Research of Water Resources on Karst Islands on the Example of the Island of Krk (Croatia)

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Abstract

Local water resources on karst islands are of high importance due to their specific location and general characteristics of karst. They are characterized by spatial detachment and isolation from the regional aquifer, as well as greater openness to the influence of the sea and salt intrusions, especially in terms of continuing and intensifying the present trend of sea level rise. Beside the use of well known hydrologic and hydrogeological methods in the research of water resources increase and their exploitation, such detachment and isolation dictates application of some new, innovative approaches.

This paper shows an analysis of the island of Krk that is located in northern Adriatic with the area of 405.2 km^2 and approximately 18,000 permanent residents. Number of inhabitants increases drastically during summer months due to numerous visitors, when the island's water reserves are minimal. The paper describes methods for estimating global water balance of the island using Langbein's method in GIS environment, detection of coastal concentrated groundwater discharges using thermal- infrared images, and the use of the results of the performed analysis for the island's aquifer functioning on specific water intake locations. The most important water resources of the Island of Krk are: coastal Njivice lake (cryptodepression) and Ponikve reservoir in the central part of the island. For these two permanent surface water phenomenon correlation analysis of the dynamics of the surface water and groundwater fluctuations will be performed. The paper also describes evaluation of the possibilities of using precipitation to meet part of the island's water needs in agriculture.

Keywords: islands, karst aquifers, Adriatic Sea, water balance, water use, water reserves studies

1. Introduction

Island of Krk is one of two largest Adriatic island (with a surface area of 405.219 km^2) and also the most populous one with 17,860 inhabitants (Duplančić Leder et al, 2004). Karst structures and processes are dominant on the island. It belongs to the Kvarner group of islands that are situated in the northern Adriatic, between Istrian peninsula in the west and the Vindol-Velebit coast in the east (Figure 1). Krk is located rather near the mainland and has been connected to it via a 1, 43 km bridge. Krk is the island that significant part of its current water needs covers from its own water resources (in public water supply, even 60-70%), which is only about 1.5% of the total water balance of the island.

Due to the “spatial separation” of the islands, there are some development constraints. Nevertheless, there are development plans for reducing of economic stagnation and depopulation of the islands. Optimization of available water balance of the island is one of priorities. This refers not only to providing additional quantities of water for public water supply but also the increase of so far minimally represented water needs for irrigation.

It can be expected that in the forthcoming period, the water needs will increase and will cause problems with water providing (from both: the local island water resources and from mainland water supply). This will happen due to the planned development of irrigation and the adverse trends in hydrological conditions. Negative regional climate changes are reflected in the increasing trends of annual mean temperature and decreasing trend of precipitation (Harding et al.,, 2009; Gajic-Čapka and Zaninović, 2006, Svensson et al, 2005, DHMZ, 2008), and as a result flow reduction and decreasing trends in water discharges and groundwater levels. At the same time the regional trends of sea level rise are present (Lambeck and Purcell, 2005; Pirazzoli 2000), and simultaneous subsidence in the North Adriatic area (Lambeck et al., 2004; Pirazzoli, 2005 including the island of Krk (Benac et al., 2004; 2008 b).

Therefore, it is obvious that in such conditions, water resources must be managed integratively, and be used in a way and extent that will not pose a threat to the karst aquifer. However, already existing water demands are several times higher during summer than in winter period due to the large number of tourists on the island. Because of that, the regional pipeline of 125 l /s capacity was constructed in the middle of 2008. This transport pipeline connects the water supply systems of the Island of Krk and the mainland water supply system of Rijeka city.

The pipeline is planned to transport up to 1 million m^3 of water a year depending on the water needs on island. These additional water quantities from mainland are added to app. 3 mil. m^3 that are used from islands water resources. However, the Irrigation Plan estimated 1 mil m^3 of water for irrigation of three locations (Vrbničko polje, Baška draga valley and Njivice polje). It is obvious that it is necessary to investigate new resources of water, as well as groundwater, surface water and rainwater as one of the neglected respectable water resources

