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Sustainable Management of Large Scale Irrigation Systems: A Decision Support Model for Gediz Basin, Turkey

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1. Introduction

While water on a global scale is plentiful, 97% of it is saline and 2.25% is trapped in glaciers and ice, leaving only 0.75% available in freshwater aquifers, rivers and lakes. About 70% of this fresh water is used for agricultural production, 22% for industrial purposes and 8% for domestic purposes. Increasing competition for water for domestic and industrial purposes is likely to reduce the water available for agriculture. Thus, water scarcity is being increasingly accepted as a major limitation on increased agricultural production and food security in the 21st century (Yazar, 2006). Climate change and hydric stress are limiting the availability of clean water. Overexploitation of natural resources has led to environmental unbalance. Present decisions relative to the management of hydric resources will deeply affect the economy and our future environment (Lermontov et al., 2011).

In developing countries, agriculture continues to be an important economic sector as it makes a significant contribution to national incomes and economic growth. As water scarcity intensifies in many regions of the world, better management of irrigation is becoming an issue of paramount importance (Hussain et al., 2007). Skilled management of irrigation should start from planning at the regional level (Lorite et al., 2007). The main problem in planning the management of deficit resources is how to allocate them among multiple users efficiently and equitably by considering the social, economic and political issues, while considering the heterogeneity in soils, crops and climate and the complexity of the water distribution system (Brumbelow et al., 2007; Chambers, 1988; Kilic & Ozgurel, 2005). Sustainable irrigation water management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment. A stable relationship should be maintained between these two objectives now and in the future, while potential conflicts between these objectives should be mitigated through appropriate irrigation practices. Cai et al. (2003) carried out an investigation on sustainability analysis for irrigation water management in the Aral Sea Region. This study presents an integrated modeling framework for sustainable irrigation management analysis and applies it to analyze irrigation water management. Based on the modeling outputs, alternative future of the irrigation practice in the region were explored and it was found that to maintain current irrigation practices would lead to worsening environmental and economic consequences. Investments in infrastructure improvements (about annualized US $ 299 million) and crop pattern change would be necessary to sustain the irrigated agriculture and the associated environment in the region. Evans et al. (2003) carried out an investigation on efficiency and equity in irrigation management. The objective of this study was to address the problems of inefficiency and inequity in water allocation in the El Angel watershed, located in Ecuador's Sierra region. Water is captured in a high-altitude region of the watershed and distributed downstream to producers in four elevation-defined zones via a system of canals. Upstream and downstream producers face different conditions with respect to climate and terrain. A mathematical programming model was created to study the consequences of addressing chronic water scarcity problems in the watershed by shifting water resources between the four zones. The objective function of the model maximizes producer welfare as measured by aggregate gross margin, subject to limited supplies of land, labor and water. Five water allocation scenarios ere evaluated with respect to efficiency in land and water use and equity in income distribution. Results revealed that although water was the primary constrained resource downstream, in the upstream zones, land was far more scarce. The current distribution of water rights did not consider these differences and therefore was neither efficient nor equitable. Improvements in efficiency and equity were associated with 1) a shift of water to the lower zone, and 2) the use of lower levels of irrigation intensity upstream. A linear optimization model was used in this investigation instead of real-time water allocation programming for different growing stages of crops.

Generally, optimal multi-cropping patterns and irrigation areas associated with appropriate reservoir operation and irrigation scheduling are essential for increasing the overall efficiency of reservoir-irrigation systems. Speelman et al. (2008) analyzed the efficiency with which water was used in small scale irrigation schemes in North-West Province in South Africa and studied its determinants. In the study area, small-scale irrigation schemes play an important role in rural development, but the increasing pressure on water resources and the approaching introduction of water charges raise the concern for more efficient water use. The Data Envelopment Analysis (DEA) techniques and sub-vector efficiencies were used in the study. This process was carried out under constant returns to scale (CRS) and variable returns to scale (VRS) conditions. The most important aspect of operation is distribution of the right quantity of water to the crops at the right time. An optimal multi-cropping pattern is important, since it provides better opportunities for water conservation and reduces the impact of water constraint on the system (Georgiou & Papamichail, 2008; Hsiao et al., 2007;). Bartoloni et al. (2007) carried out an investigation in order to evaluate the impacts of agriculture and water policy scenarios on the sustainability of selected irrigated farming systems in Italy. Five main scenarios were developed reflecting aspects of agricultural policy, markets and technologies: Agenda 2000, world market, global sustainability, provincial agriculture and local community. These were combined with two water price levels, representing stylized scenarios for water policy. The effects of the scenarios on irrigated systems were simulated using multi-attribute linear programming models representing the reactions of the farms to external variables defined by each scenario. In this study, five Italian irrigated farming systems were considered: cereal, rice, fruit, vegetables and citrus. The results showed the diversity of irrigated systems and the different effects that water pricing policy might produce depending on the agricultural policy, market and technological scenarios. On the other hand, effects of real-time irrigation programming at network level were not evaluated on water and agriculture policy scenarios in this investigation. Jalal et al. (2007) developed a model for optimal multi-crop irrigation areas associated with reservoir operation policies in an irrigation system. The objectives were to maximize the annual benefit of the system by supplying irrigation water for a proposed multi-crop pattern over the planning period. An irrigation program wasn't developed under real-time conditions at the system level.

In addition, it is complicated to analyze the management of deficit resources from the points of view of social, economics and politics, which constitute the various dimensions of management planning. Farmers decide on which crops to grow and on the associated use of resources such as land, labor, water and capital. Governments, on the other hand, develop policies (e.g., subsidies, taxation, and infrastructural developments) that are targeted at influencing decisions made at the farm level in order to achieve aggregated changes which are deemed desirable on a municipal, provincial or national scale. At national level, overall policies and decisions are formulated on sectoral allocations of resources and economic activities. Strategies, policies and programs for sectoral development are included in sector plans. At sub-national level, potentials, constraints and objectives for agricultural development are identified. In this multi-level planning approach, the plans at different levels have to be consistent and interlinked (Acs et al., 2007; Laborte et al., 2007; Mousavi & Ramamurthy, 2000;). Clemmens (2006) carried out research on improving irrigated agriculture performance through the water delivery process. Reasons for poor performance of the schemes were discussed and a method was proposed to improve its performance. According to this research, the main problem was that operation of the irrigation systems was not tied to productivity. As a result, the dispersive nature of the large open canal distribution systems causes extreme variability in water delivery service to users. Diaz et al. (2007) developed a model using data from an on-demand pressurized water distribution network located in Sector VIII of the Genil-Cabra irrigation district of Santaella, Cordoba, Spain to simulate an irrigation season, and calculate the flows that circulate in the system at any given time during the irrigation day. Water demand frequencies were estimated by using the results from model solution. Statistical distribution approach was used in this process. In addition, the most appropriate periods were studied for determining peak demand. The results showed that the statistical methods slightly underestimated demand. It was concluded that a better fit is achieved when a more flexible distribution such as Gamma Distribution is used.

Haie & Keller (2008) proposed two efficiency models: one is based on water quantity, and the other on quantity and quality, with the possibility of considering water reuse in both. These models were developed for two scales: the first was called Project Effective Efficiency, and the second Basin Effective Efficiency. The latter gives the influence of project on water resources systems of the basin while the former does not make such connection to the whole basin. The concept of equity in water allocation between large numbers of users in temporal and spatial dimensions weren't taken into consideration under the real-time programming conditions. Du et al. (2009) evaluated the Soil and Water Assessment Tool (SWAT) model for estimation of continuous daily flow based on limited flow measurements in the Upper Oyster Creek (UOC) watershed. Among the five main stem stations, four stations were statistically shown to have good agreement between predicted and measured flows. SWAT underestimated the flow of the fifth main stem station possibly because of the existence of complex flood control measures near to the station. SWAT estimated the daily flow at one tributary station well, but with relatively large errors for the other two tributaries. Any water allocation plan wasn’t prepared for the district. Varis & Abu-Zaid (2009) carried out an investigation on socio-economic and environmental aspects of water management in the 21st century: trends, challenges and prospects for the Middle East and North Africa (MENA) region. Garizabal et al. (2009) carried out an investigation in order to analyze the evolution of the agro-environmental impact in a traditional irrigation land of the middle Ebro Valley (Spain) which was experienced changes in its management. It was determined that the drought of 2005 caused more intensive water use (86%), increasing in 33% the irrigation efficiency when compared to 2001 (53%), even though a high hydric deficit (24%) was caused. Ryu et al. (2009) developed a decision support system for sustainable water resources management in a water conflict resolution framework to identify and evaluate a range of alternatives for the Geum River Basin in Korea. Working with stakeholders in a “shared vision modeling” framework, management strategies were created to illustrate system tradeoffs as well as long term system planning. A multi-criterion decision making approach using subjective scales is utilized to evaluate the water resource allocation and management tradeoffs between stakeholders and system objectives. The real-time programming wasn’t carried out in this process, and changing efficiency values for the systems in temporal and spatial dimensions weren’t taken into consideration. Sheild et al. (2009) carried out an investigation to identify and quantify stakeholder references pertaining to water management programs in order to improve water policy design. The relative importance of water management attributes was evaluated and willingness-to-pay values were estimated. Results showed that the majority of respondents weighed preserving stream health and Hawaiian cultural practices in water allocation decisions and were willing to pay $4.53 per month per household to improve stream health to an excellent condition. These results highlight the need to strongly align watershed-level preferences to better balance in-stream and offstream demands to help guide water managers to make more effective water allocation decisions.

In this investigation, the real-time irrigation programming model MONES 4.1 developed by Kilic (2010) was applied to the irrigation system known as Sector VII which is served by 28 tertiary canals in the Right Bank Irrigation System of Ahmetli Regulator in the Lower Gediz Basin, Turkey. Irrigation programs from the model for different periods were analyzed, and the results were compared with the actual irrigation applications in the system.

2. Description of the study area

This investigation was carried out on the commands of 28 tertiary canals in Irrigation District of Sector VII in Ahmetli Right Bank Irrigation Network in Lower Gediz Basin Irrigation System in Turkey. The Basin is located within the Aegean Region of western Turkey at latitude 38^0 04' - 39^0 13' N, and longitude 26^0 42' - 29^0 45' E. The main water source for the Lower Gediz Irrigation System is the Gediz River, which is 275 km in length. Drainage area of the basin is roughly 17219 km^2 (Figure 1). The Gediz Basin is a river deposit basin formed with the alluvium transported by the Gediz River and its tributaries. The basin’s topography is characterized by hills and rolling country. The tributaries of the Gediz River have been filled with eroded silt and sediment by erosion. For this reason, flood flows can easily overtop the river banks. These conditions create a problem of high groundwater in the basin, especially near the sea where the slope is minimal (Girgin et al., 1999; Kilic, 2004; Topraksu, 1971, 1974; Yonter, 2010).

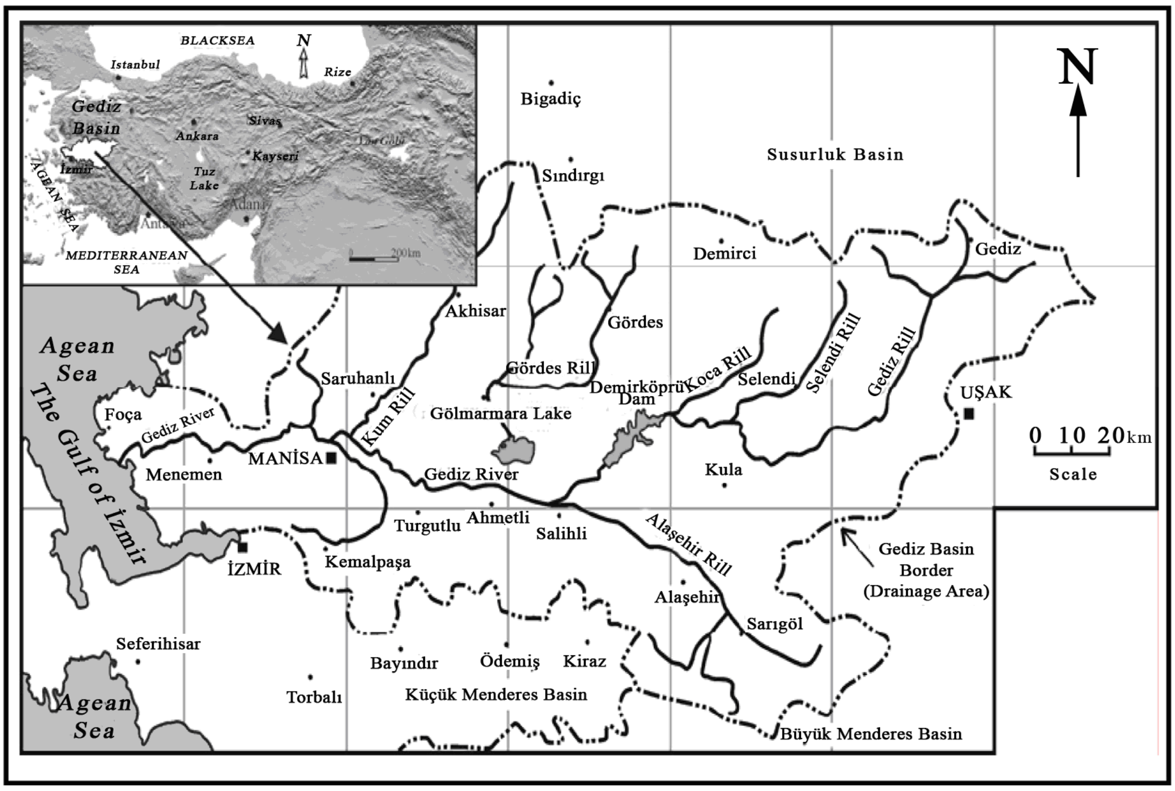


Fig. 1. General plan of the Gediz Basin in Turkey.

