WaterJPI project

SMARTControl

Smart framework for real-time monitoring and control of subsurface processes in managed aquifer recharge (MAR) applications

Deliverable D5.4

Demonstration of the SMART-Control approach at the Ezousa MAR facility, Cyprus

Real-time monitoring, lab analysis of microbial and chemical quality parameters and groundwater model set-up on the INOWAS platform

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November 2021

Project funded by:

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Short summary

This report describes the demonstration of the SMART-Control approach and developed tools at Ezousa MAR site. It provides details regarding the installation of the real-time monitoring system, which consists of three sensors that measure three water quality parameters: water level, electrical conductivity and temperature. Supplementary, groundwater is collected from five monitoring wells, which is analyzed in UCY's lab facilities in order to assess its microbial and chemical status. Furthermore, details regading the development of a groundwater flow model for Ezousa site on the INOWAS platform are provided, whereas preliminary results are shown for different numerical simulation scenarios.

Work package	WP5: Demonstration at case studies
Deliverable number	D5.4
Partner responsible	University of Cyprus (UCY)
Deliverable author(s)	Constantinos Panagiotou (UCY), Popi Karaolia (UCY)
Quality assurance	Jana Glass (TUD)
Planned delivery date	October (2020)
Actual delivery date	November 2021
Dissemination level	PU (Public)

ABSTRACT

An in-situ real-time observation system has been installed at the Ezousa MAR site (Cyprus), which is connected to the web-based INOWAS platform. In particular, this system consists of three groundwater sensors which have been installed at different locations in the catchment of the MAR site. These sensors measure three water parameters, particularly water temperature, electrical conductivity and water level on a daily basis. Consequently, these measurements are submitted to the INOWAS platform for further processing.

In addition to the real-time monitoring, lab analyses were conducted in order to assess the physicochemical and microbiological status of the groundwater. Groundwater samples were collected from five different monitoring wells, distributed along Ezousa riverbed.

Various parameters were examined on a regular basis (once every three weeks for the period January 2021 – June 2021 from which sulfates exhibit elevated values compared to the expected ones. A reason could be natural sources, such as sulfate mineral dissolution and sulfide mineral oxidation of the rock formations, or artificial sources, such as the inability of the wastewater processes to effectively reduce this type of compound.

Regarding numerical modelling, UCY team has utilized the existing tools (Tool 3) of the INOWAS platform to develop a groundwater flow model for Ezousa aquifer that includes all the major processes that took place in the region prior the construction of the MAR site. First, unsteady computations under constant boundary conditions were performed for a one-year span prior to the construction of the MAR scheme in order to determine the spatial distribution of the hydraulic conductivity and specific yield, followed by transient computations for validating the model performance based on recent data (2017-2018). For all computations, high R^2-values (around 0.99) and normalized mean squared errors less than 6 % have been achieved with respect to the available measurements.

The final task considers the use of the validated model for investigating the sustainability of the groundwater system based on the current man-made activities (pumping and artificial recharge rates). A reference scenario has been developed based on recent data for the time period 2014-2018, provided by the Water Development Department (WDD). As part of ongoing work (not shown here), additional predictive scenarios are considered, each one designed to evaluate the impact of different aspects, such as the effect on the head levels of increasing/reducing the extraction rates from specific wells, and the ability of the groundwater system to store higher amounts of treated water from the Urban Waste-Water Treatment Station.

CONTENT

FIGURES

TABLES

1 INTRODUCTION

Manage Aquifer Recharge (MAR) schemes are processes that intentionally recharge water into aquifers for future recovery or environmental benefits. These systems are considered as elegant options to address issues related to water scarcity, such as contamination of water sources, escalating population growth and rapid urbanization. However, the performance of these systems depends on site-specific factors, such as local hydrogeological conditions and source water quality. Hence, it is important to ensure that MAR schemes remain efficient while sustaining a good physicochemical/microbial groundwater quality to avoid health risks from the presence of pathogens and dissolved compounds .

During an initial assessment of the risks associated with the human health and environmnent at Ezousa MAR scheme [1], a number of actions were recommended to reduce the uncertainty of risks and to implement remediation measures, if necessary. More specific, it was suggested that more samples are needed to evaluate the risks regarding pesticides and organic chemicals within the Ezousa riverbed.

Furthermore, a more efficient control of the groundwater levels and salinity should be employed in order to improve groundwater quality. An elegant choice is to use web-based information systems since they do not inherit the typical limitations that are commonly encountered with desktop-based softwares, such as the requirement of software installation, upgrades and location dependence. Recent advancements in terms of internet speed, accessibility and computational storage have also facilitated the development of web-based tools which overcome these shortcomings.

Hence, the main objective of this deliverable is the installation of an online measuring system that can provide high quality measurements for water electrical conductivity, temperature and pressure, thus helping to monitor potential hazards in a systematic way, and to adjust the recharge/discarge rates. Supplementary, various key parameters for determining the physicochemical and microbiological quality have being examined on a regular basis (once every three weeks between January 2021-June 2021) by manually collecting water samples from different monitoring wells within the study area.

Lastly, we have used tools provided by the INOWAS platform to build and run a numerical groundwater flow model based on MODFLOW-2005 software to assess the sustainability of the groundwater system.

2 GENERAL DESCRIPTION OF THE CASE STUDY SITE

This section introduces the region of interest and provides details regarding Ezousa MAR project, such as MAR components, recharge network and major consumers of the recovered water.

2.1 MOTIVATION

The water resources available in Cyprus are scarce due to the semi-arid conditions. Annual average rainfall in Cyprus ranges between 200 and 500 *mm*, which is characteristic of semi-arid conditions. Using the Aridity Index recommended by Unesco [2], which considers the ratio between rainfall and potential evaporation, the climate of south-western Cyprus can clearly be characterized as semi-arid, with an aridity index of 0.20 (semi-arid conditions = 0.2 to 0.5). Combined with the fact that the total annual water demand exceeds the sustainable water availability of the island, motivated the authorities to adopt a more sustainable water resources management approach. A major area of interest involves the technical treatment of wastewater and its usage for artificial recharge through infiltration basins, resulting in an improvement of the treated effluent's water quality. This approach aims on replenishing the groundwater resources, which have suffered over the years due to the combined effect of low rainfall rates and over-pumping from thousands of wells. Hence, Ezousa MAR is considered an alternative option to sustain Ezousas aquifer as a regional groundwater resource for crop irrigation in the Paphos coastal plain area.