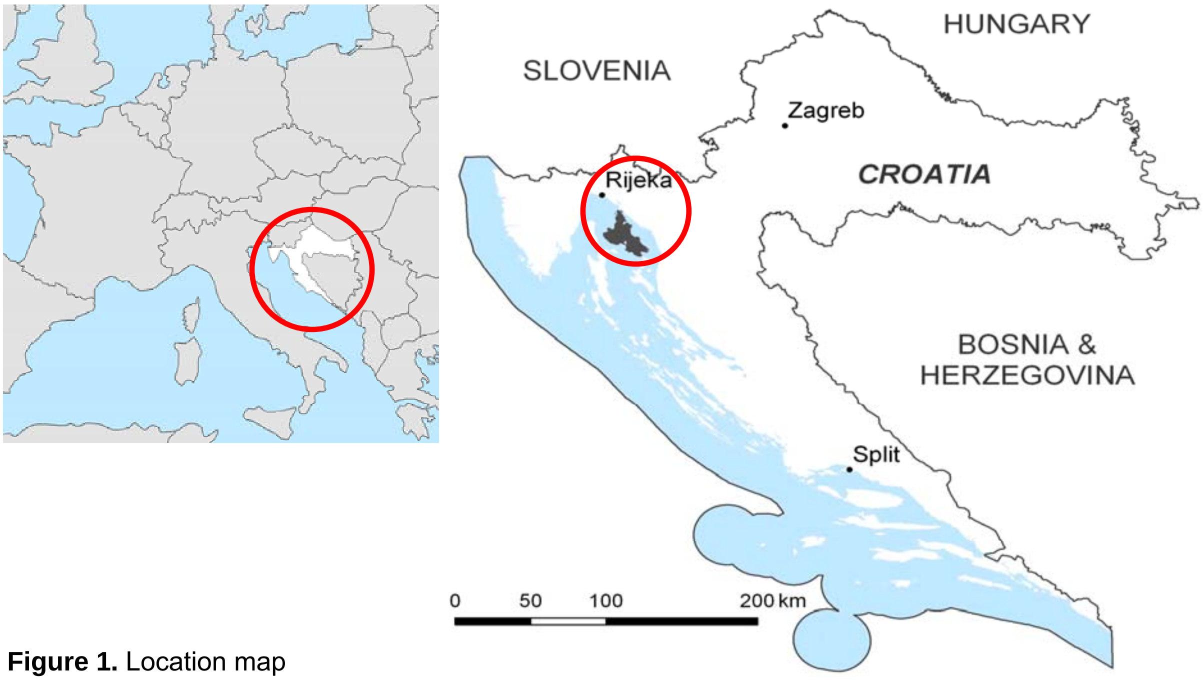

Figure 1. Location map

The paper presents available knowledge about the island water resources and on the base of that new guidelines for investigations of new water resources, are given. However, it should be emphasized that water resources are considered only from the quantitative aspect as a base for water balance of the island. This paper uses data from the unpublished hydrological and hydrogeological studies (Croatian waters, 1997; Faculty of Civil Engineering, 2006, 2009).

2. Water balance of the Island of Krk

Estimation of Spatial Distribution of Specific Annual Discharges

Assessment of water balance is based on the climatological data: digital maps of spatial distribution of average annual precipitation and temperature based on 30-year normal period of 1961-1990 (DHMZ, 2008).

The estimation of specific annual discharges was done based on digital maps of spatial distribution of air temperatures and precipitation (with raster 1 x 1 km). The runoff estimation was done using the Turc (1954) and Langbein (1962) methods, which are the most frequently applied in this region. Tests have been conducted to compare the results of hydrological modelling with measured data. The models are modified and adapted to work in a GIS environment. The results of modelling by Langbein were adopted as relevant, on the base of the results of testing differences on the measured and model calculated data (Horvat and Rubinić, 2006).

Table 1. and the Figure 2. show that there is a great difference in specific annual discharges distribution within the island, ranging between 11.2 and 22.5 $l/s/km^2$, with an average value of 16.37 $l/s/km^2$. Krk is the richest of all Adriatic islands in terms of the water balance - it has an average annual flow of 6635 m^3s^{-1}, which results in the average annual volume of produced flows of 210 mil.m^3.

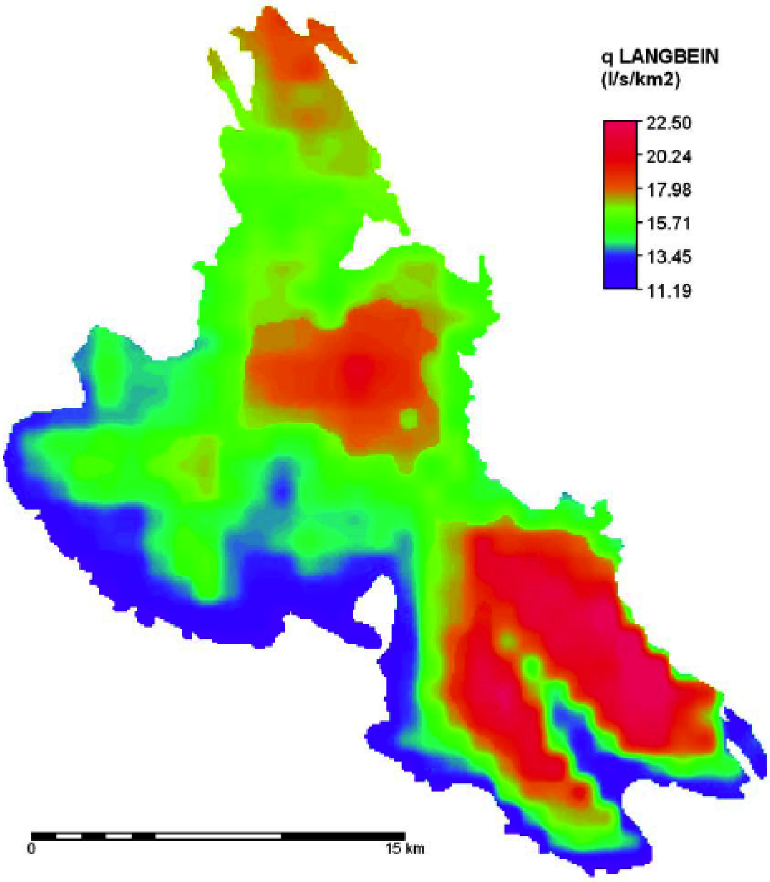

Figure 2. Detailed spatial distribution of Specific Annual Discharges for the island of Krk

Table 1. Specific Annual Discharges for the island of Krk according to Langbein method (1962)

Island	Area (km^2)	Spec. Annual Discharge ($l/s/km^2$)	Q ann avg (m^3s^{-1})	V avg (mil. m^3)
Krk	405.219	16.374	6.635	209.2

Analysis of Satellite Thermal Infrared Image

Surface hydrographic network is very poorly developed on the Island of Krk and is limited on area where siliciclastic deposits prevail, while on the major part of the island where karst landscape prevails, just a few locations of groundwater discharge are known.

