DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MULTI CRITERIA DECISION ANALYSIS FOR WATER RESOURCES MANAGEMENT IN THE GEDIZ RIVER BASIN

by
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April, 2009
İZMİR

MULTI CRITERIA DECISION ANALYSIS FOR WATER RESOURCES MANAGEMENT IN THE GEDIZ RIVER BASIN

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by
Barış YILMAZ

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Ph.D. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"MULTI CRITERIA DECISION ANALYSIS FOR WATER RESOURCES MANAGEMENT IN THE GEDIZ RIVER BASIN"** completed by **BARIŞ YILMAZ** under supervision of **PROF. DR. NİLGÜN HARMANCIOĞLU** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.

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FOR WATER RESOURCES MANAGEMENT
IN THE GEDIZ RIVER BASIN

ABSTRACT

Due to rapid increases in the world's population, global warming, improved living standards, urbanization, and industrialization, water managers have been faced with more complex and difficult problems in the early 21st century, and it is expected that coping with water problems will be harder in the future. A comprehensive assessment of water budgets and an evaluation of improved management plans have become imperative particularly in water scarce basins.

In this study, a water resources management model that facilitates indicator-based decisions with respect to environmental, social and economic dimensions in a multiple criteria perspective is developed for the Gediz River Basin in Turkey. The basic input of the proposed model is the quantity of surface water that is greatly allocated to irrigation purposes; therefore, supply and demand interrelations in agricultural water use constitute the main focus of the study. The model has been applied under three different hydro-meteorological scenarios that reflect baseline as well as better and worse conditions of water supply and demand, not only to reach a comprehensive assessment of water budget in Gediz Basin, but also to evaluate the impacts of proposed management alternatives under different conditions.

The Water Evaluation and Planning (WEAP) software is used as a simulation and evaluation tool to assess the performance of possible management alternatives, which is measured by nine indicators representing economic, social and environmental sustainability. The study has delineated the "best" management alternative on the basis of three different multi criteria decision making (MCDM) methods. Each method is also applied with seven different sets of criteria weights that represent objective judgements as well as subjective preferences of decision makers. The use of such weights facilitated a sensitivity analysis towards deriving conclusive recommendations for robust decisions.

The results of the study have indicated that the Gediz River Basin is quite sensitive to drought conditions, and the agricultural sector is significantly affected by irrigation deficits that increase sharply in drought periods. Even if the optimistic scenario is assumed to occur, it is not possible to observe a significant improvement in the water budget; however, the negative impacts of climate change can possibly exacerbate the water crisis. Therefore, efficient water management policies are crucial to ensure the sustainable use of water resources. In this regard, the maintenance of old open canals used in the water conveyance system and also crop pattern change applications are not considered as adequate measures for coping with water scarcity. The management alternative that combines the replacement of the current water distribution network by piped systems to decrease water losses and the use of 'water saver' technologies such as drip irrigation to improve irrigation efficiency is determined as 'best' alternative with respect to environmental, social and economic dimensions through the use of a multi criteria approach.

Keywords: water resources management, scenario analysis, multi criteria decision making, criteria weights, Gediz River Basin.

GEDİZ HAVZASI SU KAYNAKLARI YÖNETİMİNDE ÇOK KRİTERLİ KARAR ANALİZİ

ÖZ

Dünya nüfusundaki hızlı artış, küresel ısınma, gelişen yaşam standartları, kentselleşme ve sanayileşme gibi sebeplerle su kaynakları yöneticileri 21. yüzyılın başlarında daha karmaşık ve zor problemlerle karşılaşmıştır. Gelecekte de mevcut problemlerin artarak sürmesi beklenmektedir. Özellikle su kıtlığı çeken havzalarda, su bütçesini çeşitli arz-talep senaryoları altında inceleyen, mevcut problemlerin çözüm alternatiflerini çevresel, sosyal, ekonomik göstergeler ile değerlendiren bilimsel çalışmalara dayanan su kaynakları yönetimi sürdürülebilir kalkınma için zorunluluk halini almıştır.

Bu çalışma ile, yüzeysel su potansiyeli büyük oranda tarımsal faaliyetlere tahsis edilen Gediz Havzası için bir su kaynakları yönetim modeli geliştirilmiştir. Water Evaluation and Planning (WEAP) yazılımı ile normal, iyimser ve kötümser durumu temsil eden üç farklı hidro-meteorolojik senaryo altında sulama suyu arz ve talebindeki değişimler incelenmiştir. Su bütçesindeki açıkları azaltmaya yönelik yönetim alternatiflerinin performans değerlendirmesi çevresel, sosyal ve ekonomik göstergeler yardımıyla analiz edilmiştir. Çeşitli Çok Kriterli Karar Verme (MCDM) metotları ve kriter ağırlıkları kullanılarak ulaşılan sonuçların yanısıra, yönetim alternatiflerinin performansları üzerine yapılan detaylı irdelemelerle karar vericilerin daha güvenilir kararlar vermesi için tavsiyelerde bulunulmuştur.