2.2 SITE DESCRIPTION

Ezousa catchment is located at the south-western part of Cyprus, around 10 *km* east of Paphos urban area. There, a MAR project is operating since 2003 based on Soil Aquifer Treatment (SAT), mainly for irrigation and tourist purposes. In particular, an intense agricultural activity exists that supports the main urban centres, while touristic facilities attract a growing number of tourists. About 70 % of total groundwater abstraction is used for agricultural purposes due to the intense agricultural activities that are present in the area. The remaining 30 % of groundwater abstraction is used for domestic and industrial purposes, such as golf fields and tourism facilities [3]. Depending on the water demand, the MAR scheme recharges 1.7-4.7 Mm^3 and abstracts about 2-5.5 Mm^3 per year [4].
The MAR scheme in the Ezousa catchment utilizes treated effluent for groundwater augmentation in the coastal aquifer. Wastewater is captured from Paphos urban area, consisting of about 36,000 inhabitants, and is gathered at the Waste Water Treatment Plant (WWTP) station, where it is subjected to tertiary treatment as indicated in Figure 1.

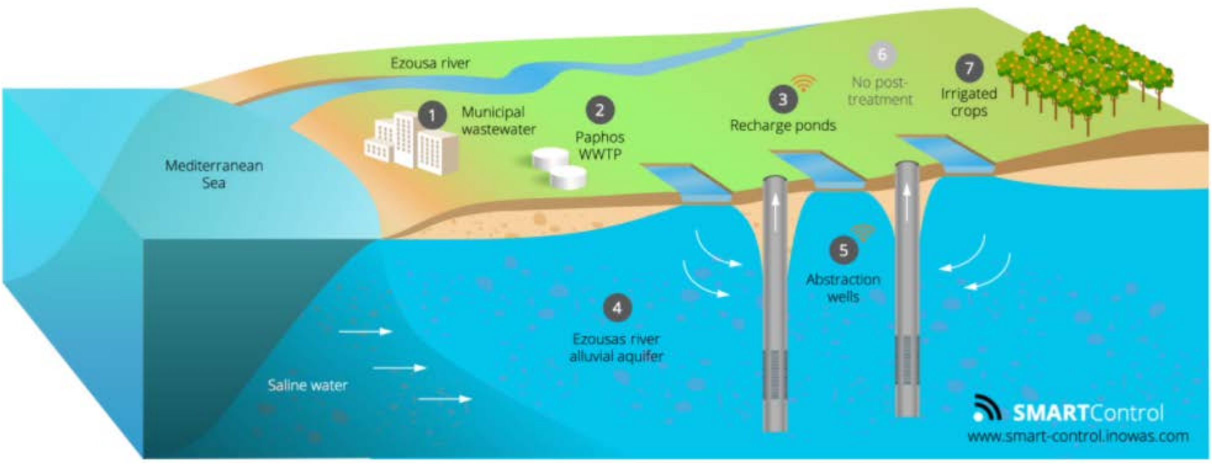

Figure 1. Schematic overview of MAR components at Ezousa SAT system.

The recharge network consists of five infiltration complexes, distributed along the entire domain of the alluvial aquifer (about 8 km upstream of the coast).

Each infiltration complex consists of two, four or six recharge ponds, with each pond covering an area of around 2000 m^2 and a depth of 1.5 m. Each pond is designed with a 1 m overflow weir to avoid erosion of their embankments from excess flow. The operational approach is to maintain a significant unsaturated zone so as to maximize the amount of water recharged and optimize the quality of the recycled water by its passage through the soil matrix. The operational pattern of wet-dry fill cycles varies from pond to pond but normally each part of the cycle lasts between 5 to 7 days. The ponds are filled from a pressurized 500 mm ductile iron main. Groundwater withdrawal occurs at nine wells located close to the infiltration basins, called production (or extraction) wells, from which the abstracted water is then distributed to the end-users through a canal. An aerial view of the site is shown in Figure 2.

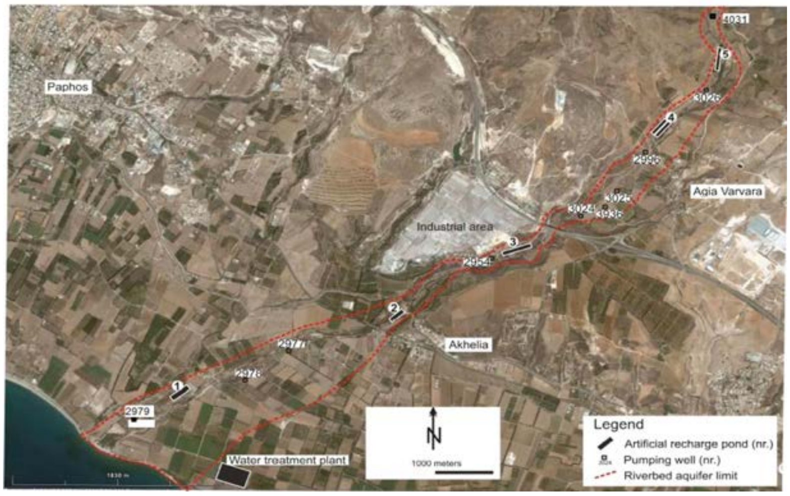

Figure 2. **Aerial view of Ezousa river bed area. Location of infiltration ponds (black polygons), wells (black circles) and treatment plant station (black rectangle at the bottom-left part of the photo).**

3 SET-UP OF CONTINUOUS MONITORING SYSTEM

A major objective of this deliverable is the installation of a real-time monitoring system at the site. In particular, five sensors have been obtained from UIT partner and three of them are currently installed at specific locations within the Ezousa riverbed. These sensors measure three water quality parameters: temperature, electrical conductivity and water level. Figure 3 shows the spatial distribution of the monitoring systems, along with the recharge ponds.

