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Protecting water resources from pollution in the Lake Badovc

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Abstract

In recent years, the international community has witnessed incidence of climate variability and human activities. The objective of this paper is protecting water resources from pollution in the catchments area of Lake Badovc. The catchments area of the Lake Badovc has a size of 109 km² and the active storage volume of the lake is assessed to 26.4 Mill.m3. Around 28% of the total population of Municipality of Prishtina supply with drinking water from Lake Badovc.

The hydrologic modelling system used, is HEC-HMS developed by the Hydrologic Engineering Centre of the US Corps of Engineers. The model is designed to simulate the rainfall-runoff processes of catchments areas and is applicable to a wide range of geographic areas.

Water samples are taken from two streams reach Lake Badovc and from the lake in three different depths (5m, 10m and 15m) at different locations. Concerning the environment impact more than 140 interviews were conducted and questionnaires filled in the period October-November for Mramor area, concentrating on the most important issues: building, water supply, wastewater disposal and west disposal.

Keywords*:* Lake Badovc, pollution; Water resources; Water supply; Water quality.

1. Introduction

Water resources in Kosova are relatively small, and the rivers are seriously polluted [1]. Water balance studies essentially are the initial stage of a hydrological systems analysis of a metropolitan area [2]. Many hydrological models have been developed to simulate and help us to understand hydrologic processes. The hydrological models are used as a watershed storm water management tool to provide a direction to utilize natural water resources effectively and beneficially. There is an increasing interest in hydrology to develop empirical spatio-temporal models of rainfall-runoff in the context of regional hydrologic analysis [3]. Terrain analysis based on digital elevation models is being increasingly used in hydrology [4].

2. Catchment area of Lake Badovc

The catchment area of Badovc Lake lies in the territory of the municipalities of Prishtina (~70%), Lipjan (~20%) and Novo Berdo (~ less than 10 %). The catchment of the Lake Badovc has a total area of 104 km². The ground elevations in the catchment area vary between 600 m.a.s.l. and 1200 m.a.s.l.

2.1 Water balance analysis

The water levels in the lake are measured manually at regular time intervals. Apart from the lake water levels the drinking water abstractions from the lake are measured continuously at the water treatment plant. The observed water levels in the lake can be combined with the lake storage capacity curve in order to calculate the changes of water volume in the lake. This can subsequently be combined with the measured drinking water abstractions from the lake to perform a water balance analysis of the Lake Badovc. The water levels in the lake can be related with the lake storage capacity curve in order to calculate the water volumes in the lake.

The monthly water levels in the Lake Badovc in the period 2002 to 2008 are listed in Table 1 and shown in Figure 1.

Table 1. Monthly water level in the Lake Badovc 2002 to 2008

	Monthly averaged water levels in the Lake Badovc [m.a.s.l.]						
	2002	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*
Jan	643.40	644.70	642.08	642.60	643.50	645.46	641.44
Feb	641.80	645.80	643.33	642.50	643.10	645.12	641.00
Mar	642.00	646.00	644.30	643.04	646.00	644.88	642.18
Apr	642.00	646.00	646.08	644.68	649.00	644.52	642.10
May	642.10	645.50	646.00	646.08	650.00	644.10	641.76
Jun	641.70	645.10	645.74	647.30	649.80	643.55	641.30
Jul	641.10	643.90	645.10	647.00	649.60	642.80	640.50
Aug	640.80	643.20	644.60	646.48	649.00	641.92	639.68
Sep	639.90	642.60	644.06	645.66	648.50	641.24	638.88
Oct	640.50	642.10	643.36	644.64	647.70	640.64	638.40
Nov	640.50	641.60	642.58	643.90	646.96	641.60	637.92
Dec	641.50	641.44	642.54	643.50	646.46	641.60	637.50

