TRANSBOUNDARY AQUIFERS IN THE REPUBLIC OF MACEDONIA

V.STAVRIC
Ministry of Environment and Physical Planning, UNDP Macedonia, NCSA Project,
III Makedonska Brigada 10b, 1000 Skopje, Republic of Macedonia

C. POPOVSKA
University Ss. Cyril and Methodius, Faculty of Civil Engineering,
Partizanski odredi bb, 1000 Skopje, Republic of Macedonia

1. THE PHYSICAL FRAMEWORK: AVAILABLE RESOURCES

Macedonia is a land-locked country on the Balkan Peninsula with a total area of 25.213 km^2, bordering with Albania, Greece, FR of Yugoslavia and Bulgaria. There exist three major catchments: Vardar River catchment flowing south to Aegean Sea covering ca 80% of the territory, the catchment of Crni Drim comprising also the Prespa and Ohrid lake catchments flowing to Adriatic Sea, and the catchment of Strumica River (Aegean). Negligible parts of the Macedonian territory drain to Danube River catchment.

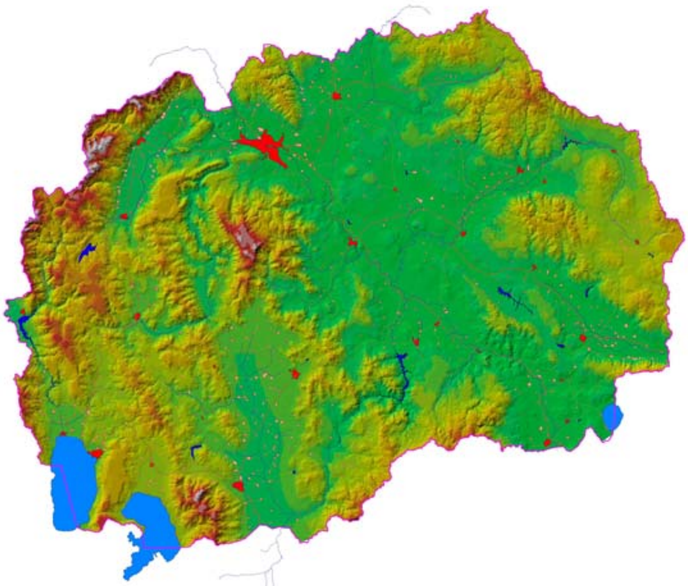

Figure 1. Map of the Republic of Macedonia

As the territory of the Republic of Macedonia is under influence of Mediterranean and Continental climate characteristics, the variation in the rainfall records, as well as other climatic parameters, is quite significant between the east, middle, and west regions.

The precipitation regime in the western part of the country has greater amount of precipitation with an average annual rainfall of more than 1000 mm than in the eastern part with an average of less than 700 mm. The central part has the lowest amount of precipitation with an average of 500 mm. The overall average precipitation in the country is 609,4 mm with a runoff coefficient of 29,90.

The geology of land of Macedonia is composed of bedrocks of varied ages spanning from Pre-Cambrian to Quaternary and strongly controlled by the Alpine movement of Tertiary age. It can be divided into tectonic belts of Serbo-Macedonian Massif on the east and Dinarids in the west that are elongated in the north-northwesterly direction parallel with the Adriatic coast. The Dinarids is farther divided into three, i.e., the Vardar Zone, Pelagonian Horst Anticlinorium and West Macedonian Zone from east to west in order. The old and hard bedrocks of Pre-Cambrian to Mesozoic are generally strong enough to be foundation of high dams, and also manageable for treatment to due water-tightness except for karstified limestone.