As one of the still unused options of detection of water occurrence on the islands was the observation of thermal reflection of groundwater discharge into the sea by using satellite thermal images. In fact, even from the observations of thermal anomalies at the Island coast, in various hydrological conditions, it is possible to locate concentrated groundwater discharges, and thus to direct investigation works in the hinterland of these phenomena. In Croatia, remote sensing data are rarely used in Water Management (Rubinić et al, 2007)

Thermal characteristics of coastal and submarine spring (vrulje) greatly differ from the thermal characteristics of the surrounding sea. Due to this difference, especially in the warmer part of the year when these differences are maximal, temperature anomaly detection using thermal infrared image is significantly higher, and the surface temperature can be used as an indicator of mixing groundwater and seawater. Some previous studies have shown that, depending on the time basis, there is good correlation between salinity and surface temperature. Due to the good spatial resolution of ETM (Enhanced Thematic Mapper) sensor, coastal and submarine springs are relatively clearly visible on Landsat thermal images. Calculation of the temperature by a given equation, gives a quantitative insight into the difference in temperature of groundwater discharges and the surrounding sea.

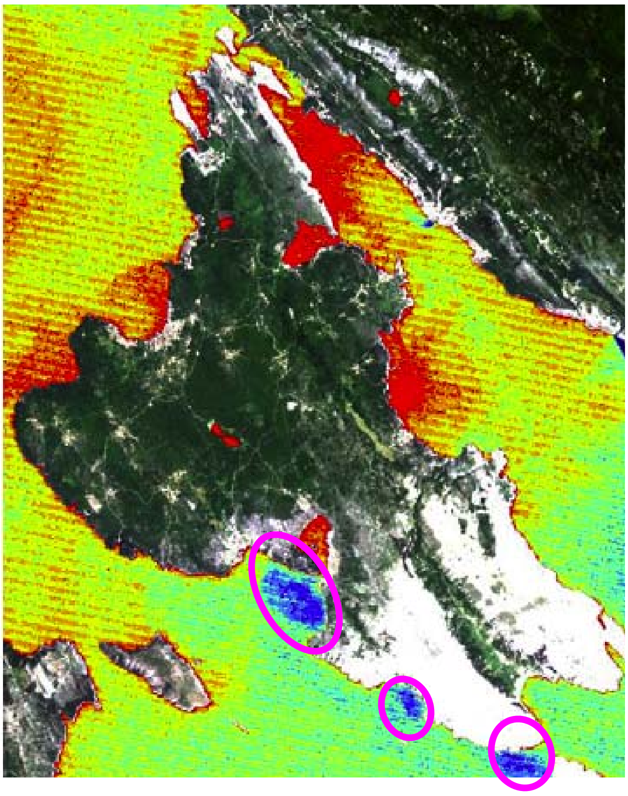

Figure 3. Processed Thermal Image of the Island of Krk (image taken on 12.6.2002) with marked zones of possible groundwater discharge

The figure only demonstrates the possibilities of application of satellite thermal infrared images. For the detailed analysis, it is necessary to ensure well defined Satellite Thermal Infrared Image with the higher spatial resolution then the one shown as the example in Figure 3. However, the Figure shows that the southern parts of the island, located between Punat and Baška settlements, there are three zones with concentrated occurrences of cold water along the coast of the island, and are indicating a possible groundwater discharge.

However, such a hypothesis should be confirmed with more detailed satellite images from different hydrological situations. In fact, colder water does not necessarily mean the groundwater discharge. In any case, the detection of such sites in different hydrological situations, even those locations of relatively small thermal anomalies could be an appropriate indicator of discharge from the island karst aquifer.

3. General geological and hydrogeological characteristics of the Island of Krk and its water resources

The island of Krk and all Kvarner area are a part of the Outher Dinarides and it is situated in the NW part of large Mesozoic Adriatic Carbonate Platform (Vlahović et al., 2005). The oldest sedimentary rocks cropping out on the surface are Lower Cretaceous limestones and dolomites found on western and south western part of the island. Minor part of the surface is covered with transitional Lower – Upper Cretaceous dolomites and diagenetic breccias, while rudist limestones outcrops of Upper Cretaceous are visible the most of the Island (Figure. 4). Paleocene-eocene foraminiferal limestones sporadically overlay Cretaceous carbonates. Eocene siliciclastic rocks with properties of flysch (mostly marls and siltstones and sandstones in alteration) dominate along the structure, stretching from Omišalj Bay to Baška Valley, which divides the Island and is considered as Palaeogene syncline. Oligocene-Miocene carbonate breccias (Jelar breccias) overlay on Cretaceous and Paleogene rocks occur only in southwestern part of the Island. The youngest Pleistocene deposits sporadically covered carbonate and siliciclastic bedrocks: terra rossa, slope deposits and proluvial fans (Babić, 2003).