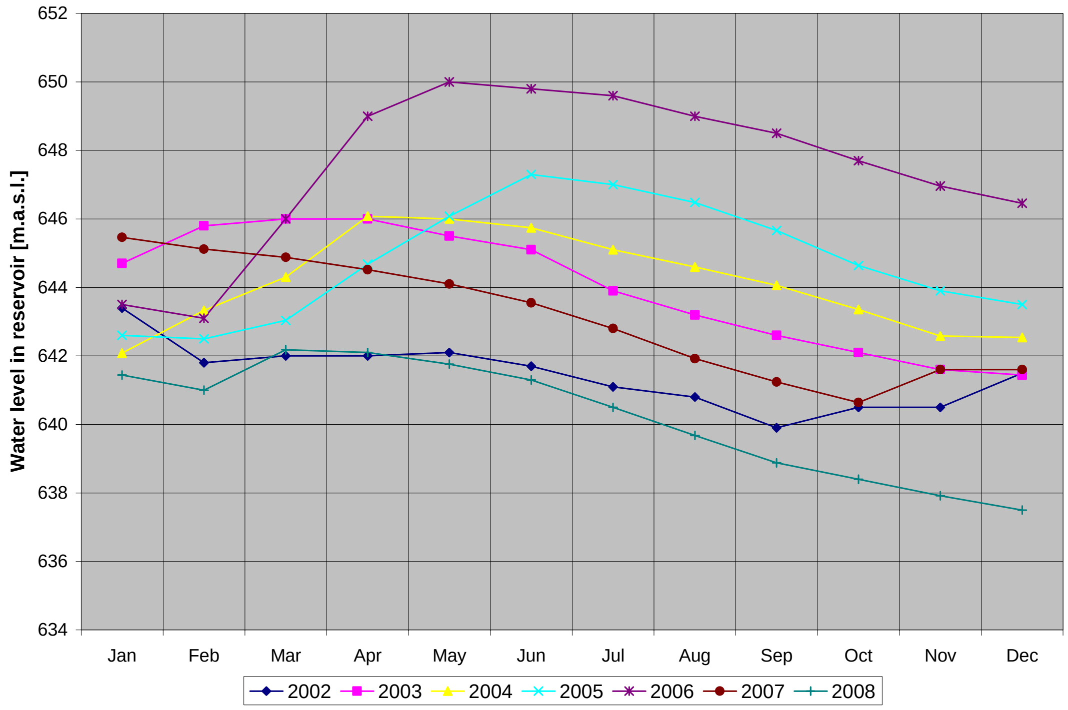

Figure 1. Monthly water level in the Lake Badocv 2002 to 2008

Therefore, the monthly readings are used for preparing the water balance. The measured water abstractions are listed in Table 2 and shown in Figure 2.

Table 2. Monthly abstractions from Lake Badovc in the period 2006 to 2008

	Monthly water abstractions from Lake Badovc [x10^6 m³]		
	2006	*2007*	*2008*
Jan	1.05	1.04	1.25
Feb	0.90	0.92	0.86
Mar	1.11	1.00	0.94
Apr	1.07	0.95	0.90
May	1.17	0.96	0.94
Jun	1.15	0.94	0.90
Jul	1.19	0.95	0.91
Aug	1.17	0.92	0.82
Sep	1.11	0.77	0.73
Oct	1.11	0.91	0.74
Nov	1.03	0.87	0.70
Dec	1.03	1.21	0.74
Total	**13.09**	**11.45**	**10.44**