The Demirköprü Dam was constructed on the Gediz River in 1960 for irrigation, energy and flood control. Total water storage in the dam reservoir determines the volume and duration of irrigation water supplies to Gediz Basin System. Roughly 751 million cubic meters of water per year is released to the Lower Gediz Irrigation System by means of three regulators constructed on the river: from upstream to downstream, Adala, Ahmetli and Emiralem (Kilic & Tuylu, 2010).

For the past decade, there has been a scarcity of water in the Lower Gediz Basin because of the increase in urban and industrial demands (Svendsen et al., 2001). Unplanned production patterns, inadequate system capacity, poor distribution and management of water, large numbers of divided and small sized plots for cropping, and uncontrolled and inappropriate use of water by the farmers are the major factors giving rise to low efficiency in the Gediz Basin Irrigation System. Water level or flow can be controlled from three points in the system: I- main regulator at the head of the main canal; II- offtake regulators at the heads of the secondary canals; and III- constant-head orifices at the turnout to each tertiary canal. The main and secondary canals are under upstream control.

The National Water Works (DSI) operates the major water control infrastructures, such as river regulators and dams. Also, water allocation to main canals is fixed by the DSI according to the size of command and cropping pattern. Irrigation associations are responsible for water delivery from the main canal to secondary canals. Water delivery to tertiary canals and plots is arranged by Village Irrigation Groups (VIGs) which are responsible to the irrigation association. VIGs are the lowest unit of the irrigation associations, and are responsible for collecting and submitting farmers' water demand forms and managing water distribution at tertiary canal level. Farmers report their water requirements to the VIGs one or two days before the desired irrigation date, and VIGs decide the allocation of water to the plots according to the reports from the farmers. During a fixed length of system rotation period, farmers receive water from the canals to their plots according to this plan. Especially in peak irrigation period and under water scarcity conditions, farmers in the tail end of the network cannot use the system equally and cannot receive an adequate amount of water on schedule. Because, the farmers especially in the head of the canals continue receiving water from the system and decide for themselves whether an adequate amount of water has been received. Disagreements between the farmers are handled by the VIGs or irrigation associations.

Tertiary name	Cotton (ha)	Grapes (ha)	Maize (ha)	Watermelons (ha)	Tomatoes (ha)
P.3	0.45	0.00	2.36	0.00	0.50
P.4	7.99	0.00	6.36	0.00	6.86
P.5	5.29	0.95	26.03	0.45	7.43
P.6	1.50	0.80	0.39	0.00	0.30
P.7	5.87	6.20	19.39	0.00	2.55
P.8	2.88	2.92	0.45	0.00	0.57
P.9	12.37	0.00	10.42	1.10	0.25
P.10	1.48	0.00	10.95	0.00	0.00
P.11	4.36	0.96	12.34	0.00	0.86
P.12	6.13	0.00	2.57	0.00	0.00
P.13	8.09	4.02	3.08	0.20	1.10
P.14	13.12	0.46	18.54	0.08	0.00
P.15	8.57	1.41	2.98	0.00	0.00
P.16	15.23	0.00	24.30	0.00	0.00
P.17	4.00	0.00	0.00	1.00	0.00
P.18	15.00	0.00	32.99	0.00	0.00
P.19	11.20	0.00	43.70	2.10	0.10
P.20	41.05	7.13	15.86	5.00	0.30
P.21	12.54	4.00	3.42	0.00	0.00
P.22	11.14	10.76	10.90	0.00	0.00
P.23	19.42	4.64	4.43	1.00	0.00
P.24	9.97	1.25	16.15	1.49	0.00
P.25	2.57	4.14	0.00	0.00	0.00
P.26	19.02	4.37	26.59	0.00	0.00
P.27	0.00	2.81	0.00	0.00	0.00
P.28	0.61	0.00	0.00	0.00	0.00
P.29	0.00	1.02	0.00	0.00	0.00
P.30	1.02	5.31	5.53	0.95	1.21

Table 1. Crop pattern and size of the area irrigated by the canals.

In the research area, water charges are collected annually by the Gediz Irrigation Association according to the crop type and size of the area. In other words, water from the open canal irrigation system is priced in TL/ha, and is paid for as a single payment for the whole season. Thus, the number of irrigations and the amount of water used in irrigation applications is not important in pricing the water.

Apart from this, producers form crop patterns according to tradition and their own preferences. This has an adverse effect on the efficient management of these systems. In addition, there is a loss of productivity because of the great age of systems like the one under study here. Size of the area irrigated by the canals and the crop patterns are shown in Table 1. In the research area, cotton, maize, tomatoes, watermelons and grapes are grown in ratios of 37.69%, 46.89%, 3.45%, 2.09% and 9.88% (Gediz Irrigation Association Reports, 2007).

The district has a continental climate. Rain falls mostly in the winter months, while summers are dry. The effect of Aegean Sea is felt inland because the mountains run perpendicular to the sea. The land is irrigated in the period from May to September when rainfall is insufficient. Annual average temperature and rainfall (1975-2006) in the district are 16.9 ^{o}C and 704.6 mm respectively (DMI Reports, 2008).

3. Description of the irrigation programming model

3.1 Water allocation stages at network level

The program performs the real-time allocation of water at network level in three main stages: 1) allocation of water from the main canal to the secondaries, 2) allocation from secondary to tertiary canals, and 3) allocation to plots.

The entire network is divided into different segments in the program. This means that the main canal cross-section between the points where two consecutive secondaries receive water is the primary level segment; a secondary canal cross-section between the points where two consecutive tertiaries receive the water is the secondary level segment, and a tertiary canal cross-section between the points where two consecutive plots receive water constitutes the third level segment. Each different level of segment takes an increasing consecutive index value from head of the network to the end. Therefore, the spatial description of each segment is carried out in the system, and the operation of the program is performed interactively in order for each level of segment.

Four main components are described for each segment in the program: 1) inflow discharge to head of the segment, 2) water conveyance loss through the segment, 3) amount of water received for irrigation from the segment, and 4) outflow discharge from the end of the segment. These data constitute one of the main components of real-time water allocation program.

Water distribution stages in the program are performed by running the seven modules interactively in order. Water is received by the plots from the tertiaries. For this reason, the planning process for tertiaries is described in detail, so as to show the effects of water allocation programs at the level of secondaries and the plots. The planning processes for other levels are also carried out in similar ways.

3.2 Description of the main modules in the program

In this section, the modules for preparing real-time irrigation programs for tertiary levels will be described. One of the modules is the structural module. This component contains all the structural and hydraulic features of the network. The main parameters in this module are water carrying capacity and length of each secondary segment; the inflow discharge to head of the secondary cross-section; water conveyance efficiency and maximum water carrying capacity and size of the command of each tertiary. In this stage, it must be taken into consideration that water is delivered from secondary canals to the tertiaries, and these two allocation levels are described interactively in this module. Some parameters in the program are shown schematically together with the layout of the canals in Figure 2.

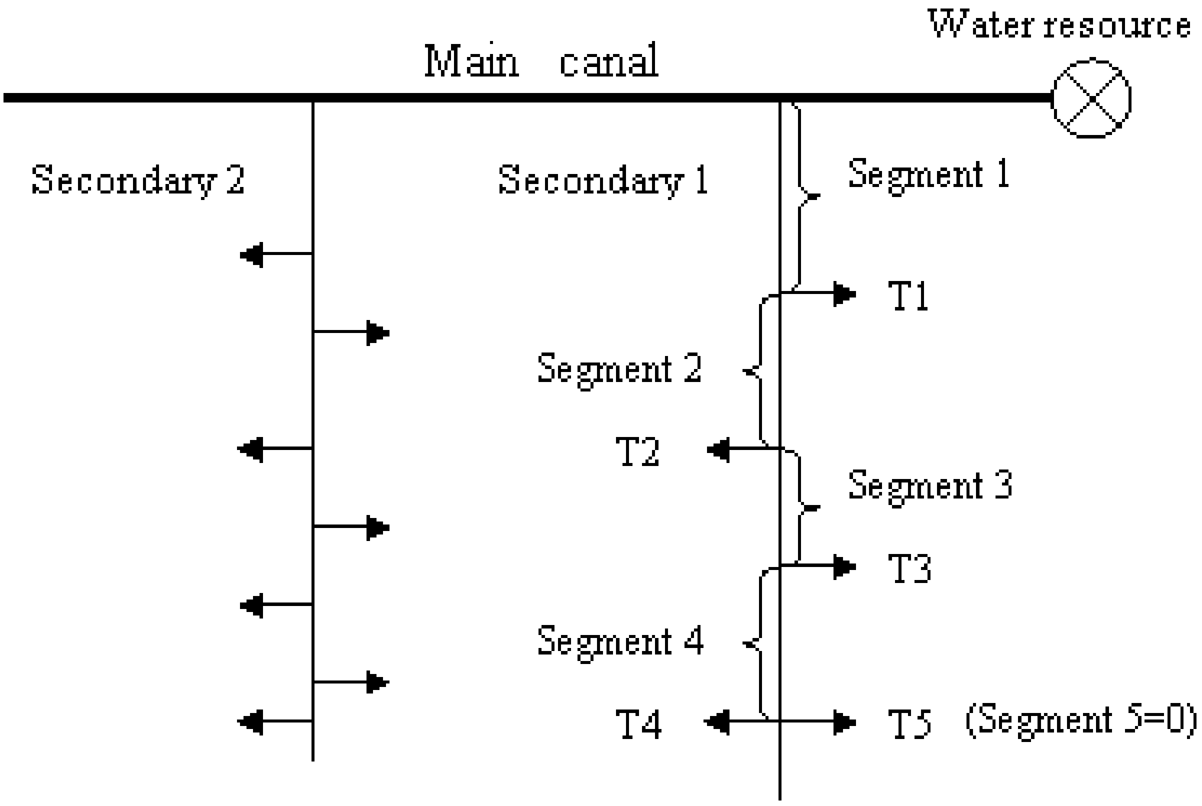
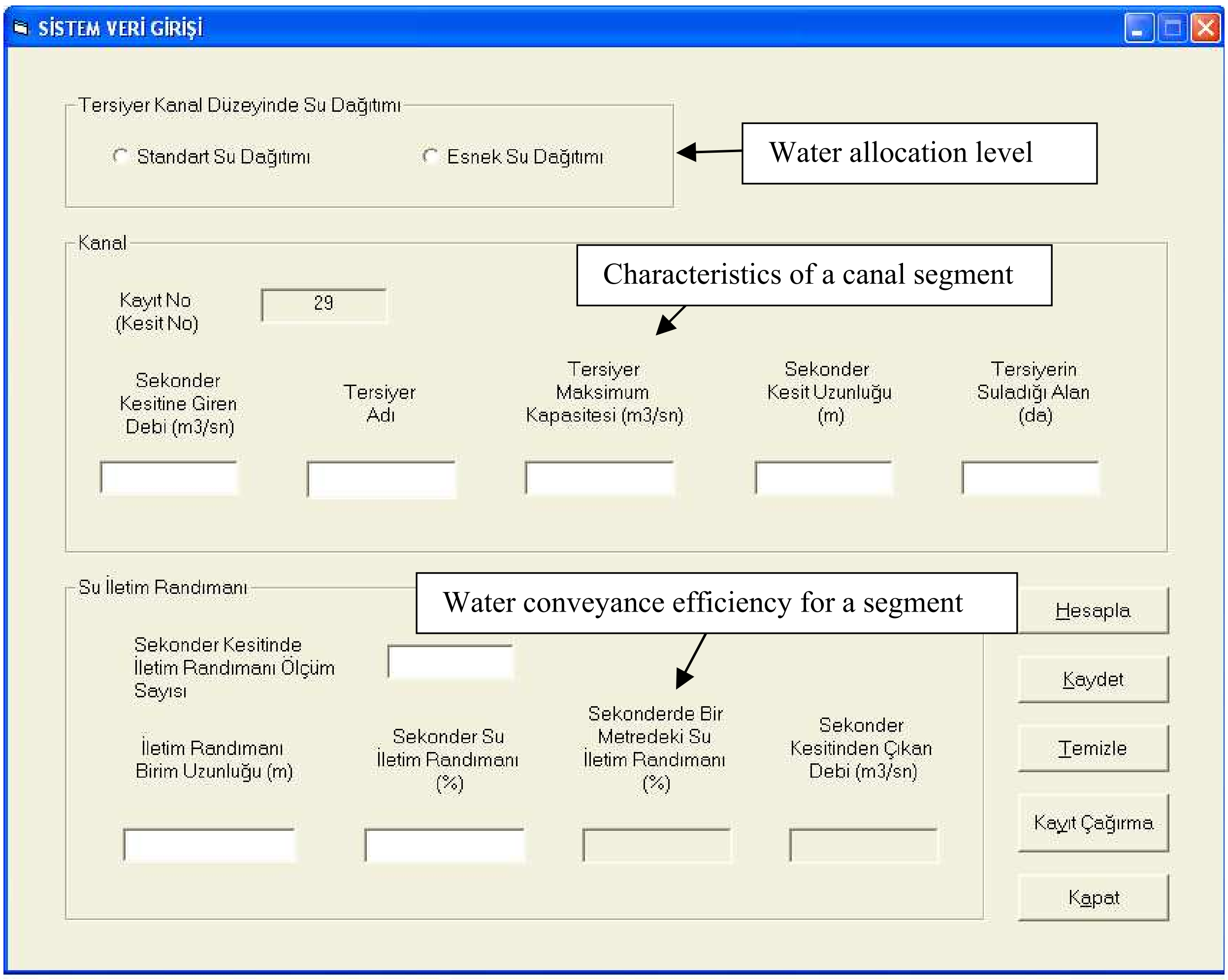


Fig. 2. Schematic description of parameters of the real-time programming model of an open canal system.