The folds and faults striking NW-SE to NNW-SSE are main tectonic features in the Island of Krk. Dominant morfostructure from Omišalj Bay to Baška Valley has been considered a Paleogene syncline confined by thrust faults. Parallel Paleogene syncilne is situated near Stara Baška (Figure 4). The main NW-SW stretching of tectonic structures has been strongly disturbed by younger diagonal and transversal strike-slipe faults during the Pliocene and Quaternary under the influence of re-oriented regional stress approximately of N-S direction.

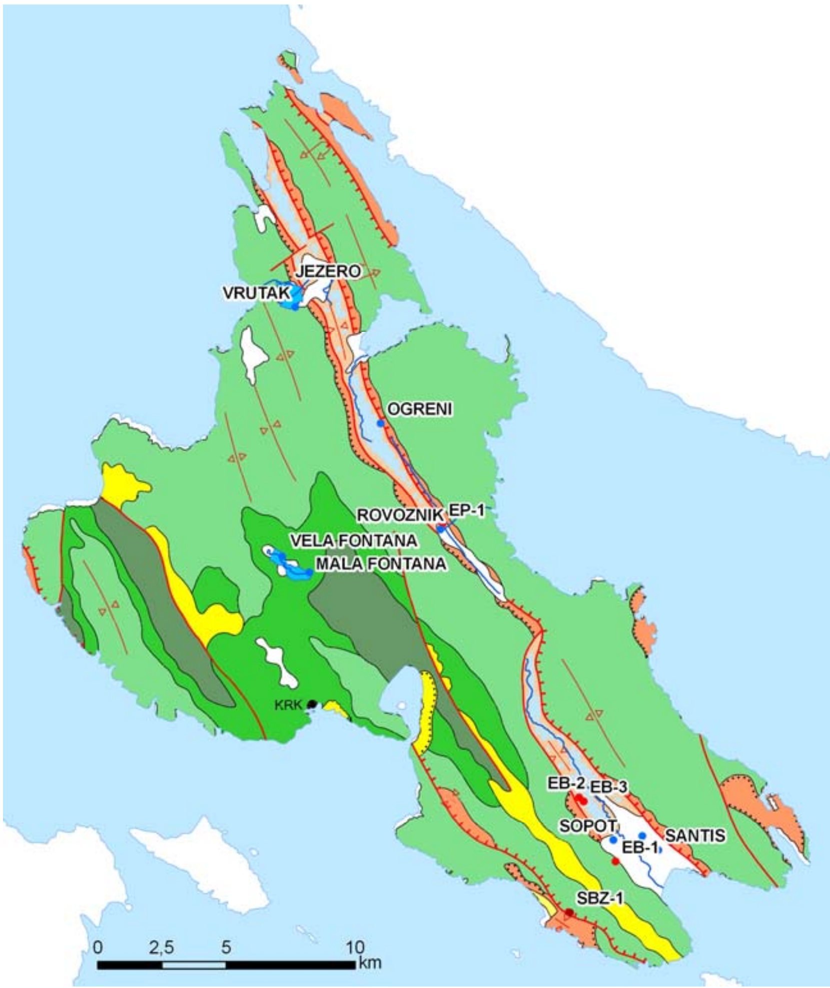

Figure 4. Geological map of Krk (according to Benac et al., 2009) and the most important water resources used for water supply

Hydrogeological properties of rocks are the following: limestone rocks are factured and deeply karstified and for this reason are mostly well permeable. Dolomite and limestone breccias that are not tectonically fractured and are classified as a less permeable rocks, while Paleogene siliciclastic rocks are considered as impermeable. Limestone rock mass is strongly karstified. The depth of karstification is more than -40 m due to longstand lower sea-level during Pleistocene (Benac and Juračić, 1998; Benac et al., 2008 a; Benac et al., 2009). In the central karst zone the most important water resources and springs used in water supply are placed. This zone is skirted by a siliciclastic zone and it strikes from Omišalj Bay through Vrbničko polje to the Baška valley. These water resources are Ponikve reservoir and Lake Njivice, springs and intakes of groundwater in Baška valley, Vrbničko polje and area of Dobrinj (Figure 4).

Ponikve reservoir and Lake Njivice are draining the central, carbonate part of the island on the southwest side of the flysch valley. In the area of Baška valley, numerous small springs (Santis, Sopot, Šibićevo) are formed on impermeable Paleogene silicislastic rock mass layers, while by deep

wells (EB-2 and EB-3) very active karst aquifer under the flysch was reached. It is assumed that the karstic area on the southwest side of the valley formed on silicilstic rock mass is the catchment area of those wells. For springs in Baška valley the catchment is assumed to be the ridge formed on carbonate rocks on the northeast side of the valley.
In the coastal area there are a large number of permanent and temporary springs. The biggest one is Jaz in the port of Malinska. For this spring hydrogeological tracing proved the connection with the ponor zone in Ponikve. Springs between the Kijac Bay and Njivice are draining waters from lake Njivice. Krk Island has some surface waters; the longest one is Ričina Bašćanska. There are other active surface watercourses, like the torrent Vretenica in Vrbnik polje.

4. Water Use -Water Supply

Water supply of the Island of Krk was for a long time resolved by combining the surface and groundwater resources. That is by intakes of springs in area of Baška, Vrbnik and Dobrinj settlements ; by intake of surface water of Lake Njivice and in Ponikve area, firstly by the intake of groundwater, and after the construction of reservoir by the intake of surface waters penetrated in the karst groundwater. Tourism development caused increase of water demands. Due to that many investigation works were preformed and resulted in much better water supply during tourist season.