Figure 3. Spatial distribution of the monitoring system. Numbers denote the borehole codes where the sensors have been/expected to be installed. Small circles denote the location of all monitoring and extraction wells, whereas cyan polygons denote the artificial ponds.

In particular, we have chosen one well that is located both close to the coast (B/H4028) and downstream the first recharge pond, in order to assess the penetration of seawater. Another well (B/H4032) has been chosen due to its proximity to the third recharge pond, located at the middle of the study area. The remaining three boreholes are located at the upper part of the domain. B/H 3025 is located between Pond 3 and 4, whereas well B/H278, located upstream of the recharge ponds, is chosen in order to assess the quality of the ambient groundwater. Table 1 shows the geographical coordinates of the sensor locations, along with the groundsurface elevation.

Table 1. Topographical data of sensor locations

Well Code	Longitude (in degrees)	Latitude (in degrees)	Ground elevation (*m.a.s.l.*)
4028*	32.463321	34.734014	7.53
4032*	32.493370	34.746741	44.41

3025*	32.505482	34.752841	60.04
3959	32.508292	34.756288	65.23
4031*	32.515049	34.768426	84.25

*already installed

The installed monitoring equipment (Figure 4) is connected via SensoWeb to the web-based INOWAS platform. From there, the data can be visualized, processed and prepared for further usage, e.g. as a boundary or observation point in a real-time groundwater flow model. Figure 5 shows the time evolution of water parameters at different sensor locations.

Figure 4. Photos taken during the installation of the monitoring system.

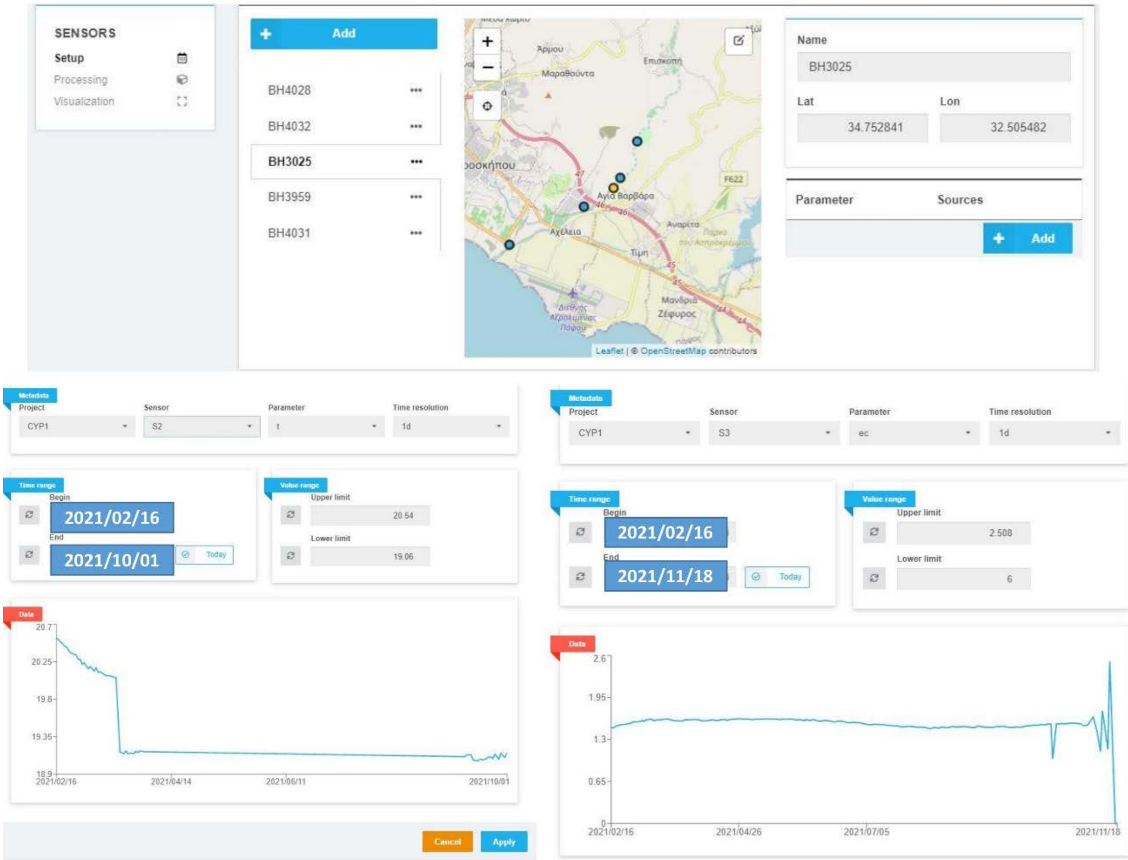

Figure 5. Top: Setup of the online monitoring at the web-based platform. Bottom: Time evolution of water parameters at a specific sensor.

4 LAB ANALYSIS OF GROUNDWATER IN TERMS OF PHYSICO-CHEMICAL AND MICROBIOLOGICAL QUALITY

In order to determine the physicochemical and microbiological quality, and the potential of the examined Ezousa MAR groundwater to induce toxic effects on organisms, various key parameters have been examined on a regular basis (once every three weeks for the period January 2021 – June 2021). Groundwater samples were collected from five monitoring wells, distributed along Ezousa riverbed. The examined parameters have been selected due to their inclusion in various legislative documents regarding groundwater and water quality, and due to the fact that they provide crucial information on water quality in general (Table 2).

In general, no major differences exist between the five examined wells, as the measurement values did not deviate significantly from each other. Sulfates were the only parameter that showed elevated concentrations compared to expected values in groundwater, something that may be caused by natural sources: i) sulfate mineral dissolution or ii) sulfide mineral oxidation of the rock formations found in the groundwater aquifer, or by external, anthropogenic addition of sulfate-containing compounds into the groundwater, such as: i) power plants, ii) phosphate refineries and iii) metallurgical refineries [5]. Another potential reason for the slightly elevated sulfate concentrations may be the inability of the wastewater treatment process to effectively reduce this type of compound, leading to its presence in the treated effluents recharged into the MAR sites.