Çalışma sonuçları, Gediz Havzası'nın kuraklığa karşı oldukça hassas olduğunu ve kurak dönemlerde şiddetli biçimde artan sulama suyu açığının tarım sektörünü ciddi biçimde etkilediğini göstermiştir. İyimser senaryo altında dahi su bütçesinde anlamlı bir iyileşme görülmezken, iklim değişikliğinden kaynaklanabilecek olumsuz etkiler su krizini rahatlıkla şiddetlendirebilmektedir. Bu sebeple, etkin su yönetim politikaları su kaynaklarının sürdürülebilir kullanımını sağlamak için çok önemlidir. Sulama suyu iletimde kullanılan eskimiş açık kanallara yapılan bakımlar ve bitki

deseni değişikliği gibi uygulamalar havzadaki su kıtlığının üstesinden gelmek için yeterli değildir. Mevcut su dağıtım hattının basınçlı sistemlerle değiştirilmesi ve damlama sulama gibi su tasarrufu sağlayan teknolojilerin birlikte kullanımını öngören yönetim alternatifi, çok kriterli bir bakış açısı altında değerlendirildiğinde çevresel, sosyal ve ekonomik kriterleri tatmin edebilecek "en iyi" alternatif olarak belirlenmiştir.

Anahtar sözcükler: su kaynakları yönetimi, senaryo analizi, çok kriterli karar verme, kriter ağırlıkları, Gediz Havzası.

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CHAPTER ONE
INTRODUCTION

1. 1 General

For centuries, water, together with land and air, has been regarded as the most basic natural resource. Water has pervaded human activities so immensely that it has become a vital element in socio-economic development. Although two thirds of the earth's surface is covered with water, the exploitable fresh water is considered to be scarce in most parts of the world. At the most basic level, two related global trends greatly exacerbate the water crisis. These trends relate to the rapid increases in population growth and economic development, both of which strongly increase water demand as well as pollution. On the contrary, the quantities of water that any country can economically develop, unfortunately, continue to decrease or remain limited. The following quote from the "Rio Declaration on Environment and Development" of the conference held in Rio de Janeiro in 1992, known as "Agenda21", summarizes the importance of freshwater resources, and the steps that have to be taken to conserve water supplies (UN, 1993):

"Water is needed in all aspects of life. The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water-related diseases. Innovative technologies, including the improvement of indigenous technologies, are needed to fully utilize limited water resources and to safeguard those resources against pollution."

For the above and a variety of other reasons like global warming, improved living standards, urbanization, and industrialization, water managers have been faced with more complex and difficult problems in the early 21st century, and it is expected that coping with water problems will be harder in the future. Therefore, the traditional water supply management approaches that consider supply enhancement investments in regional dimensions via economic analyses have been replaced by Integrated Water Resources Management (IWRM) strategies. Global Water Partnership defines IWRM as in the following (GWP, 2000):

"IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."

Although several definitions can be cited for IWRM, the three key concepts underlined in the approach are equity, efficiency and sustainability. Through these concepts, IWRM is expected to address water allocation in an equitable manner among all water users and encourages the efficient use of water while maintaining sustainable development in social, economic and environmental dimensions.

Sustainable development is a relatively recent concept that has emerged only during the past two decades. In the World Commission on Environment and Development (WCED)'s report (1987), sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Water resources management plays a crucial role in this area since water is essential for socio-economic development especially in arid and semi arid regions where agriculture is the major industry. In the light of this philosophy, many researchers have expressed that sustainability is to be measured by indicators that serve not only to understand the status and ongoing trends in a river basin, but also to assess the results of particular management approaches and practices (Harmancioglu, 2004; Walmsey, 2002).

The IWRM approach also considers the demand side of the management problem as well as the supply side. Demand management is basically based on increasing water use efficiency to save water, whether by improved technologies in domestic uses or by increased agricultural and industrial production per unit of water, preferably by both. It also strives to improve the overall productivity of water use by "soft path" measures such as pricing, public education and recycling.

Equity, as another core tenet of IWRM, emphasizes that all water users have access to water of adequate quantity and quality. Therefore, water allocation is another task that should be considered to solve the current conflicts between water users. Additionally, water allocation for environmental needs should also be fulfilled with management practices since water scarcity threats ecological life. Thus, the best way to ensure equity is to establish participation in water management by all stakeholders (Jaspers, 2003; Giupponi et al., 2006).

