ARTIFICIAL RECHARGE OF THE UNDERGROUND KARSTIC AQUIFER OF FARSALA AREA (THESSALY, CENTRAL GREECE) [1]

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ABSTRACT

The area of Farsala (Thessaly) is a representative case of overexploitation of groundwater resources, leading to the continuous exhaustion of the grained as well as the karstic aquifers. The application of the increasingly and internationally accepted method of artificial recharge on the karstic aquifer was decided to be the most effective for the restoration of balance of the hydrogeological system. Deep knowledge of the details of the geological structure and the hydrogeological conditions of the area is necessary for the success of the method, whose planning has to be made based on the principles of environmental protection and sustainable development. Use of state-of-the-art technology and estimation of all the parameters involved, which are necessary, have been taken into account.

Introduction

The study area is located northwest of Farsala (Fig. 1), around the villages of Orfana and Yperia (Fig. 2) on the border of the Larisa and Karditsa prefectures, between the hills Fillion and Htouri, where the main carbonate mass outcrops in the area. The area was selected due to the special interest of the Hellenic Ministry of Agriculture for the possibility to increase water resources that presently are being exhausted. This critical condition is confirmed by the irrigation drills, where the level has been dropping with a rate of 3-6 meters per year in the last decade.

Within these frames it was decided that the applicability and the success possibilities of artificial recharge of the karstic aquifer should be investigated.

The term artificial recharge means re-direction of the surface water to the underground aquifers. So far, experience has shown that artificial recharge, regardless its simple

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application formula, presents several problems if the details of the hydrogeological conditions in the application area are not well known. Artificial recharge is applicable with various methods such as surface flooding, local channelling, recharge channels, artificial recharge tunnels of karstic water spouts, caves, sinkholes etc. (if they exist in an area and if the hydraulic connection between the surface karstic structures and the aquifer is present) and finally with the utilization of those large natural karstic channels either directly or with the construction of access tunnels. For the best utilization of the karstic areas we must mainly examine the karst in relation to the neotectonic evolution of the Hellenic region.

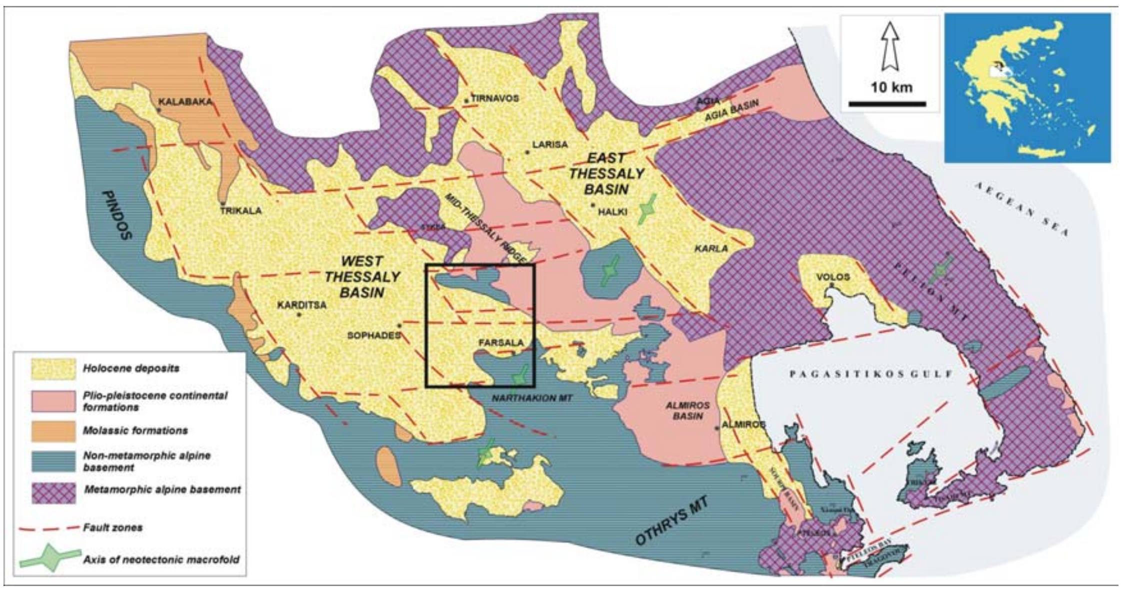

Fig. 1: *The greater area of artificial recharge application.*

Karst and artificial recharge

Artificial recharge is a composite procedure and deep knowledge of the geological structure and evolution of the area is required for its successful materialization. More specifically the detailed morphotectonic and hydrogeological study of the area must include a series of works (Mariolakos et al 2001).

