DETERMINATION OF OPTIMUM CAPACITY AND OPERATION OF RESERVOIRS FOR IRRIGATION PURPOSES

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DETERMINATION OF OPTIMUM CAPACITY AND OPERATION OF RESERVOIRS FOR IRRIGATION PURPOSES

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ABSTRACT

DETERMINATION OF OPTIMUM CAPACITY AND OPERATION OF RESERVOIRS FOR IRRIGATION PURPOSES

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Agricultural production is one of the most basic requirements of humanity to survive and water is vital for it. Therefore, human beings have been working on water resources giving the necessary importance throughout the history. Problems like irregularities in streams regime, droughts and climate change force to use water more efficiently. In addition, population growth has increased the demand for agricultural water. Nowadays, with the construction of dams for irrigation purposes, these demands can be met in a more efficient manner. However, since the construction of the dam requires large costs, optimal dimensioning of such storage facilities is very significant together with the optimal operation. The main goal of the present study is to design and operate the reservoir of a dam for irrigation purposes, in an optimum manner. Two methods, Enumeration and Generalized Reduced Gradient, are applied and a code is developed in Microsoft Excel for this purpose. Advantages and disadvantages of the two methods used in the developed code were also discussed. The developed code is validated by using reservoir operation data of the Sungurlu Dam that planning works were carried out before. In the present study, three different optimization problems are handled. These are the minimization of the reservoir capacity, the maximization of the irrigation area and the maximization of irrigation area together with the minimization of the reservoir capacity. In addition, developed code is applied by using data of Sungurlu and Yeşilkavak dams.

Keywords: Reservoir Operation, Optimization, Irrigation

ÖZ

SULAMA AMAÇLI REZERVUARLARDA İŞLETME ÇALIŞMASI YAPILMASI VE OPTIMUM REZERVUAR KAPASİTESİNİN BELİRLENMESİ

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Tarımsal üretim insanlığın hayatta kalabilmesi için en temel gereksinimlerden biridir ve su tarım için hayati önem taşımaktadır. Bu nedenle insanoğlu tarih boyunca su kaynakları üzerinde çalışmış ve ona gerekli önemi vermiştir. Akarsulardaki rejim düzensizlikleri, kuraklıklar ve iklim değişiklikleri gibi problemler insanlığın suyu daha verimli kullanma gereksinimlerini ortaya çıkarmış; nüfus artışı ise tarımsal su talebini artırmıştır. Günümüzde sulama amaçlı barajların inşaası ile bu talepler daha verimli bir şekilde karşılanabilmektedir. Fakat barajlar büyük maliyetler gerektirdiğinden, bu gibi depolama tesislerinin optimum boyutlandırılması ve depolanan suyun en uygun şekilde kullanılması gerekmektedir. Bu çalışmanın ana amacı, iki ayrı metot kulanılarak (Enumeration ve Generalized Reduced Gradient), sulama amaçlı bir barajın rezervuarını optimum bir şekilde işleterek boyutlandırabilmektir. Bilgisayar ortamında iki ayrı yöntem kullanılarak Microsoft Excel ortamında program yazılmıştır. Kullanılan iki yöntemle avantaj ve dezavantajları tespit edilmiştir. Planlama çalışmaları yapılmış olan Sungurlu Barajı işletme çalışması verileri kullanılarak program doğrulanmış, kapasite ve sulama sahası optimizasyonları yapılmıştır. Bu çalışmada üç farklı optimizasyon problemi ele alınmıştır. Bu problemler rezervuar kapasitesi minimizasyonu, sulama alanı maksimizasyonu ve eş zamanlı olarak hem rezervuar kapasitesi minimizasyonu hem de sulama alanı maksimizasyonudur. Ayrıca Sungurlu ve Yeşilkavak barajlarının verileri kullanılarak geliştirilen program üzerinde uygulamalar yapılmıştır.

Anahtar Kelimeler: Rezervuar İşletmesi, Optimizasyon, Sulama

To My Family

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CHAPTER 1

INTRODUCTION

1.1 Importance of Reservoirs

Human beings have always needed water to survive throughout the history. This need forced humanity constructing variety of structures in order to store water. The water requirement has steadily increased with the continuous increase of the population. Especially, at arid regions which have inadequate precipitation and irregularity of river regimes, efficient use of existing water resources is very important. This is why dams are necessary for these territories.

Four main purposes of dams are:

1) Municipal, potable and industrial water to meet the need of water

2) Hydroelectric power to meet the need of energy

3) Flood control

4) Irrigation of agricultural lands

Irrigation of agricultural lands is as vital for people as the other three main objectives. Each year more and more rapid increase in human population leads to nutritional requirements. To meet this increased demand, irrigation of agricultural areas should be suitable and sufficient. This optimal reservoir capacity demand is very important to satisfy the needs of present and future.

Number of flow measurements data on river affects significantly the accuracy of an optimal reservoir capacity design. In fact, observed data on river shed light on the future of the dam.

1.2 Approaches for Determination of Reservoir Storage

There are two classical methods to determine the storage for a certain location of a river namely, the mass curve analysis and the sequent peak analysis.

Mass curve analysis method is a graphical analysis method and the curve is formed with the cumulative flow volumes drawn against time. In this method, observed flow volumes are plotted cumulatively and the demand is plotted tangential to cumulative flow volumes. Maximum difference between the tangential plots is accepted as the active volume of the reservoir. This method is valid only when the demands are constant.

Sequent peak analysis method is an improved version of mass curve analysis method. The differences between cumulative summation of inflows and demands are drawn against time. The vertical difference between initial peak and lowest point before the sequent peak is accepted as the active storage capacity.

These two methods may be used to calculate reservoir storage capacity but optimum reservoir operation study is a better way to calculate required reservoir storage capacity because some of the parameters (evaporation, spill releases) are not constants and the functions of the unknown reservoir storage. To solve this problem, optimization models have to be considered by selecting the suitable method.

1.3 Literature Review

Dams are costly structures and size of dam plays an important role for investment. Since the size of the reservoir capacity is directly related to the size of the dam, obtaining optimum reservoir capacity is very crucial. In order to achieve this task, it is required to operate the reservoir in an optimal manner. The number of flow measurements on river is also important for designing optimum reservoir capacity. In fact, the observed data on river shed light on the future of the dam. Chow (1964) expressed that water resources systems need a great amount of hydrological data to examine the immense range of reaction of systems in simulation analysis.

Kuiper (1965) defined the irrigation requirement as the need of the plant considering the available precipitation. Thus, it is important to consider the irrigation necessity for reservoir capacity optimization.

Flow-storage relationship for a reservoir problem, which has direct relation with designing reservoir, is one of the fundamental hydrological analysis problems. The primary issue in storage-yield studies (U.S Army Corps of Engineers- HEC, 1977) is the designation of storage to provide a specified yield or the designation of a yield for a certain quantity of storage.

Maass et al. (1966) argued that for a certain water resources system, operation process is simply an establishment of rules for storing and releasing water from surface and ground water reservoirs. The three important decisions that have to be set concerning to the allocation of storage and discharge of water are defined as the apportionment through reservoirs, through purposes, and through time periods.

The firm yield of reservoir is determined as the average yearly flow which would reduce the reservoir to a reasonable elevation just once along the critical aridity of the record by Chow et al. (1988). In order to solve the reservoir optimization problem, firm yield is an important parameter associated to the storage-yield relationship. Mays and Tung (1992) stated that firm yield is determined as the greatest amount of flow rate which is reliable at the given site throughout the river at all time period.

Two classical methods are used to determine storage needs to understand and improve flow storage relationship for a certain stream. Mass curve analysis and sequent-peak analysis are these two methods. As expressed in Sattari, et al. (2008), Ripple (1883) developed the mass curve analysis method which is the plot of the cumulative flow volume as a function of time. The method is also called as Ripple Method. Logic of the method is identifying the critical period which leads to largest drawdown in storage. Thomas (1963) proposed the sequent-peak analysis method which computes the cumulative sum of inflows minus the reservoir releases for all time periods over the time interval of analysis (Sattari, et al. 2008).

1.4 Scope of the Study

Preliminary survey and planning works play an important role for designing of a dam. First of all, storage suitability which means topography and the water potential of stream is searched for the location of the dam axis on stream. To understand the flow potential of the stream, it is necessary to obtain flow observations for past years. Reservoir operation study is carried out by using the flow observations, and designing of reservoir is directly related to it.

The aim of the thesis is to obtain the optimum operation of reservoir with determination of the optimum reservoir capacity for irrigation purposes. The basis of this research is the determination of reservoir capacity in an optimum manner (minimization of the capacity) if the irrigational area is known; maximization of irrigation area if the reservoir capacity is known; determination of reservoir capacity and irrigation area in an optimum manner simultaneously associated with the stream flow potential, if both irrigation area and reservoir capacity are unknowns. The optimization problem is defined in Chapter 2.

To conduct these studies, a code is developed in Excel Visual Basic Application (VBA). With the developed program in Excel, reservoir operation studies are carried out by using two methods namely, Enumeration method and Generalized Reduced Gradient (GRG) method. In the thesis, a comparison of these methods is done in Chapter 3. Some information about the developed program is also given in Chapter 3. Specifically, the program inputs and outputs are discussed in Chapter 3.

Applications and Results of the code are given in Chapter 4. There are two classical methods to accomplish reservoir operation study, namely Mass Curve Method and Sequent Peak Analysis Method. These are graphical methods. In the research, these methods are also explained and applied. The results of the graphical method are also compared with the results obtained from the developed code in Chapter 4.

In summary, the thesis begins with the Introduction chapter which includes importance of reservoir, approaches for the determination of the reservoir storage and literature review. The second chapter is about formulation of optimization problem. In the second chapter, the objective functions are defined in the problem definition part. Then, assumptions made for the optimization problem are stated. Moreover, optimization problem methods are discussed. The third chapter of the thesis is about the construction and verification of the code. It contains information about developed code in Excel. It is verified by using real data which are taken from the Sungurlu Dam planning works. The forth chapter is about applications and results. In the fourth chapter, firstly, the effect of the number of flow measurements is discussed. Then, by using the data of the Sungurlu Dam, optimum reservoir operation studies are done for different irrigation areas. In addition, classical graphical reservoir operation studies are carried out with the data of the Sungurlu Dam and the results are compared. Moreover, optimum reservoir operation studies are carried out by using the data of the Yeşilkavak Dam. The last chapter of the thesis is the conclusion part where results are summarized and evaluated.

CHAPTER 2

FORMULATION OF OPTIMIZATION PROBLEM

2.1 Problem Definition

Determination of the reservoir capacity for irrigation dams is directly linked to management of the system correctly. In this study, the objective function is formed in three different ways, namely the minimization of capacity (for a given irrigation area), the maximization of irrigation area (for a given capacity) and the minimization of the capacity together with the maximization of the irrigation area.

The objective function is,

Minimize $Ka + Kd$ (1)

or

Maximize Ar (2)

or

Minimize $Ka + Kd$ and Maximize Ar (3)

where Ka is the capacity of reservoir (Active volume), Kd is the defined dead storage volume of reservoir and Ar is the total irrigation area.

One of the constraints of the optimization problem is the mass balance that has to be conserved in each time period. In other words, continuity equation has to be satisfied which is,

$$S_{i+1} = S_i + I_i + (P_i \times As) - (Ev_i \times As) - (Q_i \times Ar) - In_i - Sp_i - D_i \quad \text{for } i = 1, \ldots N \quad (4)$$

where S_{i+1} is the reservoir storage at the end of the time period i (or at the beginning of the time period $i+1$), S_i is the reservoir storage at the beginning of the time period

i, I_i is the inflow obtained from the measured flow observations in river during time period i, P_i is the precipitation into the reservoir surface area during time period i, Ev_i is the evaporation amount obtained from the meteorological observation station during time period i, As is the average reservoir surface area during the time period i which is a function of S_i, Q_i is the crop water requirement for one hectare during time period i, In_i is the seepage of water from the body of the dam during time period i, Sp_i is the total amount of spill from the reservoir during time period i which is a function of reservoir capacity, Ka, and D_i is the other demands like municipal water needs, etc.

It should be noted that considering the evaporation and precipitation in the continuity equation makes the optimization problem nonlinear since they are also functions of the unknown storage. When In_i and P_i are small compared to other parameters, they can be neglected. To obtain reliable results from the system, flow observations have to be plenty. The more observed data means reliable solution. Therefore, obtaining optimum reservoir capacity directly depends on the available flow observations.

The second constraint is that the amount of water stored in the reservoir at any time cannot be more than its capacity.

$$S_i - Ka - Kd \leq 0 \qquad (5)$$

The third constraint is that the storage at any time has to be equal or more than the dead storage.

$$S_i - Kd \geq 0 \qquad (6)$$

2.1.1 Assumptions Made for Optimization Problem

In order to determine the optimization problem correctly, the following assumptions are made in the optimization problem.

1) Reservoir storage is full at the beginning of the time period ($S_1 = Ka + Kd$).

2) Crop water demand for one hectare is distributed uniformly for each year and for all irrigation area.

3) Each parameter in continuity equation is expressed as in cubic meter per month as flow measurements are obtained in cubic meters or hectometers per month.

4) Evaporations are calculated as the arithmetic average of the storage at the beginning of month and at the end of month for each time period.

5) Reservoir storage has to drop dead volume level only once for all time period. After that, it has to be full again. If the reservoir storage drops dead volume level at the end of time period then population has to be replicated to make sure that the reservoir becomes full again.

2.2 Methods used for Optimization Problem

The optimization problem is solved by using two different methods. One is the Enumeration method and the other one is the Generalized Reduced Gradient (GRG) method.

Enumeration method is a deterministic method which guarantees the exact solution. In other words, the global optimal solution is always guaranteed with this method. The method basically tries all the possible solutions with certain increments and selects the optimum one. Although the method guarantees solution, it takes too much time to reach an optimal solution. Furthermore, increment size plays an important role to come up with the exact solution.

