ABSTRACT

Increased demand in water has led to overexploitation of groundwater potential. In particular, in areas with increased agricultural activity the water requirements for irrigation are high. The Mires Basin, which is located on the Island of Crete, has marginal groundwater resources that are extensively used for agricultural activities and human consumption. The exploitation of the underground waters of Mires basin is made almost exclusively by pumping wells, which makes the enrichment of the aquifer difficult. In addition, the future trend to reduce rainfall in the area can cause even greater problems in groundwater reserves. This study reviews the hydrological and hydrogeological settings of the basin with the most recent available data by using the Visual MODFLOW package software. Subsequently, sensitivity of the system to the quantitative pressures of the region is examined. In addition, the future condition of the underground potential is estimated based on climate scenarios, developed for the Mediterranean region, and based on the existing management practices applied in Mires basin. The present study findings show that Mires basin is susceptible to pumping when the aquifer is not sufficiently enriched. The most important factor contributing to the supply of the aquifer was found to be return irrigation and not annual precipitation. Considering that the reservoir of the area (Dam of Faneromeni) will work properly, despite the future reduction of precipitation, the basin aquifer will rise after the year 2020.

EXTENDED SUMMARY

The Mires valley as well as the region of the Messara Valley, is the most important rural area of Crete. Part of the island's economy and development is based on the primary (rural) sector by growing intensive aquatic crops. The dry-warm climatic conditions prevailing in the area create from these activities a staggered demand in water mainly during the summer period, which to date has been covered exclusively by the underground aquatic potential of the aquifer of Mires basin. The annual irrigation water needs for Mires valley are 5.000.000 m^3.

Groundwaters of Mires basin have undergone very significant pressures the last 20 years, with most important the (quantitative) exploitation over the quality (pollution) resulting environmental and economic impacts in the area. Also, in line with the institutional framework governing water (Directive 2000/60 / EC), immediate action is needed to reverse the trends of the quantitative and qualitative negative situation in order to achieve the "good status" of the waters of Mires basin and the Messara region. Addressing and remedying this problem requires considerable time and cost. It is urgent and necessary to make sustainable use of water resources by formulating appropriate management plans. The drawing of such plans is based on the use of mathematical models to simulate the behaviour of aquifers.

This postgraduate diploma thesis studies firstly the underground flow in the region of Mires in Heraklion and then studies the sensitivity of the quantitative pressures that the area receives and estimates the quantitative status of the basin in the future using the Visual MODFLOW package software. Thesis is structured in three key parts. The first part focuses on the theoretical background with references to hydrology and the description of the study area. The second part describes the Visual MODFLOW mathematical model and presents the simulation, sensitivity analysis and the future assessment of the situation. Finally, the third part presents the results of the model, analyses the conclusions that come out and suggests proposals for good practices in the study area as well as proposals for future research.

Mires valley catchment is located in the southern-western part of the Messara basin and is formed by submerged graben from the Messara basin. It is set between the forerunners of Phaistos and Vayionia. At the eastern boundary of the basin, lateral groundwater in-flow in the basin occurs from the Vayionia basin to the east of the Mires, whereas groundwater inflow is likely to also occur from the neogenic formations to the north-northwest, while at the western boundary there are groundwater escapes to the basin of Tympaki through the strait of Phaistos. Mires basin consists of other smaller claws of different levels on which floating thick plural and alluvial formations are impacted. Although a large number of pumping wells have been blasted into the basin, they do not provide details to be used to construct its geological structure. An important role in the hydrogeological conditions of the Mires basin is played by the rifts that run through it. Mires valley catchment covers an area of 50,3 Km^2 and the boundaries of the hydrogeological basin are identical with the boundaries of the lowland area and are bounded by submerged graben in which the aquifers of pleistocene formations are maintained at a satisfactory thickness and alluvial deposits with good hydrogeological properties in many zones.

The groundwater calibration was carried out for the year 2008, in which there were available data for water pumping from pumping wells, hydraulic head data from the observation wells of the area, known constant head conditions for lateral inflows and groundwater escapes (drain), hydraulic conductivity data and annual rainfall. Firstly, when the model was calibrated, the necessary parameters were introduced into the model and it simulated the underground flow of the basin. The hydraulic heads that the model was computed in the observation wells were compared to the known values of the same wells and the error was calculated. In particular, the quantitative error was calculated for the calibration of the model according to the equation below.

$$\boldsymbol{Error} = \frac{\boldsymbol{Observed\ value - Calculated\ value}}{\boldsymbol{Observed\ value}}\%$$

When calibrating a model, the acceptable error is up to 10%. As shown in the table below, the average value (%) of the errors in the calibration is satisfactory. Specifically, for the wet period of 2008, the average value of errors was estimated at 6%, while the average value of errors for the dry period was estimated at 7%.