Research has shown that, in many cases, karstified aquifers can support artificial recharge while the karstified formations surrounding various neotectonic basins can be used as transportation channels for water recharge as long as communication between them and the karstic aquifer exists. At this point it has to be mentioned that all karstic springs are recharged either through karstic formations located in greater altitude and with which they are hydraulically connected, or through unconsolidated aquifers with which they are in contact. Within the atudy area, an example of the first case is Vrisia springs, while an example of the second case is the Htouri springs (Fig.2).

By utilizing in a similar way and intervening with various technical adjustment works of current flows, mainly in karstified upland areas, it is possible to recharge karstified aquifers that develop in lowland areas, if there is or it is possible to achieve hydraulic connection. However, if there are no natural channels at the surface of a lowland area, then they have to be created with the construction of technical works such as drills and channels down to the depth where the karstified basement will be met.

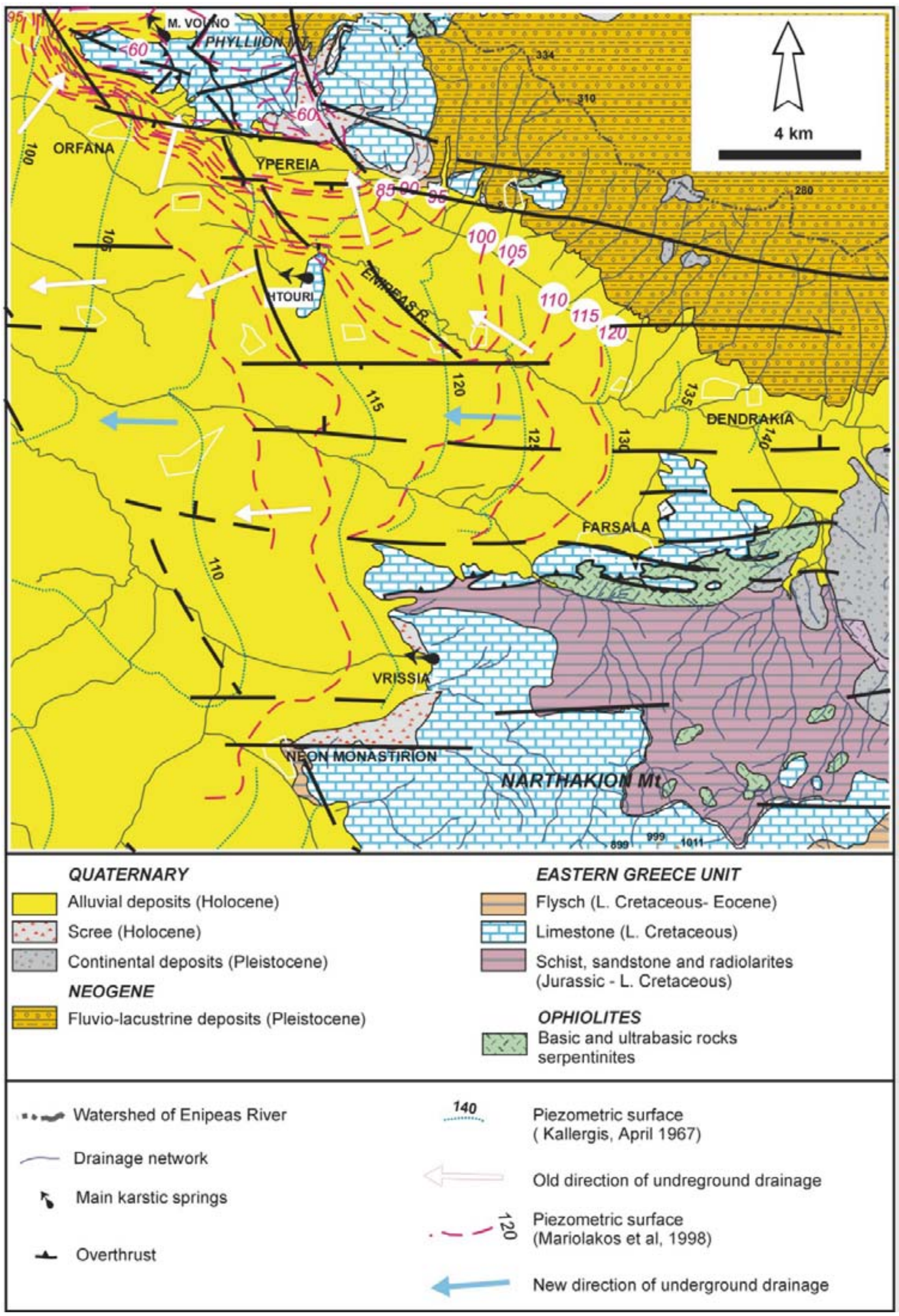

Fig. 2: *Hydrogeological map of the study area.*

At this point it should be stressed that the whole project has been designed in the frames of sustainable development. That means that the scientific team has taken into account that the management of the natural resources must satisfy the basic environmental needs and the socio-economic interest of the area.

For the preservation of the karstified underground water quantity and quality the following factors must be taken into account:

- The water must meet certain quality standards, depending on the intended use (irrigation, industry etc).
- The dangerous and toxic substances must not enter the karstic systems.
- The natural protection coming from the vegetation cover, the soil cover and other overlying elements must be preserved or improved.

The karstic aquifer of Phylliion Mt.

The present groundwater level of the karstic aquifer at the Phylliion Mt is fluctuating several tens of meters below the level of the springs of Mikro Vouno (NW part of the map), where the aquifer used to discharge before the overexploitation took place. The aim of the calculations was to approach with accuracy the volume of water represented by this level drop and stands for the water deficiency that needs to be replaced, as well as the potential of Enipeas River towards this direction.

For the performance of this calculation the following parameters were therefore determined:

- the geometry of the tectonic block that contains the karstic aquifer of Phylliion Mt. as a whole (Mariolakos et al, 2001),
- the base morphology of the post alpine deposits that represents the upper limit of the carbonates (Mariolakos et al, 2001),
- the Mikro Vouno and Htouri spring functions and their relation to each other and the hydraulic connection of Enipeas River with the aquifer of the post alpine formations and with the karstic aquifer,