IWRM is also a quite difficult decision making process that requires sound and reliable information about the river basin analyzed, where the "basin" is considered as the most appropriate unit for water management. Although the main concepts of IWRM are global, not only the physical, hydrological and demographic characteristics of basins but also the economic conditions and investment priorities of countries are different. Moreover, lack of accurate data and inherent hydrological variability cause a number of uncertainties that complicate the decision making process. Scenario analysis has been commonly used in water resources management to overcome these uncertainties. The main expectation in a scenario analysis is to find answers to "what if" questions to help decision makers (DM) make robust evaluations of possible long term planning and management practices on the basis of basin characteristics and country realities. River basin simulation models based on a node-link network representation to derive basin water balance are the essential tools to run scenarios. They enable the user to evaluate a variety of measures related to infrastructure and operational and demand management under various hydrological conditions. The indicators obtained directly by models and/or from a post-process of model results serve to test the performance of alternative management policies. Since there has been a pronounced need for coping water crisis in recent years, these quantitative evaluations provide valuable information to decision makers. However, decisions in water management are characterized by multiple objectives and multiple stakeholders, and this multiplicity has overburdened DMs in finding the *most* *satisfactory decision;* thus, a powerful tool is desired for the final selection of the best management strategy.

Multi criteria decision analysis (MCDA) is both an approach and a set of techniques, with the goal of evaluating and ranking decision alternatives to facilitate the decision maker's objectives against multiple criteria measured in different units (Zeleny, 1982; Voogd, 1983). Although MCDA is greatly pertinent to operational research studies, many researchers have found that MCDA provides an effective tool for water management by adding structure, auditability, transparency and rigor to decisions (Hajkowicz and Higgins, 2008). Moreover, DMs in water management are increasingly looking beyond conventional benefit cost analysis towards techniques of MCDA that can handle a multi objective decision environment (Prato, 1999; Joubert et al., 1997; Bana e Costa et al., 2004). Therefore, a decision support system that combines scenario analysis and MCDA techniques helps to generate more effective water resources management plans.

Based on the above considerations and needs of DMs, this research aims to develop a scenario-based decision support system for water resources management in Gediz Basin.

1. 2 Problem Statement

River basins in many Eastern and Southern Mediterranean countries suffer from water scarcity due to rapid demographic and economic development, urbanization, industrialization, tourism, and inefficient irrigation activities. Although water use quotas among sectors differ, in agriculture dominant countries like Turkey, domestic, industrial and agricultural water use ratios are almost 15%, %10 and %75, respectively. Moreover in Turkey, agriculture is vital for the economy not only by employing 45% of the workforce, but also by contributing to a great part of the national income. Since irrigation augments agricultural production, irrigation and wealth have been closely linked. Hence, agricultural areas continue to expand, and limited water resources become a key factor in socio-economic development.

The Gediz Basin along the Aegean coast of Turkey covers about 18000 km^2 and approaches a total population of 2.5 million. The basin demonstrates a broad range of water management problems, two major ones being water scarcity and pollution. Although the basin experiences recurrent droughts, water scarcity is also explained by the competition for water among various uses (water allocation problems), mainly irrigation with a total command area of 110,000 ha versus the domestic and fast growing industrial demand in the coastal zone. Current analyses on hydrological budget of the basin indicate that the overall supply of water for various uses is approximately equal to the overall demand (Harmancioglu et al., 2005). This means that there is no reserve left for further water allocation so that efficient use of water should be encouraged.

The basin has experienced periods of significant droughts in the past, the last and the most severe one to occur between 1989 and 1994. Before the drought, there was little competition for water, and the established mechanism for allocating water to users through a set of bilateral agreements worked well. In the drought period mentioned, irrigation issues in the peak summer season were reduced sharply, and the drought had an impact not only on the releases made from the reservoirs but also on changing demand. Rice used to be grown in poorly drained central parts of the Basin but has been replaced by cotton, while there has been a steady increase in grape and fruit tree areas as agro-industrial enterprises have grown up to support cash crop agriculture. Thereafter, the droughts started to frequently strike the basin to result in significant losses in agricultural yield. Low agricultural revenues worsen the economic status of the farmers and accelerate the migration from rural to urban areas, especially to Izmir, which is the third largest city in the country and an important harbor along the Aegean.

In Gediz Basin, the use of groundwater resources for domestic and industrial needs, while utilizing the surface water resources for irrigation, is the general water allocation paradigm. However, continuously growing industry and population in the metropolitan areas necessitate the use of surface waters in addition to groundwater resources for domestic and industrial purposes. The new dams, Gordes and Yigitler, will transfer water to Izmir and Kemalpasa Industrial Zone in a few years, and the competition for water is expected to increase.

The other significant pressure Gediz Basin is faced with is the poor and continuously deteriorating quality of its surface waters. The untreated domestic and industrial wastewater discharges, in addition to agricultural return flows, result water pollution in Gediz and its tributaries. In general, 60% of surface waters and 30% of groundwater are in class IV (highly polluted), according to the Turkish Water Pollution Control Regulation (MoEF, 2004). The problem is exacerbated by the failure to control the wastewater discharges to Gediz due to weak enforcement, inadequate funding for wastewater treatment plants, and inadequate public awareness.