As seen on Figure 2, tertiaries T1-T5 receive water from secondary 1. The lengths of the secondary segments between these tertiaries are shown as Segment 1, Segment 2,.... Segment 5. Average flow velocities in the vertical cross-section of the canals, which are necessary in the description of hydraulic features of the system, were determined by the Velocity-Cross Section method as explained by Mays (1996). Water conveyance losses occurring in the canals were determined by Kilic & Tuylu (2010) according to the Inflow-Outflow method (ANCID, 2003). One of the interface forms containing the parameters explained above is shown in Figure 3.



Kayıt No (Kesit No): 29

Water allocation level

Characteristics of a canal segment

Water conveyance efficiency for a segment

Fig. 3. The interface form containing some of the parameters of the model.

The second main module determines the canal rotation groups at system level. This process is based on determining the canal groups which cannot receive water at the same time. In order to obtain the highest benefit from the system, the planning process was carried out in accordance with the operation of canals at maximum capacity. In other words, it was ensured that canals received water from the network at maximum capacity. This application also constitutes one of the main principles of water allocation by the rotation method. This process was carried out by use of the formulas given below (Kilic & Anac, 2010).

$$QS_{mur} * (ESC_{mu} / 100)^{f} \geq QT\max_{mu(r+1)} \qquad (1)$$

$$f = l_{m(r+1)} - l_{mr}$$

$$(l_{m(r+1)} - l_{mr}) \geq 0 \qquad (2)$$

where, m = indices of secondary canals from head to the end of the network; u = indices of segments in secondary m from head to the end; r = indices of tertiary canals from head of the secondary to the end; QS_{mur} = discharge remaining in the secondary after water is received by tertiary r from segment u of secondary m ($m^3 sec^{-1}$); ESC_{mu} = water conveyance efficiency for segment u of secondary m (% $1km^{-1}$); $QTmax_{mu(r+1)}$ = maximum carrying capacity of the consecutive tertiary (r+1), receiving water from segment u of secondary m ($m^3 sec^{-1}$); l_{mr} = the distance from the point where tertiary r receives water to the head of secondary m (km); $l_{m(r+1)}$ = distance from the point where consecutive tertiary (r+1) receives water to the head of secondary m (km); f = Length of a secondary canal segment between the consecutive tertiaries r and (r+1) receiving water from secondary m (km).

Each tertiary canal validating the conditions indicated in formulas (1) and (2) will be in the same rotation group and can receive water in maximum capacity from the secondary at the same time. On the other hand, if the conditions are not validated by the tertiary, this canal will be in the consecutive rotation zone together with the tertiaries validating the conditions. The canal rotation groups were formed by carrying out the process repetitively for the entire network. Thus, the system is divided into different allocation zones to ensure efficient usage of resources and operation of the network.

The third module determines borders, sizes and numbers of the allocation zones devised by the model in the system. Total sizes of the commands irrigated by the canal rotation groups serving each allocation zone also describe the borders and sizes of these zones. Indices are given to the allocation zones in an increasing order from head of the network to the end. In the program, borders of the allocation zones are represented by the names and indices of the head and end segments of the canals irrigating the area. These borders are described by the formulas given below in the model.

$$AR = \sum_{z=1}^{nz_a} AT_{az} \quad \text{For a} = 1, \text{ na} \tag{3}$$

where, a = indices of allocation zones in the system (in order from head of the network to the end); na = total number of allocation zones in the system; z = indices of tertiary canals delivering water simultaneously to allocation zone a (in order from head to the end of the secondary); nz_a = total number of tertiary canals delivering the water simultaneously to allocation zone a; AT_{az} = size of the area irrigated by tertiary z in allocation zone a (ha); AR = total size of the irrigated area in allocation zone a (ha).

In the fourth module, the lengths of irrigation times to be allocated to the zones during the system rotation period are determined in accordance with the principle of delivering equal amounts of water per unit of area in each allocation zone. In other words, whatever the location of a plot in the network, the capacity of the canal receiving water from the system, or the water conveyance efficiency, this plot will benefit from the water resource and system equally in temporal and spatial dimensions. This process is described for each canal rotation group which cannot receive water at the same time. The lengths of water allocation periods for different allocation zones in a given irrigation period were determined in four main stages as explained below.

In the first stage, ratio coefficient values were determined for each allocation zone in a definite rotation period. These calculations are formulated below.

$$Q\max_{ia} = \sum_{k=1}^{nk_{ia}} QT\max_{kia} \tag{4}$$

$$t_{ia} = A_a \big/ Q\max_{ia} \quad \text{For a} = 1,\ \text{na} \ ;\ \text{For i} = 1,\ \text{ni} \qquad (5)$$

where, a = indices of the allocation zones in the system (in order from the head of the network to the end); na = the total number of allocation zones in the system; i = indices of rotation periods (in order from the beginning of the irrigation season to the end); ni = total number of rotation periods during the entire irrigation season; k = indices of tertiary canals delivering water simultaneously to allocation zone a in rotation period i (in order from the head of the secondary to the end); nk_{ia} = the number of tertiary canals delivering water simultaneously to allocation zone a in rotation period i; $QTmax_{kia}$ = maximum water carrying capacity of tertiary k delivering water to allocation zone a in rotation period i (m^3 sec^{-1}); $Qmax_{ia}$ = sum of the maximum water carrying capacities of the tertiary canals delivering water simultaneously to allocation zone a in rotation period i (m^3 sec^{-1}); A_a = total size of the irrigated area in allocation zone a in rotation period i (ha); t_{ia} = ratio coefficient of allocation zone a for rotation period i.

In the second stage, the system factor was determined for a definite rotation period.

$$SF_i = R \Big/ \sum_{a=1}^{na} t_{ia} \quad \text{For i} = 1,\ \text{ni} \qquad (6)$$

where, R = length of the rotation period for the system (hours); SF_i = system factor for the rotation period i.

In the third stage, length of irrigation time was determined for each allocation zone during a definite rotation period.

$$IRT_{ia} = t_{ia} * SF_i \quad \text{For a} = 1,\ \text{na} \ ;\ \text{For i} = 1,\ \text{ni} \qquad (7)$$

where, IRT_{ia} = length of irrigation time for allocation zone a in rotation period i (hours).

In the fourth stage, the formula shown below was obtained when all the calculation processes in the previous stages were converted to a general equation.

$$IRT_{ia} = \left[A_a \Big/ \sum_{k=1}^{nk_{ia}} QT\max_{kia} \right] * \left[R \Big/ \sum_{a=1}^{na} t_{ia} \right] \quad \text{For a} = 1,\ \text{na} \ ;\text{For i} = 1,\ \text{ni} \qquad (8)$$

As can be understood from the calculation process explained above, the planning is carried out in accordance with the operation of the system at maximum capacity. In addition however, plant pattern and soil features of the allocation zones may be different from each other, which means that the irrigation water requirements of the zones will be different from each other too. Determination of irrigation water requirements of allocation zones and analysis of water constraint levels occurring in tertiary commands is performed in the next module.

In the fifth module, irrigation water requirements of the crops grown in the command of each tertiary are determined as volume for a given period. The value of this parameter is used as a transition stage in determining the amount of water to be allocated from the resource to a given allocation zone. It is also used in determining the length of irrigation time necessary to meet the water requirements of the crops, and water deficits occurring in the canals in the entire network.

Irrigation water requirements and constraint levels occurring in the command of each tertiary canal were determined using the formulas given below.

$$WDV_{akci} = \Sigma(D_{akci} * A_{akc} * 10) \tag{9}$$

where WDV_{akci} = total amount of irrigation water requirement as volume of crop c grown in the command of tertiary k, in allocation zone a, for the rotation period i (m^3); D_{akci} = total amount of irrigation water requirement of crop c, irrigated by tertiary k, in allocation zone a, in rotation period i (mm). The value of this parameter was determined using a well known package, Cropwat (FAO, 1992). About 30-45% of available moisture between the permanent wilting point and field capacity was allowed to be depleted, and the soil moisture was refilled to field capacity at each irrigation. Exceeding the soil moisture depletion level by over 50% was not allowed, as explained by Doorenbos & Kassam (1979). A_{akc} = size of the growing area of crop c irrigated by tertiary k, in allocation zone a (ha).

Amount of irrigation water allocated to the crops grown in the command of a tertiary canal were determined by the formula given below.

$$AW_{kia} = QT\max_{kia} * IRT_{ia} * 3600 \tag{10}$$

where AW_{kia} = amount of irrigation water allocated to the crops grown in the command of tertiary k, in allocation zone a, during the rotation period i (m^3); $QTmax_{kia}$ = maximum water carrying capacity of tertiary k delivering water to allocation zone a in rotation period i ($m^3\ sec^{-1}$); IRT_{ia} = length of irrigation time for allocation zone a in rotation period i (hours); 3600 = the coefficient converting hour to second.

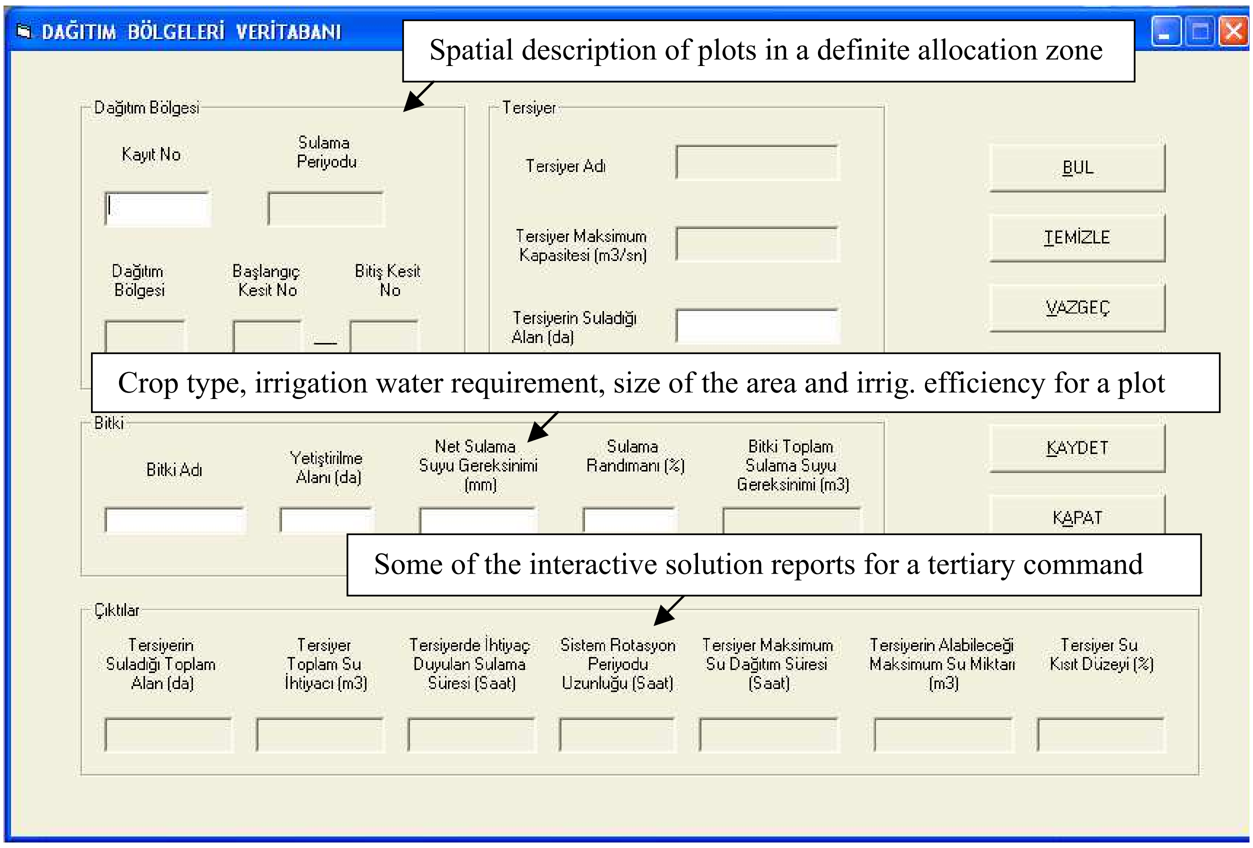
Water constraint levels occurring in the command of each tertiary were determined by the formula given below.

$$WDL_{kia} = ((WDV_{akci} - AW_{kia}) / WDV_{akci}) * 100 \ \left(\text{if } WDV_{akci} \geq AW_{kia}\right) \tag{11}$$

where WDL_{kia} = water constraint level occurring in the command of tertiary k, in allocation zone a, in rotation period i (%).

In the fourth module, the length of irrigation time allocated for each zone during the system rotation period was determined in accordance with the operation of the network at maximum capacity. In the fifth stage on the other hand, the level is determined at which the irrigation water requirements of the crops can be met by the actual infrastructure of the system. For this purpose, water constraint levels occurring in each tertiary command are determined. One of the interface forms carrying out these processes in the model is shown in Figure 4.

Irrigation water requirements of the crops vary at different growing stages. There is not a linear relationship between the amount of water given to the system and yield of crops. Thus, the Yield Response Factor (ky) takes different values at each growing stage (Kilic, 2004). Numbers and borders of allocation zones, canal rotation groups, and length of irrigation times for the zones may change depending on the conditions in different periods. The MONES 4.1 (Kilic, 2010) package provides the real-time irrigation programs by taking into consideration of varying conditions in the system.