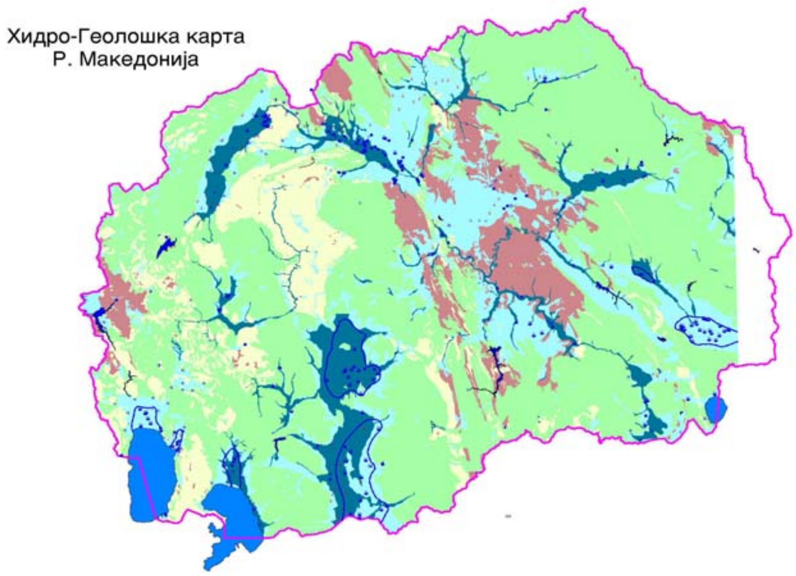

Figure 2. Hydrogeological map of the Republic of Macedonia

2. ESTIMATED GROUNDWATER RESOURCES

On the territory of the Republic of Macedonia, groundwater is used for providing demands of high-quality water for supply of population, industry and other users. The groundwater wells and intake structures have been constructed based on partial hydrogeological investigations. However, full investigation and mapping of GW reserves in Macedonia has not been completed. Mostly these intakes (wells) are located in aquifers in quarter sandy-gravel sediments next to the river beds and terraces. Some wells also exist in karstic and artesian aquifers. Systematic investigation of groundwater has been undertaken in the period 1963-1975 for the most of the territory of the country. Based on these investigations, the Hydrogeological map of the Republic of Macedonia in scale 1:200.000 has been published (Figure 2). The static reserves on regional (sub-basin) level, including freatic, artesian and sub-artesian groundwater have been estimated as shown in Table 1.

Table 1. Estimated static groundwater reserves in main valleys

Valley	River Basin	Static reserves
Polog	Upper Vardar	193 x 10^6 m^3
Skopje valley	Vardar	925 x 10^6 m^3

Kumanovo valley	Pcinja	675×10^6 m^3
Kriva Palanka valley	Kriva Reka (Pcinja)	114×10^6 m^3
Berovo-Pehcevo valley	Bregalnica	360×10^6 m^3
Ovce Pole	Bregalnica	256×10^6 m^3
Strumica valley	Strumica	850×10^6 m^3
Gevgelija-Valandovo valley	Vardar	342×10^6 m^3
Pelagonija	Crna River	6.105×10^6 m^3
Ohrid-Struga valley	Sateska	161×10^6 m^3
Kicevo valley	Treska	158×10^6 m^3

In the period following the systematic study, only local detailed investigations for exploitation purposes have been undertaken. Therefore, based on some investigations limited in scope and extent, the exploitation reserves below are purely orientationaly.

In the consolidated aquifers with free water level:

- Aquifers in alluvium of the r. Vardar in Skopje valley, with exploitation reserves of (1.750-2.000) l/sec;
- Aquifers in alluvium of the r. Pcinja (Kumanovo- Katlanovo), with exploitation reserves of (80-100) l/sec;
- Aquifers in alluvium of the r. Kriva Reka with approximate exploitation reserves of 75 l/sec;
- Aquifers in alluvium of the r. Bregalnica (Upstream from Berovo to Delcevo) with exploitation reserves of 120 l/sec;
- Aquifers in alluvium of the r. Bregalnica (Kocani-Stip, inflow of r. Lakavica) with exploitation reserves of 350 l/sec;
- Aquifers in the middle and in the lower Vardar (Zgropolci-Dubrovo, Valandovo-Gevgelija) with exploitation reserves of 520 l/sec
- Aquifers in the alluvium of the r. Crna with exploitation reserves of 180 l/sec;

Note: Those reserves are estimated on a base of the capacity of the existing extraction structures and piezometers, located and tested for local investigations.