The seaward fringe of the Gediz Delta is an important nature reserve and has recently been designated as a Ramsar site to protect rare bird species. Originally, the area received excess water from the Gediz River for much of the year, but since 1990, with restrictions on irrigation releases, the reserve suffers from water shortages. A second component of environmental demand is the water needed for waste conveyance from points of origin within the Basin to the sea. In transporting wastes, the flow must provide sufficient velocity to keep organic compounds and heavy metals adsorbed onto soil particles from settling out before reaching the sea and sufficient dilution to avoid in-stream environmental harm. Obviously, reducing the pollutant loads, which must be carried, will reduce the quantity of water needed for this purpose.

The above discussion clearly indicates that, to maintain the sustainable development of the region, to provide sufficient quantity and quality of water for all sectors, and to assess the long-term impacts of water policies, water demands and supply availability should be evaluated not only in terms of existing trends and possible future tendencies in water use, but also by possible hydro-meteorological and climate change scenarios downscaled to the basin. So far, no concrete study has been made in the basin to test the application of an IWRM model in a rational and integrated manner. Hence, a comprehensive assessment of water budget in the Gediz Basin and an evaluation of management plans in terms of economic, social and environmental criteria have become imperative.

1. 3 Objectives of the Study

The main objective of this study is to develop and illustrate a water resources management model that will facilitate indicator-based decisions with respect to environmental, social and economic dimensions in a multiple criteria perspective for Gediz Basin. Within this framework, the study serves:

a) to assess the prevailing water problems by identifying the basin in terms of hydrologic and physical characteristics, available water resources, water supply/use patterns, water management practices, socio-economic, cultural and environmental dimensions;

b) to develop hydrologic scenarios as well as demand scenarios based on systematic analyses of the basin conditions;

c) to derive water management alternatives appropriate for Gediz Basin, taking into account both the supply and the demand management alternatives;

d) to develop a methodology for analyzing supply and demand scenarios jointly and to evaluate the impact of each management option; and

e) to develop a DSS that would identify the *best solution* among different comprehensive scenarios with respect to economic, social and environmental dimensions through the use of a multi criteria approach.

1. 4 Scope of the Study

In this study, although an IWRM model is intended for all Gediz Basin, six large scale irrigation districts and the Bird Paradise are considered as water demand sites due to lack of adequate and reliable data on domestic and industrial water uses that consume groundwater resources. In addition, Alasehir catchment is excluded from the analyses since the same restrictions apply. Therefore, the surface water resources used for irrigation purposes in the Lower Gediz Basin (LGB) are selected as the main targets of the study.

The supply and demand processes in the Basin are simulated under three different climate scenarios to reflect baseline as well as better and worse conditions. The simulations covered the period between 2003 and 2030, 2003 being the last year when hydro-meteorological and land use data were published. In the simulation process, assumptions are made, based on long term hydrologic and operational data as well as on previous project reports for Gediz Basin. Gordes Dam, which will be in operation within the simulation period, is also incorporated to the analyses since it is expected to increase domestic demand while decreasing irrigation supplies.

Multi criteria decision analysis is used to identify the performance of management alternatives under economic, social and environmental criteria. Since MCDA requires a set of preference information from the DMs, different sets of criteria weights are used to carry out a sensitivity analysis and to arrive at some conclusive recommendations.

The study is presented in six chapters. The second chapter introduces the prevailing water resources management approaches and cites the relevant literature in different research areas of water management. In accordance with the aim of the study, Chapter 3 develops the methodological framework, where the modeling tool, reference scenarios, proposed management alternatives, evaluation criteria and the MCDM methods are explained. Chapter 4 focuses on the formulation of the analyses and presents an application of the methodology to the Gediz River Basin. The results are discussed in Chapter 5, where performance evaluation of management scenarios under optimistic, business-as-usual and pessimistic conditions is presented along with the multi criteria decision making process based on various criteria weights. Chapter 6 covers the general conclusions of the study and recommendations for future studies.

CHAPTER TWO
LITERATURE REVIEW

2. 1 General

Water resources management (WRM) approaches used to date are greatly interconnected with the rapid growth of the world's population and can be grouped accordingly into two main categories. The first approach, namely supply management, considers that the problems associated with the provision of safe and adequate supply of water can be solved by developing additional capacity as needed. Since the population of the world was around two billions in 1900 and available water resources were adequate and of good quality, resource managers had no difficulty in solving water problems (Radif, 1999). As a result of the rapid growth of human population (six billions in 2000) and industrialization, water demand also increased so that governments and water resources managers chose to maximize available supplies by exploiting groundwater resources and constructing new large reservoirs. Comprehensive assessment of supply alternatives was oriented mainly towards minimizing costs while maximizing the water delivered. However, these policies led to stresses on water supplies, degradation of water resources and deterioration of water quality, the latter explicitly becoming evident in the early 21st century. The competition among water use sectors for water and conflicts in the planning/management of water resources are the other notable aspects of this approach.

The second approach, namely IWRM, underpins an interdisciplinary approach to WRM to promote cross-sectoral coordination and partnerships among stakeholders and government agencies (Dungumaro & Madulu, 2003). It includes the management of both the water supply and the demand to reduce projected gaps and meet future needs in a river basin. This is a difficult task especially in highly developed basins due to the very complex socio-economic systems with different interest groups pursuing multiple and conflicting objectives.