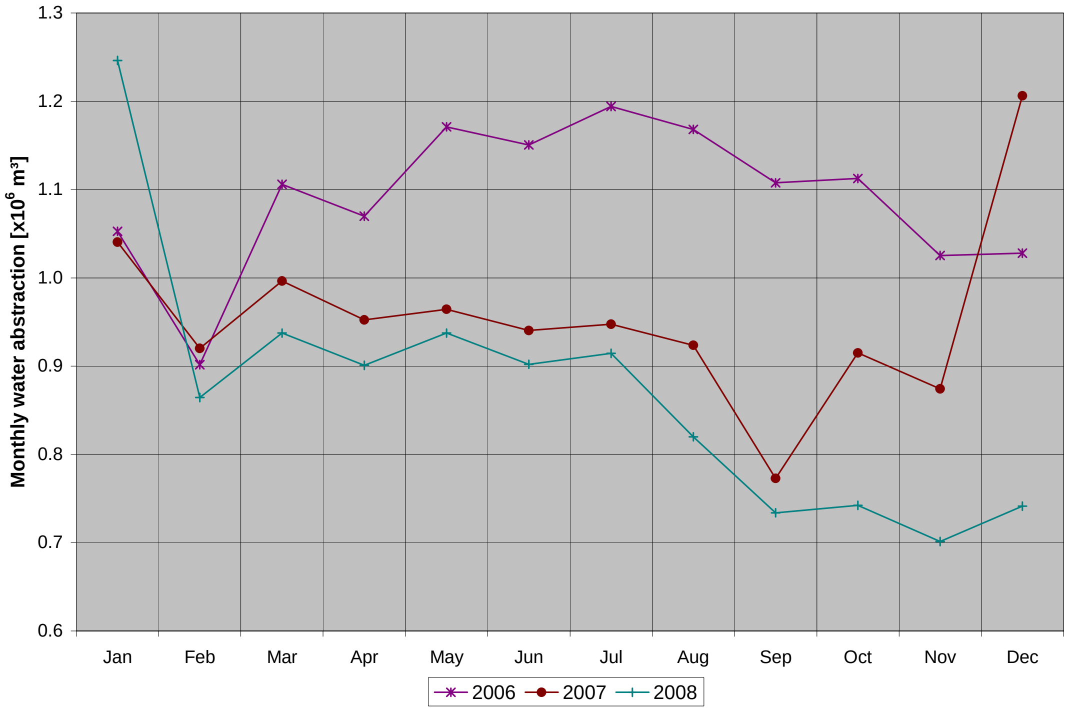

Figure 2. Monthly abstractions from Lake Badovc, 2006 to 2008

Based on the available measured data mentioned before, a water balance analysis was carried out for the years 2007 and 2008. The annual water abstractions of the years 2007 and 2008 exceed the corresponding inflows to the lake by amounts of 6.4 x106 m³ and 3.6 x106 m³ respectively. As a consequence the water level and the stored water volume in the lake decrease in this period.

2.2 Hydrological modelling

The issue of resolution effects of digital elevation models on hydrological modelling parameters and peak discharge has been discussed in recent publications [5-7] investigate the effect of digital elevation

model. There are presently no operating gauging stations in the catchment area of the Lake Badovc and therefore data on measured inflow are not available. Information obtained during study in September-October 2009 indicates that the existing gauging stations were destroyed during the war. Since no useful hydrological data was available for the study it was decided to obtain this information by means of hydrological modelling based on a rainfall-runoff computation.
The hydrologic modelling system used, is HEC-HMS developed by the Hydrologic Engineering Centre of the US Corps of Engineers. The model is designed to simulate the rainfall-runoff processes of catchment areas and is applicable to a wide range of geographic areas [8].

2.3 Digital terrain model
With the advent of geographic information systems (GIS), digital terrain models have been used to delineate drainage networks and watershed boundaries, to calculate slope characteristics, to enhance distributed hydrologic models and to produce flow paths of surface runoff.
The importance and responsibility of DTM applications makes it inevitable to provide DTMs with adequate quality measures [9]. Practical rules of thumb are nowadays available in a more or less adequate and tested form [10, 11]. The basic input information for setting up the basin model in HEC-HMS is the digital terrain model (DTM) of the area of study.
In the course of the study two main sources of data were identified and found suitable for the DTM. Raw data from a recent laser scanning with 10 m raster size was obtained from the Kosovo Cadastral Agency. The second data source consisted in older topographic maps in scale 1:25.000 with contour lines in 10 m intervals. In the areas of the catchment were laser scan data was missing or the data was inconsistent the contour lines of the topographic maps were digitized