Generalized Reduced Gradient (GRG) method is used for nonlinear optimization problems. It is basically a generalization of the reduced gradient method by permitting nonlinear constraints and arbitrary bounds on the variables. It is known that for nonlinear problems, global optimum cannot be guaranteed. It may be stuck in a local minimum or a local maximum. In addition, compared with the other method, GRG method reaches the optimum solution much faster.

In the present study, both methods are used in Microsoft Excel Visual Basic Application (VBA) in order to solve the nonlinear optimization problem. In using the second method (GRG), Microsoft Excel Solver GRG nonlinear engine is utilized.

CHAPTER 3

CONSTRUCTION AND VERIFICATION OF THE CODE

3.1 General Information about the Developed Code

All parameters and functions are defined in the Chapter 2. Then, as it is mentioned in the previous chapters, the code is developed in Microsoft Excel by using VBA. The following sections give the inputs of the code, instruction about running of the code and the output of the code, respectively.

3.1.1 Inputs of the Developed Code

First of all, it is necessary to define the input parameters for reservoir operation. Therefore, first sheet is the input sheet which is named as “Giris” in the program. When the program is opened, the first thing to do is filling the “Giris” sheet correctly. In the program, the inputs are written in red.

First cell that needs to be filled in the “Giris” sheet is about the project name and the following cell which has to be filled is about the dead volume (minimum volume) value. Dead volume part of the reservoir cannot be used for irrigation purposes or any other purposes of reservoir operation. It is due to the accumulation of bed load because of dam construction. It is calculated with respect to dams’ economic life which is taken as 50 years in Turkey. The calculation of this accumulation is also depended on drainage area (km^2) where dam is constructed. Hence, bed load efficiency (m^3/km^2/years) is also significant for the calculation of the dead volume of reservoir. The intake level of shaft for irrigation is located above or equal at the dead volume level in order to prevent any blockage for the bottom outlet structures. Dead volume is also called inactive storage volume for a reservoir.

The third section is about the inflow of the reservoir. Inflows are the past flow measurements for the corresponding years. The unit of the inflows has to be taken as cubic hectometers per month. The correctness and length of the flow measurements are important because they are the indicators of flow potential of the stream. In Turkey, General Directorate of State Hydraulic Works (DSI) accepts that the length of the flow measurements data should be minimum 20 years for irrigation purposes to obtain reliable results. By looking at the data, dry and wet years in the past can be figured out. It may also help to better understand the reservoir operation results. Table 3.1 shows the example of input sheet (Giriş) in the program for the Sungurlu Dam data.

Afterwards, water level elevation, surface area, and the corresponding volume of the reservoir should be filled (4^{th} section). It is basically about the characteristics of topography of the reservoir which has to be determined by studying on the map of the reservoir area. The elevation, area and volume have to be provided in meters, square meters and cubic meters, respectively in the program. Sometimes, after running the program, it may give a warning about the fourth section. The reason of the warning is that provided elevation, area, and the corresponding volume of the reservoir is insufficient to obtain the result due to exceeding the maximum limits. Additional data has to be integrated at the end of forth section according to the characteristics of topography of the reservoir.

The fifth section should be filled according to defined crop water requirement. The unit of the requirement is cubic meters per hectare for each month. The calculation of crop water requirement depends on the crop pattern which is defined as the ratio of various crops for a determined irrigation area at a specific period of time. In order to run the program, the second, third, fourth and fifth sections have to be defined.

The sixth section is river water requirement. It is basically the minimum required water for stream life. In Turkey, the calculation of the river water requirement is determined in the Ecosystem Assessment Report. The next section is about evaporation. It is calculated as in millimeters for each month. Evaporation depends on the reservoir surface area which changes due to reservoir storage. Initially, evaporation is calculated by using the storage at the beginning of each month. Then, the storage at the end of each month is found from the continuity making use of the calculated evaporation value. Finally, the average storage (the beginning and the end of each month) is used to calculate the corresponding evaporation for each time period.

The eighth, ninth and tenth sections are drinking water requirement, downstream water right and infiltration on dam, respectively. These sections have to be filled when it is necessary. For example, if reservoir has drinking water purposes, eighth section has to be defined. If there is water usage at downstream of the reservoir, required water has to be given in ninth section.

The last section is infiltration part. It is usually ignored because of very small values when it is compared with the other parameters. Table 3.2 and Table 3.3 show the example of input sheet (Giriş) in the program for the Sungurlu Dam data. In Table 3.3, the section of downstream water right and the section of infiltration is not used for Sungurlu Dam.

In the Enumeration Method, the optimum solution is achieved by trying the possible values of the decision variables by using certain increment size. Actually, the increment size is an important input and, affects the run time of the problem. Selection of small increment increases the calculation time of the problem together with the precision of the solution. On the other hand, large increment size provides run in a short span of time but precision of the solution decreases. In the study, for the first objective function which is the minimization of capacity, the increment size is selected as 500000 m^3 at the beginning of the running process. After the program approaches to the optimum result, the increment size is reduced to 1000 m^3. For the second objective function which is the maximization of the irrigation area, the increment size is selected as 100 ha at the beginning of the running process. After the program approaches to the optimum result, the increment size is reduced to 0.1 ha. For the third objective function which is the optimization of the irrigation area and the capacity, the increment size for the capacity is selected as 500000 m^3 at the beginning then decreased to 1000 m^3. The increment size for the irrigation area is selected as 1000 ha at the beginning and then decreased to 250 ha, 50 ha, 5 ha, 1 ha, respectively. Although the increment size is an input for the problem for all cases, the given values are the default values and cannot be changed unless the developed codes are intervened in. In addition to increment size, the value of stopping criterion is another input for the program which is the 10th section in the input sheet. It is only used for the Enumeration Method. This value is directly related to obtain an accurate optimum result. Increasing this value reduces the precision of the solution. On the contrary, decreasing this value may lead to not obtaining any result. The optimum solution may be skipped because of selecting a small value for the stopping criterion. In the study, the default value of the stopping criterion is 2000 m^3. Depending on the size of the problem, it may be changed until the optimum solution is achieved.

GRG Method does not use the increment size and the stopping criterion. In the thesis, Microsoft Excel Solver Engine is utilized for GRG Method and the default solver options are used.

Table 3.1 Example of the Sungurlu Dam Input Sheet for the Reservoir Operation Problem (for the 1st, 2nd, 3th and 10th sections)

1	**Prj.Name**	**Sungurlu Dam**												
2	**Dead Volume (m^3)**					**5156125**			10	**Stopping Cr (m^3)**				
										2000				
3						**Inflow (hm^3)**								
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Total	Avr.
1987	0.5	0.6	0.7	3.8	8.3	9.1	10.4	5.8	1.9	1.2	0.5	0.5	43.3	
1988	0.6	1.3	3.3	0.9	2.1	9.6	4.7	2.4	1.1	1.1	0.5	0.5	28.1	
1989	0.9	2.6	3.5	3.0	2.8	5.0	2.1	1.4	0.5	0.4	0.4	0.4	23.2	
1990	0.6	4.0	5.0	2.9	2.3	5.4	4.9	10.8	1.8	0.9	0.4	0.4	39.4	
1991	0.5	0.6	1.0	1.0	1.9	3.1	4.4	4.7	3.1	0.5	0.4	0.4	21.6	
1992	0.7	0.6	0.6	1.2	0.7	4.6	2.7	1.1	0.8	0.6	0.4	0.4	14.4	
1993	0.4	1.0	1.0	0.7	2.6	14.9	7.4	7.3	0.7	0.4	0.5	0.4	37.2	
1994	0.4	0.5	0.9	1.2	1.6	3.6	2.2	3.1	0.5	0.5	0.4	0.4	15.2	
1995	0.4	0.7	0.9	2.3	0.4	3.0	4.9	3.9	1.2	0.6	0.4	0.4	19.1	
1996	0.5	1.7	1.7	2.0	3.3	10.3	9.8	5.6	1.3	0.3	0.2	0.3	37.1	
1997	0.4	0.4	1.1	1.1	1.8	1.4	4.8	2.2	1.1	0.5	0.4	0.4	15.7	
1998	0.4	0.4	7.0	3.1	3.5	1.9	2.3	4.2	5.3	4.2	0.5	0.5	33.5	23.7
1999	0.4	0.6	1.7	0.9	3.5	7.6	6.9	2.3	0.2	0.4	0.6	0.4	25.5	
2000	0.4	0.7	0.3	0.3	0.6	4.8	8.0	5.1	2.0	0.5	0.5	0.4	23.5	
2001	0.6	0.9	0.9	0.6	1.0	1.1	0.4	0.8	0.1	0.1	0.1	0.1	6.6	
2002	0.4	0.4	1.7	6.5	5.5	3.2	6.7	3.1	1.4	0.5	0.5	0.5	30.3	
2003	0.4	0.6	0.4	0.2	0.5	1.8	0.8	1.8	0.1	0.1	0.1	0.2	7.2	
2004	0.3	0.1	1.1	6.6	4.3	4.2	2.9	2.1	1.1	0.5	0.4	0.4	24.0	
2005	0.2	0.6	0.7	0.5	0.7	4.5	3.5	2.9	0.7	0.1	0.1	0.1	14.7	
2006	0.3	1.9	1.2	0.8	4.6	5.4	4.4	1.4	0.3	0.4	0.1	0.2	21.1	
2007	1.2	2.0	0.8	1.0	1.4	3.6	2.4	0.1	0.4	0.1	0.1	0.1	13.0	
2008	0.4	0.4	1.0	0.7	0.5	2.2	2.6	1.0	0.6	0.5	0.4	0.4	10.7	
2009	0.1	0.1	0.1	4.8	2.5	9.6	5.8	5.0	1.0	0.3	0.1	0.1	29.5	
2010	0.2	1.7	2.7	3.6	3.7	3.2	3.5	1.2	0.9	0.6	0.1	0.1	21.5	
2011	0.4	0.4	4.1	3.6	6.8	5.8	5.8	3.6	3.9	2.2	0.6	0.5	37.8	
2012	0.7	1.0	1.1	1.2	1.1	6.4	7.2	1.2	1.3	0.3	0.2	0.1	21.9	

As can be seen from the Table 3.1, the total flow of each year and the average flow of the period are calculated.

Table 3.2 Example of the Sungurlu Dam Input Sheet for the Reservoir Operation Problem (for the 4th, 5th and 6th sections)

4	Elevation, Area, Volume Table		
	Elev. (m)	Area (m^2)	Vol. (m^3)
	818	0	0
	819	262	131
	820	3900	2212
	821	39598	23961
	822	99487	93504
	824	329212	522203
	826	536637	1388052
	828	795339	2720027
	832	1489824	7222481
	834	1852362	10564668
	835	2081967	12531832
	836	2291060	14718345
	840	3316225	25850524
	841	3646757	29332015
	842	4024599	33167692
	843	4472864	37416424
	844	5035545	42170629
	845	5574993	47475898
	846	5988126	53257457
	847	6388234	59445637
	848	6807608	66043558
	849	7196527	73045626
	850	7600668	80444223
	851	8040633	88264873
	852	8491297	96530838

5	Crop Water Requirement (m^3/ha)	
	Oct	14
	Nov	0
	Dec	0
	Jan	0
	Feb	0
	Mar	0
	Apr	0
	May	21
	Jun	507
	July	1398
	Aug	1019
	Sep	299

6	River Water Requirement (m^3)	
	Oct	214272
	Nov	207360
	Dec	214272
	Jan	267840
	Feb	338688
	Mar	669600
	Apr	596160
	May	401760
	Jun	207360
	July	214272
	Aug	214272
	Sep	207360

Table 3.3 Example of the Sungurlu Dam Input Sheet for the Reservoir Operation Problem (for the 7th, 8th, 9th and 9th sections)

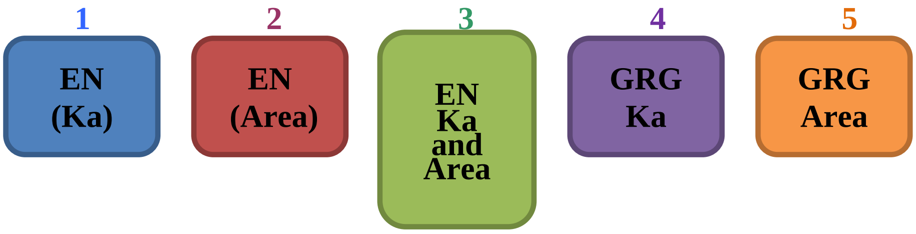
7	Evaporation (mm)		8	Drinking Water Requirement (m^3)		9	Downstream Water Right (m^3)		10	Infiltration (m^3)	
	Oct	37.37		Oct	525600		Oct			Oct	
	Nov	0.00		Nov	525600		Nov			Nov	
	Dec	0.00		Dec	525600		Dec			Dec	
	Jan	0.00		Jan	525600		Jan			Jan	
	Feb	0.00		Feb	525600		Feb			Feb	
	Mar	0.00		Mar	525600		Mar			Mar	
	Apr	7.39		Apr	525600		Apr			Apr	
	May	31.01		May	525600		May			May	
	Jun	77.45		Jun	525600		Jun			Jun	
	July	137.94		July	525600		July			July	
	Aug	137.83		Aug	525600		Aug			Aug	
	Sep	95.91		Sep	525600		Sep			Sep	

3.1.2 Instructions about Running of the Developed Code

After the inputs of the problem are defined, the user should switch to the output sheet which is named as “Sonuc” in the program. In this sheet, program can be run by using five buttons according to the goal of the user. At the top of the sheet, there are instructions to help for using each button correctly. First, second and third buttons use Enumeration Method and fourth and fifth buttons use GRG Method for the solution of the optimization problem. The first and fourth button is used for minimization of capacity (while irrigation area is known). The second and fifth button is used for maximization of irrigation area (while capacity is known). The third button is used for both maximization of irrigation area and minimization of capacity (while both are unknown). Table 3.4 shows some part of view of the “Sonuc” sheet which indicates the instructions about running of the program.