Spatial description of plots in a definite allocation zone

Crop type, irrigation water requirement, size of the area and irrig. efficiency for a plot

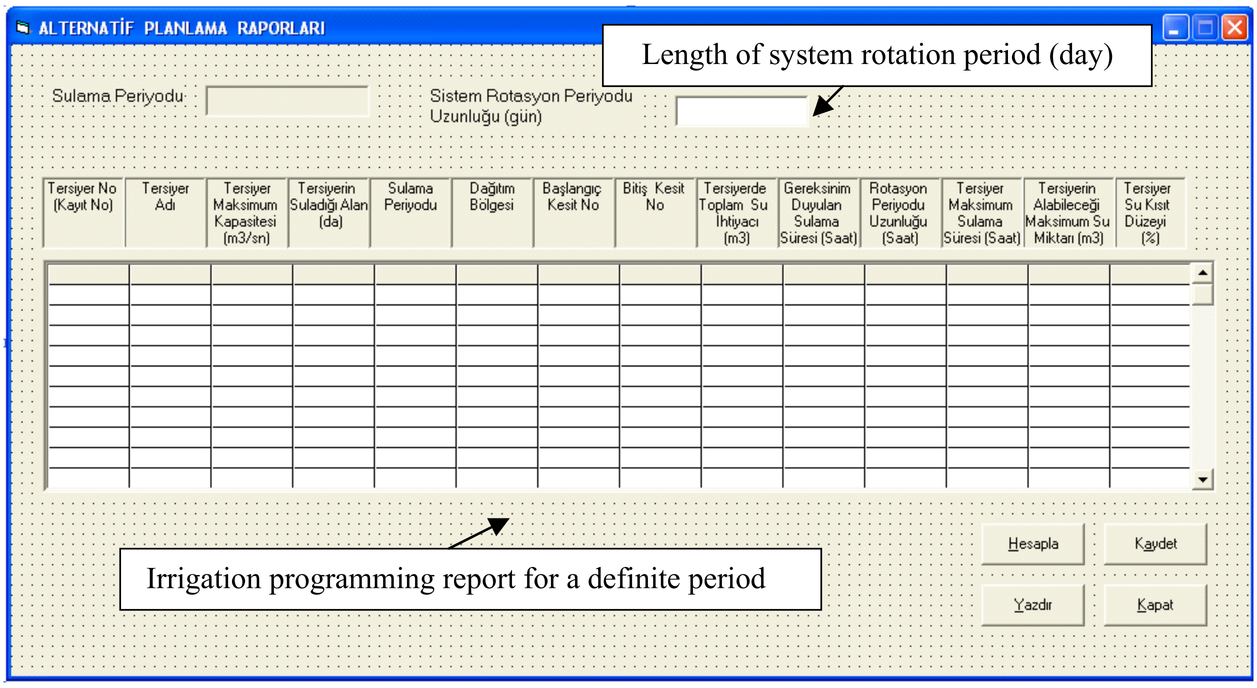
Some of the interactive solution reports for a tertiary command

Fig. 4. A sample interface form used for description of the plant pattern, irrigation water requirements of the crops, and levels of water deficit in the system.

In the sixth module, alternative irrigation programs are prepared by changing the values of parameters in the program as desired. For example, water deficiency levels occurring in each tertiary canal can be determined by changing the length of system rotation period. Thus, the most suitable length of rotation period can be decided by taking into consideration the deficit levels occurring in the entire network. This module can derive alternative solutions for desired numbers of irrigation periods. Apart from this, adequate carrying capacity of the canals needed to meet the water requirements of the crops can be determined by running this module. Also, optimum size of command which can be irrigated by the infrastructure of the network in reality can be determined. In addition, the priority and degree of maintenance and renovation works of the system can be decided by this module. Thus, insight is provided to the decision maker into the use of limited labor and financial resources at an optimum level. In this process, the results of possible operation plans from the model solution can be analyzed before making a final decision on operation strategies of the system.

In the seventh module, detailed report files are prepared for each alternative solution, and these are presented to the decision maker as tables. Therefore, an evaluation can be achieved for the entire system. A sample report file interface form for this process is shown in Figure 5.

The flow chart of the MONES 4.1 model devising irrigation programs at network level is given in Figure 6.



ALTERNATİF PLANLAMA RAPORLARI

Sulama Periyodu:

Sistem Rotasyon Periyodu Uzunluğu (gün)

Tersiyer No (Kayıt No)	Tersiyer Adı	Tersiyer Maksimum Kapasitesi (m3/sn)	Tersiyerin Suladığı Alan (da)	Sulama Periyodu	Dağıtım Bölgesi	Başlangıç Kesit No	Bitiş Kesit No	Tersiyerde Toplam Su İhtiyacı (m3)	Gereksinim Duyulan Sulama Süresi (Saat)	Rotasyon Periyodu Uzunluğu (Saat)	Tersiyer Maksimum Sulama Süresi (Saat)	Tersiyerin Alabileceği Maksimum Su Miktarı (m3)	Tersiyer Su Kısıt Düzeyi (%)

Length of system rotation period (day)

Irrigation programming report for a definite period

Fig. 5. A sample interface form for the preparation of alternative solution reports.

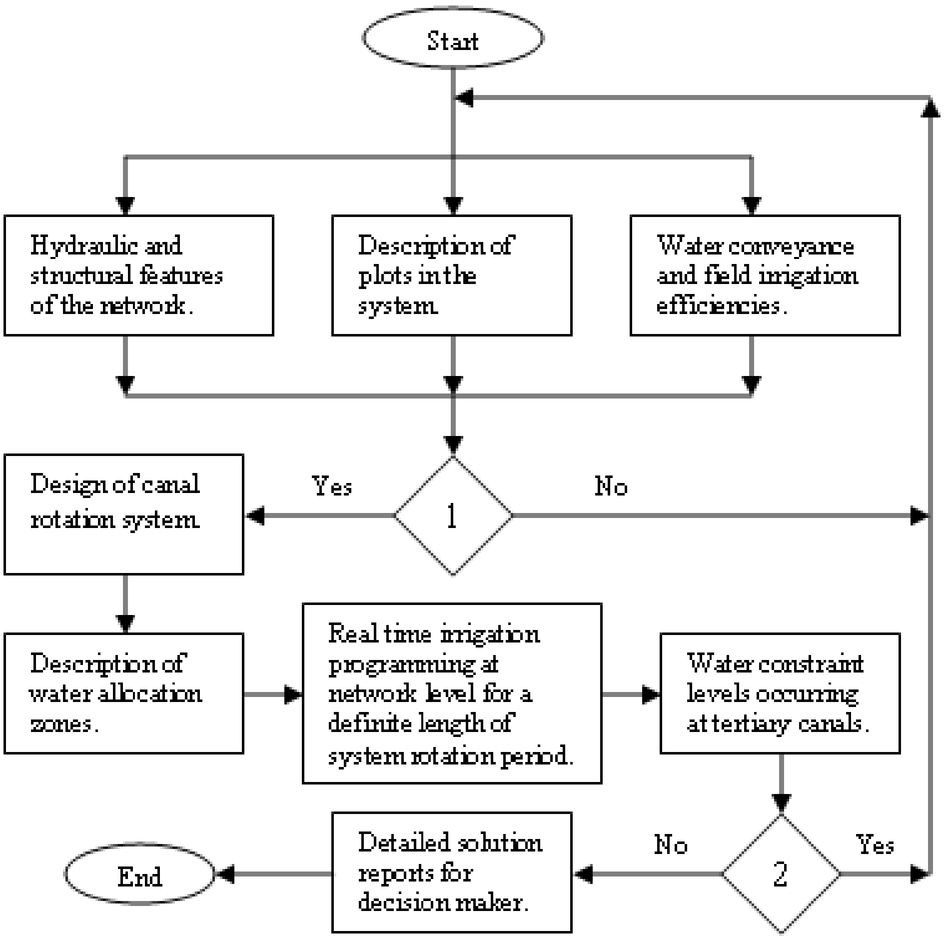


Fig. 6. Model flowchart for real-time irrigation programs.

Firstly, data input process to the related modules was carried out in the program (Figure 6). This step inquired whether data input to the system was completed or not. Another stage in running the model is derivation of alternative irrigation programs. If decision maker decides that alternative programs must be devised for a given irrigation period, the model is run again by the second conditional return, shown in the flow chart in Figure 6. By running this module, it is possible to derive alternative irrigation programs by making necessary changes to desired parameters in the model.

At the end of this process, optimum operation strategies for the system can be decided by analyzing the water constraint levels occurring in canals, the length of irrigation periods necessary for different allocation zones, the amount of water used in the network, and the allocation of deficit resources to different irrigation periods. Consequently, before deciding on an operation strategy for the system, the optimum program can be selected by analyzing alternative solutions of the model.

4. Results and discussion

Significant levels of differences occurred between the water allocation plan applied in the research area in reality and the model solution. It was determined that canal rotation groups, allocation zones and irrigation programs from the model solution were different from those applied in reality in the system.

In the research area, a 10 day system rotation period is applied by the current water allocation program in the network. Tertiaries are held open during this period by the Gediz Irrigation Association, and water is received in the plots by the farmers without any planning when it is released to the canals (Gediz Irrigation Association Reports, 2007). In other words, in the water allocation plan applied in reality, irrigation water is given to all the tertiary canals at the same time, and an attempt is made to irrigate the entire command in 10 days. This application prevents the operation of the system at maximum capacity and does not enable the optimum benefit to be obtained from production. Such a practice causes the irrigation water to be taken from the canals immediately, especially by the farmers whose plots are in the head of the network. Uncontrolled water allocation prevents it from being received in the desired amount and at the desired time by the farmers whose plots are in the tail end of the system. Consequently, it is not possible to provide social equity in temporal and spatial dimensions in use of the system and allocation of deficit resources to large numbers of users by means of the water allocation plan applied in the district in reality.

In addition, no scientific plant patterning has been carried out in the research area or elsewhere in Turkey. Thus, producers choose crop patterns according to tradition and market conditions. In this state, it is necessary to prepare real-time irrigation programs at network level, and the parameters necessary for optimum growing conditions must be taken into consideration. In this way, optimum crop yield and benefit can be obtained by using the system capacity at maximum level. Allocation Zones (AZ), canal rotation groups and size of irrigated areas obtained by running the irrigation programming model MONES 4.1 are given in Table 2.

Allocation Zone	Tertiary canal rotation groups	Total size of the irrigated area (ha)
AZI	P.3-P.22.	505.65
AZII	P.23-P.26.	115.04
AZIII	P.27-P.30.	18.46

Table 2. Allocation zones, canal rotation groups and total size of the commands in the MONES 4.1 model.

Three different allocation zones were determined in the research area, as maximum carrying capacity of the secondary canal is not adequate for delivering water to all tertiaries at the same time. The number of tertiary canals allocating water to AZ I, AZ II and AZ III also decreased progressively along the length of the secondary, as the capacity of the secondary canal diminishes from the head of the network to the end. In other words, fewer tertiary canals could deliver water at the same time to a given allocation zone at the end of the network than at the head, because of the progressive reduction of the secondary canal's capacity. For example, at the head of the network, 20 tertiary canals (P.3-P.22) can irrigate the command of AZ I at the same time, while only 4 tertiaries (P.27-P.30) can irrigate the command of AZ III simultaneously, as it is at the end of the network. In this way, all the canals in the network were operated in maximum level.

Maximum lengths of irrigation times (IRT) allocated for the zones (AZ) during the 7, 10, 11 and 12-day alternative system rotation periods (R) for the district are given in Table 3.

As can be understood from the Table 3, the maximum lengths of irrigation times allocated for different zones vary depending on the length of the alternative system rotation periods. These allocation times were planned in order to give equal amounts of water to the unit areas of different allocation zones.

Allocation Zones	Alternative system rotation periods			
	7 days (168 hours)	10 days (240 hours)	11 days (264 hours)	12 days (288 hours)
AZI	95.06	135.80	149.38	162.96
AZII	51.93	74.18	81.60	89.02
AZIII	21.01	30.02	33.02	36.02

Table 3. Lengths of irrigation times allocated for the zones during the alternative system rotation periods.

Irrigation water requirements of the allocation zones in different periods are different from each other. The whole irrigation water requirement of the allocation zones could not be met completely in the maximum length of irrigation time allocated for the zones during the system rotation period. This causes deficit irrigation applications. For this purpose, irrigation programs developed for each tertiary canal are analyzed in detail for each irrigation period. In this way it was possible to analyze the effects of the lengths of irrigation times on water deficits occurring in different periods.

In addition, irrigation times for the whole season are not determined as fixed time points at the beginning of the irrigation season in real-time programming. Irrigation times are determined in accordance with the irrigation water requirements of crops at different growing stages, size of area, location and soil features of plots receiving water from canals, infrastructure of the network, length and layout of canals, water carrying capacity of different canal segments, conveyance efficiencies and hydraulic features of the network. In this process, the most suitable length of system rotation period for the parameters stated above constitutes one of the main components in determining the irrigation times in real-time programming.

The MONES 4.1 package (Kilic, 2010) was run for the entire irrigation season in the research area, and irrigation programs were obtained. In order to bring out some of the main features of the model, three different irrigation periods were handled, beginning on 6th June, 10th July and 18th August, respectively. One of the main reasons for selecting these periods is to evaluate irrigation programs for different growing stages of the crops. Thus, the program was run for irrigation water requirements of the crops, which vary during the growing period, and the results were evaluated. The second main reason for selecting these periods was to investigate the irrigation programs of June and August, together with the program of peak irrigation period, July.