Table 2. The evaluated parameters in the Ezousa MAR groundwater wells

Physicochemical parameters	Average measurement
pH	6.8±0.1
Conductivity (μS/cm)	1432±92.5
Ammonium (mg/L)	<LOD
Nitrates (mg/L)	3.8±1
Total nitrogen (mg/L)	6.6±0.4
Phosphates (mg/L)	2.9±0.3
Total phosphorus (mg/L)	7.2±0.5
Sulfates (mg/L)	228.3±5.9
Chemical oxygen demand (COD) (mg/L)	9.2±0.2
Dissolved organic carbon (DOC) (mg/L)	<LOD
Total suspended solids (TSS) (mg/L)	2.2±0.8
Total dissolved solids (TDS) (mg/L)	953±61.3
Microbiological parameters	
Total heterotrophic plate counts*	6.4±1.5
Faecal coliforms*	<LOD
Toxicity testing	
Ecotoxicity testing using Daphnia magna	NO TOXICITY DETECTED
Phytotoxicity testing (root and shoot growth inhibition, seed germination inhibition) with the use of 3 grass species	NO TOXICITY DETECTED

*If there is evidence of increased presence of faecal pathogens in the examined samples, further analyses will be conducted for detection and enumeration of *E. coli*, *Pseudomonas aeruginosa* and *Enterococcus faecalis*.*

5 SET-UP OF GROUNDWATER MODEL

This section considers the development of a groundwater model for Ezousa alluvial aquifer to investigate the impact of both the natural and anthropogenic activities, such as rainfall, riverbed infiltration, abstraction from pumping wells and artificial recharge through infiltration ponds. This is done using the INOWAS platform which currently supports the software package MODFLOW-2005. The history-matching, also called calibration, of the groundwater models was achieved based on available hydrogeological data for the time-period October 2002-December 2003, prior to the operation of the MAR site. Hence, no artificial recharge was present during that period, which was also chosen in previous works [6, 7] for calibration purposes.
In particular, the numerical groundwater flow model is calibrated in terms of hydraulic conductivity and specific yield under transient boundary conditions from October 2002 to October 2003, whereas the resulting model is validated with respect to recent data.

5.1 AVAILABLE DATA

The data that has been compiled and used for this study was provided by the WDD. The data included:

- Topographical map at 1:1000 scale covering the Ezousa river bed area with positions of extraction wells, artificial recharge ponds and observation wells.
- Listing of boreholes containing coordinates with elevations
- Monthly water table data for the time-span 2002-2003 and 2014-2018 for 21 observation wells
- Monthly rainfall data from the Paphos airport for the time period 2002-2003. For the potential evaporation (ETP), monthly values were used from the Evretou station for the time period between 2002-2003.
- Extraction rates for the time period 2002-2003 and 2014-2018 for nine extraction wells
- Monthly recharge rates for the time period 2002-2003 and 2014-2018 for five infiltration ponds

5.2 GEOMETRY OF THE RIVERBED AQUIFER

5.2.1 Projected geometry

The geometry of the Ezousa riverbed aquifer is given by the presence of the gravel and sand deposits that overly the bedrock, either Mamonia bentonites or Lefkara chalks and marls. The lateral extension of these deposits is easily determined in the upstream aquifer portion, where they pinch out against the Mamonia unit on either side, forming smooth slopes. In the central area, where the riverbed leads through the gorge of Lefkara chalks and marls, the aquifer is delimited by the cliffs. However, in the downstream portion of the aquifer, towards the sea, the lateral extension of the riverbed deposits had to be determined with borehole records, since they laterally inter-finger with fine-grained coastal plain deposits in the subsurface, without leaving a morphological landmark. The projected geometry of the aquifer, along with the recharge ponds and the wells are shown in Figure 6.

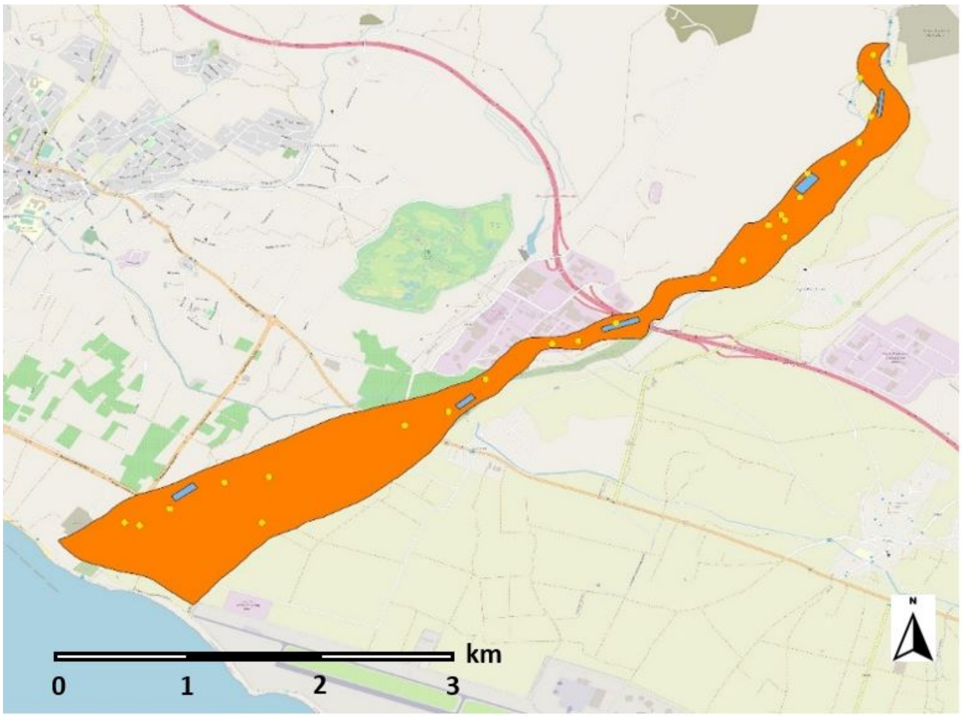

Figure 6. Projected geometry of the computational domain. Location of infiltration ponds (cyan polygons), monitoring and extraction wells (yellow circles) are also shown.