In the aquifers of consolidated type with water level under pressure (artesian) in the borders of Neogene lake deposits, up to now partly investigated static reserves are determined as follows:

- Aquifers in lower Polog with reserves of 317.000.000 m^3;
- Aquifers in Skopje valley with reserves of 311.000.000 m^3;
- Aquifers in Strumica valley with reserves of 850.000.000 m^3;
- Aquifers in Prilepsko Pole with reserves of 75.000.000 m^3;
- Aquifers in Bitolsko Pole with reserves of 96.000.000 m^3;
- Aquifers in Ohridsko-Strusko Pole with reserves of 72.000.000 m^3;

The biggest reserves of the groundwater exist in the carstic type of aquifers from which presently only the ones that naturally overflow as springs are used. Many of them are captivated and today they present around 75 % of all the water supply sources in the Republic of Macedonia. The most important are the following:

- Zeden carst with dynamic reserves of 53.200.000 m^3/year
- Suvogorski carst aquifers with dynamic reserves of 93.728.000 m^3/year
- Karst aquifer Studencica with dynamic reserves of 52.800.000 m^3/year

- Karst aquifers in Treska river basin with assessed dynamic reserves of 665.600.000 m^3/year
- Kozuv carst (Huma and oth.) 5.000.000 m^3/year
- Kozuv carst (Lukar) 25.000.000 m^3/year
- Valandovo -Dojran 20.000.000 m^3/year
- Galicica with min. assessed reserves of 500.000.000 m^3/year

Thermal and thermo-mineral groundwater has been also partially investigated. Some sources are in exploitation and the others are attractive for development spa, recreation and cure centers, utilization of the thermal energy for limited winter green-house production of early vegetables etc. Those are the following regions:
- Smokvica - Negorci, in Gevgelija region;
- Bansko in Strumica region;
- Banja and Podlog, Kocani region;
- Debarski Banji - Debar;
- Skopje valley and oth.

The Administration for Hydrometeorological Service performs systematic monitoring of the groundwater levels, as well the temperature and quality of groundwater in several regions (Polog, Skopsko Pole, Kocansko Pole, Stipsko Pole, Strumicko Pole and Strusko Pole) (see Table 2). However, due to present financial limitations the monitoring activities are limited and the data availability is decreasing by the year.

Table 2 .Groundwater monitoring

Ord.No.	Region	Number of piezometric pipes	Year of establishment
1.	Kochani - Stip	14	1951
2.	Ovce Pole	11	1959
3.	Strumica	23	1953
4.	Pelagonija	17	1952
5.	Ohrid - Strusko Pole	10	1956
6.	Polog	24	1956
7.	Skopsko Pole	15	1958

Organized groundwater data collection and management is missing, as well as the user cadastre, analysis of the balance of inflow-outflow from the groundwater sources in the function of the natural hydrological conditions.

Water from springs is used for municipal water as the most desirable one with its good quality. There are 4.265 springs in total. Of them, 3.000 springs (70%) has a discharge less than 1 liter/s. Springs with a discharge greater than 100 liters/s are only 59. Springs with a discharge of more than 10 liters/s are 326 in number, which are mostly distributed in the Shara Mountain of the Vardar River basin, the Treska and the Crn Drim River basins, currently under use for source of municipal water. The total amount of groundwater and springs water is summarized in the following Table 3:

Table 3. Number of springs in use and potential for development (in $10^6 m^3$/year)

Description	Groundwater (wells)	Spring water	Total
1. Exploited (under use)	63	195	258

2. Potential (available for development)	136	435	571
Total (1 + 2)	199	630	829

The groundwater in Macedonia is used for source of municipal water. The total number of wells is around 630. The thermal, thermo-mineral and mineral water resources in Macedonia are in total amount to 29,10 Mm^3/year. The constructed dam/reservoir capacity in the country is around 1.854 Mm^3. The most significant problems regarding water pollution are due to untreated wastewater discharged from the mining sector and industrial plants as well as discharges from large settlement and livestock farms. Water quality in surface water has been polluted in the middle and lower reaches of the Vardar main stream, the Pcinja, the Bregalnica and Crna Rivers. Deterioration of water quality in groundwater has been found near cities like Skopje and Veles in particular, while spring water remains with desirable quality.