The DPSIR (**D**riving Forces - **P**ressure - **S**tate - **I**mpact - **R**esponse) concept that is developed by the European Environmental Agency (EEA, 1999) is generally used as a framework to identify and develop environmental, social and economic indicators for IWRM. The DPSIR framework identifies cause-effect relationships and allows for the separation of management issues to design solutions. The components of the DPSIR approach are defined as follows (Walmsley, 2002; NTUA, 2005):

• **D**riving force indicators reflect pressures exerted by natural phenomena and anthropogenic activities that, in general, cannot be easily manipulated but provide essential information to understand the regional context.

• **P**ressure indicators reflect the pressures exerted on water resources and the water use groups of a region, as a result of the driving forces.

• **S**tate indicators assess the current status of water resource.

• **I**mpact indicators assess the effect that a pressure has on the state of user groups and resources.

• **R**esponses relate to the social response via policies, laws, measures etc.

Once water related problems are identified conceptually within the DPSIR framework, qualitative or quantitative indicators can be assigned to the chains on the basis of the information collected, and possible options (responses) can be defined. In the evaluation phase, hydrologic and simulation models are required to obtain the performance of responses; in fact, this is indispensable due to the presence of numerous variables which are distributed in space and time. Although the decision matrix (responses versus indicators) carries significant assessments about management alternatives, the decision making process is still difficult due to the need to satisfy multiple stakeholders with multiple objectives. The multi criteria decision making (MCDM) techniques can help identify desired measures among a variety of alternatives through analyzing multiple criteria by which the strengths and weaknesses of various adaptation options could be evaluated (Hokkanen & Salminen, 1993). Therefore, many researchers employ MCDM methods to cope with water related problems in their studies as well as in research projects that foresee the establishment of decision support systems (DSS) in acquiring sustainable development strategies.

2. 2 Previous Studies on MCDM in Water Resources Management

In literature, MCDM is generally classified depending on the domain of alternatives considered. Vàzquez & Rosato (2006) classify them as: (1) Multi Attribute Decision Making (MADM), with discrete, usually limited, predefined set of alternatives, requiring attribute comparisons and involving implicit or explicit tradeoffs; and (2) Multiple Objective Decision Making (MODM) (also known as multi objective mathematical programming), with decision variable values to be determined in a continuous or integer domain, of infinite of large number of choices, to best satisfy the DM constraints. However, in WRM, the objectives, which indicate the directions of changing state in general forms of maximization and/or minimization, are conflicting due to the shared use of the limited resource. Objectives may also be non-commensurable due to the fact that the attributes that provide the achievement levels of objectives are generally measured in different units (Loucks et al., 1981; Bogardi & Nachtnebel, 1994; Szidarovszky et al., 1986; Duckstein & Opricovic, 1980). Thus, MCDM techniques where the 'criteria' indicate either an attribute or an objective or both, have been traditionally used in WRM literature.

MCDM has been used in water resources literature as a major component of **decision support systems** (Stransbury et al., 1991; Goicoechea et al., 1992; Qureshi & Harrison, 2001; Hamalainen et al., 2001; Fassio et al., 2005; Al-Shemmeri et al., 1997; Jaber & Mohsen, 2001; Maia & Schumann, 2007; Makropoulos et al., 2008). It has been applied to an array of problems in water resources, including **river basin planning** (Tecle, 1992; Pouwels et al., 1995; Qin et al, 2008; Abu-Taleb & Mareschal, 1995; Raj, 1995; Raju et al., 2000; Eder et al., 1997), **water supply/allocation and reservoir operation** (Ko et al., 1992; Harboe, 1992; Bogardi & Duckstein, 1992; Roy et al., 1992; Srdjevic et al., 2004; Flug et al., 2000; Ridgley et al., 1997; Mahmoud & Garcia, 2000), **urban water management** (Zarghami et al., 2008, Joubert et al., 2003; De Marchi et al., 2000), **design of monitoring networks** (Harmancioglu & Alpaslan, 1992; Ozkul et al., 2000; Woldt & Bogardi, 1992), **wastewater treatment alternatives** (Tecle et al., 1988; Kholgi, 2001; Khalil et al., 2005), **water quality** (Heilman et al., 1997), **groundwater management** (Pietersen, 2006; Shafike et al., 1992), **flood control** (Tkach & Simonovich, 1997), **wetland management** (Janssen et al., 2005), and **irrigation planning** (Raju & Kumar, 1999; Tiwari et al., 1999; Pillai & Raju, 1996; Raju & Pillai, 1999; Gupta et al., 2000). Since a wide spectrum of water related problems exist, new scientific articles on the topic are continuously produced, and it must be noted that the above given references are cited just to name a few. Therefore, to represent a general outlook of MCDM applications in WRM, it is considered to be more useful to classify the studies on the basis of their decision context (strategic or operational) and type of alternatives identified (discrete or continuous).

