AGRIMAR Assignment

Zhang, Zhechen (1074448)

Luo, Weijia (1073855)

Wang, Feiran (1066589)

1. Examine the worksheets and make sure you understand the processes and conditions given above.

The worksheets describe an irrigation water supply system, which is based on the MAR method. This system is consisting of three parts, catchment, reservoir, and managed aquifer. The catchment is the source of this irrigation water, the reservoir collects water from the catchment as a buffer to store peak runoff flows and to maintain a steady input for the infiltration wells, and the reservoir is the direct source of supply which is recharged by infiltration from the reservoir and abstracted when the irrigation system requires.

The process of AGRIMAR system working is from rainfall in the catchment to the abstraction from the aquifer for irrigation. Firstly, rainfall occurs in the catchment and products runoff. And then the reservoir storage the runoff as a buffer. When the reservoir is not empty, the infiltration wells work continuously, and when there are irrigation requirements, abstraction also take places. The boundary condition of this system is the ratio of total abstraction and infiltration should not be too high in case the water becomes brackish. The threshold is 50% in our cases; in other words, when the ratio is larger than 50%, the system fails.

There are input data, parameters of the AGRIMAR system, and output in the worksheets. Input data include the rainfall and potential evaporation data around the study area. The parameters include two parts, fixed parameters, and dimension parameters. The fixed parameters in this work include the irrigation period, average irrigation requirement, and the threshold. And the dimension parameters are needed to optimize in the following procedures, which include the size of the reservoir (width, length, and depth), the size of catchment, and the infiltration and abstraction capacity. The output includes the dynamic processes of infiltration and abstraction, the fail days, and some visual output, such as the variation of water volume in the reservoir.

2. Try to optimize the dimensions of the catchment area, the reservoir, the infiltration, and abstraction capacities in order to find a system which does not fail during 8 years. The degree of failure can be seen in the graph of worksheet "Sys fail Ned" or as a value in Cell Q20 of worksheet "Model Ned". The value in Cell Q20 is the percentage of irrigation days, during which the system fails. Try to minimize the dimensions above, as they determine the costs of the AGRIMAR system. The unit costs for the four variables are:

This question can be seen as a two-objective optimization problem. The first objective is the system can not fail during 8 years, and the second one is to get the minimum of system building up costs. Obviously, these two objectives are competitive. Increasing the dimension of the irrigation system results in the ability to buffer and infiltration improved, which can enhance the stability and reduce the uncertainty brought by the temporal and spatial variation of hydrological items; while increasing the dimension parameters must cost more.

Because the fail days can not occur, this objective can be seen as a limitation condition. The two-objectives problem can be translated into a one-objective optimization with one boundary condition. The sole objective of the translated problem is to minimum the costs with the boundary condition of no fail days occurring. Thus, in the optimization process, we should search for the parameters' range to meet the boundary condition.

Different parameters bring different influences on the system, so the analysis of parameter effect is essential for the optimization. The abstraction capacity has no influence on the system, as the abstraction volume is determined by the irrigation requirement. Thus, the abstraction capacity only needs to be equal to the irrigation requirement 20 m^3/day. The catchment area determines the total available volume of infiltration water. Thus, the catchment area needs to be big enough to give enough available water to infiltration to avoid that the fail days occur. The reservoir size is determined by three dimensions parameters (width, length, and depth) and is related to the catchment area. The relation between reservoir and catchment is almost negatively, when the infiltration rate is fixed. When the catchment is larger, the available water volume is larger for the same rainfall process, which means less buff needed to carry out; thus, the less reservoir should be carried out. The dominating effect of reservoir size is from the volume of the reservoir, while when the volume is fixed, the distribution of three dimensions has a little influence on the system. The distribution of width, length, and depth only affect the reservoir volume variation based on precipitation and evaporation. And considering the rationality, we fix the width and length as 10 meters and only change the depth in this optimization. The infiltration capacity is based on the infiltration wells, so the infiltration capacity has to be multiples of ten cubic meters per day.