In irrigation programming in the model, depletion of 30-45% of the available moisture between permanent wilting point and field capacity was allowed, and the soil moisture was refilled to field capacity at each irrigation. Exceeding the soil moisture depletion level by over 50% was not allowed, as explained by Doorenbos & Kassam (1979).

The extent to which irrigation water requirements of the crops could be met on 6 June, 10 July and 18 August for system rotation periods of 7, 10, 11 and 12 days was determined by running the model. In other words, it was shown by alternative solutions to what level the irrigation water requirements of crops in given periods could be met by system capacity. The length of alternative rotation periods stated above did not cause any problem from the point of view of minimum irrigation intervals of the crops (Kilic & Ozgurel, 2005; Kodal et al., 1997; Sagardoy et al., 1982). However, it was determined that water deficit levels in some canals exceeded 45%, especially in rotation periods which were shorter than necessary. These canals serve a larger area than they can irrigate, because of the unplanned production pattern. In this state, irrigation water requirements of the crops cannot be met completely because of the inadequate carrying capacity of some canals and a shorter length of rotation period than necessary. Summarized results of the MONES 4.1 package are given in Tables 4-6.

As seen in Table 4, water deficits reaching 38.15% (P.7 tertiary) occurred for the 10 day system rotation period in the irrigation applications beginning on 6th June. The maximum levels of water deficit occurring during the 7, 11 and 12 day system rotation periods were 56.31%, 32.10% and 26.05%, respectively. An increase in the length of rotation period diminished the levels of water constraints occurring in the canals. The lengths of these periods were also suitable for minimum irrigation interval of the crops in the research area. However, it is clear that 56.31% water deficiency level occurring in the 7 day system rotation period is not suitable for optimum irrigation and growing conditions of these crops. On the other hand, irrigation water requirements of all 25 tertiaries, except P.7, P.9 and P.26, were met completely during the 12 day system rotation period.

Tertiary name	Total irrigation water requirement (m³)	Water deficit levels occurring in the length of alternative system rotation periods (%)			
		7 days	10 days	11 days	12 days
P.3	4767.272	0	0	0	0
P.4	28708.209	0	0	0	0
P.5	60016.997	0	0	0	0
P.6	4015.468	0	0	0	0
P.7	39412.259	56.31	38.15	32.10	26.05
P.8	9088.454	0	0	0	0
P.9	30811.573	44.48	21.26	13.51	5.77
P.10	18433.697	6.28	0	0	0
P.11	26643.547	36.01	9.14	0.19	0
P.12	12028.759	0	0	0	0
P.13	22117.774	23.18	0	0	0
P.14	46031.517	26.13	0	0	0
P.15	17683.992	4.25	0	0	0
P.16	57319.330	0	0	0	0
P.17	6567.543	0	0	0	0
P.18	70256.602	0	0	0	0
P.19	83344.510	18.54	0	0	0
P.20	94137.366	0	0	0	0
P.21	26919.283	36.65	10.06	1.20	0
P.22	44876.254	0	0	0	0
P.23	39653.301	0	0	0	0
P.24	40992.809	31.92	3.31	0	0
P.25	8675.461	0	0	0	0
P.26	70853.951	47.18	25.11	17.76	10.40
P.27	3564.963	0	0	0	0
P.28	812.503	0	0	0	0
P.29	1294.043	34.06	6.37	0	0
P.30	19086.784	0	0	0	0

Table 4. Water deficit levels occurring in the alternative rotation periods for the irrigation applications beginning on 6th of June.

July is the peak irrigation period in the district. The results obtained from model solution for the irrigation applications beginning on 10th July are given in Table 5.

As seen in Table 5, 64.91%, 50.43%, 45.61% and 40.78% of maximum water constraints occurred respectively for system rotation periods of 7, 10, 11 and 12 days. It is not suitable for optimum irrigation conditions that water constraint levels occurring in the rotation periods of 7 and 10 days be over 50% (Doorenbos & Kassam, 1979). In other words, high water requirements in some canals cannot be met completely because of the inadequate canal carrying capacity and shorter than necessary length of rotation period. It is clear that a 10 day system rotation period applied in reality in the network caused a yield loss, especially in the peak irrigation period. However, irrigation water requirements of all 25 tertiaries except P.7, P.9 and P.26 were met completely during the 12 day system rotation period.

Tertiary name	Total irrigation water requirement (m^3)	Water deficit levels occurring in the length of alternative system rotation periods (%)			
		7 days	10 days	11 days	12 days
P.3	4908.777	0	0	0	0
P.4	29787.900	0	0	0	0
P.5	58798.374	0	0	0	0
P.6	4147.970	0	0	0	0
P.7	49443.972	64.91	50.43	45.61	40.78
P.8	9229.546	0	0	0	0
P.9	35387.586	51.49	31.27	24.53	17.79
P.10	19003.545	9.05	0	0	0
P.11	27568.383	38.11	12.15	3.49	0
P.12	12696.326	0	0	0	0
P.13	23099.029	26.39	0	0	0
P.14	47988.167	29.08	0	0	0
P.15	18626.505	9.03	0	0	0
P.16	59186.227	0	0	0	0
P.17	6949.991	0	0	0	0
P.18	72267.113	0	0	0	0
P.19	86136.363	21.13	0	0	0
P.20	98793.526	0	0	0	0
P.21	28307.164	39.69	14.41	5.98	0
P.22	46591.310	0	0	0	0
P.23	41744.648	0	0	0	0
P.24	42601.463	34.44	6.91	0	0
P.25	9010.986	0	0	0	0
P.26	73765.516	49.22	28.02	20.95	13.88
P.27	3624.255	0	0	0	0
P.28	868.814	0	0	0	0
P.29	1315.566	35.12	7.88	0	0
P.30	19554.267	0	0	0	0

Table 5. Water deficit levels occurring in the alternative rotation periods for the irrigation applications beginning on 10th of July.

Results obtained by running the model for irrigation period beginning on 18th August are given in Table 6.

Tertiary name	Total irrigation water requirement (m³)	Water deficit levels occurring in the length of alternative system rotation periods (%)			
		7 days	10 days	11 days	12 days
P.3	4367.812	0	0	0	0
P.4	27970.355	0	0	0	0
P.5	52577.673	0	0	0	0
P.6	3981.409	0	0	0	0
P.7	44672.084	61.30	45.28	39.94	34.60
P.8	8976.829	0	0	0	0
P.9	32689.617	47.60	25.70	18.41	11.12
P.10	16509.593	1.81	0	0	0
P.11	24626.182	30.87	0	0	0
P.12	11958.468	0	0	0	0
P.13	22001.799	22.78	0	0	0
P.14	43465.261	21.84	0	0	0
P.15	17676.586	4.21	0	0	0
P.16	53336.634	0	0	0	0
P.17	6818.113	0	0	0	0
P.18	64475.342	0	0	0	0
P.19	75985.677	10.77	0	0	0
P.20	93733.214	0	0	0	0
P.21	27051.418	36.95	10.49	1.68	0
P.22	43428.077	0	0	0	0
P.23	40029.311	0	0	0	0
P.24	38629.018	27.84	0	0	0
P.25	8779.407	0	0	0	0
P.26	67129.658	44.33	21.03	13.27	5.50
P.27	3520.494	0	0	0	0
P.28	852.726	0	0	0	0
P.29	1277.901	33.25	5.21	0	0
P.30	18020.521	0	0	0	0

Table 6. Water deficit levels occurring in the alternative rotation periods for the irrigation applications beginning on 18th of August.

Maximum levels of water constraints occurring in the system rotation periods of 7, 10, 11 and 12 days were 61.30%, 45.28%, 39.94% and 34.60% respectively in the P.7 tertiary (Table 6). These ratios were lower than the maximum deficiency levels which occurred in the irrigation period beginning on 10th July. However, the water deficiency level (45.28%) which occurred in the 10 day system rotation period which was applied in reality in the research area was quite high. On the other hand, irrigation water requirements of all 25 tertiaries, except P.7, P.9 and P.26 were met completely during the 12 day system rotation period.

4.1 Irrigation water requirements of allocation zones and amounts of water allocated to them in alternative system rotation periods

Allocation of irrigation water in the research area was evaluated at the level of zones. Three different irrigation applications, started on 6 June, 10 July and 18 August, were taken into consideration for the allocation zones, which were served by different canal rotation groups. Irrigation water requirements in tertiaries, length of irrigation times for the canals and water deficit levels occurring in these areas were analyzed for irrigation programs devised for 7, 10, 11 and 12 day alternative system rotation periods. Results were evaluated from the point of view of water use effectiveness at the network level.

The irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods for the irrigation applications started on 6 June are shown in Figure 7.

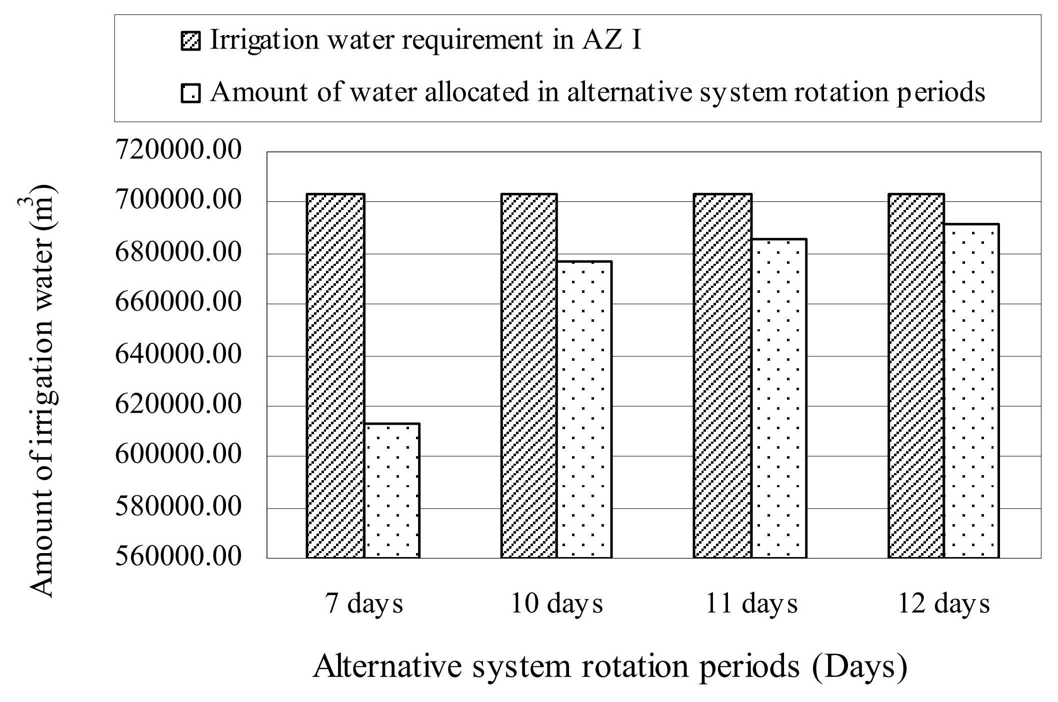


Fig. 7. Irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June.

As seen in Figure 7, as the length of alternative system rotation periods increased, the amount of water delivered to AZ I increased and deficit levels diminished. In the 7 day system rotation period, 95.06 hours of irrigation time were allocated to AZ I for the irrigation application started on 6 June (Table 3). In this process, a 12.78% water deficit occurred in this zone (Figure 7). In contrast, it was seen that 56.31%, 44.48%, 36.01% and 36.65% water deficits occurred in tertiaries P.7, P.9, P.11 and P.21 of AZ I respectively (Table 4).

When the length of the system rotation period was increased to 10 days, 135.80 hours of irrigation time was allocated to AZ I. In this state, the water deficit level in tertiary P.7 took the value of 38.15% (Table 4). In the 11 day system rotation period, the water deficit level decreased to 32.10% in tertiary P.7 (Table 4) for 149.38 hours of irrigation time (Table 3) and a 2.44% water constraint occurred in AZ I (Figure 7). As a result, most of the irrigation water requirement of AZ I was met in the 11 day system rotation period. Therefore, it was decided that the 11 day rotation period was suitable for AZ I in the irrigation applications started on 6 June.

The irrigation water requirement of AZ II and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June are shown in Figure 8.

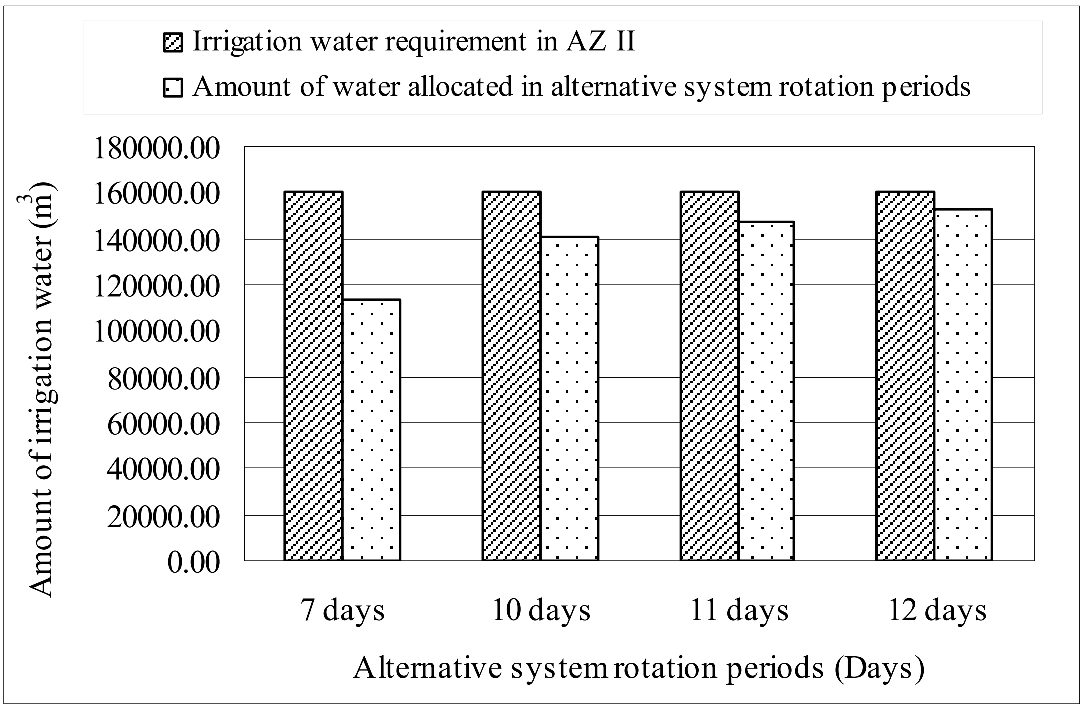


Fig. 8. Irrigation water requirement of AZ II and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June.

