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USE OF ARTIFICIAL GROUNDWATER RECHARGE METHODS FOR THE WATER RESOURCE MANAGEMENT IN THE CONTEXT OF CLIMATE CHANGE

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Abstract

Artificial groundwater recharge is of great importance in the sustainable and integrated management of water resources, particularly in the context in which our country shows a water deficit in certain areas, which is expected to increase over the next few years under the influence of climate change. Due to the fact that the artificial groundwater recharge systems are commonly designed with the aim of increasing the groundwater resources and/or improving their quality, implementing these systems may result in solving the issues relating to water resource management in the context of climate change. In this respect, this paper reviews a case study that describes how water discharges coming from an artificial canal infiltrate in order to provide the recharge rates needed for the safe operation of the drillings of Voronet capture zone, Suceava County. This canal poses two problems, namely the fact that it is not located parallel to the capture zone, and therefore the drillings located at greater distances do not capture sufficient water discharge and the second one, the fact that this canal might get silted. The results obtained from the analytical calculation of the wells discharges in the context of water infiltration from canal, have pointed out that the solution proposed leads to increase in water demand for that capture zone.

Key words: *artificial recharge methods, climate change, water resource management.*

INTRODUCTION

The influence of climate change on water resources is a matter of interest worldwide requiring an in-depth analysis which should correlate and compare the results of various studies and projects within a thorough study.

The main effects generated by climate change phenomenon consist of: air temperature rise, change in precipitation regime, groundwater level decrease, favouring the occurrence of drought phenomenon, as well as of severe meteorological phenomena.

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

From 1880 to 2012, average global mean temperature increased by 0.85ºC (from 0.65 ºC to 1.06 ºC) and from 1951 to 2012 by 0.72 ºC. The last three decades (from 1983 to 2012) have been successively warmer than any preceding decade since 1850. The decade 2003 – 2012 was the warmest, exceeding the records of all preceding years (IPPC, 2014).

Effects of climate change in Romania have reflected in changes in air temperature, which have been observed since 1901. In comparison with the increase in the global average annual temperature by 0.6ºC from 1901 to 2000, in Romania the annual mean recorded an increase by merely 0.3ºC, and from 1901 to 2006 the increase was 0.5ºC as compared to 0.74ºC worldwide (1901-2005) (the Ministry of Environment and Sustainable Development, 2008).

The change in the climate regime of Romania falls within the global context, taking into account the regional conditions: the temperature rise will be even higher in summer, whereas, in the north-western Europe the highest increase is expected in winter. Thus, a rise in the annual average temperature is expected in Romania compared to the period 1980 – 1990, similar to the entire European space, with small differences between the results of the patterns with respect to the first decades of the XXIst century and higher with respect to the end of the century (National Administration for Romanian Waters, 2014):

- from 0.5^{0}C to 1.5ºC, for the period 2020 – 2029;
- from 2.0ºC to 5.0ºC, for 2090 – 2099, depending on the scenario (example: from 2.0 ºC to 2.5 ºC in case of the scenario projecting the lowest rise in global average temperature and from 4.0 to 5.0 ºC in case of the scenario with the highest rise in temperature).

From the precipitation point of view, from 1901 to 2000, a notable general tendency of decrease in the annual amounts of precipitation occurred, with an intensification of the drought events in the southern part of the country after 1960. For certain regions, an increase in the annual frequency of very rainy (the highest 12% daily amounts) and extremely rainy (the highest 4% daily amounts) days occurred from 1946 to 1999. From 2000 to 2007 two opposite extreme rainfall events were recorded at the level of Romania, namely the drought in 2000 and 2007 and the floods in 2005. An extreme temperature event was recorded in 2007. The winter of 2006 – 2007 was the warmest winter ever occurred since observational measurements started in Romania, when major deviations of maximum/minimum temperature in relation to the multiannual average regime persisted over long periods of time (GASC, 2008).