Table 3.4 Instructions about Running of the Developed Code

	INSTRUCTIONS
1)	Button 1, Button 2 and Button 3 use Enumeration Method while Button 4 and Button 5 use GRG Nonlinear Optimization method
2)	Use Button 1 and Button 4 to optimize the reservoir capacity (minimization of reservoir capacity while irrigation area is known)
3)	Use Button 2 and Button 5 to optimize the irrigation area (maximization of irrigation area while capacity is known)
4)	Use Button 3 to optimize both irrigation area and capacity (while both is unknown)



3.1.3 Outputs of the Developed Code

After the program is run, the results of the reservoir operation problem can be seen in summary and in detail at the bottom of the “Sonuc” sheet. Table 3.5 and Table 3.6 are the example of the summary and the detailed information about the reservoir operation problem of the Sungurlu Dam for 2452 ha irrigation area, respectively. The operation study is carried out by using Enumeration Method. On the other hand, when GRG Method is used for the optimization problem, the obtained results are similar to obtained results of Enumeration Method. In Table 3.6, only a part of the solution is provided. Full result can be seen at Appendix A Table A1. In Table 3.6, initial and ending storages, inflows, crop water requirements, evaporations, river water requirements, drinking water requirements, water rights, infiltrations and spills can be seen in monthly basis.

Table 3.5 Summary of Reservoir Operation Results of the Sungurlu Dam

	SUNGURLU DAM	
	SUMMARY OF RESERVOIR OPERATION TABLE	
SUMMARY OF RESERVOIR OPERATION TABLE	Normal volume level	845.11 m
	Min. volume level (dead volume level)	830.16 m
	Normal volume (total volume) (*Ka*+*Kd*)	48.13 hm^3
	Min. volume (dead volume (*Kd*))	5.16 hm^3
	Active volume	42.97 hm^3
	Net irrigation area	2452 ha
	Gross irrigation area	2724.44 ha
	Annual average flow	23.65 hm^3
	Height btw. thalweg and normal volume Lvl.	27.11 m
	Annual crop water requirement	3258.51 m^3/ha
	Regulation percentage	76.31%
	Given water to irrigation area	7.99 m^3/year
	Given water to drinking purposes	13.14 m^3/year
	Given required water for river	3.75 m^3/year
	Downstream water right	0.00 m^3/year

Table 3.6 Detailed Results about Reservoir Operation of the Sungurlu Dam

SUNGURLU DAM DETAILED TABLE OF RESERVOIR OPERATION									
Years	**Mon.**	**Initial Stor. (hm^3)**	**Inflow (hm^3)**	**Crop Water Req. (hm^3)**	**Evap. (hm^3)**	**River Water Req. (hm^3)**	**Drink. Water (hm^3)**	**Spill (hm^3)**	**End. Stor. (hm^3)**
1987	Oct	48.13	0.50	0.03	0.21	0.21	0.53	0.00	47.65
	Nov	47.65	0.60	0.00	0.00	0.21	0.53	0.00	47.52
	Dec	47.52	0.70	0.00	0.00	0.21	0.53	0.00	47.48
	Jan	47.48	3.84	0.00	0.00	0.27	0.53	2.40	48.13
	Feb	48.13	8.35	0.00	0.00	0.34	0.53	7.49	48.13
	Mar	48.13	9.07	0.00	0.00	0.67	0.53	7.87	48.13
	Apr	48.13	10.43	0.00	0.04	0.60	0.53	9.27	48.13
	May	48.13	5.76	0.05	0.17	0.40	0.53	4.61	48.13
	Jun	48.13	1.92	1.24	0.43	0.21	0.53	0.00	47.64
	July	47.64	1.17	3.43	0.74	0.21	0.53	0.00	43.89
	Aug	43.89	0.46	2.50	0.69	0.21	0.53	0.00	40.42
	Sep	40.42	0.48	0.73	0.45	0.21	0.53	0.00	38.99
	TOT		**43.29**	**7.99**	**2.75**	**3.75**	**6.31**	**31.63**	**38.99**
1988	Oct	38.99	0.56	0.03	0.17	0.21	0.53	0.00	38.60
	Nov	38.60	1.26	0.00	0.00	0.21	0.53	0.00	39.13
	Dec	39.13	3.25	0.00	0.00	0.21	0.53	0.00	41.64
	Jan	41.64	0.92	0.00	0.00	0.27	0.53	0.00	41.77
	Feb	41.77	2.12	0.00	0.00	0.34	0.53	0.00	43.02
	Mar	43.02	9.65	0.00	0.00	0.67	0.53	3.35	48.13
	Apr	48.13	4.72	0.00	0.04	0.60	0.53	3.56	48.13
	May	48.13	2.40	0.05	0.17	0.40	0.53	1.24	48.13
	Jun	48.13	1.13	1.24	0.43	0.21	0.53	0.00	46.85
	July	46.85	1.11	3.43	0.73	0.21	0.53	0.00	43.05
	Aug	43.05	0.45	2.50	0.68	0.21	0.53	0.00	39.59
	Sep	39.59	0.52	0.73	0.45	0.21	0.53	0.00	38.19
	TOT		**28.08**	**7.99**	**2.68**	**3.75**	**6.31**	**8.15**	**38.19**

3.2 Verification of the Developed Code

The data of reservoir operation of the Sungurlu Dam is used to verify the code created in Microsoft Excel VBA. 26 years of monthly flow data, which are measured between 1987 to 2012 years, are used in the reservoir operation problem. Each flow data is measured on monthly basis (hm^3/month). In addition to irrigation, the reservoir has to release water for river and drinking water requirements. The available data are applied and the results obtained from the constructed program are used to verify the developed code. It is seen from the data taken from the planning report of the Sungurlu Dam that the net irrigation area, *Ar* is 2452 ha, the normal volume of reservoir, (*Ka*+*Kd*) is 48.32 hm^3 and the height of storage is 27.15 m. In fact, in the planning report of Sungurlu Dam which is worked by AKAR-SU Eng. and Cons. Ltd. Company (2013), the net irrigation area is calculated more than 2452 ha because limited irrigation concept is used in the report. In this concept, demands are not provided one hundred percent in the drought years. By this way, total irrigation area is increased. Therefore, the net irrigation area was calculated as 2769 ha in the report. On the other hand, net irrigation area was calculated as 2452 ha in the planning report studies of the Sungurlu Dam without this concept. In the thesis, net irrigation area is accepted as 2452 ha in order to compare with the developed code results.

3.2.1 Minimization of Capacity

Validation procedure is carried out by using first objective function which is the minimization of the capacity, (*Ka*+*Kd*). In this situation, the actual net irrigation area, *Ar* is taken as a constant input and the corresponding optimum capacity is solved for. Table 3.7 shows the reservoir operation result for *Ar*=2452 ha area of the Sungurlu Dam.

As can be seen from Table 3.7, normal volume of the reservoir is calculated as 48.13 hm^3 and the height between thalweg and the normal volume level is 27.11 m. The results given in the planning report are 48.32 hm^3 and 27.15 m, respectively. The capacity difference between the planning report and the calculated value is only 0.19 hm^3. It means that the difference is approximately 0.4%. Actually, this difference is mostly due to the evaporation calculations and most of the time, it is much smaller than 0.4%. Evaporation depends on the reservoir surface area which changes due to reservoir storage. Initially, evaporation is calculated by using the storage at the beginning of each month. Then, the storage at the end of each month is found from the continuity making use of the calculated evaporation value. Finally, the average storage (the beginning and the end of each month) is used to calculate the corresponding evaporation for each time period.

Table 3.7 Sungurlu Dam Reservoir Operation Results for 2452 ha Irrigation Area (by using 26 years of flow data)

Normal volume *(Ka+Kd)*	48.13 hm^3
Height btw. thalweg and normal volume level	27.11 m

The change of reservoir storage over the years can easily be seen form Figure 3.1 and Figure 3.2. Figure 3.1 shows the minimum reservoir storage of each year whereas Figure 3.2 shows all the operation observed on monthly basis between 1987 and 2012. In 2009, the reservoir storage drops to the dead volume level which means that reservoir is empty. Then, in 2012, the reservoir capacity is full again as required.

In order to achieve the optimum reservoir capacity, the reservoir storage has to drop to the dead volume level only once for all time period. After that, it has to be full again to guarantee the irrigation for all time period. Examining these figures, it can be concluded that the reservoir operation is carried out and the capacity of reservoir volume is determined properly for the defined 2452 ha irrigation area. If the capacity of reservoir is calculated to be greater than 48.13 hm^3 for the given 2452 ha irrigation area, the reservoir storage will never drop to the dead volume level. It means that the water volume that is between the dead volume and the lowest point of the reservoir storage is never used. The example of this is shown in Figure 3.3 which capacity of reservoir is taken as 60 hm^3. On the other hand, if the capacity of reservoir is taken to be smaller than 48.13 hm^3 for the given 2452 ha irrigation area, the reservoir storage drops to the dead volume level more than ones. It means that the available storage cannot irrigate 2452 ha area for the corresponding time period.

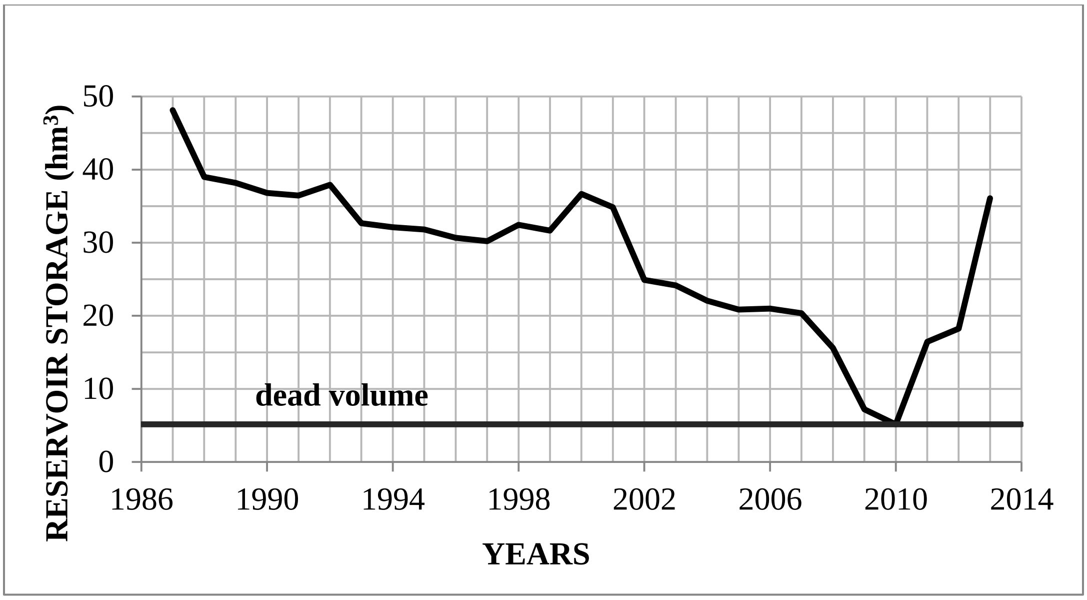


Figure 3.1 Minimum Reservoir Storage in accordance with Years for a Capacity of 48.13 hm^3 (yearly basis)

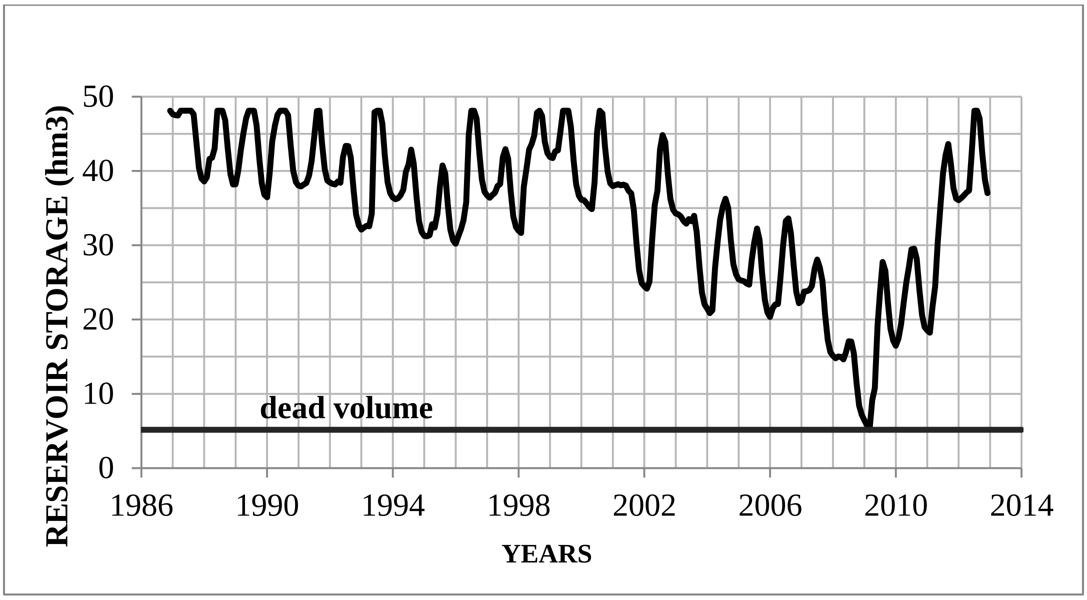


Figure 3.2 Reservoir Storage in accordance with Years for a Capacity of 48.13 hm^3 (monthly basis)

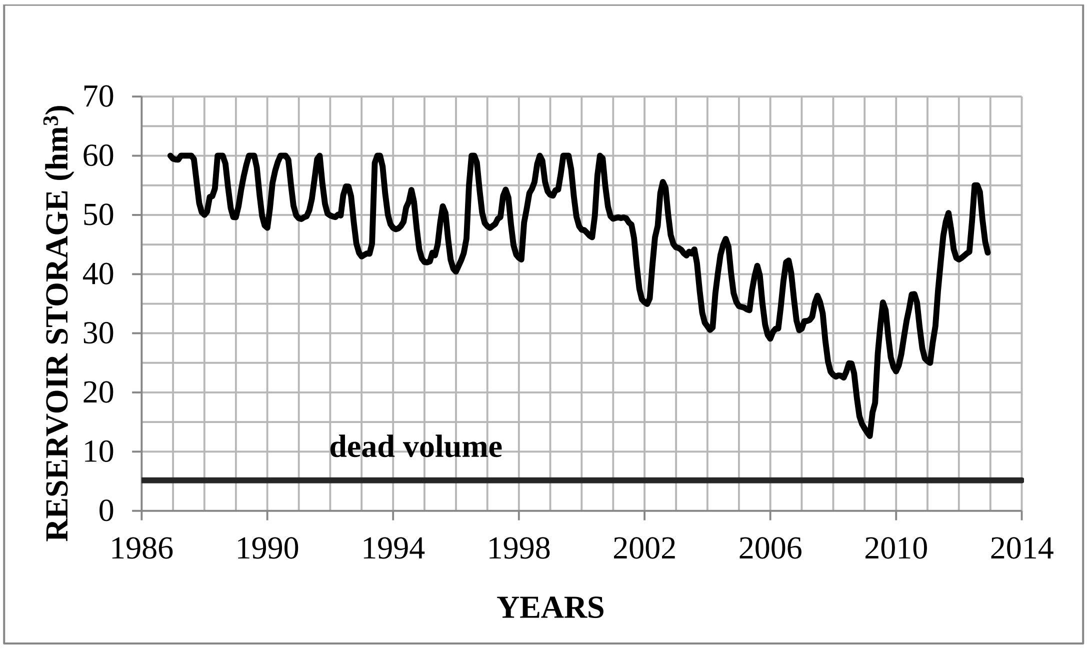


Figure 3.3 Reservoir Storage in accordance with Years for a Capacity of 60 hm^3 (monthly basis)

3.2.2 Maximization of Irrigation Area

When the second objective function is considered and the capacity of the reservoir is given to be 48.13 hm^3, the maximum irrigation area is optimized as 2452 ha which is consistent with the previous case. Table 3.8 shows the reservoir operation results for 48.13 hm^3 normal volume.