Table 1 Calibration results and errors

	Hydraulic head data (m)		Calibration results (m)		Error (%)	
Observation Well	**0 - 180 days**	**180 - 360 days**	**0 - 180 days**	**180 - 360 days**	**0 - 180 days**	**180 - 360 days**
M3	44,27	26,7	45,37	23,51	2%	12%
M6	42,37	21,8	45,75	22,59	8%	4%
M11	56,41	37,3	56,64	39,77	0%	7%
99	61,27	46,6	59,3	44,29	3%	5%
M7	48,96	35,1	52,4	39,11	7%	11%
M8	70,17	54,7	70,9	53,47	1%	2%
M-A2	45,98	30,6	47,82	27,19	4%	11%
M1	47,35	29,4	49,23	29,91	4%	2%
M12	30,27	19,7	36,19	19,94	20%	1%
M4	31,8	16,8	35,29	19,05	11%	13%
M5	35,42	20,8	33,96	18,41	4%	11%
A.V.					6%	7%

The model was validated for the year 2009 for which we have known rainfall and hydraulic heads data from the observation wells. The results of the model were compared with the known hydraulic heads of the observation wells and the error calculated based on the above equation. The acceptable error when validating a model is 20%. The following table shows the results of the model validation as well as the calculated errors.

Table 2 Validation results

	Hydraulic head data (m)		**Validation results (m)**		**Error (%)**	
Observation Well	**360 - 540 days**	**540 - 720 days**	**360 - 540 days**	**540 - 720 days**	**360 - 540 days**	**540 - 720 days**
M3	45,4	21,45	46,82	22,84	3%	6%
M6	46,8	23,75	47,39	22,46	1%	5%
M11	55,14	41,2	56,67	39,55	3%	4%
99	58,35	45,68	59,19	44,17	1%	3%
M7	51,78	40,1	53,17	39,63	3%	1%
M8	69,84	52	70,58	53,20	1%	2%
M-A2	50,57	25	51,14	25,98	1%	4%
M1	54,65	26,58	53,43	28,10	2%	6%
M12	38,88	20,24	38,26	19,30	2%	5%
M4	36,45	18,72	37,21	18,28	2%	2%
M5	34,25	16,75	35,86	17,68	5%	6%
A.V.					2%	4%

From this process firstly emerged that the model is reliable as it simulates the system of the Mires valley catchment correctly and gives values similar to the real ones. It is therefore suitable to estimate the status of groundwater in the future, for years which no data are available.

Through the process of calibration and validation of the model, known facts for the study area were confirmed regarding the direction of the underground flow, the water speeds and the hydraulic heads in parts of the area of greatest interest. More specifically, the direction of water flow follows the course from east to west with higher flow rates in the eastern part. Higher hydraulic heads values occur at the eastern boundary of the basin where there are lateral groundwater in-flows from the Vayionia basin, while lower values take the western boundary where we have groundwater escapes (leaks) to the Tympaki basin via the strait of Phaistos. Subsequently, the model continued the simulation until the year 2018 where there were known available data on annual rainfall. Until 2017, the results of the model for each year showed a similar situation to previous years.

For the year 2018, which was expected to cover a large part of the needs of the reservoir water the dam of Faneromeni, pumpings were modified. In particular, the water level of the reservoir was reduced considerably and it was not feasible to supply water to the area. Also, the year 2018 it is a dry year with reduced rainfall. According to the local Organization of Rehabilitation Organization (TOEB) in the area, the needs would also be covered by the private pumping wells in the area, which we had not included in the model. However, the pumpings of the private wells were knows and so we could incorporate them into the existing pumping wells. Therefore, we increased the volume of pumping water by 80%. The results of this year showed a decrease in the aquifer level in the central part by 8 m in the wet period and by 16.5 m in the dry period. In addition, during the dry period the level at the western boundary was reduced by 7 m. Following measurements made in July 2018 in the central part of the basin at wells B (B1, B6 etc.), the hydraulic head in this area was 6.5 m. This value is also confirmed by the model. The following figure shows the dry period of year 2018, where the 6.5 m equipotential head is observed, as well as the ground water flow data mentioned above.