Table 2. shows concessions for water supply with the approved quantities of water to use, as well as data on average water use during the period between ages 2000 and 2007. If you compare the data on the total concession approved amounts (6.9 million m^3) and the recent average annual water use (2.9 million m^3), it is obvious that less than half of the approved amount of water is used. However, if you compare approved maximal pumping quantities (225.5 l / s) with the maximal registered pumping quantity (252.7 l /s), it is apparent that current use is app. 10 % greater than the amount of water provided by the concession. The difference is even greater if one looks at the structure and regime of use off different springs. It is evident that in relation to the concession granted, Ponikve is overused. In the case of Ponikve, this difference is the consequence of over pumping of Vela Fontana intake-pumping quantities are twice larger than those allowed by the concession. This result in water quality decreases because over pumping causes the infiltration of surface waters from the reservoir.

Table 2. Water use permits for water supply springs/ intakes on Krk Island (

Water intake/ Spring/ Well	Permitted yr concesion ($*10^6 m^3$)	Permitted max use (l/s)	Average yr use ($*10^6$ m^3)	Max. registered average monthly use (l/s)
Ponikve	2.681	85	1.600	131
Jezero – Njivice	2.018	64	0.450	57
Vrutak	0.157	5	0.431	22
Sopot	0.252	8	0.020	2.2
Santis	0.315	10	0.020	2.8
EB1	0.788	25	0.021	8.3
EB2	0.346	11	0.290	27
Rovoznik	0.006	6	0.021	2.0
Grabovnik	0.35	11.5		
Ogreni			0.006	0.4
Total Krk	**6.913**	**225.5**	**2.859**	**252.7**

Ponikve reservoir has special meaning for the water supply of the island and represents the most important water resource on the island.

PONIKVE RESERVOIR

Ponikve reservoir is formed in the karst depression located in the central part of the island. It is a karst uvala that is app 2000 m long and 150- 450 m wide. Its bottom is covered by Quaternary deposits thickness up to app. 44.4 m Due to the geomorphological shape and the altitude this location represents the base for the local flow. So, groundwater and surface waters from the surrounding cathment area are flowing to Ponikve. At the lowest part of the karst dolina is a ponor zone with its lowest part at 7 m above sea level. Therefore, even in the natural conditions, this depression was periodically flooded and was dried during dry periods by draining through ponor zone. Groundwater tracing proved that water sinking through the ponor zone is occurring on coastal springs in the area of Malinska.

The first intake was made in 1936 and in 1967 intake Vela Fontana was constructed. During 1987 a dam was built. Dam height is 19:14 m a.s.l. This dam separated the ponor zone and surface reservoir with the volume of app. 2.2 million m^3 of water and the area of 0.87 km^2, was formed. This reservoir is shallow and its maximum depth is only about 6 m. Beside the retention of water in the surface part of the reservoir, its primary function was to maintain high groundwater level in order to increase the amount of groundwater pumping during dry periods. After the formation of reservoirs in 1987, the accumulation didn't dry out. During the time its initial function changed - due to the increase of water use on Vela Fontana intake, over-abstraction of groundwater occurred and resulted in increase of infiltration of surface water from the reservoir into the intake gallery. This resulted in the decrease of water quality.

The plans for the 2^{nd} Phase of reservoir construction are recently activated. This happened because of the limited possibilities for water use increase from existing intakes and too optimistic forecasts of providing water from Ponikve). The 2^{nd} Phase implies the raising of dam up to 24 m a.s.l, with the volume of about 7.0 million m^3. The 2^{nd} Phase constructions will consist of the reservoir increase and construction of injection curtain. This will enable new intakes for the abstraction of groundwater. The plan is to construct 5 new intakes on the skirts of the reservoir with the average capacity of 75 l /s (
Even the hydrological analysis of Ponikve reservoir functioning (Croatian Waters, 1997) showed that the mean annual discharge during extremely dry periods varies in the range between 0,123 (1989) and 0215 m^3s^{-1} (1990). These values are much lower than predicted discharges according to the 2^{nd} Phase project. It is obvious that with the planned intakes for abstractions of groundwater around the reservoir the capacity of 75 l /s can not be achieved. Even the later performed investigation works in Mala Fontana background, proved that for this location smaller quantity of groundwater can be expected than those planned.