In this period, 51.93 hours, 74.18 hours, 81.60 hours and 89.02 hours of irrigation time were allocated to AZ II in 7, 10, 11 and 12 day alternative system rotation periods respectively (Table 3). A 29.04% water constraint occurred in AZ II for the 7 day system rotation period (Figure 8). However, if water deficits are analyzed at tertiary level for this period, it is seen that 31.92% and 47.18% water deficits occur in canals P.24 and P.26 respectively (Table 4). In other words, water deficits occurring in these tertiaries were higher than the deficit level of AZ II. The reason for this is that some of the canals serve larger areas than they should.

As seen in Figure 8, water deficits in AZ II showed a diminishing trend in the 10, 11 and 12 day system rotation periods, taking the values of 11.95%, 7.86% and 4.60% respectively. Although the water constraint level was 11.95% in AZ II in the 10 day system rotation period for the irrigation applications started on 6 June, a high (38.15%) level of deficit occurred in tertiary P.7 in AZ I in the same period. This made the 11 day system rotation period suitable for AZ II also.

The irrigation water requirement of AZ III and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June are shown in Figure 9.

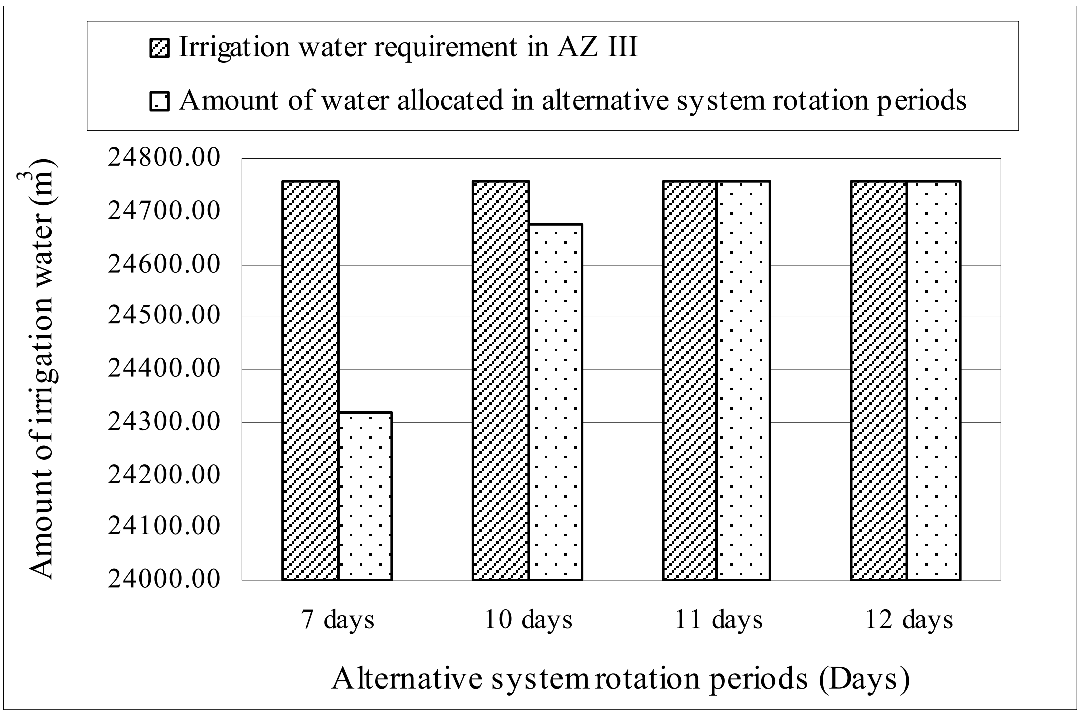


Fig. 9. Irrigation water requirement of AZ III and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June.

In irrigation applications started on 6 June, 21.01 hours and 30.02 hours of irrigation time were allocated to AZ III in the 7 and 10 day alternative system rotation periods (Table 3). As the hydraulic features of the canals in this zone were suitable for water requirements of the crop pattern and size of the irrigated area, most of the water requirements were met in this command. In the 7 and 10 day system rotation periods, 1.78% and 0.33% water deficits occurred respectively in AZ III. No water constraint occurred in the 33.02 hours of irrigation time allocated for the 11 day system rotation period in the same zone. In addition, it was a desired condition from the point of view of irrigation programming that the 11 day system rotation period was also suitable for AZ I and AZ II, and that no water constraint occurred in AZ III for this period. As a result, an 11 day system rotation period and 149.38 hours, 81.60 hours and 33.02 hours maximum irrigation times allocated to AZ I, AZ II and AZ III respectively for the irrigation applications started on 6 June were found to be suitable.

The irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July are shown in Figure 10.

In irrigation applications started on 10 July, which is in the peak period in the research area, a 15.39% water deficit occurred in AZ I during the 7 day system rotation period (Figure 10). In contrast, the water deficit at tertiary level in this zone increased depending on the rising irrigation water requirements in the peak period. High levels of water constraint (64.91%, 51.49%, 38.11% and 39.69%) occurred in the commands of tertiaries P.7, P.9, P.11 and P.21 respectively during the 7 day system rotation period (Table 5).

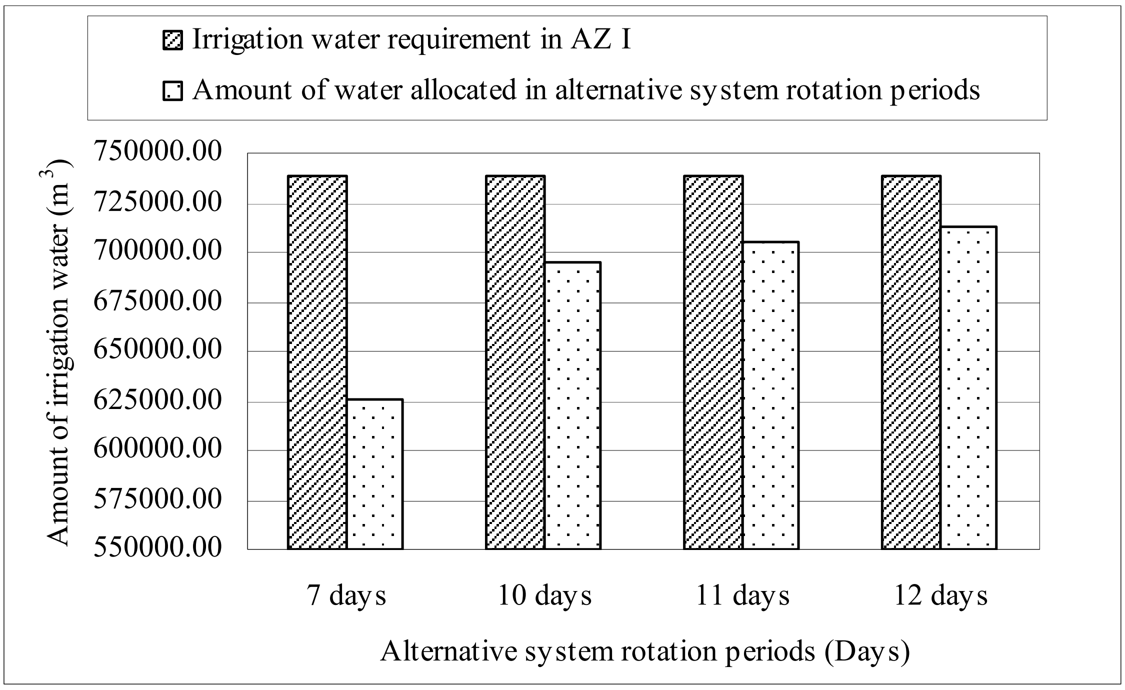


Fig. 10. Irrigation water requirement of AZ I and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July.

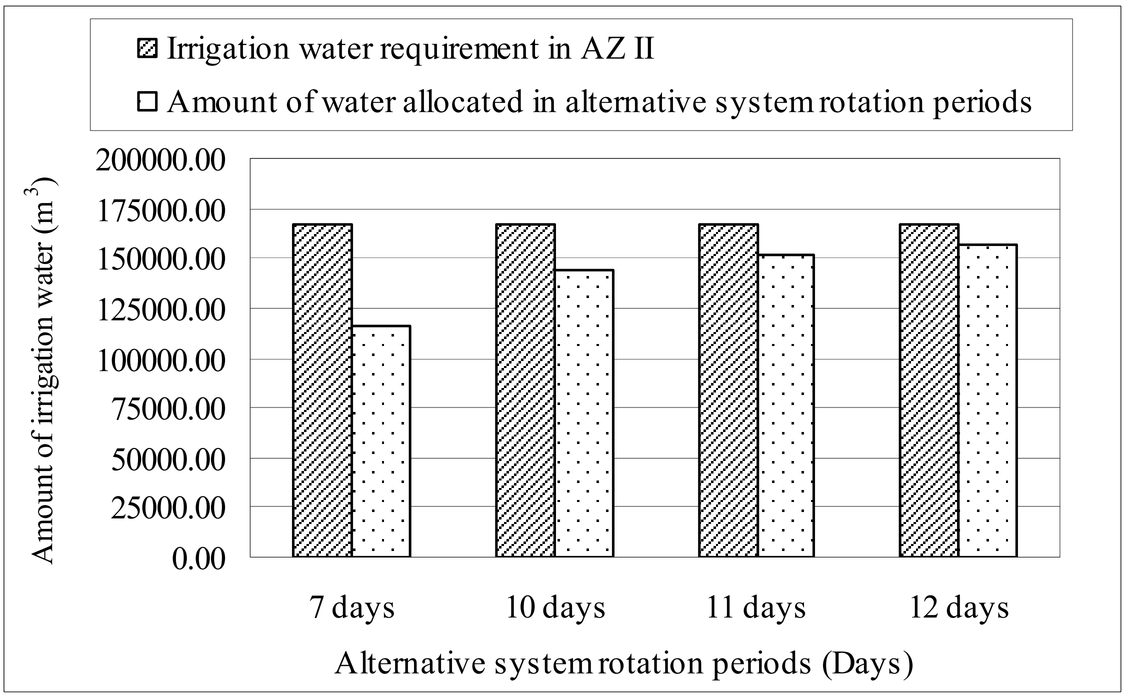


Fig. 11. Irrigation water requirement of AZ II and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July.

Although a low water deficit of 5.88% occurred in AZ I in the 10 day system rotation period, a fairly high level of water constraint (50.43%) occurred in tertiary P.7 in the same zone. Also, a water deficit of 4.59% occurred in AZ I in the 11 day system rotation period;

however, a 45.61% water constraint continued its effect in tertiary P.7. As these irrigation applications were in the peak period, the water requirements of the crops increased, and water constraint levels in the tertiaries also rose. As the water constraint decreased to 3.58% in AZ I for the 12 day system rotation period, the deficit level in the command of tertiary P.7 also diminished to 40.78%. Thus, the 12 day system rotation period was suitable in AZ I for the irrigation applications started on 10 July.

The irrigation water requirement of AZ II and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July are shown in Figure 11.

In irrigation applications started on 10 July, 51.93 hours of irrigation time was allocated to AZ II for the 7 day system rotation period (Table 3), and a 30.50% water deficit occurred in this zone (Figure 11). In this period, a high (49.22%) level of water deficit, which occurred in tertiary P.26 in AZ II, caused an increment of the water constraint level for the entire zone. 14.13%, 9.25% and 6.13% water constraints occurred in the 10, 11 and 12 day alternative system rotation periods respectively in AZ II. As seen on Figure 11, as the length of the alternative system rotation periods increased, water constraint levels showed a decreasing trend in this zone. Thus, the 12 day system rotation period was found to be suitable in AZ II for irrigation applications started on 10 July, owing to the fact that this rotation period was also suitable for AZ I, and that the lowest water constraint occurred in AZ II with a ratio of 6.13% in this period.

The irrigation water requirement of AZ III and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July are shown in Figure 12.