Table 3.8 Sungurlu Dam Reservoir Operation Results for 48.13 hm^3 Reservoir Capacity (by using 26 years of flow data)

Net irrigation area	2452 ha
Height btw. thalweg and normal volume level	27.11 m

For all those runs considering both of the objective functions which are the minimization of reservoir capacity and the maximization of irrigation area, two optimization methods, Enumeration and GRG methods are used. The similar results are obtained from both methods. As expected, the Enumeration Method takes longer time compared to the GRG method to reach the optimum result, depending on the increment size used. Selection of small increment increases of the calculation time of the problem together with the precision of the solution. On the other hand, large increment provides run in a short span of time but precision of the solution decreases.

3.2.3 Minimization of Capacity together with the Maximization of Irrigation Area

The third objective function is the minimization of capacity and the maximization of irrigation area simultaneously. In this case, not only the reservoir capacity (Normal volume) but also the net irrigation area is unknowns.

The third objective function can be carried out by using Enumeration method.

Table 3.9 shows the outcomes of the third objective function of the Sungurlu Dam. The change of reservoir storage over the years can be seen in yearly and on monthly basis in Figure 3.4 and Figure 3.5, respectively.

Table 3.9 Sungurlu Dam both Minimization of Capacity and Maximization of Irrigation Area

Normal volume (*Ka+Kd*)	48.50 hm^3
Net irrigation area	2462 ha
Height btw. thalweg and normal volume Lvl.	27.18 m

The table above indicates that the optimal normal volume is 48.50 hm^3 and the optimal net irrigation area is 2462 ha. From these results, it can be concluded that normal volume cannot be greater than 48.50 hm^3 and the net irrigation area cannot exceed the value of 2462 ha. Technically, these are the optimum results for the given aspect of flow potential. However, by considering the economical point of view, these may not be the optimum results. The cost of the project should be considered to finalize the dimensioning.

If net irrigation area is taken greater than the 2462 ha into the program for the first objective function (minimization of the capacity) or if the reservoir capacity is taken greater than the 48.50 hm^3 for the second objective function (maximization of irrigation area), the program gives warning and recommends to decrease the input values which are the irrigation area and the reservoir capacity.

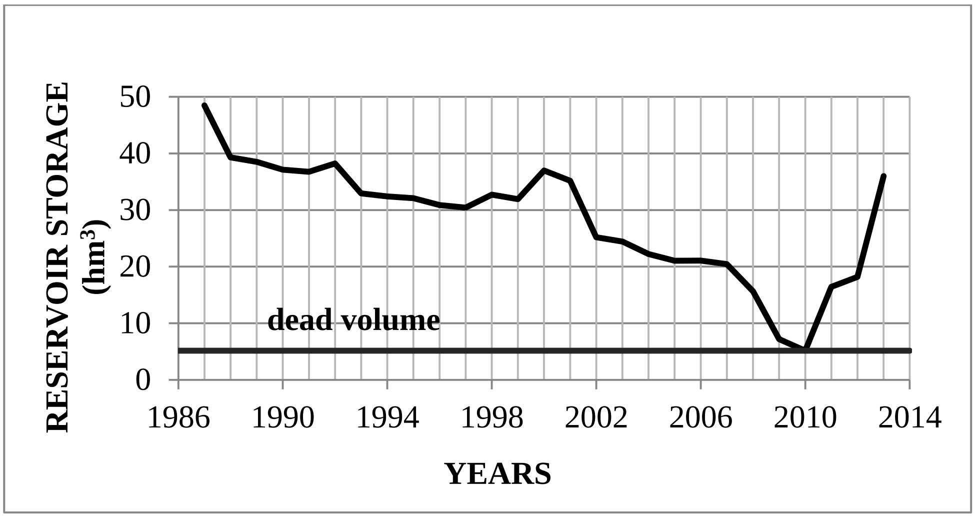


Figure 3.4 Minimum Reservoir Storage in accordance with Years for a Capacity of 48.50 hm^3 and 2462 ha Irrigation Area (yearly basis)

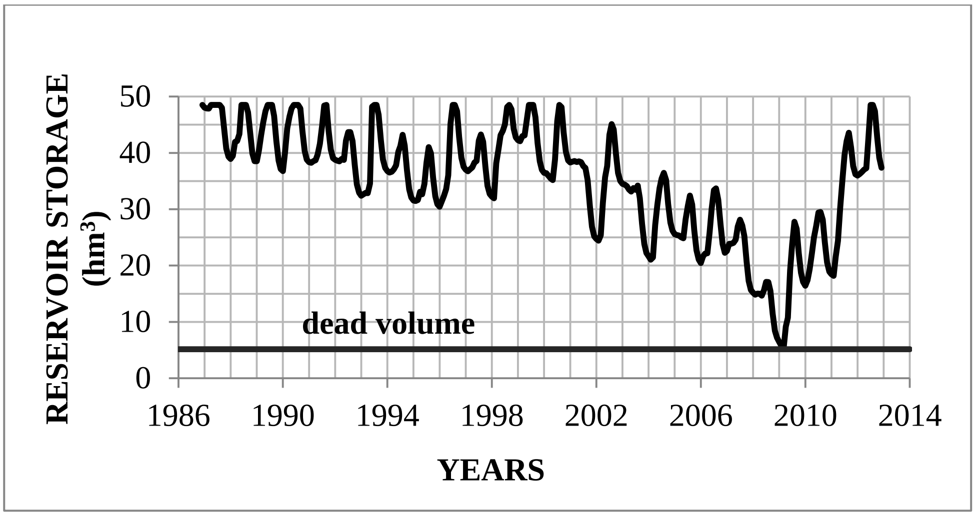


Figure 3.5 Reservoir Storage in accordance with Years for a Capacity of 48.50 hm^3 and 2462 ha Irrigation Area (monthly basis)

CHAPTER 4

APPLICATIONS AND RESULTS

4.1 Effect of the Number of Flow Measurement Data

The number of flow measurements on river has direct effect on determination of reservoir capacity. In actual case, 26 years of flow data is used in the reservoir operation problem. For example, if 14 years of flow data which is between 1987 and 2000 are years used for the operation study, the optimum reservoir capacity becomes 19.34 hm^3 for the defined 2452 ha irrigation area which is much smaller than the reservoir capacity of actual case. If 19.34 hm^3 capacity were used for the design in real life, probably, 2452 ha irrigation area could never be irrigated. The reason is that there are some drought years in flow measurements between 2000 and 2012 which are not taken into consideration. In fact, 14 years of flow observations do not reflect the real case appropriately. Table 4.1 shows the reservoir operation information for *Ar*=2452 ha area of the Sungurlu Dam by using 14 years of flow data. The change of reservoir storage over the years can be seen in yearly and on monthly basis in Figure 4.1 and Figure 4.2, respectively.

Table 4.1 Sungurlu Dam Reservoir Operation Results for 2452 ha Irrigation Area (by using 14 years of flow data)

Normal volume (*Ka*+*Kd*)	19.34 hm^3
Height btw. thalweg and normal volume Level	19.66 m

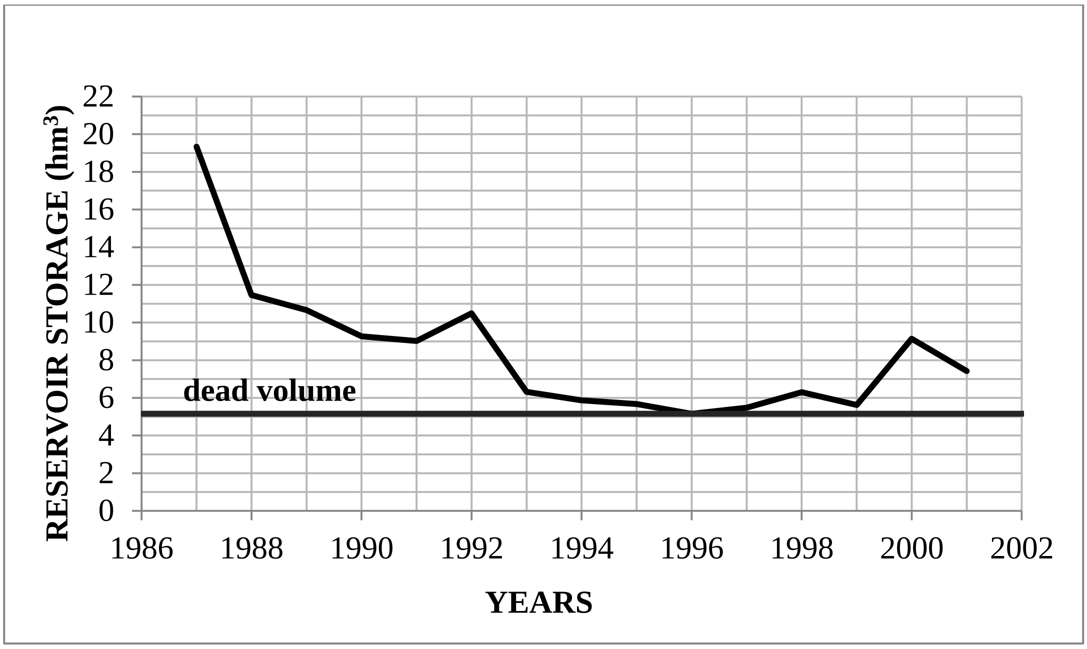


Figure 4.1 Minimum Reservoir Storage in accordance with Years for a Capacity of 19.34 hm^3 (yearly basis)

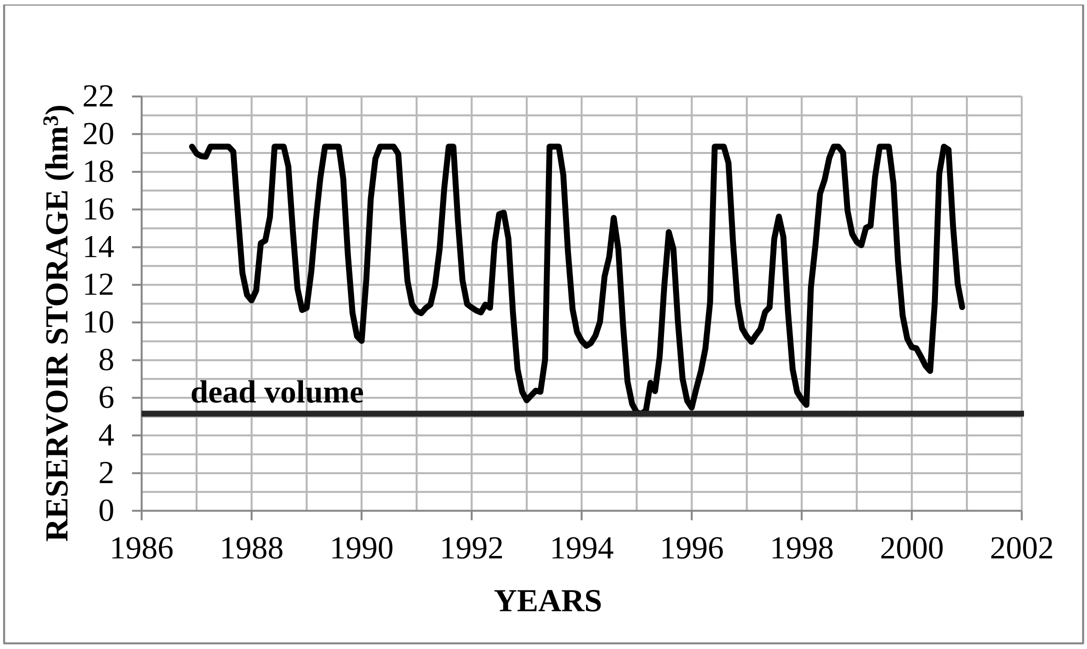


Figure 4.2 Reservoir Storage in accordance with Years for a Capacity of 19.34 hm^3 (monthly basis)

4.2 Application of the Sungurlu Dam Reservoir Operation for Different Irrigation Areas

Table 4.2 gives minimum capacities for different irrigation areas. In other words, it shows the calculated maximum irrigation areas for various capacities. Different optimization case results can be seen in Figure 4.3 and Figure 4.4 which gives the height (between thalweg and normal volume level) versus irrigation area curve and normal volume versus irrigation area curve, respectively. For all these reservoir optimization problems crop water requirement is assumed as the same value for different irrigation areas.