- the hydraulic parameters of the karstic aquifers and the post alpine formations,
- the limestone mass that must be recharged with water and the volume of the voids that is the water needed for the recharging (Table 1),
- the volume of the voids in the post alpine formations that represent the column that needs to be refilled,
- the charging of the karstic aquifer (Table 1),
- the charging of the unconsolidated aquifer in the study area (origin and quantity),
- the water volume accepted by the study area directly from precipitation, from underground charging and from Enipeas River (Table 1),
- The water volume that corresponds to the annual level drop of the karstic aquifer due to its over-exploitation (Table 1).

For the verification of the relationships between the karstic aquifers, and the tracing of the relationship of the unconsolidated aquifer with Enipeas River and the karstic springs as well, the following were taken into account:

- The piezometric surface of the aquifers and the circulation of water during wet and dry season (SOGREAH 1974).
- The average evaporotranspiration coefficient, infiltration and discharge for the whole of the basin (Kallergis et al 1973).
- The latest data for the over-exploitation regime, as well as data for the average water supply of Htouri and Mikro Vouno areas.

The data collected from the above sources could be summarised as following:

- The Htouri springs are located in an altitude of 116 metres. The springs of Mikro Vouno are located in an altitude of 102 metres. The Enipeas River bank in the Orfana area is located in an absolute altitude of 110 metres. If we regarded the water tables as a uniform aquifer with those altitudes, the mean hydraulic gradient would be nearly 1.6% towards north, that is, towards Mirko Vouno springs.
- The Htouri springs, that have been strongly influenced by over-exploitation since 1989 had a mean yield of 0.3 m^3/sec, that is, a mean discharge of nearly 9.3 million m^3 per year.
- The Mikro Vouno springs, that have been strongly influenced by over-exploitation till 1985 had a mean supply of 0.2 m^3/sec, that is, a mean annual discharge of nearly 6.2 million m^3 per year.
- It seems that Htouri springs were discharging a local "tank" of increased permeability and storability intercalating the area of the unconsolidated aquifer. This karstic tank was supplied from the east and was discharging towards the west through the unconsolidated aquifer, as the direct supply by the precipitation would not justify the yield of those springs. Moreover, this regime was permanent and did not present seasonal fluctuation as the karstic aquifer of Phyllion Mt. did.
- These conclusions show that the unconsolidated aquifer is the main source of the karstic aquifers in the specific area and possibly the only reason that these supplies of the aquifer were not depleted during the years of over-exploitation. Also the charging of the Phylliion by the surface aquifer and Enipeas River can be considered as given, a fact that corresponds to the quality of the water that enters the limestone.