2.4 Basin model
The basin model of the Lake Badovc was created using the additional software package HEC-Geom., which is a geo-spatial hydrologic modelling extension for ArcGIS. Basically, HEC-GeoHMS allows to process spatial information, to document watershed characteristics, to perform spatial analyses, to delineate sub-basins, and to create inputs for hydrologic models. The first step for creating the basin model is the processing the terrain data. The resulting data sets are used as spatial database for the study. The basin delineation was further processed and refined by determination of watershed characteristics and the run-off situation. The delineation of streams and sub-basins used in the hydrologic model of the Lake Badovc is shown in Figure 3. The catchment area is subdivided into four main sub-basins. The areas of the main sub-basins and of the sub-basins are summarized in Table 3.
For all sub-basins the following methods for calculating the losses (interception, infiltration, storage, evaporation), transform (runoff of excess precipitation) and base flow (sustained runoff of prior precipitation stored temporarily in the watershed) were used:

- Loss method: Deficit and constant loss
- Transform method: SCS Unit hydrograph
- Base flow method: Constant monthly base flow.

2.5 Meteorological model
The rainfall station Mramor lies inside the catchment of the Lake Badovc. The rainfall station Prishtina is also located near the area of study. Unfortunately no rainfall data could be obtained for these two rainfall stations.
Concerning the values of evaporation needed for the hydrologic modelling the same considerations apply as in the modelling of the catchment of the Lake Badovc. The monthly values of evaporation used in the hydrologic model are given in Table 4.

3. Computation of inflows to Lake Badovc

A calibration of the main parameters of the hydrologic model of the lake Badovc is not possible since no observed flows exist in the streams of the catchment. Because of their spatial proximity it is assumed that both catchments areas had similar rainfall conditions. The computed total monthly flows of each main sub-basin and the total catchment of the Lake Badovc are presented in Table 5.
The results in Figure 4 show significant differences between the computed inflows to the Lake Badovc and the values calculated from the water balance analysis. Especially the values in the first half of 2007

and in the winter months of 2008 do not match. In both years considered the computed annual inflow to the Lake Badovc far exceeds the value calculated from the water balancing.
Assuming that the computed annual inflows of 2007 and 2008 are reliable, the annual total inflow to the Lake Badovc under average rainfall conditions amounts to about 9.0 Million m³.

4. Water quality Lake Badovc

Two streams reach Lake Badovc in the Mramor area. In the lake, water samples are taken at different locations and results are summarised in Table 6.
Chemical parameters, for which analyses were done, are in general in the acceptable range for raw water for water supply [12]. Also Lake Badovc is used as recreation area during summer. Bacteriological analyses should be verified during the next years [13].