Table 4.2 Sungurlu Dam Height and Normal Volume Values for Various Net Irrigation Areas

Sungurlu Dam		
Irrigation area (ha)	**Normal Volume (*Ka*+*Kd*) (hm^3)**	**Height of storage (m)**
0	11.59	16.52
250	13.16	17.29
500	14.78	18.02
750	16.5	18.64
1000	18.5	19.36
1250	21.12	20.3
1500	23.73	21.24
1750	26.34	22.14
2000	32.63	23.86
2250	40.63	25.68
2452	48.13	27.11
2462	48.50	27.18

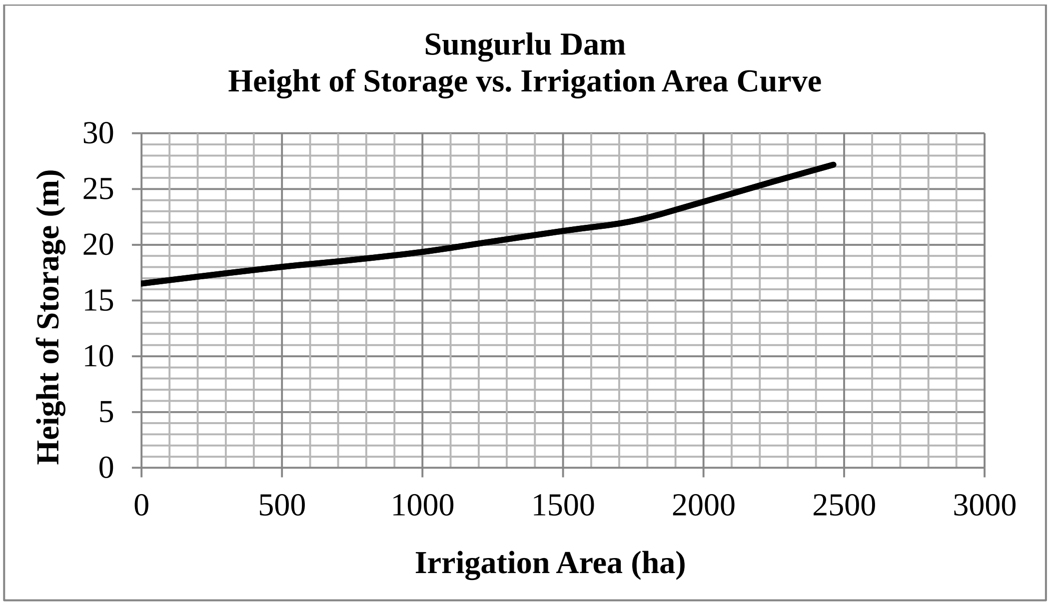


Figure 4.3 Height vs. Irrigation Area Curve for Sungurlu Dam

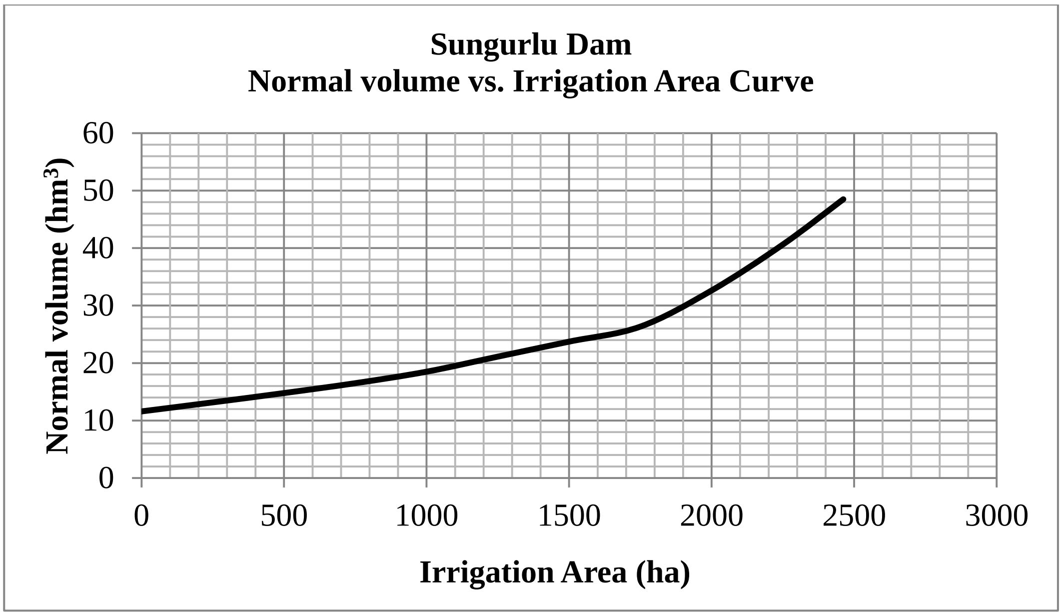


Figure 4.4 Normal Volumes vs. Irrigation Area Curve for Sungurlu Dam

4.3 Application of Classical Approaches for Determination of Reservoir Storage for the Sungurlu Dam

4.3.1 Application of Mass Curve Method (Ripple Method)

For this method, since reservoir releases have to be taken as constant, annual crop water requirement (2452 ha irrigation area of the Sungurlu Dam) and river water requirement are distributed uniformly for each month. Drinking water requirement is already defined as constant for each month. Cumulative observed flow volumes and demands (crop water requirement, river water requirement and drinking water requirement) of the Sungurlu Dam are plotted. Then, demand line is plotted tangential to cumulative flow volumes. Maximum difference between the tangential plots is calculated as 22.67 hm^3. The defined dead volume of the reservoir for Sungurlu Dam is 5.16 hm^3. Therefore, the required capacity is calculated as 27.83 hm^3. Figure 4.5 and Figure 4.6 show plot of mass curve method.

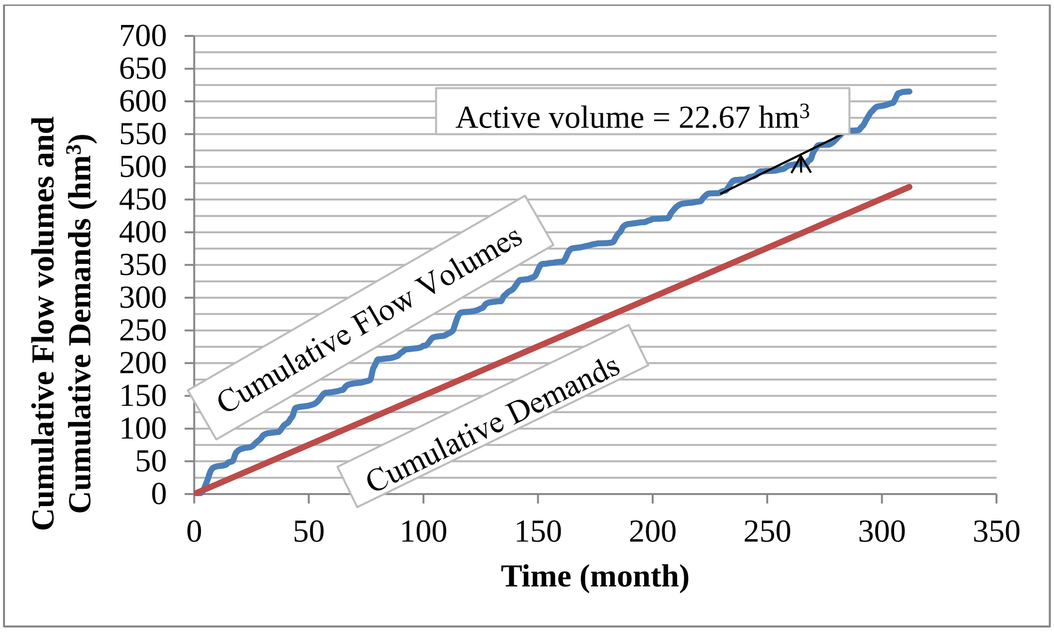


Figure 4.5 Result of Mass Curve Method

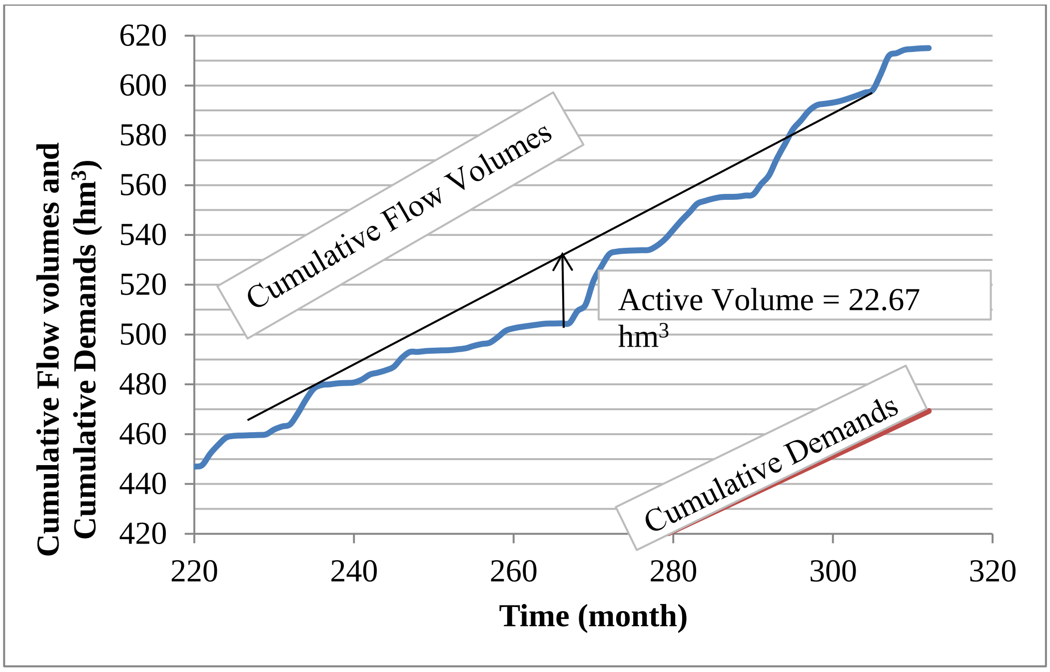


Figure 4.6 Result of Mass Curve Method (zoomed)

4.3.2 Application of Sequent Peak Analysis Method

As it mentioned in the first chapter, sequent peak analysis method is an improved version of the mass curve analysis method. Figure 4.7 shows the cumulative summation of inflows minus the reservoir releases (crop water requirement of 2452 ha area, river water requirement and drinking water requirement of the Sungurlu Dam) are plotted against time. The maximum vertical difference between sequent peaks is calculated as 27.59 hm^3. The defined dead volume of the reservoir for Sungurlu Dam is 5.16 hm^3. Therefore, the required capacity is calculated as 32.75 hm^3.

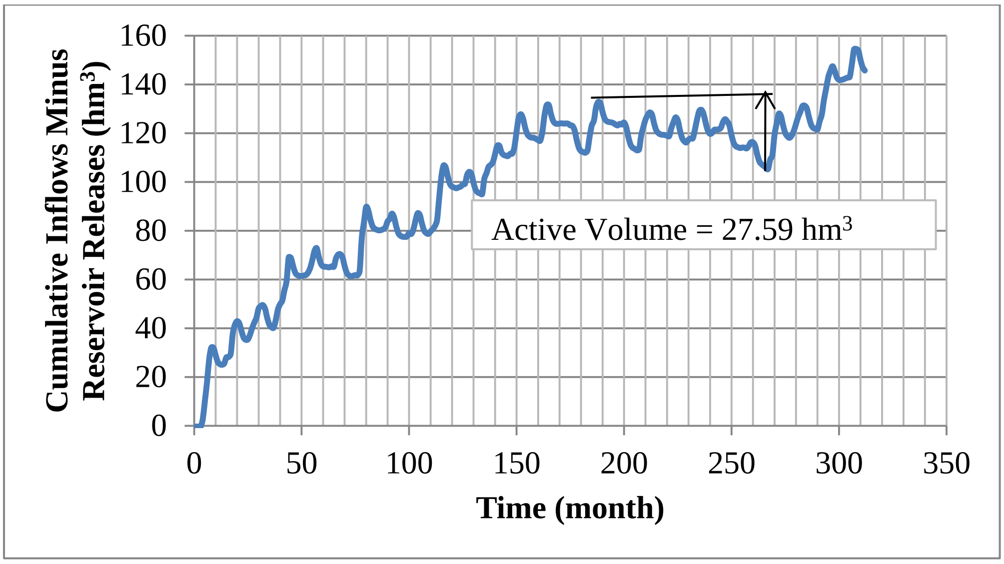


Figure 4.7 Result of Sequent Peak Analysis Method

The optimum reservoir capacity of 2452 ha area for the Sungurlu Dam is calculated as 48.13 hm^3 by using developed code. The result obtained by the ripple method is 27.83 hm^3 and the result obtained by the sequent peak method is 32.75 hm^3. The first reason of calculation of small reservoir capacity for mass curve method and sequent peak analysis method is the evaporation parameter which is ignored because it is function of unknown storage. Actually, Evaporation depends on the reservoir surface area which changes due to reservoir storage. Another reason is spill releases from the reservoir. Spill releases cannot be considered in the calculation of reservoir capacity in the classical graphical analysis methods. Since, these releases are taken into consideration in the optimum reservoir operation method, the required reservoir capacity increases due to irregularities in the inflow.

4.4 Application to the Yeşilkavak Dam Reservoir Operation

4.4.1 Inputs of the Yeşilkavak Dam Reservoir Operation

37 years of monthly flow data are used in the reservoir operation problem which are measured between 1970 and 2006 years. All input data are given in Figure 4.7, Figure 4.8 and Table 4.3. Figure 4.7 indicates the plot of inflow data drawn against

time and Figure 4.8 shows the plot of the elevation, area, and the corresponding volume of the reservoir. In addition, Table 4.3 shows the (input) data of crop water requirement, river water requirement and evaporation. The dead volume of the reservoir is 0.75 hm^3.