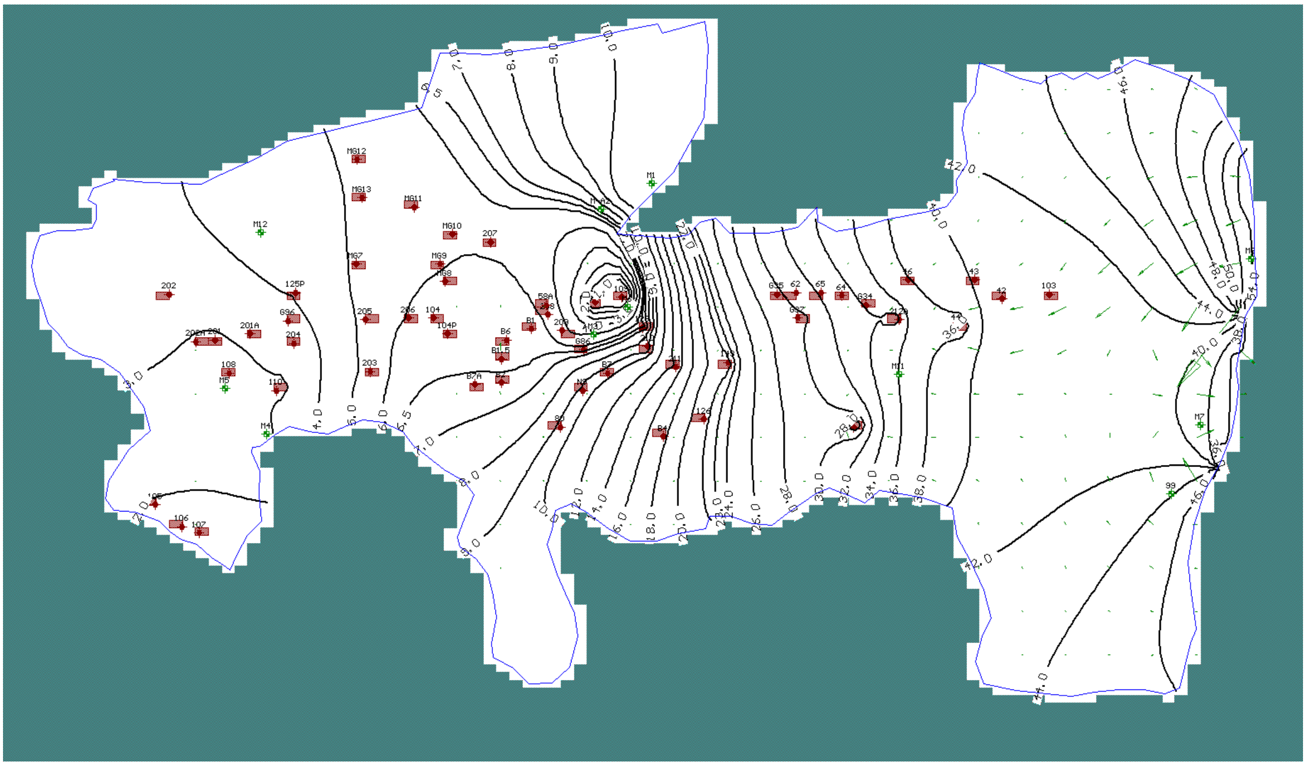

Figure 1 Dry period 2018

Subsequently, the sensitivity of the system to the quantitative pressures it receives and its quantitative status in the future was studied. The years studied were 2020-2021, 2025-2026 and 2030-2031. The annual rainfall rates were obtained from a scientific survey chart which estimates the trend of the annual rainfall in the study area by 2100. For the assessment of this trend, climatic scenarios B1, A1 and A1b were used. From other studies that characterize whether a hydrological year is wet, dry or intermediate on the basis of annual precipitation heights, desirable years were classified as wet years, but the last two years are marginal to this category. In addition, considering the River Basin Management Plan of the Water Department of Crete (GR13) and the practices of TOEB, for a wet year the needs in the area should be covered by 80% from the reservoir of Faneromeni Dam and the remaining 20% from existing pumping wells. Therefore, in our estimation we consider that the reservoir will have water and will function adequately in the years to come. The results of the model for the examined years showed an increase in the level of the aquifer in the central part, which has the largest number of pumping wells and does not receive any lateral groundwater in-flows from another basins. Moreover, based on the results it was found that the two boundaries of the basin (east and west) maintained the hydraulic heads of the years 2008-2017. In the following table are given the hydraulic heads of the eastern, western and central section of the basin that calculated the model at the crucial years.