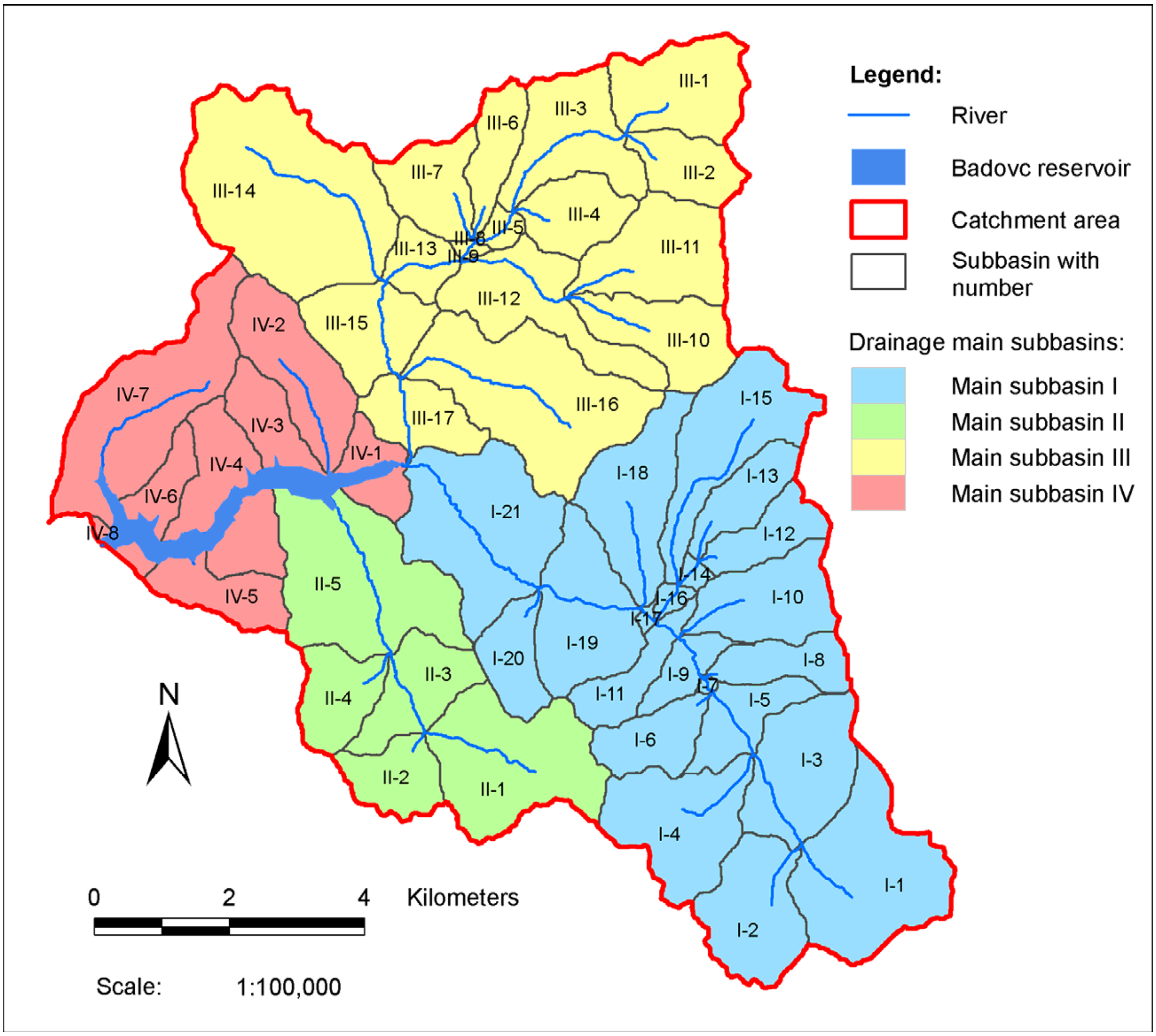

Figure 3. Sub-basins of the catchment area of the Lake Badovc

Table 3. Catchment area and sub-basins of the Lake Badovc

Main sub-basin I	Area [km²]
SB I-1	4.26
SB I-2	2.59
SB I-3	2.89
SB I-4	3.10
SB I-5	1.39
SB I-6	1.37
SB I-7	0.06
SB I-8	1.26
SB I-9	0.80
SB I-10	2.30
SB I-11	1.18
SB I-12	1.24
SB I-13	1.27
SB I-14	0.17
SB I-15	3.22
SB I-16	0.21
SB I-17	0.09
SB I-18	2.80
SB I-19	2.99
SB I-20	1.28
SB I-21	4.53
Total MSB I	**39.0**

Main sub-basin II	Area [km²]
SB II-1	4.05
SB II-2	1.37
SB II-3	1.85
SB II-4	1.55
SB II-5	5.12
Total MSB II	**13.9**