3. INSTITUTIONAL AND LEGAL FRAMEWORK

Water Resources. The water resources are completely in the responsibility of the Administration of Water Economy within the Ministry of Agriculture, Forestry and Water Economy of RM, and are regulated by the Law on Waters and the Water Master Plan of the Republic of Macedonia.

Environmental Protection. The Ministry of Environment and Spatial Planning is responsible for the issues of environmental protection and spatial planning.

Responsible Institutions. Beside the two above mentioned Ministries, the Ministry of Health is responsible for the drinking water quality and standardization, the Ministry of Economy is responsible for the mineral and groundwater resources and hydro-power production, the Ministry of Transport and Communications for municipal and industrial water supply.

International Legal Framework. Republic of Macedonia has undertaken all obligations and international Conventions as a successor of former SFR Yugoslavia. Bilateral agreements exist with Albania and Greece regarding water resources issues. However, due to various reasons, the cooperation does not function recently and has to be re-established.

Even though Macedonia is not included in the list of countries for accession into European Union, reform of the legal system is undertaken in the country in order to harmonize the legislation with the EU regulations. In this respect, the EU Water Framework Directive is a guiding principle for streamlining of the water related legislation.

4. TRANSBOUNDARY WATER RESOURCES

In general, Macedonia is an upstream country. All Macedonian rivers flow into neighboring countries. Transboundary river catchments in Macedonia are: Crn Drim catchment including Ohrid and Prespa Lakes (MK-AL-GR), Vardar/Axios catchment (MK-GR) where small part inflows from Yugoslavia (Lepenec and Pcinja rivers) (MK-YU), Strumica/Struma catchment (MK-BG) and Lake Dojran catchment (MK-GR). Regarding shared groundwater resources, the Prespa - Ohrid lake system and Lake Dojran are examples of a groundwater - surface water interaction with influence on the catchment environment. In the last decade, dramatic decrease of the water surface level on lakes Prespa and Dojran have occurred. Dojran Lake, being a shallow warm-water lake experiences extreme pressure to its environment, because three quarters of the volume of water disappeared in the period 1988-2002. Some recovery is noted due to two wet years and the construction of supplementary supply system from wells in Gjavato region. Prespa Lake and Ohrid Lake are hydraulically connected through karstic massif of Galicica Mountain. Exploration of this connection is necessary in order to re-establish the water balance in the catchment. There is a requirement for a general planning and management of shared water resources in the region. Regarding Prespa and Ohrid Lakes, several projects are already under way. Regarding Lake Dojran, international cooperation in research, investigations and management is of utmost importance.

4.1 AQUIFERS SHARED WITH REPUBLIC OF GREECE

There are several types of aquifers of significance in the areas adjacent and shared with Republic of Greece:

4.1.1 SEDIMENTARY AQUIFERS

Sedimentary aquifers in the Pelagonija region. Unconfined sedimentary aquifer formed in the Quaternary sediments of the Pelagonia basin. A layer of alternately placed clay, gravel, sand, marl and other material, with thickness of (0,5-30) m forms a cover over a Neogene's lake complex. The groundwater table is (0,8-3,0) m deep in the central part of the basin, and (5-14) m deep at the basin boundaries. The yield of shallow water intake structures is (2-5) l/s. Confined sedimentary aquifer formed in Pliocene sediments of Pelagonia basin formed by alternate occurrence of clay, gravel, sand, marl, carbon, carbon clay etc. The depth of the water –bearing layers is between (30-160) m with thickness of (5-30) m. The yield of the intake structures (wells) ranges between 2 and 10 l/s.

Sedimentary unconfined and confined aquifers in the alluvium of the lower River Vardar and in the quaternary sediments of Gevgelija valley. Unconfined sedimentary aquifer in the alluvium of R. Vardar consist of sand and gravel around 12 m thick, narrowing in this part of the valley whose sides are made of poorly permeable diabase; The quaternary sediments of Gevgelija valley are made of sand and gravel sediments with thickness of up to 60 m with high permeability (filtration coeff. n = 1×10^{-1}–1×10^{-2} cm/s). The groundwater table is (2-3) m close to the ground surface. According to previous investigation the capacity of intake structures may be (40-50) l/s. Confined sedimentary aquifer formed in the Pliocene sedoments completely covered with quaternary deposits. They are composed of alternately placed clay, gravel, sand and other material in which the clayey component is predominant. These sediments have low permeability and the reserves of groundwater are limited.