In terms of precipitation regime, from 1901 to 2010 the analyses conducted show the existence, particularly after 1961, of a general decreasing trend of the annual amounts of precipitation at the level of the entire country and particularly a pronounced increase in the deficit of precipitation to the south and east of Romania (ANAR, 2014).

According to (EEA, 2010) there are projected seasonal changes in river flows due to climate change. For example, higher temperatures will push the snow limit in Northern Europe and mountainous regions upwards and reduce precipitation in the form of snow. This would result in a marked drop in winter retention and higher winter run-off in Northern European and Alpine rivers such as the Rhine, Rhône and Danube. As a result of the declining snow reservoir, earlier snow-melt and a general decrease in summer precipitation, longer periods of low river flow may be observed in late summer and early autumn in many parts of Europe.

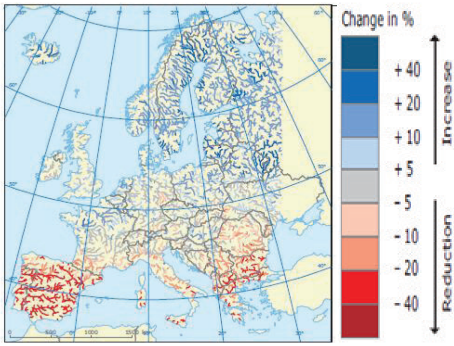

Figure 1. Relative change in annual river flow and change in seasonal river flow for three large European rivers between scenario (2071–2100) and reference period (1961–1990) (EEA, 2010)

According to the Ministry of Environment and Sustainable Development, 2013, „adaptation to climate change is the capacity of natural and human systems to respond to (actual or expected) climate change effects, including climate variability and extreme meteorological events to moderate potential damages, to take advantage of opportunities and to properly cope with climate change consequences, considering that society and ecosystems feel the individual and cumulated effect of all these components".

Adaptation requires actions at all levels– local, regional, national and international – and in all fields – industry, agriculture and fishing, tourism, public health, civil engineering and infrastructure, transport, water resources, forests, power, biodiversity, insurance, recreational activities and education.

As a measure to adapt to the climate change effects, this article shows the possibility of using artificial groundwater recharge methods for water resource management, for the purpose of increasing the groundwater storage capacity.

Artificial groundwater recharge may be globally defined as the recharge generated when the natural groundwater recharge is deliberately modified to increase the groundwater resources.

The artificial aquifer recharge consists of all human activities monitoring surface water infiltration into the aquifer at flow rates higher than those naturally occurring.

This technique solves a wide range of surface and particularly groundwater resource management problems at the local and regional levels, but thorough knowledge on the application conditions for the correct selection of technical and economic solutions is required to this end.

MATERIALS AND METHODS

A case study has been reviewed in order to highlight the possibility to use artificial groundwater recharge methods as a solution for solving the problems relating to water resource management. This case study shows how water discharges coming from an artificial canal infiltrate in order to provide the recharge rates needed for the safe operation of the drillings of Voronet capture zone, Suceava County(Figure 2).

Figure 2. Layout plan of Voronet capture zone and of the artificial recharge canal

In terms of soil stratification in the wells area, the following have been taken into account: at the surface, a 0.5-1.4 m thick topsoil followed by a 0-3 m thick yellowish-sandy clay layer. The unconfined aquifer is formed of large heterogeneous gravel with cobble and boulders, in different sand, 5-11 m in thickness. Below this layer, there is a grey, continuous clay layer, forming the impermeable bed of the phreatic layer.

Both alternatives with functional (unsilted) and silted canals were reviewed in order to analyse the discharges infiltrated in the artificial recharge structure.

This canal poses two problems: (1) it is not located parallel to the capture zone, therefore the drillings located at greater distance do not capture sufficient water discharge and (2) this canal might get silted.