5.2.2 Vertical delimitation of the aquifer

Identification of the groundsurface and bedrock topography underlying the alluvial deposits was done by means of 29 borehole logs. The groundsurface was defined based on the elevation of the boreholes, whereas the bedrock surface was determined by substracting the elevation of the groundsurface from the depth of the boreholes. As in previous works [6,7], we have assumed that the well depth is similar to the aquifer thickness.

We have considered a single vertical layer, in contrast to Tzoraki et al. 2018 [7] who added a thin layer (1 meter thickness), to model the effective precipitation due to rainfall and evapotranspiration. For simplicity, we have decided to remove this layer since it was found through preliminary computations (not shown in this report) to have trivial impact on the results.

In order to produce smoother profiles, additional topographical points within the computational domain were obtained using Google Earth and used through the interpolation process. The bedrock elevations at these points were then determined based on the depth of nearby boreholes. The resulting layer of the groundwater model is shown in Figure 7.

Regarding the grid resolution, an uniform grid size of the study area with a size of $3.2\ km^2$ was set to 22 *m* x 22 *m*, containing about 6600 number of grid elements.

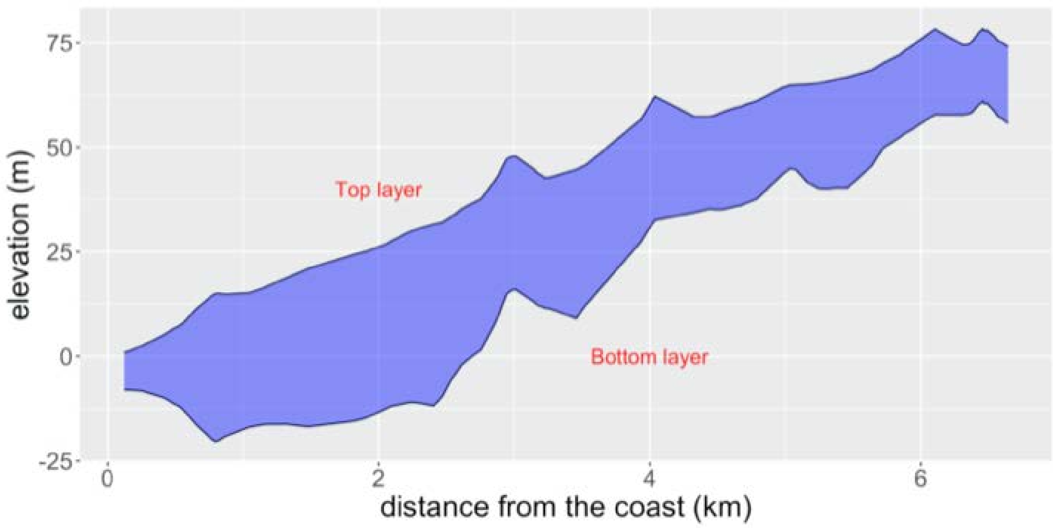

Figure 7. Vertical profile (in *m.a.s.l.*) of Ezousa riverbed aquifer as a function of the distance from the sea. Shaded area denotes the aquifer thickness.

5.3 HYDRAULIC PROPERTIES

The spatial distribution of the hydraulic conductivity (K) was analysed using 19 interpreted pumping test results (interpreted by WDD). Interpretation of the spatial distribution of the hydraulic conductivity values as well as the range of values encountered in the alluvial deposits is important for the calibration phase of the numerical model. The pumping tests yielded the transmissivity (T) at each location. To obtain the hydraulic conductivity (K), the transmissivity was normalised by the screened section in the borehole or depth of borehole (d) ($K = T/d$). The qualitative evaluation of the pumping test results was used for the calibration of the numerical model using a trial and error process.

As in [7], the computational domain was divided into four homogeneous zones to determine the values of the saturated hydraulic conductivity, where uniform values were taken for the specific yield and specific storage (Figure 8).

Figure 8. Conceptual model of the Ezousa MAR site. Coloured areas (labeled from 1 to 4) denote the saturated zones.

5.4 BOUNDARY CONDITIONS

Monthly water levels of an observation well, located close to the upper part of the study area, were used to determine the northern boundary domain as time-variant specific head (MODFLOW CHD package). A constant hydraulic head condition of *h*=0 *m.a.s.l.* was imposed along the entire shoreline at the southern part of the domain since the coastline acts as a physical barrier. Artificial recharge into five infiltration ponds were defined using the MODFLOW RCH package to simulate the specified recharge rates (*m/day*), determined based on the data obtained from the Water Development Department of Cyprus (WDD). Riverbed infiltration has been simulated in the numerical model by means of head boundary conditions for the period 2002-2003, whereas it was neglected during subsequent time periods due to the construction of a dam upstream of the study area. No-flow conditions are applied along the upper and lower borders of the domain.

Wells are classified into two categories. Observation wells are used for determining the northern head boundary condition and for the calibration of the hydraulic parameters. Nine pumping wells are present within the study area, which are defined using the MODFLOW WEL Package to simulate the specified flux (m^3/day). Four of these wells are located in the downstream portion of the aquifer, extracting a long-term average of 45 % of the total extraction rate, whereas the remaining five wells are situated in the upstream portion of the aquifer. Lastly, the effective infiltration due to rainfall and evapotranspiration was neglected for simplicity because it was found to have trivial effect on the results during the considered time period.

6. GROUNDWATER MODEL RESULTS

This section describes the simulation results for (a) calibration process, (b) validation process, and (c) base-scenario.