Sedimentary aquifers in the Quaternary and neogene sediments in the region of Lake Dojran, confined and unconfined. Unconfined sedimentary aquifer in the Quaternary sediments in the region of Lake Dojran, formed by several permeable, water-bearing layers of sandy gravel; Sedimentary confined aquifers in the part of the Quaternary and neogene sediments in the region (Asanli, Crnicani, Furka, etc.). Groundwater table is close to the terrain surface. The yield of water intake structures is estimated to more than 20 l/s.

4.1.2 KARSTIC AQUIFERS

Karstic aquifers in marble in the Dojran region. Karstic aqifer spread between v. Asanli and location Vladaja, as well as between villages of Tatarli and Meseista, formed in well karstified marble rocks with sides bounded by poorly permeable Old Paleozoic schists. The aquifer is drained by wells of very varied capacity from several to several tens of liters per second. Deep wells of 100 m in this region yield (30-60) l/s.

Karstic & fractured rock aquifers formed in Nidze and Kozuv mountains. In Paleozoic marble, schists and dolomites. The drainage is through springs of very varying capacity from several up to 100 l/s.

Fractured rock aquifers. In the massifs of Selecka and Baba mountains and east sides of m. Kozjak. Formed in paleozoic granites, schists, gneisses, filites, argiloschists etc., shallow in the rock fractures. The recharge is from precipitation and overflow from other aquifers, and the drainage through small springs with less than 1 l/s capacity. Do not present significant groundwater reserves.

4.2 AQUIFERS IN THE BOUNDARY ZONE WITH REPUBLIC OF BULGARIA

Sedimentary aquifers. Formed in alluvium of Strumica river and the quaternary sediments in the eastern part of the valley in several layers of sand and gravel, capacity of 10 l/s and coefficient of filtration k >10 $^{-2}$ cm/s.

Karstic aquifers. Aquifer formed in isolated permeable karstified Mesozoic limestones northwest from Delcevo. The yield of springs is very varied with capacities from several up to 100 l/s.

Fractured rock aquifers. This kind of aquifers are formed on Ograzden, Malesevo, Golak and Osogovo mountains in the rock fractures of shallow Paleozoic gneisses, schists, sienites, granites, grano-diorites and other rocks. The recharge is from precipitation and overflow from other aquifers, and the drainage through small springs with less than 1,0 l/s capacity. Do not present significant groundwater reserves.

4.3 AQUIFERS SHARED WITH SERBIA & MONTENEGRO

Fractured rock aquifers. Aquifers exist in the fractured rocks of German, Kozjak, Skopska Crna Gora, in Paleozoic gneisses, mikaschists, and schists with capacities of less than 1 l /s. On the eastern sides of Zeden mountain shallow aquifers in the fractured rock structure of serpentine and peridotite exist with spring capacities of more than 1 l/s. The recharge is from precipitation and overflow from other aquifers, and the drainage through small springs. Do not present significant groundwater reserves.

4.4 AQUIFERS SHARED WITH REPUBLIC OF ALBANIA

Karstic aquifers. Aquifer is formed in the Galicica mountain massif, in the Triassic karstified limestones, lying on aquitard of Paleozoic metamorphites. The massif is placed between Ohrid and Prespa lakes. The surface water altitude of Prespa is 158 m than the one in Ohrid. The karstic aquifer contains significant water reserves and represents direct hydraulic connection between the two lakes. The water from Prespa constantly flows through and recharges Ohrid Lake. The aquifer itself is recharged from Prespa Lake and from direct infiltration of precipitation. The drainage is through numerous surface and underwater springs. Due to large reserves the inflow into Ohrid Lake is uniform, with seasonal and annual variations.

5. REFERENCES

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