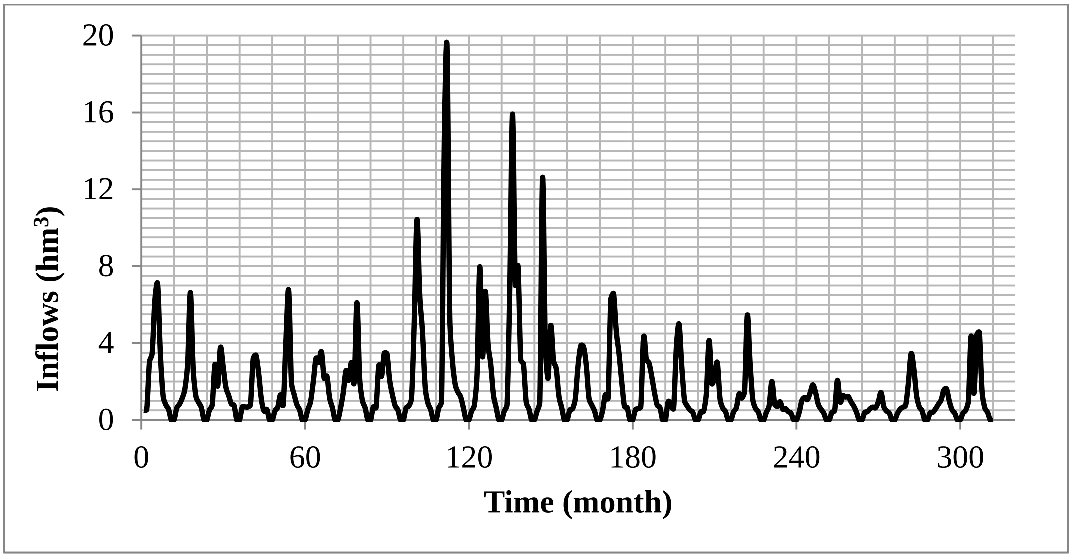


Figure 4.8 37 Years of Inflow Data Measured between 1970 and 2006 Years

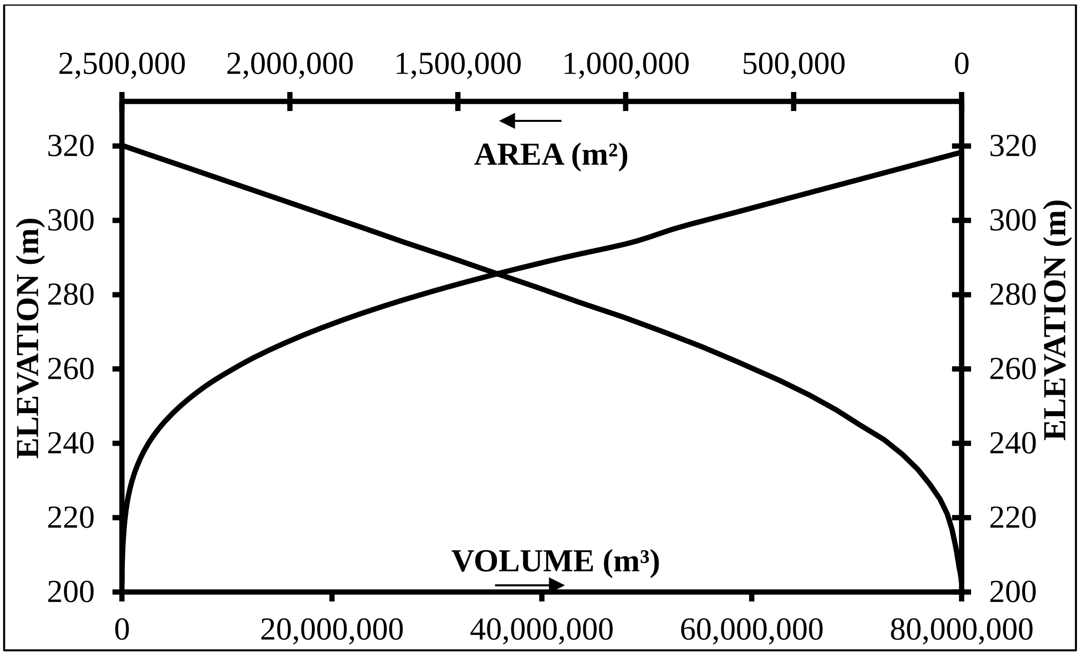


Figure 4.9 Elevation, Area, Volume Curve

Table 4.3 The Data of Crop Water Requirement, River Water Requirement and Evaporation for the Yeşilkavak Dam

5	Crop Water Requirement (m^3/ha)		6	River Water Requirement (m^3)		7	Evaporation (mm)	
	Oct	161		Oct	140856		Oct	32.01
	Nov	0		Nov	136312		Nov	0.00
	Dec	0		Dec	140856		Dec	0.00
	Jan	0		Jan	140856		Jan	0.00
	Feb	0		Feb	127225		Feb	0.00
	Mar	0		Mar	140856		Mar	0.00
	Apr	67		Apr	136312		Apr	0.00
	May	410		May	140856		May	71.43
	Jun	1252		Jun	136312		Jun	129.72
	July	1538		July	140856		July	157.24
	Aug	1447		Aug	140856		Aug	150.20
	Sep	1027		Sep	136312		Sep	107.88

4.4.2 Outputs of the Yeşilkavak Dam Reservoir Operation

Firstly, the data taken from the planning report of Yeşilkavak Dam are compared to the results obtained from the developed code. In the planning report, the net irrigation area, *Ar* is 1750.10 ha, the normal volume of reservoir, (*Ka*+*Kd*) is 29.91 hm^3, and the height of storage is 78.63 m.

By using the first objective function which is the minimization of the capacity, (*Ka*+*Kd*), the reservoir capacity of the Yeşilkavak Dam for *Ar*=1750.10 ha is calculated as 29.89 hm^3 and the height of the storage is calculated as 78.61 m. The capacity difference between the planning report and the calculated value is only 0.02 hm^3.

By using the second objective function which is the maximization of the irrigation area, the irrigation area of the Yeşilkavak Dam for a capacity of 29.89 hm^3 is calculated as 1750.10 ha and the height of the storage is calculated as 78.61 m which is consistent with the first case. On the other hand, when the reservoir capacity is taken as 29.91 hm^3 for the second objective function, the irrigation area is calculated as 1750.50 ha.

By using the third objective function which is the minimization of the capacity together with the maximization of the irrigation area, reservoir capacity is calculated as 40.85 hm^3 and the net irrigation area is 2000 ha. In addition, the height of the storage is 86.63 m. Results of the third objective function states that the capacity cannot be greater than 40.85 hm^3 and net irrigation are cannot exceed the value of 2000 ha.

The first and the second optimization problems are calculated by using both Enumeration method and GRG method in the program. The results of the two methods are consistent. However, it is seen that GRG nonlinear method reaches the optimum solution much faster than the classical Enumeration method. The third objective function is calculated only with Enumeration method. GRG method cannot be used for third objective function in the program.

The following table shows the results of the first, second and third objective functions together with the results of the planning report. The inputs are given in red for each case.

Table 4.4 Summary of the Results of the Yeşilkavak Dam

	Ar (ha)	***Ka+Kd*** ***(hm^3)***	**Height of Storage (m)**
Result of Planning Report	1750.10	29.91	78.63
Minimization of ***Ka+Kd***	1750.10	29.89	78.61
Maximization of ***Ar*** **(Case 1)**	1750.10	29.89	78.61
Maximization of ***Ar (Case 2)***	1750.50	29.91	78.63
Minimization of ***Ka+Kd &*** **Maximization of Ar**	2000.00	40.85	86.63

CHAPTER 5

CONCLUSION

5.1 Summary of the Thesis

This study aims to determine the optimum reservoir capacity and the operation of irrigation dams. Determination of the reservoir capacity for irrigation dams is directly linked to the management of the system. To optimize the system, it is substantial to specify and ensure all flow requirements. The minimization of capacity (for a given irrigation area) and the maximization of irrigation area (for a given capacity) are the two different objective functions used to develop the optimization problem which are both subject to the continuity and bound constraints on the reservoir storage.

The study begins with literature surveying to examine past studies related to the optimization of reservoir storage. Furthermore, it is also crucial to accomplish better understanding about the subject. After literature surveying is fulfilled, the next step is defining the problem properly; which means that the objective functions are defined namely, the minimization of active volume, the maximization of irrigation area, and both minimization of capacity and maximization of irrigation area. After that, all the constraints and the decision variables are specified. Since the optimization formulation is defined, the problem is set in Excel Visual Basic Application and codes are written to optimize the problem. After writing the codes and generating the program process is finished, validation of the program is carried out to demonstrate the preciseness of the study.

The optimization problem is solved by two methods. The first one uses the Enumeration method and the code is written in Microsoft Excel VBA. The second one is the GRG method, for which, the Microsoft Excel solver engine is used for GRG nonlinear optimization method in order to solve the nonlinear problem. After development of the codes, the validation of the program is carried out. This validation process is performed with the project data, namely Sungurlu Dam. Finally, it is seen and revealed that GRG nonlinear method reaches the optimum solution much faster than the Enumeration Method. In addition to Sungurlu Dam, optimum reservoir operation studies are also carried out by using data of Yeşilkavak Dam,

The third objective function which is composed of both minimization of capacity and maximization of irrigation area is handled only with Enumeration method.

In this study, in addition, the importance of the length of the flow measurements is emphasized. By ignoring the drought years of flow measurement data, the optimization is carried out again and different optimum results are obtained. In other words, ignoring the drought years leads to wrong design.

In the present research, mass curve method and sequent peak analysis method are explained and applied. The results of the graphical methods are also compared with the results obtained from the developed code. Optimum reservoir operation study is a better way to calculate required reservoir storage capacity because some of the parameters (evaporation, spill releases) are not constants and the functions of the unknown reservoir storage.

5.2 Future Research

The developed code can be improved easily by users. Although, it is used for optimum operation of reservoirs with determination of the optimum reservoir capacity for irrigation purposes, different cases may be studied. Additional codes may be integrated to the existing code. By improving the code, it may be used for more complex problem. For example, energy purposes or flood control purposes may be appended to the problem.

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APPENDIX A

SUNGURLU DAM DETAILED TABLE OF RESERVOIR OPERATION

Table A1 Detailed Information about the Reservoir Operation Problem of Sungurlu Dam for 2452 ha Irrigation Area.

Years	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
1987	Oct	48.13	0.50	0.03	0.21	0.21	0.53	0.00	47.65
	Nov	47.65	0.60	0.00	0.00	0.21	0.53	0.00	47.52
	Dec	47.52	0.70	0.00	0.00	0.21	0.53	0.00	47.48
	Jan	47.48	3.84	0.00	0.00	0.27	0.53	2.40	48.13
	Feb	48.13	8.35	0.00	0.00	0.34	0.53	7.49	48.13
	Mar	48.13	9.07	0.00	0.00	0.67	0.53	7.87	48.13
	Apr	48.13	10.43	0.00	0.04	0.60	0.53	9.27	48.13
	May	48.13	5.76	0.05	0.17	0.40	0.53	4.61	48.13
	Jun	48.13	1.92	1.24	0.43	0.21	0.53	0.00	47.64
	July	47.64	1.17	3.43	0.74	0.21	0.53	0.00	43.89
	Aug	43.89	0.46	2.50	0.69	0.21	0.53	0.00	40.42
	Sep	40.42	0.48	0.73	0.45	0.21	0.53	0.00	38.99
	TOT		**43.29**	**7.99**	**2.75**	**3.75**	**6.31**	**31.63**	**38.99**
1988	Oct	38.99	0.56	0.03	0.17	0.21	0.53	0.00	38.60
	Nov	38.60	1.26	0.00	0.00	0.21	0.53	0.00	39.13
	Dec	39.13	3.25	0.00	0.00	0.21	0.53	0.00	41.64
	Jan	41.64	0.92	0.00	0.00	0.27	0.53	0.00	41.77
	Feb	41.77	2.12	0.00	0.00	0.34	0.53	0.00	43.02
	Mar	43.02	9.65	0.00	0.00	0.67	0.53	3.35	48.13
	Apr	48.13	4.72	0.00	0.04	0.60	0.53	3.56	48.13
	May	48.13	2.40	0.05	0.17	0.40	0.53	1.24	48.13
	Jun	48.13	1.13	1.24	0.43	0.21	0.53	0.00	46.85
	July	46.85	1.11	3.43	0.73	0.21	0.53	0.00	43.05
	Aug	43.05	0.45	2.50	0.68	0.21	0.53	0.00	39.59

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	Sep	39.59	0.52	0.73	0.45	0.21	0.53	0.00	38.19
	TOT		**28.08**	**7.99**	**2.68**	**3.75**	**6.31**	**8.15**	**38.19**
1989	Oct	38.19	0.95	0.03	0.17	0.21	0.53	0.00	38.20
	Nov	38.20	2.64	0.00	0.00	0.21	0.53	0.00	40.10
	Dec	40.10	3.50	0.00	0.00	0.21	0.53	0.00	42.86
	Jan	42.86	3.04	0.00	0.00	0.27	0.53	0.00	45.11
	Feb	45.11	2.85	0.00	0.00	0.34	0.53	0.00	47.09
	Mar	47.09	4.95	0.00	0.00	0.67	0.53	2.73	48.13
	Apr	48.13	2.13	0.00	0.04	0.60	0.53	0.97	48.13
	May	48.13	1.35	0.05	0.17	0.40	0.53	0.20	48.13
	Jun	48.13	0.48	1.24	0.43	0.21	0.53	0.00	46.20
	July	46.20	0.45	3.43	0.72	0.21	0.53	0.00	41.76
	Aug	41.76	0.44	2.50	0.66	0.21	0.53	0.00	38.30
	Sep	38.30	0.39	0.73	0.43	0.21	0.53	0.00	36.80
	TOT		**23.17**	**7.99**	**2.62**	**3.75**	**6.31**	**3.89**	**36.80**
1990	Oct	36.80	0.59	0.03	0.16	0.21	0.53	0.00	36.45
	Nov	36.45	3.99	0.00	0.00	0.21	0.53	0.00	39.71
	Dec	39.71	5.04	0.00	0.00	0.21	0.53	0.00	44.01
	Jan	44.01	2.91	0.00	0.00	0.27	0.53	0.00	46.13
	Feb	46.13	2.30	0.00	0.00	0.34	0.53	0.00	47.57
	Mar	47.57	5.42	0.00	0.00	0.67	0.53	3.66	48.13
	Apr	48.13	4.91	0.00	0.04	0.60	0.53	3.74	48.13
	May	48.13	10.75	0.05	0.17	0.40	0.53	9.60	48.13
	Jun	48.13	1.80	1.24	0.43	0.21	0.53	0.00	47.52
	July	47.52	0.89	3.43	0.74	0.21	0.53	0.00	43.50
	Aug	43.50	0.44	2.50	0.69	0.21	0.53	0.00	40.01
	Sep	40.01	0.40	0.73	0.45	0.21	0.53	0.00	38.50
	TOT		**39.45**	**7.99**	**2.69**	**3.75**	**6.31**	**17.01**	**36.45**
1991	Oct	38.50	0.48	0.03	0.17	0.21	0.53	0.00	38.04
	Nov	38.04	0.61	0.00	0.00	0.21	0.53	0.00	37.92
	Dec	37.92	1.02	0.00	0.00	0.21	0.53	0.00	38.19
	Jan	38.19	0.98	0.00	0.00	0.27	0.53	0.00	38.38