Considering the abovementioned conditions, this study attempted to determine the following issues:

- The discharges coming from the recharge canal the capture zone is to be recharged with, for the provision of a flow rate of 3.6 – 4 l/s and well;
- The minimum and maximum distances from the wells for the execution of the canal;
- The qualitative forecast of canal siltation over time taking into account the water extraction from surface source.

An analytical calculation of the well discharges in the context of infiltration from canal was performed in order to determine these issues.

For the purposes of determining these aspects, an analytical calculation of the wells flow rates was performed considering infiltration from canal.

The discharge of the row of wells supplied by infiltration from canal was determined using the equivalent perfect drain method, considered in the same site and with the same discharge extracted per capture zone unit.

In the first calculation stage, this makes the row of wells replaceable with a perfect drain with the same flow rate per ml front, creating the same general dislevelments in the field. The parameters typical of the row of wells shall be determined in the second stage: flow rates for certain distances between wells and additional dislevelments in the well.

In this case, calculation was performed using two assumptions:

a) Unsilted canal

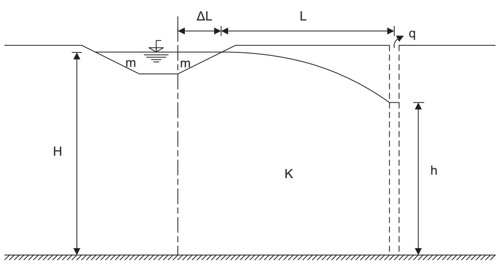

Figure 3. Calculation scheme for unsilted canals

Discharge extracted per drain unit length:

$$q = \frac{k(H^2 - h^2)}{2(L + \Delta L)}$$

where $\Delta L = \lambda H$ and $\lambda = \frac{m}{1+2m}$

where m – canal slope.

Dupuit equation to determine the discharge *q* can be used when infiltration into the permeable layer is made through a vertical gradient of elevation *H*.

As in this case infiltration into the permeable layer is made from the canal slope and bottom situated in the permeable layer thickness, an equivalent schematic with vertical gradient situated at a distance ΔL from the intersection line of the water level in its canal and gradient shall be adopted.

The extension of the infiltration domain substitutes the load losses resulted from curving the current lines at the normal infiltration into the canal.

b) Silted canal

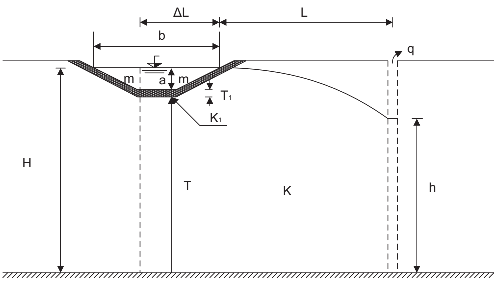

Figure 4. Schematic for silted canal

If water in canal contains suspended solids, which will settle due to low movement velocity and will be partly entrained into the soil pores under the action of infiltration thus causing siltation, the schematic changes according to the previous figure.

The discharge captured by the equivalent perfect drain shall be in this case:

$$q = \frac{k(H^2 - h^2)}{2(L + \Delta L)}$$

where:

$$\Delta L = \sqrt{\frac{K}{K_1} T T_1 cth\left(b\sqrt{\frac{k_1}{kTT_1}}\right)}$$

T_1 and K_1 are the thickness and permeability coefficient of the silted layer.

After the flow of the equivalent perfect drain is determined, the actual capture conditions are considered, using wells, determining the flow of a well and the additional dislevelment in the well.

The flow rate of a well is obtained from the following relationship:

$$Q = \sigma \cdot q$$

Where σ is the distance between wells, and *q* is the specific discharge (m^3/sm) of the equivalent perfect drain.