Table 3 Crucial years results

Crucial year	East - Wet (m)	Middle - Wet (m)	West - Wet (m)	East - Dry (m)	Middle - Dry (m)	West - Dry (m)
2020-2021	76	55	12	52	39,5	10
2025-2026	76	54	12	52	39	10
2030-2031	76	54	12	52	37,5	10
A.V.	76	54,3	12	52	38,7	10

Indicatively, in the following figure shows the simulation of the dry period of 2030 - 2031, in which the equipotential heads and the groundwater flow directions are presented.

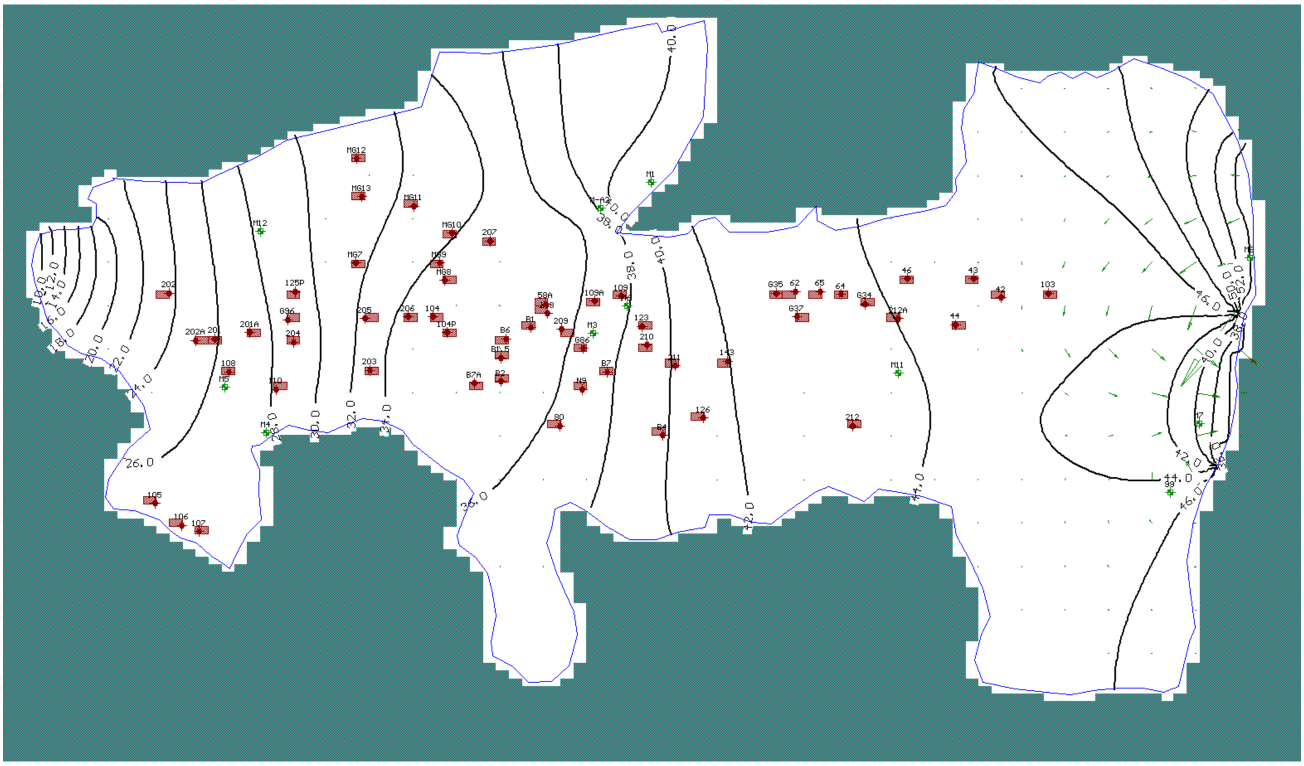

Figure 2 Dry period 2030-2031

The main conclusion that emerged from the study of this thesis is the initial sensitivity of Mires basin to the quantitative pressures it receives. Additionally, despite the fact that the trend of future rainfall is decreasing and despite the reduction in rainfall days, the model estimates that the level of the aquifer in the area will increase. This is due to the fact that the system is primarily affected by enrichment through return irrigation from the reservoir water (Dam of Faneromeni) and secondarily, by the enrichment due to precipitation. Therefore, it is necessary that the reservoir at Faneromeni dam will function properly to give water to the valley of Mires and cover the irrigation needs. In this way, the basin aquifer will be enriched and there will be sufficient water for pumping in the case of a dry year in which the needs will be covered by pumping. Therefore, the objectives set out in Directive 2000/60 / EC can be met in the future through good practices and management of the area's reservoir.