Therefore, the possible values of infiltration are discrete, while the possible values of other parameters are continuous. In the optimization process, we can fix different infiltration capacity values and optimize the size of the reservoir and catchment to determine the optimal result (lowest cost) for each infiltration capacity. Then, by comparing the optimal values under different infiltration capacity situations, the optimization results of the entire system are determined. When optimizing each infiltration condition, we firstly set the catchment area to a particularly huge value. At this time, because the required buffer is very small, the minimum reservoir size that can meet the condition on failure days not occurring is also very small. Then it starts to reduce the catchment area and increase the reservoir size at the same time under the condition of no fail days, until the declining cost of reducing the catchment area could not offset the increasing cost of increasing the reservoir capacity. At this point, the optimization was almost over. Because our model is implemented in Excel, we can also use plug-in Solver to further optimize it, which will be more accurate than our manual optimization. However, the optimization of the Solver is based on the starting value, and the search range is limited, so we have to manually search for a relatively low cost, and then use the Solver to get better. Table 1 lists the optimization results under different infiltration capacity.

Table 1 Optimization results under different infiltration capacity

Number	Infiltration capacity (m^3/day)	Reservoir width (m)	Reservoir length (m)	Reservoir depth (m)	Catchment area (m^2)	Abstraction capacity (m^3/day)	Total costs (€)
1	30	10	10	6.90	57000	20	116478
2	40	10	10	5.00	51000	20	105984
3	50	10	10	3.71	50006	20	103559
4	60	10	10	2.93	50000	20	104645
5	70	10	10	2.26	50001	20	106298
6	80	10	10	2.16	50000	20	110813

From Table 1, the lowest total costs (103559 €) occur at 50 cubic meters per day infiltration capacity. From the optimization results table, the catchment area is very similar between different situations. And notable results are that with the infiltration capacity increasing, the reservoir depth declines. This is because the more infiltration rate means the more rate to translate one rainfall process to groundwater in groundwater, in other words, the less buff needed to carry out. Following Figure 1 and 2 shows the variation of reservoir volume and ratio abstraction to infiltration under the most optimal conditions.