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	Feb	38.38	1.87	0.00	0.00	0.34	0.53	0.00	39.38
	Mar	39.38	3.12	0.00	0.00	0.67	0.53	0.00	41.31
	Apr	41.31	4.38	0.00	0.04	0.60	0.53	0.00	44.53
	May	44.53	4.70	0.05	0.17	0.40	0.53	0.00	48.08
	Jun	48.08	3.11	1.24	0.44	0.21	0.53	0.66	48.13
	July	48.13	0.52	3.43	0.75	0.21	0.53	0.00	43.74
	Aug	43.74	0.44	2.50	0.69	0.21	0.53	0.00	40.25
	Sep	40.25	0.39	0.73	0.45	0.21	0.53	0.00	38.72
	TOT		**21.63**	**7.99**	**2.70**	**3.75**	**6.31**	**0.66**	**37.92**
1992	Oct	38.72	0.66	0.03	0.17	0.21	0.53	0.00	38.44
	Nov	38.44	0.57	0.00	0.00	0.21	0.53	0.00	38.28
	Dec	38.28	0.64	0.00	0.00	0.21	0.53	0.00	38.18
	Jan	38.18	1.21	0.00	0.00	0.27	0.53	0.00	38.60
	Feb	38.60	0.69	0.00	0.00	0.34	0.53	0.00	38.42
	Mar	38.42	4.63	0.00	0.00	0.67	0.53	0.00	41.86
	Apr	41.86	2.67	0.00	0.04	0.60	0.53	0.00	43.37
	May	43.37	1.13	0.05	0.16	0.40	0.53	0.00	43.36
	Jun	43.36	0.78	1.24	0.39	0.21	0.53	0.00	41.78
	July	41.78	0.56	3.43	0.65	0.21	0.53	0.00	37.51
	Aug	37.51	0.44	2.50	0.59	0.21	0.53	0.00	34.12
	Sep	34.12	0.39	0.73	0.39	0.21	0.53	0.00	32.66
	TOT		**14.38**	**7.99**	**2.39**	**3.75**	**6.31**	**0.00**	**32.66**
1993	Oct	32.66	0.37	0.03	0.15	0.21	0.53	0.00	32.11
	Nov	32.11	1.00	0.00	0.00	0.21	0.53	0.00	32.38
	Dec	32.38	0.98	0.00	0.00	0.21	0.53	0.00	32.62
	Jan	32.62	0.73	0.00	0.00	0.27	0.53	0.00	32.56
	Feb	32.56	2.57	0.00	0.00	0.34	0.53	0.00	34.26
	Mar	34.26	14.85	0.00	0.00	0.67	0.53	0.00	47.92
	Apr	47.92	7.36	0.00	0.04	0.60	0.53	6.00	48.13
	May	48.13	7.30	0.05	0.17	0.40	0.53	6.15	48.13
	Jun	48.13	0.67	1.24	0.43	0.21	0.53	0.00	46.40
	July	46.40	0.43	3.43	0.72	0.21	0.53	0.00	41.94

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	Aug	41.94	0.46	2.50	0.66	0.21	0.53	0.00	38.49
	Sep	38.49	0.42	0.73	0.43	0.21	0.53	0.00	37.01
	TOT		**37.16**	**7.99**	**2.61**	**3.75**	**6.31**	**12.15**	**32.11**
1994	Oct	37.01	0.37	0.03	0.16	0.21	0.53	0.00	36.45
	Nov	36.45	0.48	0.00	0.00	0.21	0.53	0.00	36.19
	Dec	36.19	0.89	0.00	0.00	0.21	0.53	0.00	36.34
	Jan	36.34	1.20	0.00	0.00	0.27	0.53	0.00	36.74
	Feb	36.74	1.58	0.00	0.00	0.34	0.53	0.00	37.46
	Mar	37.46	3.61	0.00	0.00	0.67	0.53	0.00	39.88
	Apr	39.88	2.17	0.00	0.04	0.60	0.53	0.00	40.89
	May	40.89	3.12	0.05	0.15	0.40	0.53	0.00	42.88
	Jun	42.88	0.48	1.24	0.39	0.21	0.53	0.00	41.00
	July	41.00	0.45	3.43	0.64	0.21	0.53	0.00	36.64
	Aug	36.64	0.44	2.50	0.58	0.21	0.53	0.00	33.27
	Sep	33.27	0.39	0.73	0.38	0.21	0.53	0.00	31.81
	TOT		**15.19**	**7.99**	**2.34**	**3.75**	**6.31**	**0.00**	**31.81**
1995	Oct	31.81	0.37	0.03	0.14	0.21	0.53	0.00	31.27
	Nov	31.27	0.66	0.00	0.00	0.21	0.53	0.00	31.20
	Dec	31.20	0.90	0.00	0.00	0.21	0.53	0.00	31.35
	Jan	31.35	2.28	0.00	0.00	0.27	0.53	0.00	32.84
	Feb	32.84	0.42	0.00	0.00	0.34	0.53	0.00	32.39
	Mar	32.39	3.04	0.00	0.00	0.67	0.53	0.00	34.23
	Apr	34.23	4.89	0.00	0.03	0.60	0.53	0.00	37.97
	May	37.97	3.90	0.05	0.15	0.40	0.53	0.00	40.74
	Jun	40.74	1.25	1.24	0.37	0.21	0.53	0.00	39.64
	July	39.64	0.59	3.43	0.62	0.21	0.53	0.00	35.45
	Aug	35.45	0.44	2.50	0.56	0.21	0.53	0.00	32.09
	Sep	32.09	0.41	0.73	0.37	0.21	0.53	0.00	30.66
	TOT		**19.14**	**7.99**	**2.24**	**3.75**	**6.31**	**0.00**	**30.66**
1996	Oct	30.66	0.46	0.03	0.14	0.21	0.53	0.00	30.21
	Nov	30.21	1.74	0.00	0.00	0.21	0.53	0.00	31.22
	Dec	31.22	1.68	0.00	0.00	0.21	0.53	0.00	32.15

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	Jan	32.15	2.00	0.00	0.00	0.27	0.53	0.00	33.36
	Feb	33.36	3.31	0.00	0.00	0.34	0.53	0.00	35.80
	Mar	35.80	10.31	0.00	0.00	0.67	0.53	0.00	44.92
	Apr	44.92	9.78	0.00	0.04	0.60	0.53	5.40	48.13
	May	48.13	5.62	0.05	0.17	0.40	0.53	4.47	48.13
	Jun	48.13	1.32	1.24	0.43	0.21	0.53	0.00	47.04
	July	47.04	0.34	3.43	0.73	0.21	0.53	0.00	42.48
	Aug	42.48	0.25	2.50	0.67	0.21	0.53	0.00	38.82
	Sep	38.82	0.29	0.73	0.44	0.21	0.53	0.00	37.21
	TOT		**37.09**	**7.99**	**2.62**	**3.75**	**6.31**	**9.88**	**30.21**
1997	Oct	37.21	0.43	0.03	0.17	0.21	0.53	0.00	36.70
	Nov	36.70	0.43	0.00	0.00	0.21	0.53	0.00	36.40
	Dec	36.40	1.10	0.00	0.00	0.21	0.53	0.00	36.76
	Jan	36.76	1.12	0.00	0.00	0.27	0.53	0.00	37.08
	Feb	37.08	1.76	0.00	0.00	0.34	0.53	0.00	37.99
	Mar	37.99	1.45	0.00	0.00	0.67	0.53	0.00	38.24
	Apr	38.24	4.78	0.00	0.04	0.60	0.53	0.00	41.86
	May	41.86	2.23	0.05	0.16	0.40	0.53	0.00	42.95
	Jun	42.95	1.08	1.24	0.39	0.21	0.53	0.00	41.66
	July	41.66	0.45	3.43	0.65	0.21	0.53	0.00	37.29
	Aug	37.29	0.44	2.50	0.59	0.21	0.53	0.00	33.91
	Sep	33.91	0.39	0.73	0.38	0.21	0.53	0.00	32.45
	TOT		**15.66**	**7.99**	**2.37**	**3.75**	**6.31**	**0.00**	**32.45**
1998	Oct	32.45	0.43	0.03	0.15	0.21	0.53	0.00	31.96
	Nov	31.96	0.43	0.00	0.00	0.21	0.53	0.00	31.66
	Dec	31.66	6.99	0.00	0.00	0.21	0.53	0.00	37.91
	Jan	37.91	3.08	0.00	0.00	0.27	0.53	0.00	40.20
	Feb	40.20	3.55	0.00	0.00	0.34	0.53	0.00	42.88
	Mar	42.88	1.94	0.00	0.00	0.67	0.53	0.00	43.63
	Apr	43.63	2.30	0.00	0.04	0.60	0.53	0.00	44.77
	May	44.77	4.24	0.05	0.17	0.40	0.53	0.00	47.86
	Jun	47.86	5.34	1.24	0.43	0.21	0.53	2.67	48.13

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	July	48.13	4.22	3.43	0.77	0.21	0.53	0.00	47.40
	Aug	47.40	0.51	2.50	0.74	0.21	0.53	0.00	43.93
	Sep	43.93	0.46	0.73	0.49	0.21	0.53	0.00	42.43
	TOT		**33.50**	**7.99**	**2.79**	**3.75**	**6.31**	**2.67**	**31.66**
1999	Oct	42.43	0.43	0.03	0.19	0.21	0.53	0.00	41.90
	Nov	41.90	0.57	0.00	0.00	0.21	0.53	0.00	41.73
	Dec	41.73	1.66	0.00	0.00	0.21	0.53	0.00	42.65
	Jan	42.65	0.90	0.00	0.00	0.27	0.53	0.00	42.77
	Feb	42.77	3.48	0.00	0.00	0.34	0.53	0.00	45.38
	Mar	45.38	7.62	0.00	0.00	0.67	0.53	3.67	48.13
	Apr	48.13	6.89	0.00	0.04	0.60	0.53	5.73	48.13
	May	48.13	2.33	0.05	0.17	0.40	0.53	1.18	48.13
	Jun	48.13	0.21	1.24	0.43	0.21	0.53	0.00	45.93
	July	45.93	0.39	3.43	0.71	0.21	0.53	0.00	41.44
	Aug	41.44	0.63	2.50	0.65	0.21	0.53	0.00	38.17
	Sep	38.17	0.39	0.73	0.43	0.21	0.53	0.00	36.67
	TOT		**25.50**	**7.99**	**2.63**	**3.75**	**6.31**	**10.58**	**36.67**
2000	Oct	36.67	0.39	0.03	0.16	0.21	0.53	0.00	36.12
	Nov	36.12	0.67	0.00	0.00	0.21	0.53	0.00	36.06
	Dec	36.06	0.29	0.00	0.00	0.21	0.53	0.00	35.62
	Jan	35.62	0.32	0.00	0.00	0.27	0.53	0.00	35.14
	Feb	35.14	0.58	0.00	0.00	0.34	0.53	0.00	34.86
	Mar	34.86	4.83	0.00	0.00	0.67	0.53	0.00	38.50
	Apr	38.50	7.97	0.00	0.04	0.60	0.53	0.00	45.31
	May	45.31	5.07	0.05	0.17	0.40	0.53	1.11	48.13
	Jun	48.13	2.03	1.24	0.43	0.21	0.53	0.00	47.74
	July	47.74	0.46	3.43	0.74	0.21	0.53	0.00	43.29
	Aug	43.29	0.49	2.50	0.68	0.21	0.53	0.00	39.86
	Sep	39.86	0.39	0.73	0.45	0.21	0.53	0.00	38.34
	TOT		**23.50**	**7.99**	**2.67**	**3.75**	**6.31**	**1.11**	**34.86**
2001	Oct	38.34	0.57	0.03	0.17	0.21	0.53	0.00	37.97
	Nov	37.97	0.87	0.00	0.00	0.21	0.53	0.00	38.10