In earlier studies, the dominance of multi objective mathematical programming methods, which are based on multiple optimizations for operational decisions, is noticeable. The examples can be found in Haimes et al. (1974), where the use of multi objective methods in water resources planning is discussed; in Cohon & Marks (1975) who presented a review of multi objective programming techniques; and in Goicoechea et al. (1982) who discussed engineering and business applications. By the use of multi objective methods, the researchers aim to identify a feasible set of alternatives, e.g., for water allocation where the alternatives are implicitly defined as a combination of decision variables subject to certain constraints. In this case, the objective of the analysis is optimization among an infinite range of possibilities or, in other words, a continuous set of possibilities. This kind of analysis has been usually done at the operational level. Harboe (1992) and Ko et al. (1992) can be cited for reservoir management, and Shafike et al. (1992) and Woldt & Bogardi (1992) for groundwater management. The multiple optimization applications include Bazzani et al. (2005) and Prathapar et al. (1997), where the objective has been to identify the optimal combinations of crops regarding their water consumption; Heilman et al. (1997), where the effects of the quality of pollutants and economic returns are evaluated on different managements systems; and Lee & Wen (1997), where the optimal solution is derived from pollution assimilative capacity and the cost of treatment of wastewater.

In most cases, however, optimization results are not applicable in reality due not only to unstable environmental and social conditions but also to political reasons, and DMs need to express their preferences and points of view by using qualitative information. Moreover, the large number of conflicting and non-commensurable objectives cannot always be formulated with mathematic expressions. Thus, the evaluation of discrete alternatives defined by DMs or of the set of feasible options that are obtained by an optimization procedure has gained importance in strategic level of water management by the use of MCDM techniques that include many different types of procedures. Such procedures include Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP), ELimination Et Choice Translating Reality (ELECTRE), Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE), and Compromise Programming (CP).

Raj (1995) demonstrated the use of ELECTRE in selecting the most suitable plan for development of reservoirs with their associated purposes in Krishna river basin, India. A total of twenty seven reservoir combinations with six criteria (irrigation, power production, drinking water, environmental quality, flood control and cost of the project) are compared. Al-Shemmeri et al. (1997) evaluated the strategic water planning alternatives determined under technical, managerial, pricing and regulatory categories with economic and development priority constraints under a large set of quantitative and qualitative criteria. The PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation) method, one of the outranking methods in MCDM, is used to rank alternatives in this study. Srdjevic et al. (2004) applied the TOPSIS method to evaluate the effects of water management scenarios where the criteria set were established by reservoir performance indicators. They concluded that the method was comprehensive and confident in concept and relatively simple in computation.

Selection of the best compromise irrigation plan that deals with three conflicting objectives, i.e., net benefits, agricultural production and labour employment, was examined by Raju & Kumar (1999) where a three-stage procedure was adopted to combine multi objective optimization, cluster analysis and MCDM methods, namely, PROMETHEE and EXPROM. The same case study was also subjected to the use of other MCDM methods, including ELECTRE, AHP and CP (Pillai & Raju, 1996). Tiwari et al. (1999) developed a framework for environmental and economic decision making using AHP and CP, which included sustainability criteria and preferences of local people in the context of a lowland irrigated agriculture system.

Integrated urban water management is another important study area in MCDM. Zarghami et al. (2008) investigated the integration of several demand management measures such as leakage detection on a water distribution network, water metering, and low volume water fixtures, as well as the conjunctive use of surface and groundwater resources of Zahedan city, Iran. The objectives included minimizing the cost, maximizing water supply, and minimizing the social hazards due to water management plans, where the CP was used to reach the best long-term plan. Similar studies can be found in De Marchi et al (2000), who combined participatory and institutional approaches for the multi criteria evaluation of water issues in Troina, Sicily, and in Joubert et al. (2003) who referred to planning of water provision to the City of Cape Town, South Africa.

Water resources problems are typically characterized by uncertainties with respect to hydrologic and meteorological events as well as to demand patterns. Assigning inaccurate values to these events and patterns can invalidate the results of the study and the accruing decisions. Therefore, a scenario analysis that can model many water problems is an alternative approach in strategic decision making by describing a set of possible future outcomes. Moreover, scenarios can be used by DMs to test the resilience of plans against assumptions. Through the development of scenarios and alternative strategies, future states of water supply and water demand can be assessed under varying climatic and hydrological conditions (Varis et al., 2004; Jeong et al., 2005; Pallottino et al., 2005), water resources development plans (Koch et al., 2005), and water demand management practices (Chen et al., 2005; Lévite et al., 2003). Loukas et al. (2007) presented a modeling system to evaluate the sustainability of water resources management strategies in the two major basins of Thessaly Region in Greece.