6.1 CALIBRATION AND VALIDATION PROCESS

The calibration process involved two separate computations. A pseudo steady-state computation was first conducted to construct an initial mapping of the hydraulic heads. Based on the available data, we have chosen the 7th of October 2002 as the starting date, for which values are provided at sixteen observation wells within the computational domain.
Constant head values were imposed at seven of these wells, while the remaining nine wells were used to evaluate the agreement between the simulated and the observed values through regression analysis.
Next, transient computations were conducted in order to determine the hydraulic parameters for the period October 2002-October 2003, before the MAR scheme became operational (January 2004). Hence, riverbed infiltration and ambient flow were the only source terms during that period, whereas the pumping from the extraction wells and the outflow from the coastline constitute the sink terms.
The calibration was done manually by trial and error using monthly measured observation heads.
By comparing observed and simulated hydraulic heads, the goodness of fit of the model was calculated using the root mean square error (RMSE) and the normalized mean square error (NMSE),

$$RMSE = \sqrt{\sum_{i=1}^{N} \frac{(h_s - h_o)^2}{N}}, \tag{1}$$

$$NRMSE = \frac{RMSE}{h_{max} - h_{min}}, \tag{2}$$

where subscripts *o* and *s* refer to the observed and simulated values respectively, whereas *max* and *min* denote the minimum and maximum values of the dataset. Also, *h* and *N* denote the groundwater hydraulic head and the total number of the data points used in the fitting process respectively. The calibration was found to be acceptable with an overall RMSE less than 3.5 meters and an NRMSE less than 6.5 %, in accordance with the recommended values in the literature (less than 10 %) [4].
As a next step, the calibrated groundwater flow model was validated for the time period October 2017-October 2018 in the presence of the MAR scheme. As in the calibration process, the coastline was assigned a constant hydraulic head of *h=0 m.a.s.l.,* whereas a time-variant CHD boundary condition was applied at the northern boundary based on the head values of a nearby well. Artificial recharge and pumping rates were assigned to the infiltration ponds and nine extraction wells respectively according to the data provided by the WDD for the prescribed time frame. Lastly, river infiltration was neglected due to the construction of a dam in 2005, located upstream of the study area (not shown here).

After conceptualization of the numerical model, the calibration procedure is considered for determining suitable values for the saturated hydraulic conductivity and the specific yield. As already mentioned, the study area was divided into different zones according to the geological observations. The calibration of the saturated hydraulic conductivity was thereby constrained to: i) yield higher values in the upstream area, decreasing towards the sea and ii) lie within the range of the field measurements. Table 3 shows the zonal distribution of the calibrated hydraulic parameters.

Table 3. Zonal values of the hydraulic properties

Zone	Specific yield (*1/m*)	Hydraulic conductivity (*m/day*)
1 (Orange)	0.21	30
2 (Green)	0.21	50

3 (Yellow)	0.21	120
4 (Pink)	0.21	120

Figure 9 shows a comparison between MODFLOW predictions and the field measurements from 11 observation wells for the groundwater hydraulic head for the calibration and validation model. An R^2 value close to 0.99 is achieved for the calibration process, suggesting a good agreement between the simulated and the observed head values. The RMSE and NRMSE are found to be 3.43 meters and 4.5 % respectively, in accordance with Waterloo guidelines [8].

Nine observation wells were used to validate the performance of the developed numerical model for the time period 2017-2018. Similar to the calibration case, the R^2 value is found to be close to 0.99, whereas the residuals for most of the data points (>80 %) are found to be less than 5 *m*. Taking into account the size of the study area, the levels of the groundwater hydraulic heads, the amount of the data used (number of wells times twelve time instants) to calibrate the model and the assumptions that has been adopted, the resulting overall RMSE of 4.5 meters and the overall NRMSE of 5.3 % were regarded sufficient for the purpose of validation.

Part of the discrepancies between the observed values and the MODFLOW predictions can be attributed to unknown factors, such as additional extraction through non-public wells, unaccounted leakages of the groundwater system from the upper and lower boundaries of the study area and additional recharging due to riverbed infiltration during the wet season.