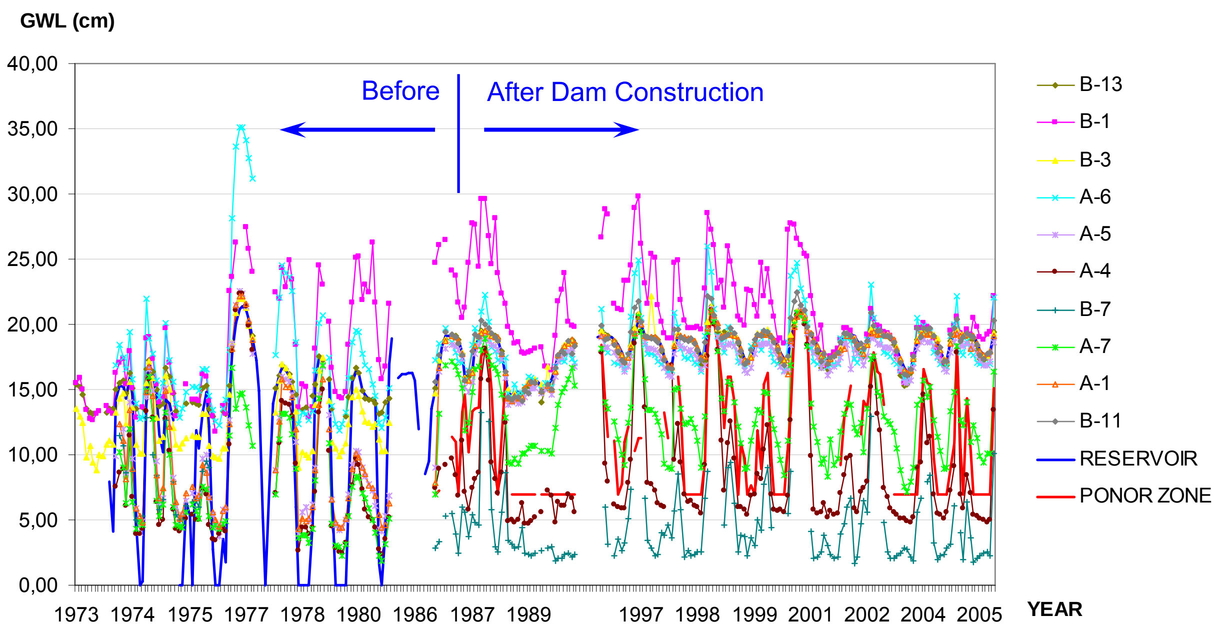

Figure 5. Water levels in reservoir and groundwater level fluctuations (1973 - 2005) (Rubinic et al., 2007). There is no doubt that larger reservoir would create conditions for a better water balance in dry periods, but it is possible that in case of longer dry periods (such as those recorded at the end of the eighties), it would have some negative impacts. Namely, each rising of the dam causes changes in dynamics of groundwater flow. So, even the raising of water levels on Ponikve for the I phase (19,14 m a.s.l) caused increase in groundwater level in ponor zone. This indicates that the raising of water levels in reservoir caused increase in groundwater flow gradient (Figure 5).

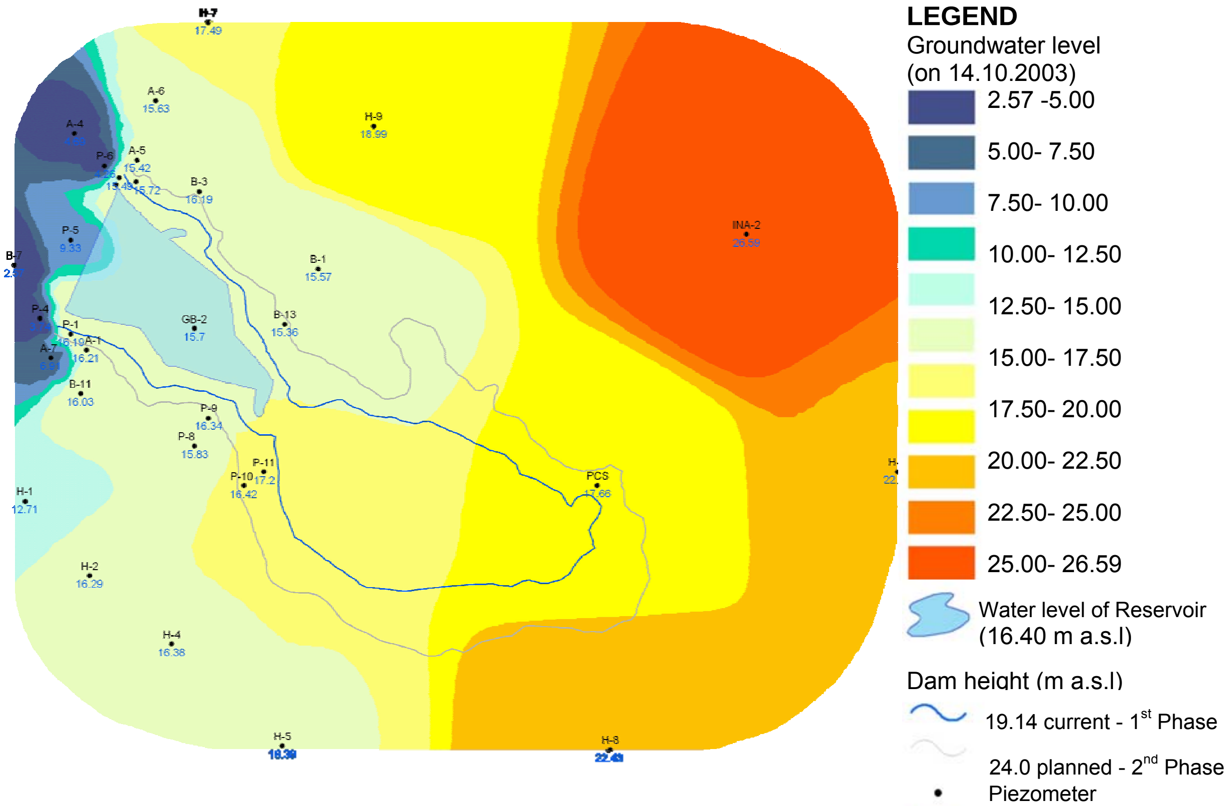

Figure 6. The result of the spatial interpolation of groundwater levels (for 14.10.2003)

Analysis of the dynamics of groundwater level fluctuations, in the current conditions (Rubinić et al, 2007), showed that in longer dry periods there is a zone of water loss in active ponor zone and in major part of left bank of the reservoir (Figure 6).