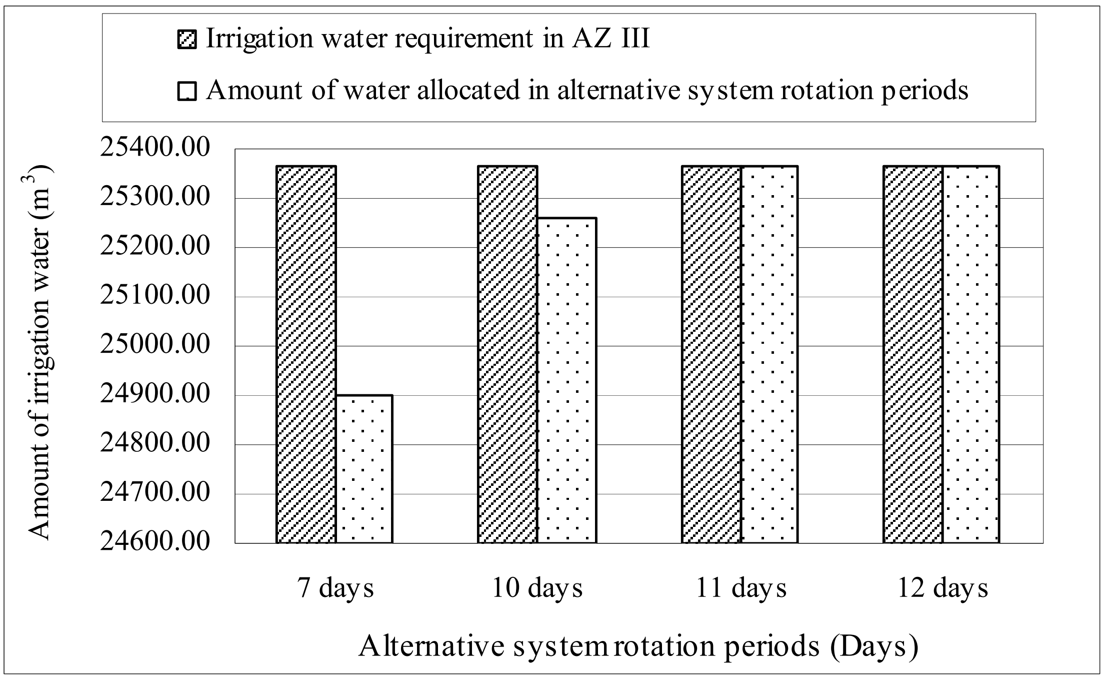


Fig. 12. Irrigation water requirement of AZ III and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July.

In the 7 and 10 day system rotation periods, 1.81% and 0.41% water deficits occurred in AZ III. No constraint occurred in AZ III for the 11 and 12 day rotation periods (Figure 12). Since the water carrying capacities of the canals were adequate for the size of the irrigated area and the water requirements of the crops in this zone, most of the requirements were met in that district. Thus, 12 day system rotation period was found to be suitable for the entire district containing three of the zones for the irrigation applications started on 10 July, which was in the peak period.

The irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods for the irrigation applications started on 18 August are given in Figure 13.

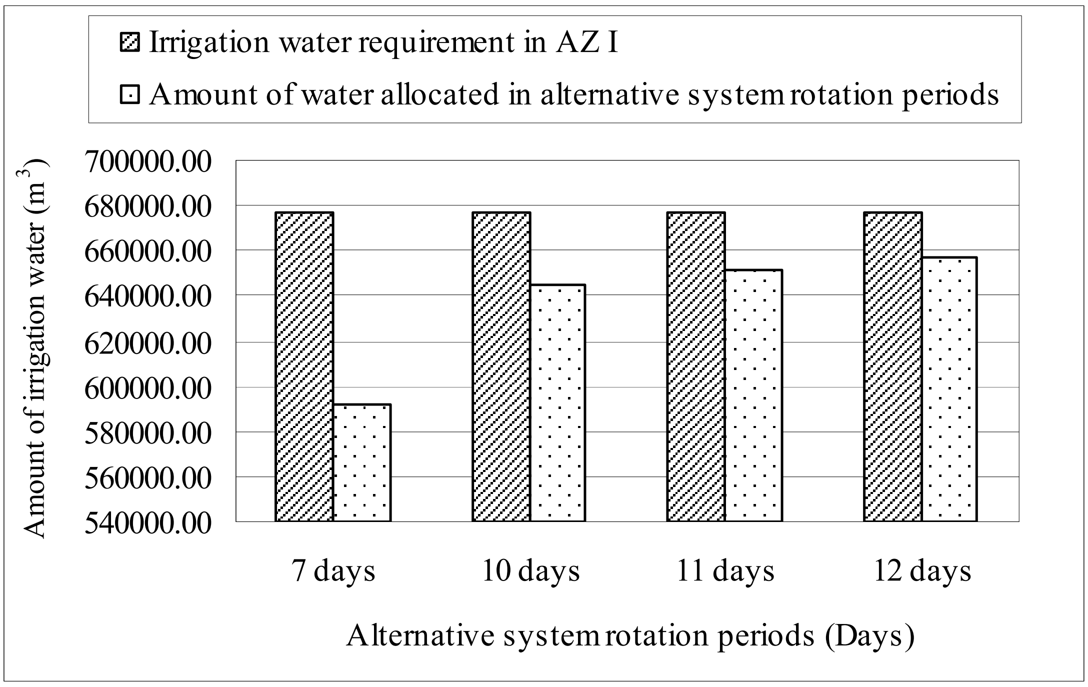


Fig. 13. Irrigation water requirement of AZ I and amount of water allocated to this zone during the alternative system rotation periods for the irrigation applications started on 18 August.

In irrigation applications started on 18 August in the research area, 12.42%, 4.70%, 3.60% and 2.82% water deficits occurred in AZ I for the 7, 10, 11 and 12 day alternative system rotation periods respectively (Figure 13). In addition , a high level of water constraint occurred in some tertiaries in AZ I.

In the 7 day system rotation period, 95.06 hours of irrigation time were allocated to AZ I (Table 3). During this process, 61.30%, 47.60% and 36.95% water deficits occurred in tertiaries P.7, P.9 and P.21 respectively (Table 6). For the 10 day system rotation period, 135.80 hours of irrigation time was allocated to AZ I, and a 45.28% water deficit occurred in tertiary P.7. When 149.38 hours of irrigation time was allocated to this zone in the 11 day system rotation period in order to reduce the water constraint in this canal (Table 3), the deficit level diminished to 39.94% in tertiary P.7 (Table 6). Since no constraint occurred in most of the canals in AZ I, the 11 day system rotation period was found to be suitable for this zone in this period.

The irrigation water requirements of AZ II and the amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August are shown in Figure 14.

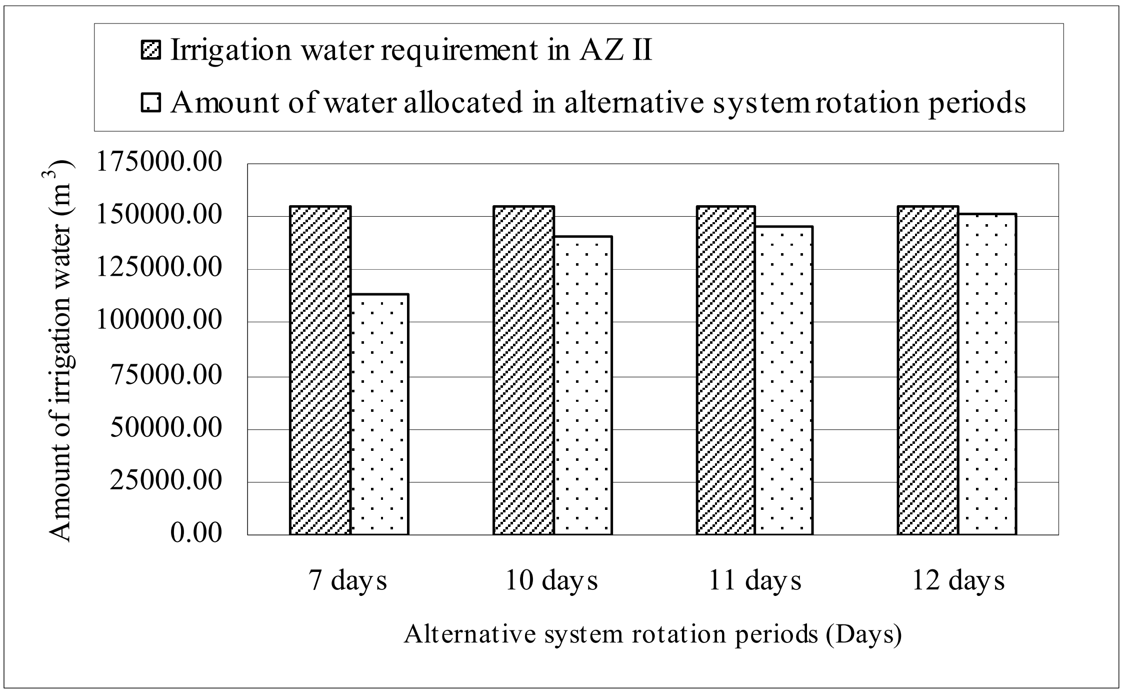


Fig. 14. Irrigation water requirements of AZ II and amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August.

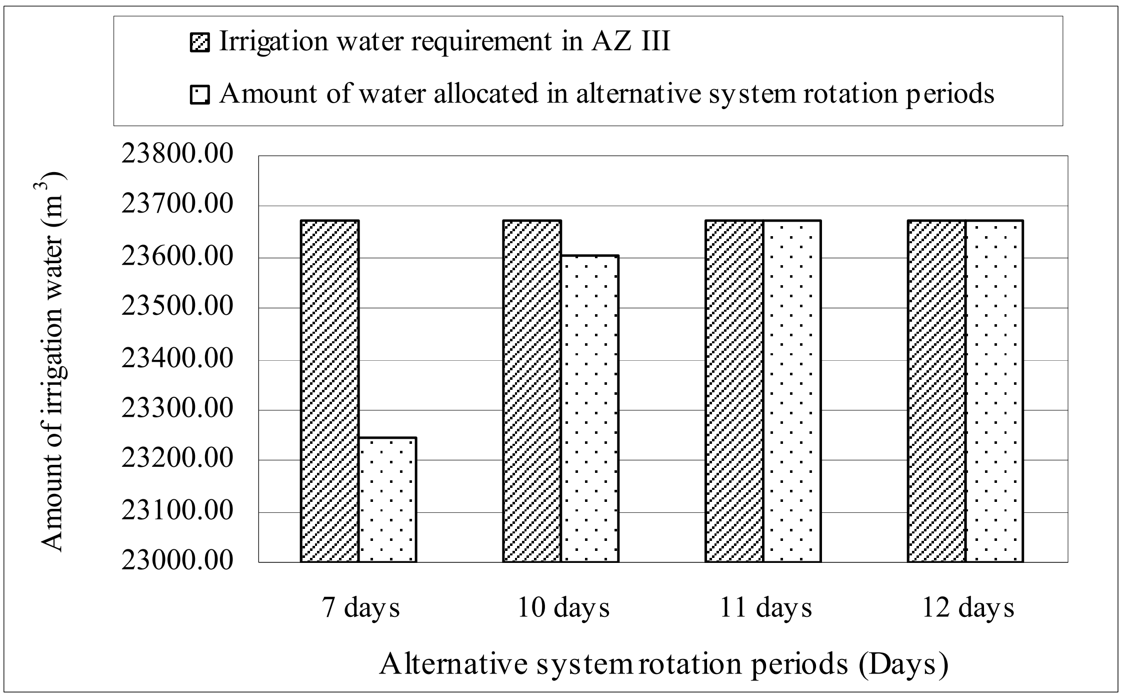


Fig. 15. Irrigation water requirements of AZ III and amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August.

In the irrigation applications started on 18 August, 51.93 hours and 74.18 hours of irrigation time were allocated to AZ II in the 7 and 10 day system rotation periods (Table 3), also 26.21% and 9.13% water constraints occurred in AZ II in these rotation periods respectively (Figure 14). A 44.33% water constraint occurred in tertiary P.26 in the 7 day system rotation period. This deficit level fell to 21.03% in the 10 day rotation period (Table 6). On the other hand, since the 11 day system rotation period was suitable for AZ I and nearly 71% of the tertiaries serving the entire district were in AZ I, these conditions affected the rotation period of AZ II, and 11 days were found suitable for this zone in this irrigation period.

Irrigation water requirements of AZ III and the amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August are shown in Figure 15.

In this period, 1.79% and 0.28% water deficits occurred in the 7 and 10 day system rotation periods respectively in AZ III. No water constraint occurred in the 11 day rotation period in this zone (Figure 15).

As a result, the 11 day system rotation period was found to be suitable for irrigation applications started on 18 August, and 149.38 hours, 81.60 hours and 33.02 hours maximum irrigation times were allocated to AZ I, AZ II and AZ III respectively.

5. Conclusions

In this investigation, irrigation programming model MONES 4.1 (Kilic, 2010) was applied to Sector VII in the Right Bank Irrigation System of Ahmetli Regulator in the Lower Gediz Basin, Turkey. Irrigation programs were devised for different growing stages and irrigation periods of the crops in the research area for 7, 10, 11 and 12 day system rotation periods.

Considerable differences occurred between the water allocation plan applied in the research area in reality and the model results, from the points of view of irrigation programs, canal rotation system, water allocation zones and deficit levels occurring in canals with different lengths of rotation periods. During the 10 day system rotation period which was applied in reality in the research area, all the tertiaries were kept open, no canal rotation program was applied on the network, and the irrigation area was not divided into different allocation zones in reality by the irrigation association. However, maximum water carrying capacity of the secondary canal serving Sector VII was inadequate for distribution of water to all tertiaries at the same time (Kilic, 2004; Kilic & Tuylu, 2010). Because of this, the tertiary canals in the network could not be operated at their maximum capacities according to the water allocation plan in reality.

In addition, for the 7 and 10 day system rotation periods, deficit levels exceeded 45% in some canals, because the lengths of these periods were not suitable for the infrastructure of the system, the hydraulic features of the canals, and the actual production pattern. As a result, it was not possible to irrigate the whole area during the 7 and 10 day system rotation periods.