Regarding the hydrogeological system of Phylliion Mt. the following conclusions have been extracted:

- The limestone mass of Phylliion Mt., together with the smaller mass of Htouri to the south, represent two isolated karstic tanks, which under normal conditions are connected to the aquifer that develops in the unconsolidated post alpine material (Mariolakos et al 2001).
- The development of springs west of Htouri and north of Phylliion (Mikro Vouno) is the result of the altitudinal difference of the free surface of the unconsolidated material on either side of the limestone masses, in combination with the sudden water velocity reduction at the front of the substratum contact between the limestone and the granular material.

- At Htouri, under normal conditions water flows from the east through the unconsolidated aquifer and discharge to the west, while the same phenomenon is observed at Phylliion mt., but with a south towards north direction.
- Practically, the two limestone masses are not but just two open tanks of high water conductivity that intercalate in the continuous underground draining of the plain surface through the unconsolidated aquifer.
- The charging quantities of the karstic aquifers are mainly controlled by the unconsolidated aquifer and in a smaller scale by the atmospheric precipitation.
- Before over- exploitation, the piezometry of the unconsolidated aquifer presented a double function. During the dry period the aquifer was charged by the karstic aquifer, due to the use of water from the post-alpine table, while during the wet period the karstic aquifer was replenished by the unconsolidated aquifer.
- Today, taking into account the disturbance of this balance and the fact that the water loss in the karstic aquifer is not replaced but increases annually, its double function and the charging route from the karstic aquifer towards the unconsolidated aquifer has stopped, as we are going through a period of low water supply.
- The replacement of the Phylliion karstic tank supplies is expected to restore the reverse flow direction towards the unconsolidated aquifer (this time during the wet period were the recharge will take place), from the moment that the level in the limestone will reach the level of the unconsolidated aquifer and until the operation of the Mikro Vouno springs is restored. This fact will have as a result the reduction of the rate of rise of the water table in the limestone, since the inflowing quantities will also have to cover the loss within the unconsolidated aquifer.

Prospects for artificial recharge

The part of the drainage that is of interest for utilization through artificial recharge corresponds to the quantities available during the wet months since they are going to maintain the river diet of Enipeas during the recharge period.

Taking into account Agenda 21 (Rio) and mainly the point that every human attempt of intervention to the various physicogeological systems must keep within the frames of sustainable development, the management of the problem and the application of the calculations in relation to the quantities of Enipeas River that could be used for artificial recharge, should follow the next pattern:

- In any case, the charging of Enipeas should not be disturbed during the summer (dry) period, during the months May to September. During these months the charge of Enipeas is less than $1m^3$/sec at the Dendrakia measuring station (Fig. 2).
- During the wet period water should be extracted only when the river charge is greater than $1m^3$/sec.

Taking into account the above, calculations were made in order to find out the quantities that can be received from Enipeas River. The following parameters were determined:

- The supply of Enipeas, that is, the extreme values and the average supply at the closest possible location from the site of interest, which is Phylliion area.
- The correlation of the Enipeas River supplies to the rainfall and if possible the tracing of the river reaction in relation to the precipitation per sub-basin.
- The mean annual water volume that runs through Enipeas River and any extreme values.
- The quantities that can be extracted without disturbing the river.

According to the calculation and the obtained data, the mean yearly amounts that can be received by Enipeas in the future, in order to recharge the underground aquifer and through that the micro-permeable aquifer, is roughly16.7 million m^3 per year. From a quantity point of view the potential of the underground aquifers in the greater area of Yperia – Orfana is possible to increase by 16.7 million m^3 per year, without disturbing the natural recharge since during the warm period, that is during the months May to September, water will not be extracted by the river. The necessary quantities for the recharge can be seen in table 1, and by the comparison with the useful supplies it is clear that the available quantities are sufficient for the balancing of the annual increase of the deficiency of the karstic aquifer and for its gradual counterbalance of the total deficiency.

Table 1: AVAILABLE QUANTITIES OF ENIPEAS RIVER AND REQUIRED WATER SUPPLY FOR THE COUNTERBALANCE OF WATER DEFICIENCY.