This fact should be taken into account, because due to the planned raising of the dam, changes in the hydraulic potential are possible. This changes could in certain hydrological conditions cause lateral runoff and increase of water loss from the reservoir.

5. Irrigation and Rainwater Harvesting

Irrigation

Analysis of water demands for irrigation in the Island of Krk and the possibility of satisfying this needs were estimated within the Irrigation Plan of Primorsko-goranska County

In the above-mentioned plan, for the island of Krk, 4223 ha of potentially suitable areas were analyzed. These areas are placed on 11 locations However; only three locations were evaluated as the appropriate areas (Table 3). Table 3 shows the structure of agricultural production and estimation of water amount that is needed to provide the irrigation in average hydrological conditions.

It is estimated that, in average hydrological conditions, irrigation of 680 ha of agricultural land requires app 0.90 million m^3 of water. According to different locations, this amounts varies between 0,082 million m^3 (Polje Njivice) and 0, 582 million m^3 (Baška draga valley polje). It should be noted that in dry years this needs could be twice as large. This is because the estimation of water amount needed for irrigation was made on the base of climatological data from Rijeka station, which was selected as a reference for the entire area of the county. Due to the geographic location of the island and its climatological conditions, it is certain that the resulting needs could be higher than estimated.

Table 3. The structure of agricultural production and estimation of water amount that is needed to provide the irrigation in average hydrological conditions

Location	Total Area (ha)	Structure of agricultural production (%)			Average water needs (mm)	Average total netto needs (m^3)
		Vegetable	Fruit	Vinyards		
Vrbničko polje	200	15	15	70	120	240.000
Bašćansko polje	418	30	40	30	140	582.200
Polja kod Njivica	62	50	30	20	130	82.000
Total	**680**					**904.200**

But it can be expected that beside this 3 locations mentioned in Irrigation Plan, the water needs for irrigation will increase. This will consequently increase the pressure on the existing island's water resources. In this context, as one of the possible forms of satisfying such extensive demands is use of rainwater for irrigation. Use of rainwater on the islands is traditional and is still present in water supply (after the construction of public water supply systems mainly as a supplement).

Rainwater Harvesting

Use of rainwater and water from public water supply system is compatible and should be encouraged, especially on the islands where water resources are relatively limited. Greater use of rainwater can contribute to greater conservation of local water resources and is the most effective way of using water resources.

The analysis of possibilities of rainwater use for irrigation was conducted as a part of the Project: The analysis of the global water balance of the island's resources-North Adriatic islands in PG County. Regarding the land fragmentation, even on relatively small agricultural areas there is interest in irrigation. Due to that, small local irrigation systems using rainwater as a water resource are especially suitable for consideration. For the analyzed area, total amount of rain is significant, but the problem is its temporal distribution. Annual precipitation is such that the maximum rainfall is occurring during the autumn while the greatest needs for water are during the summer. Therefore, in order to use the rainwater, it is necessary to accumulate it.

In order to demonstrate the possibilities of rainwater use for irrigation of small island properties, the simulation of irrigation systems using rainwater was carried out. The simulation was conducted by computer model with the input data of monthly rainfall, monthly water demands, the volume of storage tank and catchment area. The program simulates the fluctuation of water level in the tank for given conditions, and the result is the degree of providing water needs, or a percentage of total water needs for the treated culture. 30-year series of precipitation were taken as referent for monthly rainfall. Water needs are analyzed in a way that they take two irrigation unit agricultural area of 1000 m^2. One area is taken as representative for vegetable culture (tomatoes), and other one for woody culture (grapevine).

A detailed analysis of the degree of satisfying the water needs was performed on the base of the modelling results for each of the 4 locations. Analysis was made by varying in one case the volume of storage tank (with constant surface areas of 150, 250 and 500 m^2) - Table 4, and in another case by varying catchment area for constant tank volumes of 50, 100 and 200 m^3) - Table 5.

Table 4. Required volume of tanks for providing 90% of water demands for irrigation for different catchment area and for the irrigated area of 1000 m^2

Required volume of tank [m^3] for providing 90% of water demands for irrigation						
	F_{NAK}= 150m^2		F_{NAK}= 250m^2		F_{NAK}= 500m^2	
	Grapevine	Tomato	Grapevine	Tomato	Grapevine	Tomato
Mali Lošinj	56	116	37	85	19	69
Cres	51	96	31	80	12	60
Rab	51	99	32	80	15	61
Krk	46	89	24	76	10	57

Table 5. Required catchment area for providing 90% of water demands for irrigation for different tank volumes and for the irrigated area of 1000 m^2 (Faculty of Civil Engineering, 2006/9??)

Required catchment area [m^2] for providing 90% of water demands for irrigation						
	V_{CIST}= 50m^3		V_{CIST}= 100m^3		V_{CIST}= 200m^3	
	Grapevine	Tomato	Grapevine	Tomato	Grapevine	Tomato
Mali Lošinj	145	1000	96	173	94	144
Cres	126	700	89	145	87	129
Rab	129	800	90	149	86	127
Krk	99	650	87	133	71	111

It is evident that the size of tanks and catchment area significantly influences the degree of providing water needs, as well as the type of culture that is irrigated. In general, vegetable culture has a greater demand for water than woody culture. In agriculture it is common to take 90% of water demands, and that on average every ten years may happen that you do not provide a fully satisfying the needs for water for irrigation.