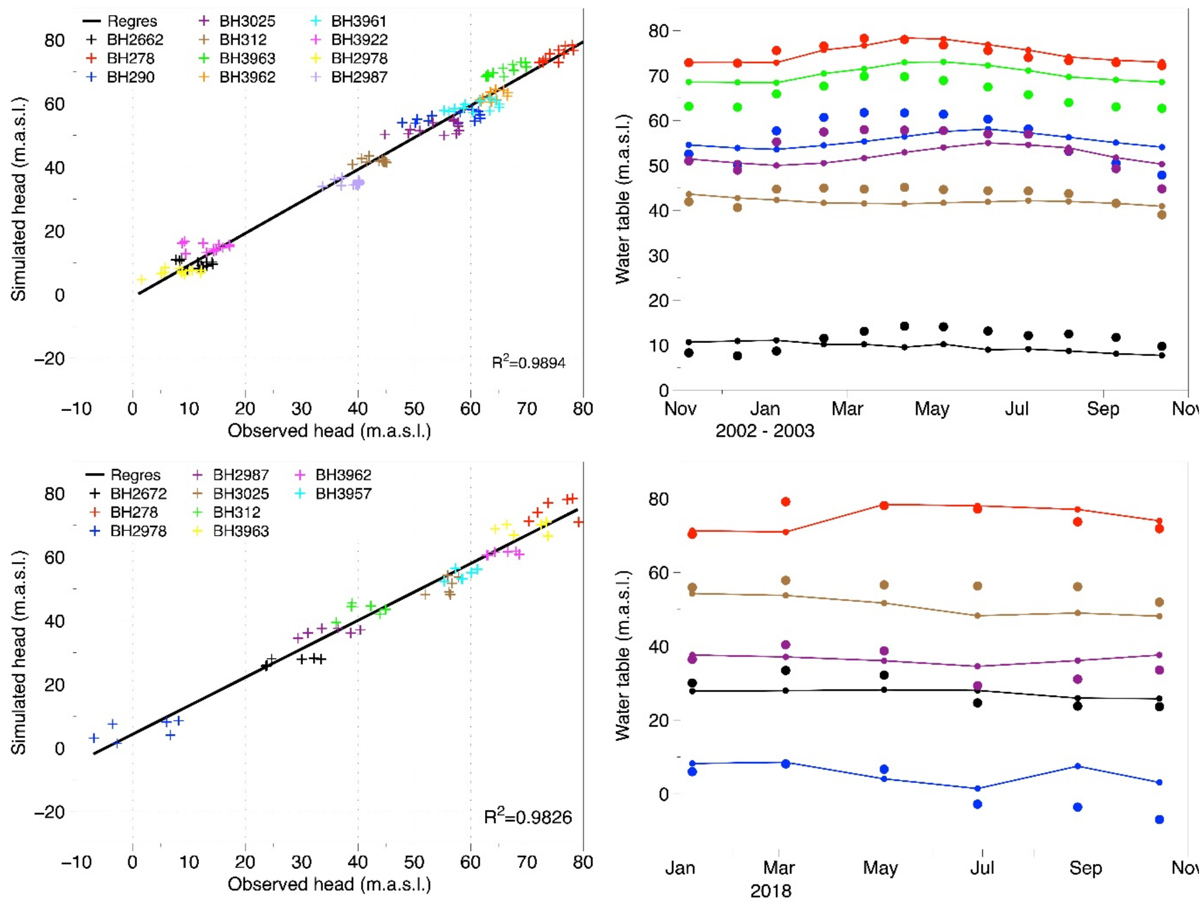

Figure 9. Regression curves between simulated and observed groundwater hydraulic heads (*left*) and time series of the water-table elevation (*right*) for the calibration period October 2002-October 2003 (*top*) and the validation period October 2017-October 2018 (*bottom*). Filled big circles denote the observed water tables and lines denote the simulated water-table elevation during the study period.

6.2 BASE-CASE SCENARIO

After validating the groundwater model, a transient computation over a four-year period (2014-2018) was carried out in order to assess the sustainability of the groundwater system. This time span has been chosen since it corresponds to the time period for which the most recent data was available. Subsequently, the results obtained from this scenario has been used as a guide for constructing predictive scenarios to analyze the sensitivity of the aquifer to variations of the man-made activities, particularly artificial and pumping rates.

Figure 10 shows the time evolution of the cumulative amounts of pumping and artificial recharge within the specified time-frame. The highest pumping is observed at the upstream part of the aquifer, particularly B/H2978 and B/H2977, whereas B/H 2996 exhibits the highest pumping values within the upstream . This pattern is also present in the previous simulation (not shown here). Also, Pond 5 exhibits the highest artificial recharge rates (uppermost part of the study area), followed by Pond 2, 4 and 3, whereas Pond 1 has the lowest contribution, especially during the period 2017-2018 (downstream part).

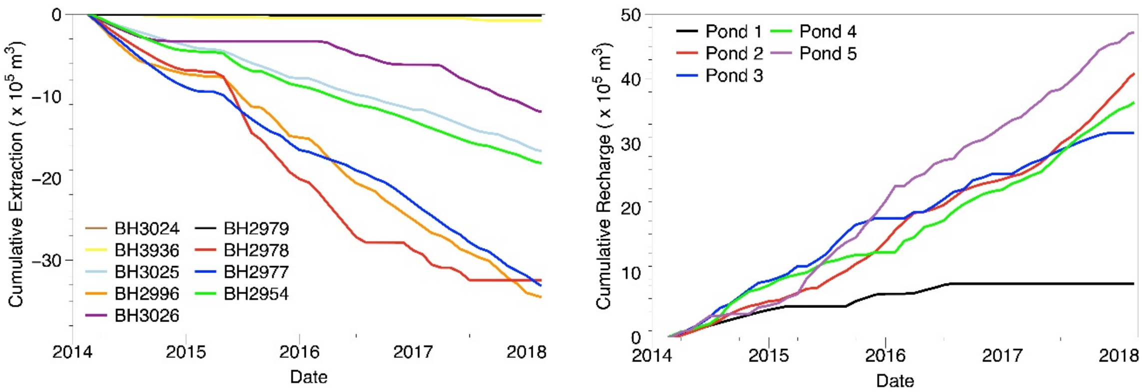

Figure 10. Time evolution of cumulative (a) pumping and (b) artificial recharge for time period February 2014 - February2018 (base scenario). Downstream wells are B/H2979, B/H2978, B/H2977 and B/H2954, whereas the remaining wells are upstream

Figure 11 shows a summary of the groundwater budget for the time period 10/2014-10/2015, as provided by the visualization tools of the web-based INOWAS platform. It can be seen that the artificial recharge is the dominant source term, followed by the ambient inflow from the northern border of the computational domain. On the other hand, groundwater abstraction from the pumping wells contributes the most to the sink terms, followed by the outflow along the coastline.

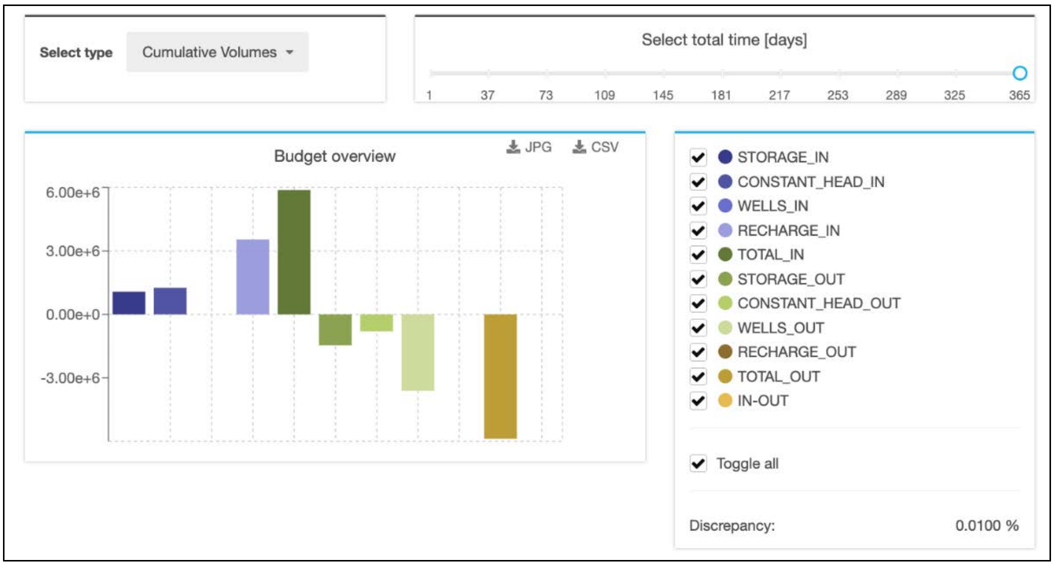

Figure 11. Overview of the groundwater budget for time period 10/2014-10/2015.

