield of Q = 50 l/sec. The springs at Zeleznec Village, the spring at Babino Village in Demir Hisar, and Zrze and Nebregovo Villages in Prilep belong to this karst aquifers.

B.6.8.3 Groundwater Resources

(1) Quaternary and Pliocene Aquifers

In the Pelagonia valley, the surface area and the average thickness of the Quaternary and Pliocene sediments are estimated to be 30 m and 1010 km^2, and the porosity of the aquifer is assumed to be 0.2. The static amount of groundwater resources in the Quaternary and Pliocene sediments of the Pelagonia valley is calculated to be 6060 million m^3. The average hydraulic conductivity is assumed to be $8x10^{-3}$ cm/sec. The hydraulic gradient is estimated to be 0.01 along the flowpath of 50 km. Therefore, the dynamic amount of groundwater resources in the Quaternary and Pliocene sediments of the Pelagonia valley is calculated to be 1.2 m^3/sec.

B.6.9 Skopje Valley

The Skopje Valley belongs to the Vardar tectonic zone and is presented by the watershed of Vardar River and its tributaries, Treska and Lepenec Rivers. The Skopje valley is surrounded by mountainous chains: Kitka, Vodno, Zeden and kopska Crna Gora.

B.6.9.1 Geology

The Skopje valley represents a depression surrounded from all sides by mountains and hills composed of Precambrian and Paleozoic rocks, while there are Tertiary and Quaternary sediments as shown in Figure B.46.

The Precambrian rocks are distributed in the southern part of Kitka and Suva Planina Mountains and are represented by dolomite, marble, graphitic schist, biotite-muscovite schist, amphibole and amphibolitic schists, granodiorite and gneiss.

The Paleozoic rocks are distributed in the mountains of Vodno and Osoj and the Fush River basin and are presented by quartzite, biotite and quartz sericite schist, albititic phyllite-mica-schist, graphitic-sericite schist, granodiorite and gneiss.

The Mesozoic rocks are represented by Triassic sandstone and chart, Jurassic Diabase-hornstone formation and Upper Cretaceous sandstone and flysch series, massive limestone, platy limestone, serpentinite and dunite.

The Tertiary rocks are represented by Miocene sediments of sandstone, marl and clay, and Pliocene sediments of sand, clay and gravel.

The Quaternary rocks are largely represented in the Skopje valley and by alluvial sediments, dilluvial and proluvial deposits, spring sediments and young effusive rocks.

The Vardar zone is subdivided into some blocks by intensive intersections of longitudinal faults. The Skopska Crna Gora block is built up of Paleozoic formations.

B.6.9.2 Hydrogeology

From hydrogeological point of view, the following rocks form aquifers with inter-granular porosity and with karst porosity as shown in Figures B.47 and B.48.

(1) Inter-granular and unconsolidated aquifer

The rocks with inter-granular porosity are actually non-coherent sediments. The rocks represented in Skopje valley are alluvial sediments, dilluvial and proluvial deposits and Pliocene sediments. These sediments form inter-granular and unconsolidated aquifers. The alluvial sediments were classified to be a good aquifer with a yield of over 10 l/sec. The following wells belong to this aquifer: the wells at Zelenikovo, Makedonija pat, Bardovci, Volkovo, Saraj, Pobozje and Kozara.

(2) Fissured aquifer

The fissured aquifers are formed in graphitic schist, banded muscovite gneiss, amygdaloidal gneiss, granodiorite, mica-schist and albitic gneiss. The springs at St. Petka and Brodec belong to the fissured aquifers, which are formed in schist and classified to be a poor aquifer with a yield of less than 1.0 l/sec.

(3) Karst aquifer

The karst aquifers are formed in limestones and marbles. The Rashche spring belongs to the aquifers and is used for water supply to Skopje. The Rashche spring with a yield of about 2-5 m^3/sec originates from the karst aquifer, which is formed in the karst limestone of the Zeden Mountains as shown in Annex 1.

B.6.9.3 Groundwater Resources

(1) Quaternary and Pliocene Aquifers

In the Skopje valley, there are four types of aquifers in the Quaternary and Pliocene sediments: 1) high-yield, 2) good-yield, and 3) low-yield, and in the karst limestone.