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	Dec	38.10	0.86	0.00	0.00	0.21	0.53	0.00	38.22
	Jan	38.22	0.65	0.00	0.00	0.27	0.53	0.00	38.07
	Feb	38.07	0.96	0.00	0.00	0.34	0.53	0.00	38.17
	Mar	38.17	1.06	0.00	0.00	0.67	0.53	0.00	38.03
	Apr	38.03	0.45	0.00	0.03	0.60	0.53	0.00	37.32
	May	37.32	0.79	0.05	0.14	0.40	0.53	0.00	37.00
	Jun	37.00	0.13	1.24	0.33	0.21	0.53	0.00	34.82
	July	34.82	0.13	3.43	0.55	0.21	0.53	0.00	30.23
	Aug	30.23	0.12	2.50	0.49	0.21	0.53	0.00	26.62
	Sep	26.62	0.07	0.73	0.32	0.21	0.53	0.00	24.91
	TOT		**6.65**	**7.99**	**2.03**	**3.75**	**6.31**	**0.00**	**24.91**
2002	Oct	24.91	0.43	0.03	0.12	0.21	0.53	0.00	24.45
	Nov	24.45	0.43	0.00	0.00	0.21	0.53	0.00	24.15
	Dec	24.15	1.69	0.00	0.00	0.21	0.53	0.00	25.10
	Jan	25.10	6.51	0.00	0.00	0.27	0.53	0.00	30.82
	Feb	30.82	5.47	0.00	0.00	0.34	0.53	0.00	35.42
	Mar	35.42	3.17	0.00	0.00	0.67	0.53	0.00	37.39
	Apr	37.39	6.68	0.00	0.04	0.60	0.53	0.00	42.92
	May	42.92	3.06	0.05	0.16	0.40	0.53	0.00	44.84
	Jun	44.84	1.43	1.24	0.41	0.21	0.53	0.00	43.89
	July	43.89	0.51	3.43	0.68	0.21	0.53	0.00	39.55
	Aug	39.55	0.50	2.50	0.62	0.21	0.53	0.00	36.19
	Sep	36.19	0.46	0.73	0.41	0.21	0.53	0.00	34.78
	TOT		**30.35**	**7.99**	**2.43**	**3.75**	**6.31**	**0.00**	**24.15**
2003	Oct	34.78	0.43	0.03	0.15	0.21	0.53	0.00	34.28
	Nov	34.28	0.61	0.00	0.00	0.21	0.53	0.00	34.15
	Dec	34.15	0.44	0.00	0.00	0.21	0.53	0.00	33.86
	Jan	33.86	0.21	0.00	0.00	0.27	0.53	0.00	33.27
	Feb	33.27	0.49	0.00	0.00	0.34	0.53	0.00	32.90
	Mar	32.90	1.84	0.00	0.00	0.67	0.53	0.00	33.54
	Apr	33.54	0.84	0.00	0.03	0.60	0.53	0.00	33.23
	May	33.23	1.84	0.05	0.13	0.40	0.53	0.00	33.96

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	Jun	33.96	0.08	1.24	0.31	0.21	0.53	0.00	31.75
	July	31.75	0.13	3.43	0.50	0.21	0.53	0.00	27.21
	Aug	27.21	0.12	2.50	0.45	0.21	0.53	0.00	23.64
	Sep	23.64	0.16	0.73	0.29	0.21	0.53	0.00	22.05
	TOT		**7.18**	**7.99**	**1.86**	**3.75**	**6.31**	**0.00**	**22.05**
2004	Oct	22.05	0.29	0.03	0.11	0.21	0.53	0.00	21.46
	Nov	21.46	0.13	0.00	0.00	0.21	0.53	0.00	20.86
	Dec	20.86	1.13	0.00	0.00	0.21	0.53	0.00	21.25
	Jan	21.25	6.57	0.00	0.00	0.27	0.53	0.00	27.02
	Feb	27.02	4.33	0.00	0.00	0.34	0.53	0.00	30.49
	Mar	30.49	4.22	0.00	0.00	0.67	0.53	0.00	33.51
	Apr	33.51	2.89	0.00	0.03	0.60	0.53	0.00	35.25
	May	35.25	2.13	0.05	0.13	0.40	0.53	0.00	36.27
	Jun	36.27	1.06	1.24	0.33	0.21	0.53	0.00	35.03
	July	35.03	0.46	3.43	0.55	0.21	0.53	0.00	30.77
	Aug	30.77	0.44	2.50	0.50	0.21	0.53	0.00	27.47
	Sep	27.47	0.39	0.73	0.32	0.21	0.53	0.00	26.08
	TOT		**24.05**	**7.99**	**1.97**	**3.75**	**6.31**	**0.00**	**20.86**
2005	Oct	26.08	0.22	0.03	0.12	0.21	0.53	0.00	25.40
	Nov	25.40	0.59	0.00	0.00	0.21	0.53	0.00	25.26
	Dec	25.26	0.65	0.00	0.00	0.21	0.53	0.00	25.17
	Jan	25.17	0.50	0.00	0.00	0.27	0.53	0.00	24.88
	Feb	24.88	0.68	0.00	0.00	0.34	0.53	0.00	24.69
	Mar	24.69	4.54	0.00	0.00	0.67	0.53	0.00	28.04
	Apr	28.04	3.53	0.00	0.03	0.60	0.53	0.00	30.43
	May	30.43	2.94	0.05	0.12	0.40	0.53	0.00	32.27
	Jun	32.27	0.70	1.24	0.30	0.21	0.53	0.00	30.70
	July	30.70	0.13	3.43	0.49	0.21	0.53	0.00	26.17
	Aug	26.17	0.12	2.50	0.43	0.21	0.53	0.00	22.62
	Sep	22.62	0.10	0.73	0.28	0.21	0.53	0.00	20.97
	TOT		**14.71**	**7.99**	**1.76**	**3.75**	**6.31**	**0.00**	**20.97**
2006	Oct	20.97	0.25	0.03	0.10	0.21	0.53	0.00	20.35

Table A1 (Continued)

Yrs.	**Mon.**	**Initial Stor. (hm^3)**	**Inflow (hm^3)**	**Crop Water Req. (hm^3)**	**Evap. (hm^3)**	**River Water Req. (hm^3)**	**Drink. Water (hm^3)**	**Spill (hm^3)**	**End. Stor. (hm^3)**
	Nov	20.35	1.92	0.00	0.00	0.21	0.53	0.00	21.53
	Dec	21.53	1.24	0.00	0.00	0.21	0.53	0.00	22.03
	Jan	22.03	0.84	0.00	0.00	0.27	0.53	0.00	22.08
	Feb	22.08	4.56	0.00	0.00	0.34	0.53	0.00	25.77
	Mar	25.77	5.43	0.00	0.00	0.67	0.53	0.00	30.01
	Apr	30.01	4.42	0.00	0.03	0.60	0.53	0.00	33.28
	May	33.28	1.43	0.05	0.12	0.40	0.53	0.00	33.61
	Jun	33.61	0.25	1.24	0.30	0.21	0.53	0.00	31.58
	July	31.58	0.42	3.43	0.50	0.21	0.53	0.00	27.32
	Aug	27.32	0.14	2.50	0.45	0.21	0.53	0.00	23.77
	Sep	23.77	0.19	0.73	0.29	0.21	0.53	0.00	22.21
	TOT		**21.08**	**7.99**	**1.80**	**3.75**	**6.31**	**0.00**	**20.35**
2007	Oct	22.21	1.18	0.03	0.11	0.21	0.53	0.00	22.50
	Nov	22.50	2.01	0.00	0.00	0.21	0.53	0.00	23.78
	Dec	23.78	0.78	0.00	0.00	0.21	0.53	0.00	23.81
	Jan	23.81	0.95	0.00	0.00	0.27	0.53	0.00	23.97
	Feb	23.97	1.41	0.00	0.00	0.34	0.53	0.00	24.51
	Mar	24.51	3.56	0.00	0.00	0.67	0.53	0.00	26.88
	Apr	26.88	2.35	0.00	0.03	0.60	0.53	0.00	28.08
	May	28.08	0.05	0.05	0.11	0.40	0.53	0.00	27.05
	Jun	27.05	0.36	1.24	0.26	0.21	0.53	0.00	25.18
	July	25.18	0.13	3.43	0.41	0.21	0.53	0.00	20.73
	Aug	20.73	0.12	2.50	0.36	0.21	0.53	0.00	17.24
	Sep	17.24	0.07	0.73	0.23	0.21	0.53	0.00	15.62
	TOT		**12.97**	**7.99**	**1.51**	**3.75**	**6.31**	**0.00**	**15.62**
2008	Oct	15.62	0.37	0.03	0.09	0.21	0.53	0.00	15.13
	Nov	15.13	0.39	0.00	0.00	0.21	0.53	0.00	14.79
	Dec	14.79	0.96	0.00	0.00	0.21	0.53	0.00	15.01
	Jan	15.01	0.75	0.00	0.00	0.27	0.53	0.00	14.97
	Feb	14.97	0.52	0.00	0.00	0.34	0.53	0.00	14.62
	Mar	14.62	2.18	0.00	0.00	0.67	0.53	0.00	15.61
	Apr	15.61	2.60	0.00	0.02	0.60	0.53	0.00	17.07

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
	May	17.07	1.02	0.05	0.08	0.40	0.53	0.00	17.04
	Jun	17.04	0.57	1.24	0.18	0.21	0.53	0.00	15.45
	July	15.45	0.46	3.43	0.29	0.21	0.53	0.00	11.45
	Aug	11.45	0.44	2.50	0.24	0.21	0.53	0.00	8.42
	Sep	8.42	0.39	0.73	0.14	0.21	0.53	0.00	7.20
	TOT		**10.66**	**7.99**	**1.03**	**3.75**	**6.31**	**0.00**	**7.20**
2009	Oct	7.20	0.05	0.03	0.05	0.21	0.53	0.00	6.43
	Nov	6.43	0.08	0.00	0.00	0.21	0.53	0.00	5.77
	Dec	5.77	0.12	0.00	0.00	0.21	0.53	0.00	5.15
	Jan	5.15	4.79	0.00	0.00	0.27	0.53	0.00	9.16
	Feb	9.16	2.47	0.00	0.00	0.34	0.53	0.00	10.76
	Mar	10.76	9.59	0.00	0.00	0.67	0.53	0.00	19.15
	Apr	19.15	5.82	0.00	0.02	0.60	0.53	0.00	23.83
	May	23.83	5.01	0.05	0.10	0.40	0.53	0.00	27.76
	Jun	27.76	1.02	1.24	0.26	0.21	0.53	0.00	26.54
	July	26.54	0.30	3.43	0.43	0.21	0.53	0.00	22.24
	Aug	22.24	0.13	2.50	0.38	0.21	0.53	0.00	18.74
	Sep	18.74	0.11	0.73	0.24	0.21	0.53	0.00	17.14
	TOT		**29.48**	**7.99**	**1.49**	**3.75**	**6.31**	**0.00**	**5.15**
2010	Oct	17.14	0.17	0.03	0.09	0.21	0.53	0.00	16.46
	Nov	16.46	1.73	0.00	0.00	0.21	0.53	0.00	17.45
	Dec	17.45	2.65	0.00	0.00	0.21	0.53	0.00	19.36
	Jan	19.36	3.62	0.00	0.00	0.27	0.53	0.00	22.19
	Feb	22.19	3.71	0.00	0.00	0.34	0.53	0.00	25.03
	Mar	25.03	3.24	0.00	0.00	0.67	0.53	0.00	27.07
	Apr	27.07	3.53	0.00	0.03	0.60	0.53	0.00	29.46
	May	29.46	1.17	0.05	0.11	0.40	0.53	0.00	29.54
	Jun	29.54	0.89	1.24	0.27	0.21	0.53	0.00	28.18
	July	28.18	0.61	3.43	0.45	0.21	0.53	0.00	24.16
	Aug	24.16	0.11	2.50	0.40	0.21	0.53	0.00	20.63
	Sep	20.63	0.07	0.73	0.26	0.21	0.53	0.00	18.98
	TOT		**21.50**	**7.99**	**1.62**	**3.75**	**6.31**	**0.00**	**16.46**

Table A1 (Continued)

Yrs.	Mon.	Initial Stor. (hm^3)	Inflow (hm^3)	Crop Water Req. (hm^3)	Evap. (hm^3)	River Water Req. (hm^3)	Drink. Water (hm^3)	Spill (hm^3)	End. Stor. (hm^3)
2011	Oct	18.98	0.43	0.03	0.10	0.21	0.53	0.00	18.54
	Nov	18.54	0.43	0.00	0.00	0.21	0.53	0.00	18.24
	Dec	18.24	4.14	0.00	0.00	0.21	0.53	0.00	21.64
	Jan	21.64	3.61	0.00	0.00	0.27	0.53	0.00	24.46
	Feb	24.46	6.77	0.00	0.00	0.34	0.53	0.00	30.36
	Mar	30.36	5.81	0.00	0.00	0.67	0.53	0.00	34.98
	Apr	34.98	5.84	0.00	0.03	0.60	0.53	0.00	39.67
	May	39.67	3.58	0.05	0.15	0.40	0.53	0.00	42.12
	Jun	42.12	3.88	1.24	0.39	0.21	0.53	0.00	43.63
	July	43.63	2.25	3.43	0.68	0.21	0.53	0.00	41.03
	Aug	41.03	0.57	2.50	0.64	0.21	0.53	0.00	37.72
	Sep	37.72	0.46	0.73	0.42	0.21	0.53	0.00	36.29
	TOT		**37.77**	**7.99**	**2.41**	**3.75**	**6.31**	**0.00**	**18.24**
2012	Oct	36.29	0.71	0.03	0.16	0.21	0.53	0.00	36.07
	Nov	36.07	1.01	0.00	0.00	0.21	0.53	0.00	36.35
	Dec	36.35	1.11	0.00	0.00	0.21	0.53	0.00	36.72
	Jan	36.72	1.18	0.00	0.00	0.27	0.53	0.00	37.10
	Feb	37.10	1.13	0.00	0.00	0.34	0.53	0.00	37.37
	Mar	37.37	6.43	0.00	0.00	0.67	0.53	0.00	42.60
	Apr	42.60	7.16	0.00	0.04	0.60	0.53	0.48	48.13
	May	48.13	1.16	0.05	0.17	0.40	0.53	0.01	48.13
	Jun	48.13	1.31	1.24	0.43	0.21	0.53	0.00	47.03
	July	47.03	0.32	3.43	0.73	0.21	0.53	0.00	42.46
	Aug	42.46	0.25	2.50	0.66	0.21	0.53	0.00	38.81
	Sep	38.81	0.11	0.73	0.43	0.21	0.53	0.00	37.02
	TOT		**21.89**	**7.99**	**2.62**	**3.75**	**6.31**	**0.49**	**36.07**