Main sub-basin III	Area [km²]
SB III-1	2.50
SB III-2	1.36
SB III-3	2.64
SB III-4	1.52
SB III-5	0.31
SB III-6	1.20
SB III-7	1.66
SB III-8	0.00
SB III-9	0.11
SB III-10	2.14
SB III-11	2.72
SB III-12	2.86
SB III-13	0.91
SB III-14	6.87
SB III-15	2.15
SB III-16	5.23
SB III-17	1.51
Total MSB III	**35.7**

Main sub-basin IV	Area [km²]
SB IV-1	1.14
SB IV-2	2.60
SB IV-3	1.29
SB IV-4	2.88
SB IV-5	1.55
SB IV-6	1.23
SB IV-7	4.70
SB IV-8	0.09
Total MSB IV	**15.5**

Table 4. Monthly average values of evaporation catchment area Lake Badovc

Month	Monthly average Evaporation [mm/month]
Jan	1.8
Feb	7.2
Mar	22.2
Apr	49.4
May	95.4
Jun	139.7
Jul	175.7
Aug	144.7
Sep	76.7
Oct	44.3
Nov	19.2
Dec	4.4

Table 5. Computed monthly total flows from main sub-basins of Lake Badovc, 2007 and 2008

	Monthly total flow of main sub-basins computed with hydrological model [x10^6 m³/month]				Monthly total inflow to the lake computed with hydrologic model [x10^6 m³/month]	Monthly total inflow to the lake obtained from water balance analysis [x10^6 m³/month]
	MSB I	MSB II	MSB III	MSB IV		
Jan/ 2007	0.50	0.18	0.46	0.20	1.34	-0.55
Feb/ 2007	0.44	0.16	0.41	0.18	1.18	0.43
Mar/ 2007	0.45	0.16	0.41	0.18	1.20	0.65
Apr/ 2007	0.30	0.11	0.27	0.12	0.80	0.43
May/ 2007	0.61	0.22	0.56	0.26	1.66	0.36
Jun/ 2007	0.10	0.03	0.09	0.08	0.30	0.28
Jul/ 2007	0.01	0.00	0.01	0.01	0.04	0.08
Aug/ 2007	0.03	0.01	0.03	0.01	0.09	-0.07
Sep/ 2007	0.06	0.02	0.06	0.03	0.17	0.13
Oct/ 2007	0.09	0.03	0.09	0.04	0.25	0.34
Nov/ 2007	0.65	0.23	0.59	0.31	1.79	1.79
Dec/ 2007	0.44	0.16	0.40	0.17	1.17	1.21
Jan/ 2008	0.48	0.17	0.44	0.19	1.29	1.09
Feb/ 2008	0.44	0.16	0.40	0.17	1.17	0.45
Mar/ 2008	0.83	0.30	0.76	0.35	2.23	2.09
Apr/ 2008	0.30	0.11	0.27	0.12	0.80	0.81
May/ 2008	0.40	0.14	0.36	0.19	1.09	0.59
Jun/ 2008	0.04	0.02	0.04	0.02	0.12	0.47
Jul/ 2008	0.01	0.00	0.01	0.01	0.04	0.15
Aug/ 2008	0.05	0.02	0.05	0.03	0.14	0.06
Sep/ 2008	0.03	0.01	0.03	0.01	0.08	0.01
Oct/ 2008	0.03	0.01	0.02	0.01	0.07	0.31
Nov/ 2008	0.07	0.02	0.06	0.03	0.18	0.29
Dec/ 2008	0.50	0.18	0.45	0.19	1.32	0.47
Total 2007	3.70	1.31	3.37	1.58	9.97	5.07
Total 2008	3.18	1.13	2.90	1.33	8.54	6.80