Figure 12 shows contour maps of the groundwater levels for two time instances: at the beginning (18/2/2014) and at the end (17/2/2018) of the simulation period. A reduction of the maximum head value at the end of the simulation period can be observed, associated with the CHD boundary conditions at the northern border. Regarding the upstream area, the distribution of the contour lines is slightly affected during the simulation period whereas the spatial variability of the head values is higher close to the coastline at the end of the simulation.

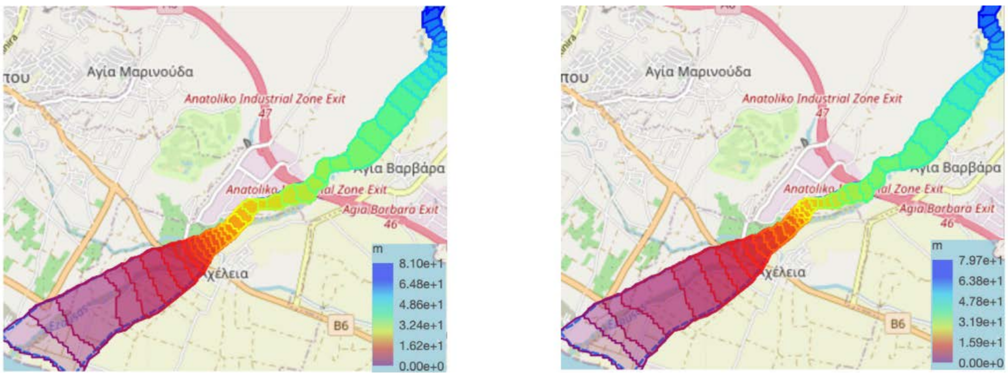

Figure 12. Contour maps of the groundwater head at time instants 18/2/2014 (*left*) and 17/2/2018 (*right*).

To further illustrate this point, the simulated groundwater heads over time are shown in Figure 13 at three observations points: downstream (BH2978), midstream (BH2987) and upstream (BH278).

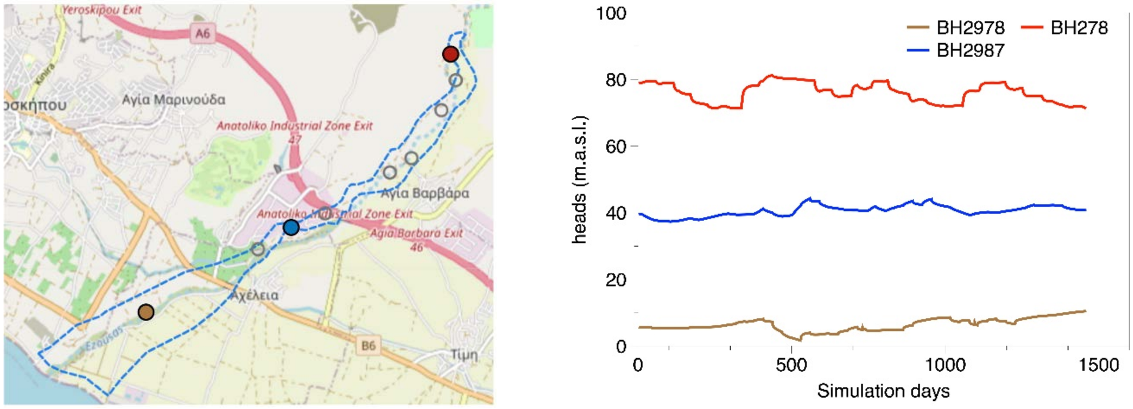

Figure 13. ***Left*: Location of the three observation points (filled circles) at which the time traces of the head are obtained. Open circles denote the remaining observation wells, considered during the validation procedure. *Right*: Time trace of the groundwater head values at the three observation points for the time period 2/2014-2/2018.**

For all three observation locations, a non-decreasing trend of the head values for the simulation period is observed, suggesting that the groundwater losses due to natural and anthropogenic activities are sufficiently recovered, suggesting that the groundwater system is sustainable in terms of water levels.

7. SUMMARY AND OUTLOOK

The present report aims on demonstrating the SMART-CONTROL approach, an innovative web-based, real-time monitoring and control system (RMCS) along with existing tools on the INOWAS platform which are used for the development of a groundwater model.

Grounwater sensors for temperature, electrical conductivity and water level have been installed within the Ezousa riverbed. The sensor locations have been chosen in order to assess seawater intrusion and the impact of the artificial ponds on the ambient groundwater. The data collected from the sensors are sent to the web-based platform, where they can be further elaborated.

Groundwater samples were collected from five different monitoring wells and analyzed in the lab in order to assess the chemical and microbial status of the groundwater. Elevated values for sulfates were observed which might be related either to natural sources (sulfate mineral dissolution or sulfide mineral oxidation of the rock formations) or insufficient technical treatment within the WWTP.

A groundwater flow model for the Ezousa catchment has been set up and a pseudo steady-state flow calibration was conducted to obtain the spatial distribution of the hydraulic conductivity. We have also performed transient computations, which were used to calibrate the specific yield coefficient. The best results were achieved for a specific yield equal to 0.21 (R^2-value around 0.99), whereas the mean normalized squared error is around 4.5 %. The validity of the calibrated model was evaluated based on field measurements obtained during the period 2017-2018. Similar to the calibration case, the R^2 value is close to 0.99, whereas the residuals for most of the data points (>80 %) are less than 5 *m*.

Lastly, we have used the resulting model to conduct a base-case scenario over a four-year time span, particularly the time period 2014-2018. It was observed that the anthropogenic activities are driving the evolution of the aquifer in a sustainable manner as the groundwater levels show a non-decreasing trend. Based on these observations, additional scenarios are currently considered by using different combinations of artificial recharge and pumping rates, since these anthropogenic-related activities are dominating the groundwater processes. These scenarios are based on additional information from local stakeholders, particularly WDD and Paphos Sewage Board. More details will be provided in the final report of the project.

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