Influence of spatial position and different climatic conditions in the analyzed island's location, on the degree of satisfying the need for water for irrigation is visible from Table 5 and 6. It is evident that the best conditions are in Malinska, and that the least favorable situation is in Mali Lošinj. It is only a general review of meeting water needs, and in the future steps, the analysis can be expanded with more of other cultures, catchment area and volumes.

6. *Uninvestigated water resources of groundwater*

Some perspective areas on the Island of Krk are selected for further research of water resources (Figure 7). The selection was made on the base of the results of previous investigations and analysis.

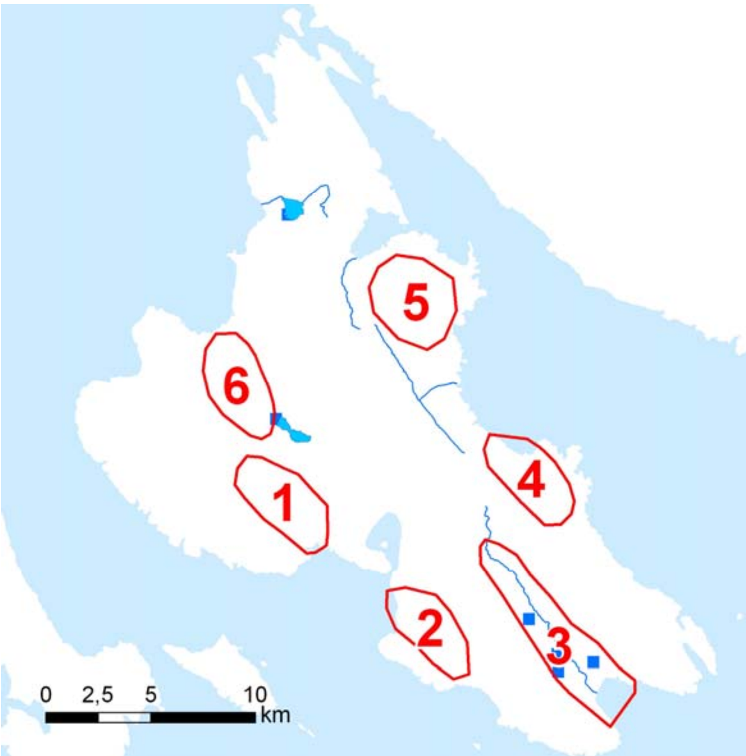

Figure 7. Perspective areas for additional research of groundwater resources on the Island of Krk

1. The area between the valley near village Vrh the and the city of Krk. Significant amounts of water discharges near the city of Krk, are indicating the potential hydrogeological barrier that directs groundwater flow.
2. The area between Punat and Stara Baška. The existence of hydrogeological barriers and indications of significant quantities of water discharge between Puntarska draga and Konoba bay

are indicating the existence of potentially significant karst aquifer. Geomorphological analysis and thermal image showed groudwater discharge.
3. In the area of Baška, there are springs around the valley. Due to their bad quality, these springs are not used for water supply. Analysis suggests the possibility of using the water from these springs for other purposes (irrigation etc.).
4. In the area between Dobrinj and Šilo there is a possibility of accumulation / retention forming for the keeping groundwater and surface water. This water should be used for irrigation.
5. For the area between Vrbnik and the Cape Glavina, reinterpretation of existing structural- tectonic and hydrogeological relations based on remote analysis is proposed.
6. The area between Ponikve depression and Malinska. Available data on the monitoring of groundwater levels in the ponor zone of Ponikve, indicated that the area represents a groundwater drain, which ends in a wider coastal spring zone of Malinska. The distance between Ponikve and Malinska is app. 5 km. It could be expected that with the possible future intake, a part of water loss from Ponikve reservoir could be reached together with groundwaters that drains from wider area.

7. Conclusion

The island of Krk has significant water potential, represented by the largest permanent water phenomena like Ponikve depression, Lake Njivice and watercourse Ričina Bašćanskaanska. However these water resources are still insufficiently known and not optimally used. Despite the proximity of land and connection to mainland water supply system, it is necessary to continue efforts of providing additional water resources on the island and to ensure new needs for water - primarily for irrigation, which has so far been only a minor represented. The unfavorable climate variations and present trends indicate that it is not possible to ensure stable agricultural production without the assurance of water for irrigation.

The investigations proved that in estimating water balance and evaluation of water resources of island, should take into account all aspects of water - the potential of rainfall, surface and groundwater, and even treated wastewater. The paper shows the analysis of possibility of rainwater use, which have not generally been recognized as very available and relatively predictable water resource.

Investigation of groundwaters and possibility of using karst aquifer on the Island of Krk I has so far carried out partially and was mainly focused on securing additional quantities for water supply. Because of insufficient hydrological monitoring of surface and groundwaters, it was hard to quantify them. Due to this, it is necessary to apply different approach for investigation of groundwater resources in the islands. This approach includes a wider use of remote sensing methods: the analysis of digital orthophotos of high-resolution; analysis of multispectral images and radar images.

Some perspective areas for further research are selected and should be analyzed in the context of providing water needs for irrigation. Of course, interest of the local community and the need for water (especially irrigation) will greatly impact on the dynamics of future research on some of the selected sites. This paper can be considered as the starting point for such future research.

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