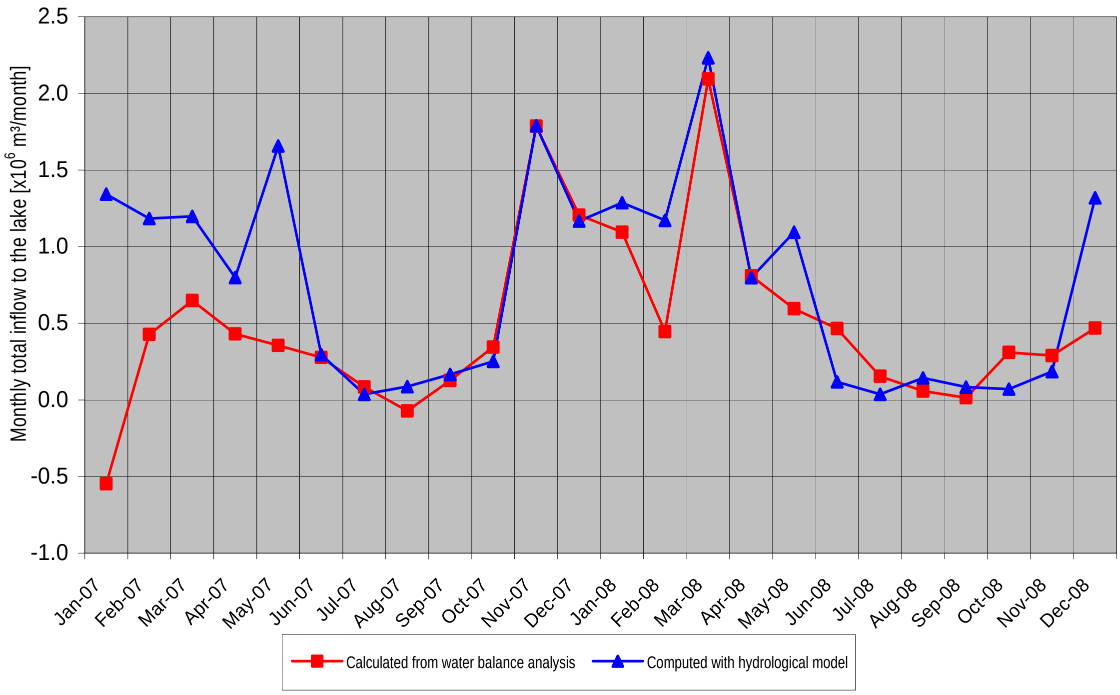

Figure 4. Monthly total inflows to the Lake Badovc 2007 and 2008

Table 6. Water quality of Lake Badovc

Parameter	A	B	C	D
Turbidity (NTU)	1.25	2.48	4.2	3.16
pH	8.7	8.6	8.61	8.62
NH_4-N (mg/L)	0.03	0.05	0.02	0.02
NO_2-N (mg/L)	0.058	0.038	0.033	0.052
NO_3-N (mg/L)	1.2	1.7	1.6	1.9
Cl (mg/L)	22	16	18	19
$KMnO_4$ (mg/L)	12.4	13.06	13.09	13.96
DO (mg/L)	4.6	4.1	4	5
Fe (mg/L)	0.36	0.037	0.376	0.075
Hardness (°dH)	-	-	-	-
SO_4^{2-} (mg/L)	41	40.7	41.7	40.7
PO_4^{3-} (mg/L)	0.142	0.173	0.142	0.163
K (µS/cm)	375	376	379	380
Mn (mg/L)	0.087	0.111	0.063	0.082
Cu (µg/L)	0.063	0.052	0.016	0.069
Zn (mg/L)	0.237	0.168	0.159	0.167
Al^{3+} (mg/L)	0.02	0.01	0.01	0.03

5. Pollution sources

Also regarding these important planning themes no up to date information was available for the catchment area. Assessing this situation, the study is prepared a questionnaire and organised a household survey in the Mramor area, concentrating on the most important issues. Around 140 interviews were conducted and questionnaires filled in the period October-November 2009 (Table 7).