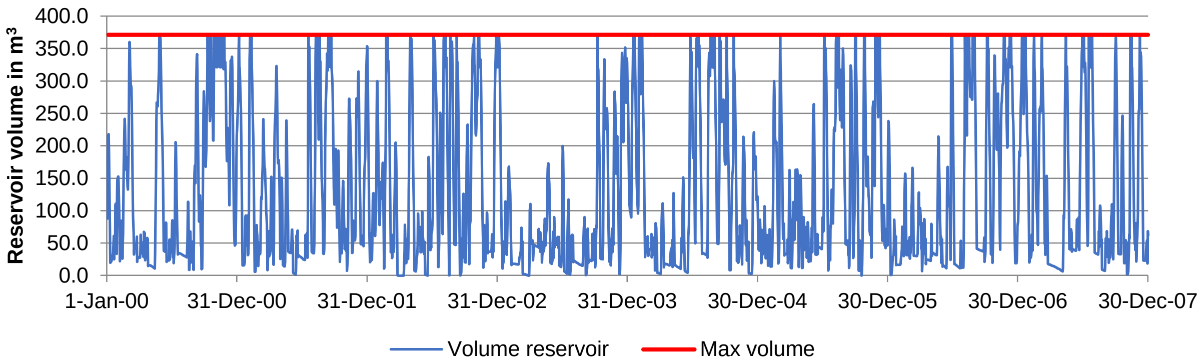

Figure 1 Variation of reservoir volume in Netherlands case

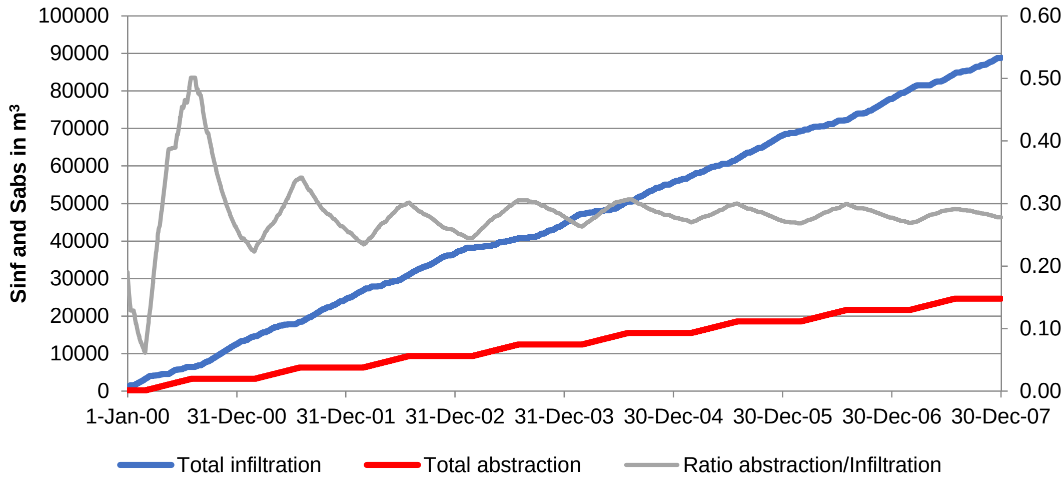

Figure 2 Total infiltration and abstraction in Netherlands case

Figure 1 shows the good operation results of the reservoir. The reservoir reaches full capacity in certain periods of high precipitation, which means no waste of storage capacity. In the dry season, the reservoir is basically not dry up, and the reservoir is in normal operation most of time. This shows that the matching of the reservoir capacity and catchment area and infiltration rate is suitable.

Figure 2 shows the change in the ratio of pumping and infiltration. The ratio shows an obvious inter-annual cyclical change, because the abstraction takes place at a specific time period each year. We can see that the highest ratio appears in the first year, and this ratio gradually stabilizes over time. This is because the total amount of infiltration before the first year is small, but the amount of pumped water is consistent every year. In order to keep the ratio in the first year below 50%, it is necessary to increase the rate of infiltration. Therefore, in subsequent years, this ratio is reduced to about 0.3, which means that the infiltration capacity is wasted. If a certain amount of water can be infiltrated without pumping in the first few years before system working, the rate of infiltration can be further reduced, thereby saving costs.

3. Suppose you allow system failure during 20 % of the irrigation days, does this make a lot of difference in system dimensions and costs?

Table 2 Optimization results under 0% and 20% fail conditions

Fail days (%)	Infiltration capacity	Reservoir width	Reservoir length	Reservoir depth	Catchment area	Abstraction capacity	Total costs

	(m^3/day)	(m)	(m)	(m)	(m^2)	(m^3/day)	(€)
0	50	10	10	3.71	50006	20	103559
20	30	7	7	2.7	21964	20	53579

There are obvious differences in system dimensions and costs between 0% and 20% fail days listed in Table 2. The dimensions and cost of the system has been significantly reduced by about 50%. But the guarantee rate of the system has only been reduced by 20%. It can be explained that in order to meet the requirements of a day without fail, the size and cost of the system have increased a lot. This shows that the cost of solving some extreme conditions is very high, such as extreme drought conditions, and the time distribution of rainfall is extremely uneven. If the requirements of the guarantee rate can be appropriately relaxed, the cost will be significantly reduced.

4. Answer question 2 for the Portugal case.

The same optimization method as question 2 is used in Portugal case. The results of the optimization are listed in Table 3. And the visual graph is shown in Figures 3 and 4. The infiltration capacity, reservoir size and catchment area in Portugal are larger than the values in Netherlands cases. There are two reasons for these large parameters. The first one is the average irrigation requirements increasing from 20 m^3/day to 30 m^3/day. The second reason is the large evaporation and little and discontinuous precipitation. It can be seen from Figure 3 that the storage of the reservoir has changed more drastically than the Netherlands case. Because evaporation is large, fast infiltration can reduce the evaporation loss caused by the water in the reservoir. Figure 4 shows that the change in the ratio of abstraction and infiltration is similar to the conclusion of the Netherlands case. The only difference is that the ratio of Portugal is generally higher than that of the Netherlands. This shows that the Portugal AGRIMAR system is more efficient than the Netherlands system.

Table 3 Optimization result for Portugal case with no fail days

Fail days (%)	Infiltration capacity (m^3/day)	Reservoir width (m)	Reservoir length (m)	Reservoir depth (m)	Catchment area (m^2)	Abstraction capacity (m^3/day)	Total costs (€)