Storability (%)	Volume of voids (water deficiency) between boundary levels (millions m^3)		Mean annual increase of deficiency (million m^3)	Mean annual infiltration of limestones (million m^3)	Expected annual charge by the unconsolidated aquifer (million m^3)	Annual available water quantities by Enipeas (million m^3)	
	+102m - +65m	+65m - +38m					
4.22	27.2	25.6	2.1	4.5	19.0	Mean	16.7

Suggested works

For the selection of the appropriate method and the design of the artificial recharge works in the specific area, the following factors have been taken into account:

- The geological – tectonic – neotectonic structure and evolution of the area.
- The karstification of the carbonate formations.
- The geometry of the deep karstic aquifers and mainly those that develop west of the imaginary line between Htouri and Yperia.
- The acceptance that the karstified limestone of Phylliion mountain has a lateral hydraulic connection with the underground karstic aquifers.
- The fact that the lateral and underground karstified aquifers are hydraulically connected with the unconsolidated aquifers.

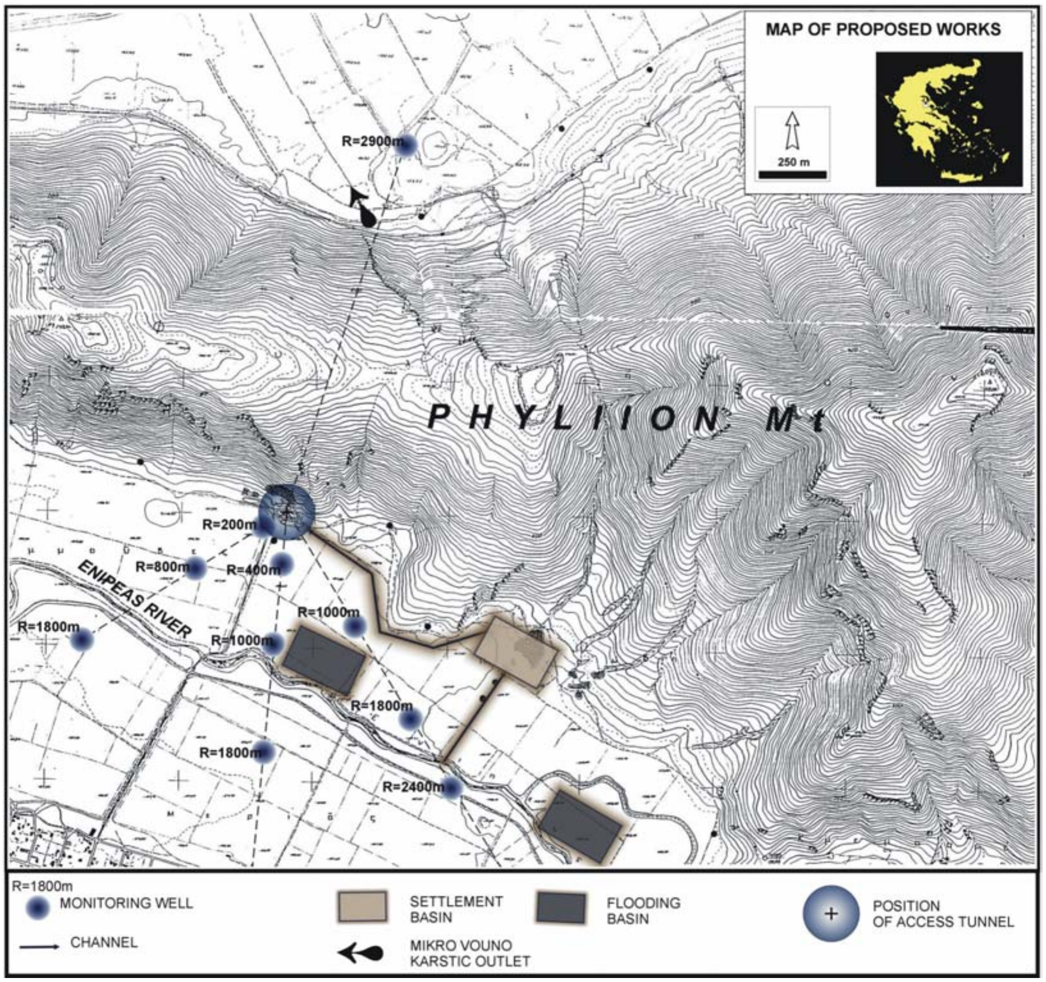

Fig. 3: *General maps of the suggested works for the artificial recharge.*

For the recharge, part of the winter discharge of Enipeas River will be used. The main works will be as follows (Fig. 3):