It should be noted that the studies mentioned above are quite new, and they show that scenario analysis for evaluating the strategic plans in accordance with MCDM to overcome the current and possible future water problems is suitable for IWRM. This is also confirmed by many multi-partner research projects. In this regard, MULINO (Multi-sectoral Integrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale), WSM (Developing Strategies for Regulating and Managing Water Resources and Demand in Water Deficient Regions), SMART (Sustainable Management of Scarce Resources in the Coastal Zone), and OPTIMA (Optimization for Sustainable Water Management) are significant projects financed by European Union (EU). Relevant publications can be found on the web sites of the above projects.

The OPTIMA project, where the overall aim was to develop, implement, test, critically evaluate, and exploit an innovative, scientifically rigorous yet practical approach to water resources management intended to increase efficiencies and to reconcile conflicting demands, can be cited as the most powerful and primary study that focuses on water management in the Gediz River Basin. In that case, a simulation based water resources planning and optimization system was developed and applied to address water issues in terms of quantity and quality, demand and supply, surface and groundwater usage, efficient use of water, allocation strategies, and cost-benefits (Harmancioglu et al., 2008). Although water budget in Gediz Basin and achievements of alternative management plans were evaluated in OPTIMA with appropriately selected economic and sustainability criteria, assessments were based on one-year-simulations of a dry and a wet year, as well as an instant implementation of the instruments to reduce water demand. This is particularly because the simulation model used operates on a yearly basis.

2. 3 Literature Review Summary

The above literature review indicates that considerable amount of work has been done for water resources management, which can be differentiated on the basis of the approaches and techniques used, the hydrologic inputs and demand patterns handled, the scope of management options developed, and the preferences weighted in the decision context. In recent years, plans and governmental statements related to water resources have emphasized the need for multi criteria decision analysis (making), since such planning and management activities inherently involve numerous, conflicting, non-commensurable goals and objectives. As a result, MCDM has become a primarily important aspect in every paradigm development. On the other hand, for complex water resources systems, developing management strategies in the light of the 'sustainability' concept is an underlying necessity. Simulation models that can demonstrate the real-world water systems in aggregation with the hydrological processes and the demand features are valuable tools not only to evaluate possible scenarios but also to illustrate the impacts of management strategies. Therefore, the joint venture of the scenario based simulations and MCDM is approved as a suitable approach in IWRM. Accordingly, the proposed study is a modest attempt that combines the evaluation of possible water management strategies under different hydro-meteorological scenarios and under the use of different MCDM techniques, as well as different weight sets of social, environmental and economic criteria.

CHAPTER THREE
METHODOLOGY

3. 1 General

The water resources management model developed in this study aims to ascertain ‘the best’ among pre-defined management alternatives that satisfy the objectives and constraints with regard to social, environmental and economic factors. The basic input of the proposed model is the quantity of surface water that is greatly allocated to irrigation purposes; therefore, supply and demand interrelations in agricultural water use constitute the main focus of the methodology. In addition, the study is carried out under different hydro-meteorological scenarios that affect supply availability and water demand, and different MCDM methods are applied using different criteria weights. Figure 3.1 presents the overall methodology which is divided into four successive phases, *analysis*, *scenario generation*, *evaluation* and *decision*, each referring to a major step.

The *Analysis Phase,* in which the representative water problems of the basin are described, identifies the topology of the water system in terms of main rivers and their tributaries, physical structures like reservoirs and natural lakes, transmission links and demand sites. Hydrologic and meteorological data preparation is another important module of this phase to delineate supply side features where land use and crop pattern are the essential inputs for demand calculations. In addition, reservoir operation rules and underlying assumptions are also identified in this phase. The goal of this phase is to define the water distribution system as it currently exists as well as to specify the hydrologic and meteorological characteristics of the basin studied. This phase essentially produces the basic inputs to the scenario generation phase.

In the *Scenario Generation Phase,* water balance scenarios are developed as “developments which can not be directly influenced by the decision makers”, i.e., changes such as hydro-meteorological variability or population growth. Since such changes influence the water balance in terms of demand and supply, it is significant to demonstrate different scenarios, especially representing the baseline, the best, and the worst cases, not only to evaluate the outcomes of alternative management practices, but also to estimate future basin conditions.