The surface area and the average thickness of the high-yield Quaternary sediments are estimated to be 11.2 m and 113 km^2, and the porosity of the aquifer is assumed to be 0.21. The static amount of groundwater resources is calculated to be 313 million m^3. The average hydraulic conductivity is assumed to be 1.1x10^{-1} cm/sec. The hydraulic gradient is estimated to be 0.01 along the flowpath of 14 km. Therefore, the dynamic amount of groundwater resources is calculated to be 1.725 m^3/sec.

In the case of the good-yield aquifer, the surface area and the average thickness of the good-yield Quaternary sediments are estimated to be 15 m and 130 km^2, and the porosity of the aquifer is assumed to be 0.2. The static amount of groundwater resources is calculated to be 390 million m^3. The average hydraulic conductivity is assumed to be 3.4x10^{-2} cm/sec. The hydraulic gradient is estimated to be 0.02 along the flowpath of 9.8 km. Therefore, the dynamic amount of groundwater resources is calculated to be 1 m^3/sec.

Regarding the low-yield aquifer, the average hydraulic conductivity is assumed to be 7.6x10^{-3} cm/sec. The hydraulic gradient is estimated to be 0.008 along the flowpath of 9 km. Therefore, the dynamic amount of groundwater resources is calculated to be 0.098 m^3/sec.

(2) Karst Aquifer

Regarding determination of the amount of karst groundwater resources in the karst aquifer of the Zeden Mountains, the infiltration area is estimated to be 150 km^2 and the average coefficient of infiltration and hydraulic head gradient are 1.18 m/sec and 0.75, respectively. Therefore, the amount of karst groundwater resources in the Zeden Mountains is calculated to be 4.2 m^3/sec.

B.6.10 Veles Valley

The Veles Valley belongs to the Vardar tectonic zone and to the Vardar River basin.

B.6.10.1 Geology

The Veles valley is composed of Precambrian, Paleozoic, Mesozoic, Tertiary and Quaternary rocks.

The Precambrian rocks are represented by marble, graphitic mica-schist, mics-shist, muscovite-biotite gneiss and amygdaloidal augen-gneiss. These metamorphic rocks are intruded by granodioritic rocks.

The Paleozoic is characterized by biotite, quartz-sericitic schist, quartzite, green schist, phyllite and quartz-graphitic schist.

The Triassic rocks are represented by Lower Triassic conglomerates, sandstone, shale and platy limestone, Middle Triassic limestone, and Upper Triassic massive limestone. The Jurassic is represented by diabase-chart formation, volcanic-sedimentary assemblage. The Cretaceous rocks are developed as red quartzose conglomerate, sandstone and massive limestone.

The Tertiary rocks are represented by Upper Eocene conglomerates, sandstone, and flysch, and Pliocene conglomerates, sands and clays.

The Quaternary rocks are characterized by alluvial sediments, proluvial and dilluvial deposits, and fluvio-glacial materials. The alluvial sediments are developed in the riverbeds of the large rivers: Vardar, Babuna and Topolka Rivers.

B.6.10.2 Hydrogeology

The rocks with intergranular porosity and karst-fissured porosity and rocks with fissured porosity are represented from a viewpoint of hydrogeology.

(1) Inter-granular and unconsolidated aquifer

The inter-granular and unconsolidated aquifers are formed in the alluvial sediments, which are classified to be a good yield aquifer with $Q > 10$ l/sec. The thickness of the alluvial deposits in the riverbed of Vardar River is 15 - 20 m. The wells at Gradsko, HIV - Zgropolci and the well in the factory "Porcelanka" belong to the alluvial aquifers. The inter-granular aquifers in the proluvial and dilluvial deposits and fluvio-glacial materials are formed. The water permeability of these deposits is medium to poor, and the yield is low.

(2) Fissured aquifer

These rocks encompass biotite and quartz-sericite schist, green schist, phyllite, and quartz-graphitic schist. The fissured aquifers are water-permeable with extremely low yield at shallow depth under the ground surface of the terrain, but they are water-impermeable at greater depth.

(3) Karst aquifer

This group of rocks encompasses platy limestone, massive limestone, quartzite and marble. The low-yield karst aquifers are developed in this area.