For the calculation of the additional dislevelment in well (ΔS) it was used the relationship:

$$\Delta S = \frac{Q}{2\pi K h_{mediu}} \ln \frac{\sigma}{\pi D}$$

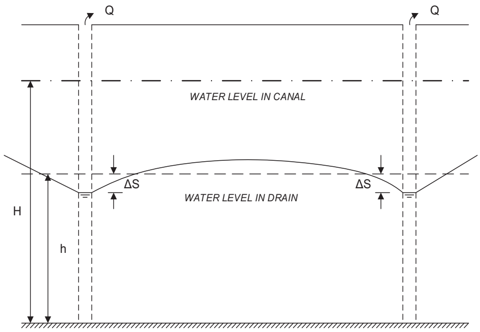

Figure 5. Schematic for additional dislevelment

RESULTS AND DISCUSSIONS

To show the variety of design elements resulted, the hydraulic calculations were performed taking into account several values of these parameters. Using them and the formulas shown above, tables containing the values of *q/K* depending on the distance between the canal and the equivalent perfect drain *(L),* the dislevelment created in drain *(S),* and the thickness of the groundwater layer *(H)* were prepared

a) Unsilted canal

The design elements used in this case were: *H*, *h*, *L*, *m* and *s*, which were assigned various values.

The graphs in Figure 6 and 7, where the variation of *q/K* for various values of *H* and *s*depending on *L* was represented, were prepared based on such values.

By reviewing these graphs, note than the flow rate decreases with the increase in distance *L* and also decreases in proportion with *H*.

a) Silted canal

The values of *q/k* for the silted canal were determined using the following assumptions: thickness of silted layer was considered constant and the permeability coefficient of the silted layer was considered to decrease to 1/10, 1/50, 1/100 in relation to the initial value of the permeability coefficient of the aquifer, and also the values for the remaining parameters were varied.

Using these data, corresponding data tables were prepared $\frac{k_1}{k} = 0.1$; $\frac{k_1}{k} = 0.02$ and $\frac{k_1}{k} = 0.01$. Graphs (Figures 8, 9, 10) representing the variation of qc/k depending on $\frac{k_1}{k}$, *L, H,* and *s* were prepared using these data.

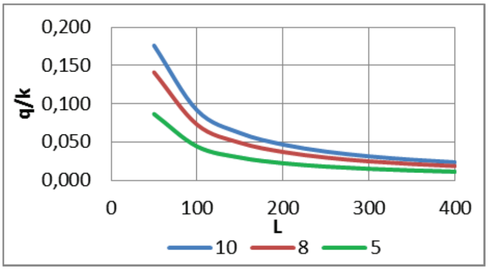

Figure 6. Unsilted canal, s = 1 m.

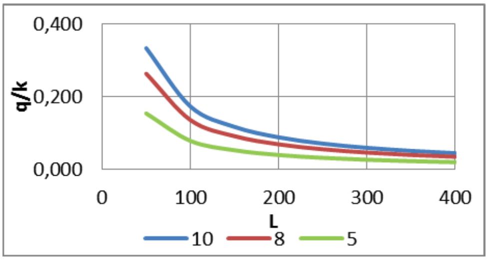

Figure 7. Unsilted canal, s = 2 m.

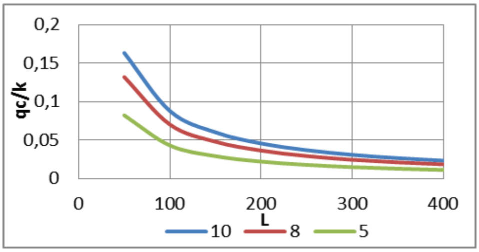

Figure 8. Silted canal k1/k=0.1; s=1 m; a=1.00 m.