In order to operate the system at the optimum level, the research area must be divided into allocation zones by running the entire network at maximum capacity. In order to achieve this, the canal rotation groups which are most suitable for the system must be determined.

In addition, irrigation water requirements of the crops grown in the district must be estimated in a scientific way for different growing stages. In this way, the amount of irrigation water to be allocated from the resource to the allocation zones in different periods can be determined accurately.

Whatever the location of a plot in the network, the capacity of the canal receiving water from the system, or the water conveyance efficiency, this plot must benefit from the water resource and system equally in temporal and spatial dimensions. In this process, the optimum length of irrigation time must be determined for each allocation zone by taking into consideration such parameters as the infrastructure of the network, the hydraulic features of the canals, the water conveyance efficiency, the soil features of the district, the location and size of the plots, the plant pattern, and the irrigation water requirements of the crops. Since there are a large number of water users in the system, irrigation applications must be monitored continuously by the technical personnel of the association. All these processes should be carried out serially with the aid of computers in real time conditions.

Apart from this, maintenance, repair, renovation and cleaning activities in the network must be performed regularly by the association, because these processes have a direct effect on to the irrigation programming and allocation of water at network level.

The most important point is that decision support systems enabling real time irrigation programming at network level should be used in order to obtain the optimum benefit per unit amount of deficit resources.

The MONES 4.1 model enabled operation of the system at maximum capacity by dividing the research area into three different allocation zones by taking into consideration the parameters stated above. Also, the most suitable length of system rotation periods according to the model solution was determined to be 11 days for June and August, and 12 days for the peak irrigation period in July. For the irrigation applications started on 6 June and 18 August, 149.38 hours, 81.60 hours and 33.02 hours maximum irrigation times allocated to AZ I, AZ II and AZ III respectively were found to be suitable. In irrigation applications started on 6 June, 2.44% and 7.86% water deficits occurred in AZ I and AZ II respectively. No water constraint occurred in AZ III in this period. In addition, 162.96 hours, 89.02 hours and 36.02 hours maximum irrigation times were allocated to AZ I, AZ II and AZ III respectively for the irrigation applications started on 10 July in the peak period. Also, while 3.58% and 6.13% water deficits occurred in AZ I and AZ II respectively, no water constraint occurred in AZ III in this period. For the irrigation applications started on 18 August, 3.60% and 5.76% water constraints occurred in AZ I and AZ II. On the other hand, no water deficit occurred in AZ III in this period. Since the water-carrying capacities of the canals were adequate for the size of the irrigated area and the water requirements of the crops in AZ III, most of the requirements could be met in that district in different irrigation periods.

As a result, it can be seen that the application of irrigation programming techniques to such systems has a vital importance both for optimum operation of the system and for the sustainability of deficit resources.

6. References

Acs, S., Berentsen, P.B.M. & Huirne, R.B.M. (2007). Conversion to organic arable farming in The Netherlands: A dynamic linear programming analysis. *Agricultural Systems*, 94(2): 405-415.

ANCID. (2003). Open Channel Seepage and Control V (1.4) – *Best Practice Guideline for Channel Seepage Identification and Measurement Australian National Committee on Irrigation and Drainage (ANCID)*, p. 95 (http:/www.ancid.org.au/pdf/seepreports 141003/Vol1.4_Guidelines.pdf)

Bartolini, F., Bazzani, G.M., Gallerani, V., Raggi, M. & Viaggi, D. (2007). The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: An analysis based on farm level multi-attribute linear programming models. *Agricultural Systems*, vol. 93, 90–114.

Brumbelow, K. & Georgakakos, A. (2007). Optimization and Assessment of Agricultural Water Sharing Scenarios under Multiple Socioeconomic Objectives. *Journal of Water Resources Planning and Management*, 133(3): 264-274.

Cai, X., McKinney, D.C. & Rosegrant, M.W. (2003). Sustainability analysis for irrigation water management in the Aral Sea region. *Agricultural Systems*, vol. 76, 1043–1066.

Chambers, R. (1988). *Managing Canal Irrigation: Practical Analysis from South Asia*. Cambridge University Press, Cambridge, U.K.

Clemmens, A.J. (2006). Improving Irrigated Agriculture Performance Through an Understanding of the Water Delivery Process. *Irrigation and Drainage* 55: 223-234.

Diaz, J.A.R., Poyato, E.C. & Luque, R.L. (2007). Model to Forecast Maximum Flows in On-Demand Irrigation Distribution Networks. J. *Irrigation and Drainage Engineering* 133(3): 222–231.

DMI (National Meteorology Works) Reports. (2008). *Manisa and Akhisar Meteorology Reports*. Ankara, Turkey. (In Turkish)

Doorenbos, J. & Kassam, A.H. (1979). *Yield Response to Water*. FAO Irrigation and Drainage Paper No. 33, p. 193.

Du, B., Ji, X., Harmel, R.D. & Hauck, L.M. (2009). Evaluation of a Watershed Model for Estimating Daily Flow Using Limited Flow Measurements. *Journal of the American Water Resources Association* (JAWRA) 45(2): 475-484.

Evans, E.M., Lee, D.R., Boisvert, R.N., Arce, B., Steenhuis, T.S., Prano, M. & Poats, S.V. (2003). Achieving efficiency and equity in irrigation management: an optimization model of the El Angel watershed, Carchi, Ecuador. *Agricultural Systems* vol. 77, 1–22.

FAO. (1992). *Cropwat; A Computer Program for Irrigation Planning and Management*. Irrigation and Drainage Paper No. 46, Food and Agriculture Organization, Rome, Italy.

Garizabal, G.I., Valenzuela, C.J. & Abrahao, R. (2009). Evolution of the efficiency and agro-environmental impact of a traditional irrigation land in the middle Ebro Valley (2001-2007). *Spanish J. of Agricultural Research*, 7(2): 465-473.

Gediz Irrigation Association Reports. (2007). Manisa, Turkey.

Georgiou, P.E. & Papamichail, D.M. (2008). Optimization Model of an Irrigation Reservoir for Water Allocation and Crop Planning Under Various Weather Conditions. *Irrig. Sci*. 26: 487-504.

Girgin, A., Gencel, G. & Gul, S. (1999). *Gediz Havzasındaki Sulamaların Su Yönetimi Acısından Başarı Durumları*. Izmir Su Kongresi, Izmir- Turkey, 4-5 Haziran, s. 317-334.

Haie, N. & Keller, A.A. (2008). Effective Efficiency as a Tool for Sustainable Water Resources Management. *Journal of the American Water Resources Association* (JAWRA) 44(4): 961-968.

Hsiao, T.C., Steduto, P. & Fereres, E. (2007). A Systematic and Quantitative Approach to Improve Water Use Efficiency in Agriculture. *Irrig. Sci.* 25: 209-231.

Hussain I., Turral H., Molden D. & Din Ahmad U.M. (2007). Measuring and Enhancing the Value of Agricultural Water in Irrigated River Basins. *Irrig. Sci.* 25: 263-282.

Jalal, M.M., Haddad, O.B., Karney, W.B. & Marino, A.M. (2007). Reservoir Operation in Assigning Optimal Multi-Crop Irrigation Areas. *Agric. Water Manage.* 90: 149-159.

Kilic M. & Anac, S. (2010). Multi-Objective Planning Model for Large Scale Irrigation Systems: Method and Application. *Water Resources Management*, DOI: 10.1007/s11269-010-9601-4.

Kilic, M. (2004). *Determining the Optimum Water Allocation in Irrigation Networks by Nonlinear Programming Method*. Ph.D. Thesis, Ege Üniversitesi Fen Bil Enst, Bornova, Izmir, Turkiye, s. 137. (In Turkish with English abstract)

Kilic, M. (2010). MONES 4.1, *A Computer Program for Management, Operation and Evaluation of Large Scale Irrigation Systems*. (with Turkish interface)

Kilic, M. & Ozgurel, M. (2005). Resource Leveling and Optimization of Irrigation in a Tertiary Canal Irrigation Unit. *Ege Univ. J. Agric. Fac.* 42(2): 97–108, Bornova, İzmir, Turkey. (In Turkish with English abstract)

Kilic, M. & Tuylu, G.I. (2010). Determination of water conveyance loss in the Ahmetli Regulator Irrigation System in the Lower Gediz Basin, Turkey. *Irrigation and Drainage*, Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/ird.602.

Kodal, S., Aküzüm, T., Çakmak, B. & Kendirli, B. (1997). Irrigation Schedules with Adequate and Limited Water of Some Field Crops Grown in Urfa Region. *VI. National Kültürteknik Congress*, 5-8 June, Kirazlıyayla, Bursa, p. 354-362. (In Turkish with English abstract).

Laborte, A.G., Van Ittersum, M.K. & Van Den Berg, M.M. (2007). Multi-Scale Analysis of Agricultural Development: A Modeling Approach for Ilocos Norte, Philippines. *Agric. Sys*. 94: 862-873.

Lermontov, A., Yokoyama, L., Lermontov, M., & Machado. M.A.S. (2011). *A Fuzzy Water Quality Index for Watershed Quality Analysis and Management, Environmental Management in Practice*, Elzbieta Broniewicz (Ed.), ISBN: 978-953-307-358-3, InTech, Available from: http://www.intechopen.com/articles/show/title/a-fuzzy-water-quality-index-for-watershed-quality-analysis-and-management

Lorite, I.J., Mateos, L., Orgaz, F. & Fereres, E. (2007). Assessing Deficit Irrigation Strategies at the Level of an Irrigation District. *Agric. Water Manage*. 91: 51-60.

Mays, L.M. (1996). *Water Resources Handbook*. McGraw-Hill, N.Y.

Mousavi, H. & Ramamurthy, A.S. (2000). Optimal Design of Multi-Reservoir Systems for Water Supply. *Advances in Water Resources*, 23: 613-624.

Ryu, J.H., Palmer, R.N., Jeong, S., Lee, J.H. & Kim, Y.O. (2009). Sustainable Water Resources Management in a Conflict Resolution Framework. *Journal of the American Water Resources Association*, 45(2): 485-499.

Sagardoy, J.A.I., Bottrall, A. & Uittenbogaard, G.O. (1982). *Organization, Operation and Maintenance of Irrigation Schemes*. FAO Irrigation and Drainage Paper No. 40, p. 166.

Sheild, L.D., Gopalakrishnan, C. & Chan-Halbrendt, C. (2009). Aligning Stakeholders' Preferences with Public Trust in Managing In-stream Flow: The Case of Hawai'i. *Water Resources Development*, Vol. 25(4): 657–679.

Speelman, S., D'Haese, M., Buysse, J. & D'Haese, L. (2008). A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa. *Agricultural Systems*, vol. 98, 31–39.

Svendsen M., Murray-Rust, D.H., Harmancioglu, N. & Alpaslan, N. (2001). Governing Closing Basins: The Case of the Gediz River in Turkey. In: Abernethy, C.L. (Ed.), *Intersectoral Management of River Basins. International Water Management Institute (IWMI) and German Foundadtion for International Development (DSE)*, Colombia, Sri Lanka, p. 183–214.

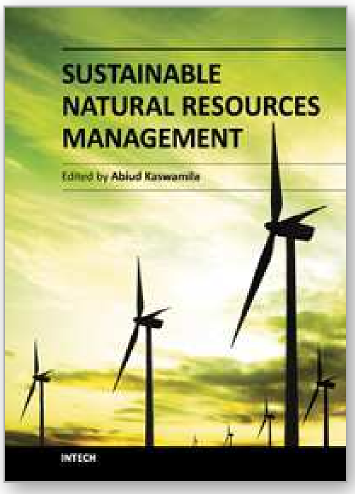
Topraksu. (1971). *Menemen Ovası Temel Toprak Etüdü*. Topraksu Gen. Müd., Toprak Etüd ve Haritalama Dairesi, Yayın No. 236, Ankara.

Topraksu. (1974). *Gediz Havzası Toprakları*. Topraksu Gen. Müd., Yayın No. 302, Ankara.

Varis, O. & Abu-Zeid, K. (2009). Socio-economic and Environmental Aspects of Water Management in the 21st Century: Trends, Challenges and Prospects for the MENA Region. *Water Resources Development*, 25(3): 507–522.

Yazar, A. (2006). Introduction. *International Symposium on Water and Land Management for Sustainable Irrigated Agriculture*, Adana, Turkey, p. 1-6.

Yonter, G. (2010). Effects of Polyvinylalcohol (PVA) and Polyacrylamide (PAM) as soil conditioners on erosion by runoff and by splash under laboratory conditions. *Ekoloji*, 19 (77): 35-41, doi: 10.5053/ekoloji.2010.776



Sustainable Natural Resources Management
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Natural resources conservation is one of the dilemmas currently facing mankind in both developed and the developing world. The topic is of particular importance for the latter, where the majority depend on terrestrial ecosystems for livelihood; more than one billion people live in abject poverty earning less than a dollar per day; more than 3.7 billion suffer from micronutrient deficiency and more than 800 million suffer from chronic hunger. Population increase, resource use conflicts, technological advancements, climate change, political doldrums, and unsustainable use and harvesting of resources have all put more pressure on natural resources leading to land degradation and poverty. To achieve a win-win situation, we need to change our mindset by thinking outside the box through advocating integrated and holistic approaches in managing our natural resources. This book presents a variety of sustainable strategies and/or approaches including use of GIS and Remote Sensing technologies, decision support system models, involvement of stakeholders in major decisions regarding use of natural resources, community level initiatives, and use of surveillance and monitoring mechanisms.

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