0	100	15	15	5.15	113006	40	240752

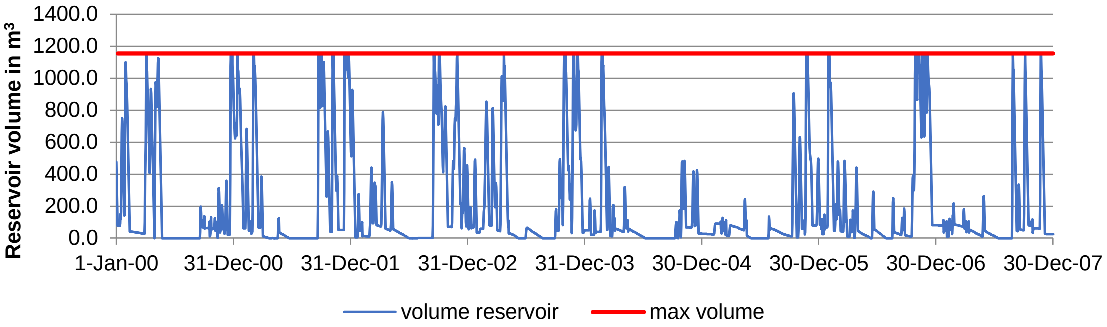

Figure 3 Variation of reservoir volume in Portugal case

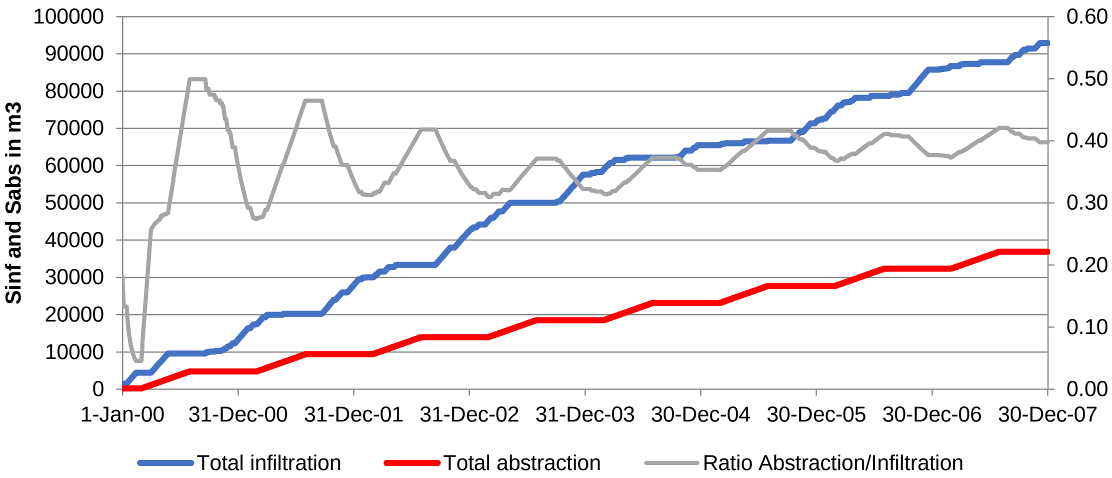

Figure 4 Total infiltration and abstraction in Portugal case

5. Look at cells B2944 to K2946 at the bottom of "Model Ned" and" Model Por" worksheets. Can you explain the difference between the Netherlands and Portugal cases on the basis of these average annual figures?

Table 4 Average annual feature data in Netherlands and Portugal cases

Case	Average prec	Average evap	Aver eff prec	Aver runoff catch	Aver runoff to res	Aver res to MAR	Aver irr req	Evr irr req	Aver MAR to irr	Aver prec-evap res
	mm/yr	mm/yr	mm/yr	mm/yr	m^3/yr	m^3/yr	mm/yr	m^3/yr	m^3/yr	m^3/yr
NED	806	614	267	267	11673	10981	306	3060	3060	20
POR	452	983	130	130	12792	11488	459	4590	4590	-45

The natural hydrological conditions of the Netherlands and Portuguese cases are very different. The precipitation in the Netherlands is abundant, continuous and greater than evaporation. However, the precipitation in Portugal is low, discontinuous and less than evaporation. Therefore, we can see from the optimization results mentioned above that the infiltration rate in the Netherlands is not large but continuous, but the infiltration strategy in Portugal is to infiltrate effective rainfall to groundwater as soon as possible. Although this strategy of Portugal increases the cost of the system, it can only be done to reduce the impact of evaporation. In addition, due to different hydrological conditions, another significant difference is the relationship between evaporation and rainfall in the reservoir area. In the Netherlands reservoir area, rainfall replenishes the water in the reservoir, while in Portugal, evaporation is greater than rainfall, and the storage capacity of the reservoir decreases due to evaporation. Therefore, if conditions permit, the surface area of the reservoir should be minimized in Portugal

6. Why do you think excess irrigation would ne be needed in a dry region around Faro, Portugal?

The reason is in the dry region in Portugal the potential evaporation is much larger than the precipitation. From Table 4, the value of precipitation minus evaporation is -45 m^3/year, which is equal to 202 mm/year, in the reservoir area. This value shows the high evaporation in this area. And if the available water is enough, the evaporation from the irrigation area in the irrigation period is near 1 mm/day. Thus, excess irrigation is essential in Portugal study area.