- Small retaining dam at the watercourse of the river. From this point the water will be directed straight to the precipitation basin.
- Precipitation basin that will have such dimensions in order to cover the supplies that are going to be used for the recharge.
- Transport channels from the precipitation basin to the recharge location through which the free from suspended material water in the precipitation basin will be directed through a channel to a rest tank.
- Rest tank, which can be a well of relatively small depth.
- Recharge channel, which must have a crosscut of at least 3m x 3m and initial length of 30m and a dip allowing the movement of special vehicles, such as small drilling vehicles, vehicles carrying excavation material, vehicles for filter cleaning etc.
- Wells within the recharge channel that will be constructed every five meters and will have small dimensions (1mx1mx1m).

- Piezometers with 100m mean depth in various locations around the supply area for the monitoring of the aquifer response to the recharge.
- Automatic digital recording and transmission stations of the qualitative and quantitative characteristics of the water for the recharge at the point of supply and uphill and downhill of this point for the reasons that are explained in the following paragraphs.

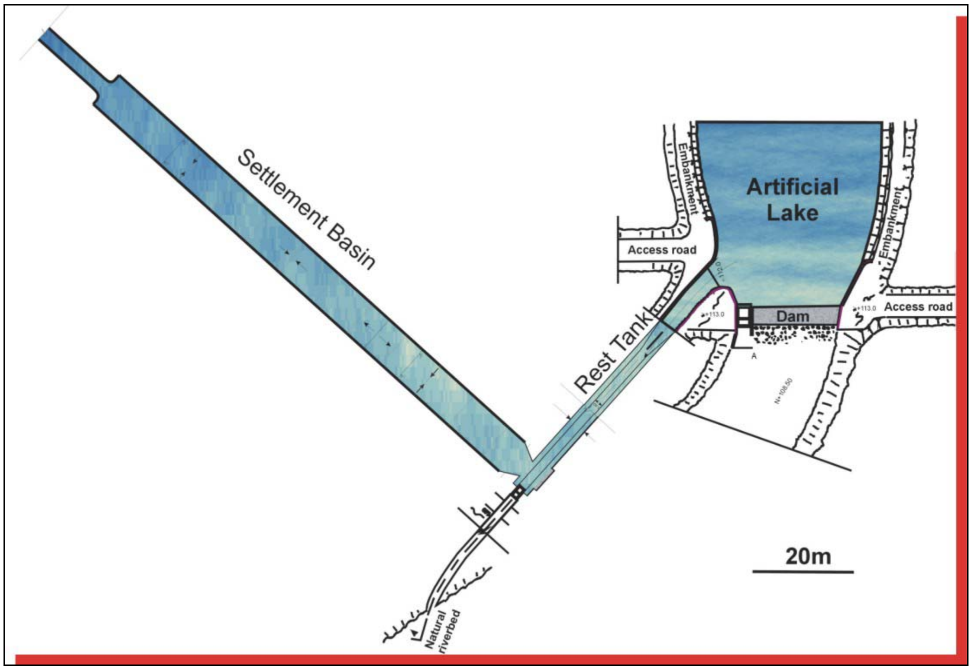

Fig. 4: *Part of the suggested works for the artificial recharge in detail.*

Conditions for the protection of the aquifer system

The recharge of the karstic aquifer is not to be done in expense of the natural recharge of the unconsolidated aquifer. After all, the volume and the quantity of Enipeas water that will reach the lowlands of the interest areas should not affect negatively the existing ecosystems and hydrogeological conditions.

Therefore, as a necessary condition for the operation of the project, together with the construction of the recharge works the installation and the equipment of certain monitoring stations and measurements with autographic instruments, for the parameters that it is technologically possible. At those stations there will be continuous monitoring of the supply and the level of Enipeas, continuous analysis of specific pollutants in order to avoid recharge with polluted water, and measurements of the solid load of Enipeas. In this way the necessary quantities and expected quality are ensured.

In the downhill station the continuous monitoring of the supply and the level of Enipeas will record any losses from the recharge location until this point.

Finally, the piezometry must be perimetrically and systematically monitored in the recharged karstic and unconsolidated aquifer in various locations from the recharge location.

When the measurements exceed some specific crucial limits for the supply, the pollutants and the solid load, the recharge will automatically be interrupted until the end of the unfavourable conditions.

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