Table 7. Survey Badovc Mramor, Oct-Nov. 2009, summary all buildings

		Building		Persons			Water supply			Wastewater Disposal		Waste Disposal		
		new	seasonal	residents	employees	guests	public	well	water tank	septic tank	dis. field	container	burning	nature
Private Houses / Buildings														
Total	127	15	0	654	0	0	0	110	0	82	30	10	14	87
Percent %	92	12	0					87	0	65	24	8	11	69
Shop/ Commerce														
Total	5	0	0	21	19	0	0	0	5	4	1	0	0	0
Percent %	4	0	0					0	100	80	20	0	0	0
Restaurant / Hotel														
Total	3	0	0	9	12	1100	0	3	0	3	0	0	0	0
Percent %	2	0	0					100	0	100	0	0	0	0
Other Buildings														
Total	3	0	0	0	17	160	0	0	3	3	0	0	0	0
Percent %	2	0	0					0	100	100	0	0	0	0
Grand Total	138	15	0	684	48		0	113	8	92	31	10	14	87
Percent %	100	11	0				0	82	6	67	22	7	10	63

Farmers informed that they concentrate on grains, e.g. wheat and corn as well as some vegetables. Fertilisers are occasionally applied, as well as pesticides. However, estrogens were also detected in streams in areas with intensive agriculture [14]. Overall the agricultural activities cannot be classified as intensive.

Only three established restaurants were identified, but with more than 1.000 guest seats. There is no information on day-visitors during the summer months. There is no piped water supply in the Mramor area or elsewhere in the catchment area.

Around 80 % of the buildings have private wells, and the others receive their water from a tanker truck. Questions regarding water consumption could not be answered by the interviewees. The concentrations of estrogens in wastewater treatment plant influents and effluents were measured in several countries [15]. Two-thirds of the buildings have septic tanks and from the remaining buildings wastewater is discharged to the field.

6. Discussion and conclusion

The annual abstraction of drinking water from the Lake Badovc in the period 2006 to 2008 is average to about 11.5 Mill. m³/a. This value corresponds to the maximum treatment capacity of the Water Treatment Plant Badovc of 40,000 m³/d or 14.6 Mill. m³/a.

The results of the modelling show that the minimum, average and maximum total annual inflows to the lake can be expected with around 6.3 Mill.m³/a, 9 Mill.m³/a, and 24.2 Mill.m³/a, (for low, average and high total annual rainfall).

The active storage volume of the Lake Badovc is assessed to 26.4 Mill. m³. Based on these assessments following conclusions are realistic:

- Average annual rainfall generates an inflow of only approx. 62% of the maximum abstraction rate for the water treatment plant
- Assuming average annual inflow over a longer period and the maximum required abstraction for the water treatment plant the storage capacity would be exhausted (minimum water level reached) within 4 to 5 years.
- In the case of having a long period of extreme low rainfall the storage capacity would be already exhausted after 2 years.

These conclusions are based on a limited amount data, but provide a first realistic assessment and an input for the determination of required additional raw water resources in order to satisfy the increasing water demand. In order to obtain more precise results detailed rainfall information is required, meaning records covering 20 and more years.

The present average annual abstraction volume cannot be increased, and must not be decreased. With a sequence of 2 very dry years, a temporary reduction of the average abstraction can occur. A detailed statistical evaluation of the “safe average abstraction volume” requires correct long term rainfall records from the catchment area.

Increased bacteriological contamination has to be addressed as public health issue, because also Lake Badovc is used for recreation during summer.

In general, buildings should have a septic tank and infiltration pit/soak away for the disposal of wastewater. Direct discharges to fields, drainage channels and water course should not be allowed any longer.

For larger settlements, located close to the lakes, most probably a sewerage system will be required in the medium term. This definitely depends on the village/ area development plans and should be investigated in more detail, when the planning of a central water supply system starts. Considering these conditions, most likely in the Mramor area at Lake Badovc will become the first area where a sewerage system will be needed.

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