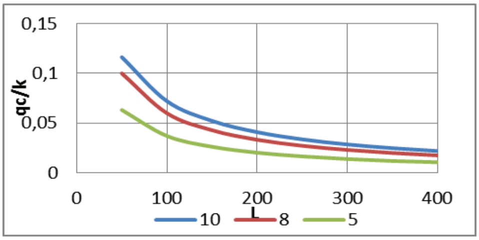

Figure 9.Silted canal k1/k=0.02; s=1 m; a=1.00 m

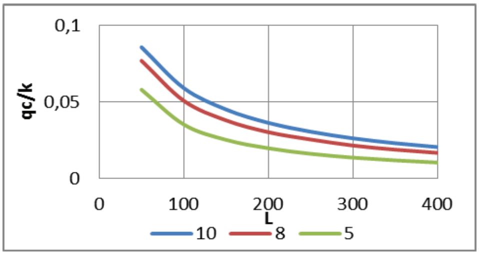

Figure 10.Silted canal k1/k=0.01; s=1 m; a=1.00 m

The graphs show a decrease in the flow rate with the increase in the distance *L* and with the decrease of *H*. These graphs can easily determine the value of *qc/k* for a certain distance of the row of wells in relation to the canal and for *H* and *s* values proposed.

After the value of this ratio is determined, knowing the permeability of the aquifer, the captured discharge can be found. Thus, the discharge for any well of the capture system can be calculated, by knowing the required soil elements.

The graphs in the Figures 11,12,13 highlight the variation of the values *qc/q* depending on the distance *L*, the phreatic layer thickness *H* and the siltation degree $\frac{k_1}{k}$.

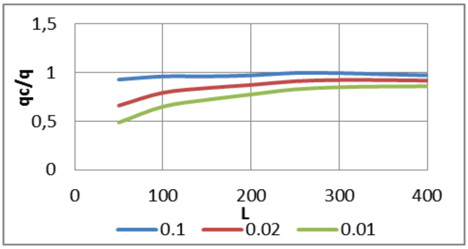

Figure11. Silted canal, H=10 m, s=1 m, a=1m

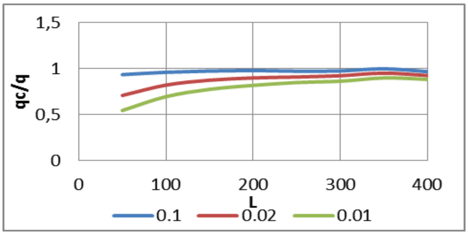

Figure 12.Silted canal, H=8 m, s=1 m, a=1m

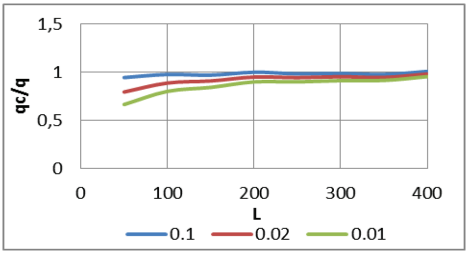

Figure 13. Silted canal, H=5 m, s=1 m, a=1m

Note that for short distances, for great depths of the phreatic layer and in particular for $\frac{k_1}{k} = 0.01$, the discharge for the silted canal decreases by about 50%.

The decrease is less felt as distance *L* increases. This is explained by the fact that for long distances, the discharge is relatively low for the unsilted canal, too.

By systematic measurements of the discharge of each well, the siltation degree can be determined by means of these graphs, therefore the moment when dredging of the canal should be performed may be determined.

CONCLUSIONS

Using the artificial recharge methods for water resource management in the context of climate change is an up-to-date technical solution.

The solution analysed in this paper connects an artificial groundwater recharge canal to a row of wells extracting groundwater. The alternatives subject to review have led to the following conclusions:

- The distance between the canal and the capture system line greatly influences the infiltrated and respectively captured discharges;
- The dislevelment created between the water level in wells and canal is important as long as the distance between the two systems is short; the longer the distance the smaller the importance of this factor;
- The canal siltation over time contributes to the reduction in the infiltrated discharge; but the intensity of this influence decreases as the distance between the row of wells and canal increases;
- The aquifer thickness is of little importance on the discharge, with increasing trend as the distance between the capture line and the infiltration line decreases.
- Consequently, the correct selection of the design solution is very important; the efficiency of the maintenance measures (e.g. desilting) is highly dependent on the constructive solution adopted.

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