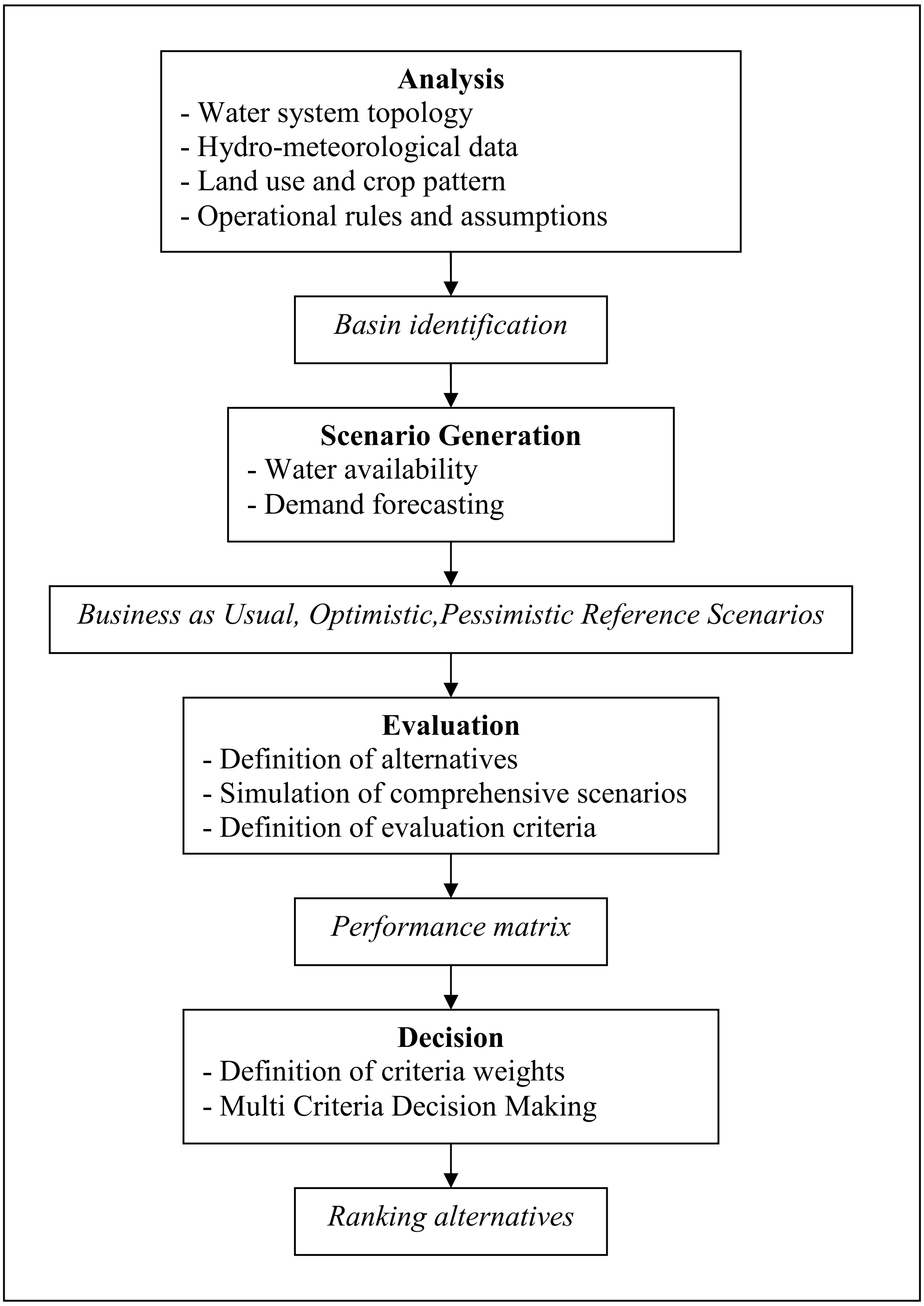


Figure 3.1 Overall methodology of the study

In the *Evaluation Phase*, the performance of each management alternative is tested against multiple criteria for each scenario. The three main modules in this phase include the definition of possible alternatives with their reasonable time frame of application, generation of comprehensive scenarios that combine reference scenarios and their alternatives, and the designation of evaluation criteria.

The *Decision Phase* aims to rank alternatives through the use of multi criteria decision making methods. The performance matrix obtained from the previous phase is the basic instrument for decision making, but the criteria weights is another important component that can manipulate the decisions. Therefore, in order to reach robust decisions, more than one MCDM method and different criteria weight sets are used in this phase, using the literature cited.

Accomplishment of the above water management model requires computer software (simulation model) as an essential tool to account for water availability and demand scenarios, and also to evaluate possible management plans based on supply enhancement and/or demand management. There are lots of software packages for water resources management on river basin scale. In this study, *Water Evaluation and Planning System* (WEAP), developed by the Stockholm Environment Institute, is used as it is compatible with the methodological approach proposed in this study. WEAP, which is free for academic use, is also a user friendly and easy-use software. The main features and computation algorithms of WEAP are explained in the next section.

3.2 Water Evaluation and Planning System (WEAP)

WEAP is a practical tool for water resources planning, which incorporates both the water supply and the water demand issues in addition to issues of water quality and ecosystem preservation, as required by an integrated approach to basin management. WEAP places the demand side of the problem (water use patterns, equipment efficiencies, re-use, prices and water allocation) on an equal footing with the supply side (stream flow, groundwater, reservoirs and water transfers). Thus, WEAP is a laboratory for examining alternative water development and management strategies. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options and takes into account multiple and competing uses of water systems (SEI, 2007).

3.2.1 Main Features

WEAP21, the last release of the software, is Windows-based and is developed in Delphi by Borland. The graphical user interface consists of five different "views", namely *Schematic, Data, Results, Overviews and Notes*. They are accessed by specific buttons on the *View Bar* placed at the left of the interface main screen, where each view is displayed (Figure 3.2).

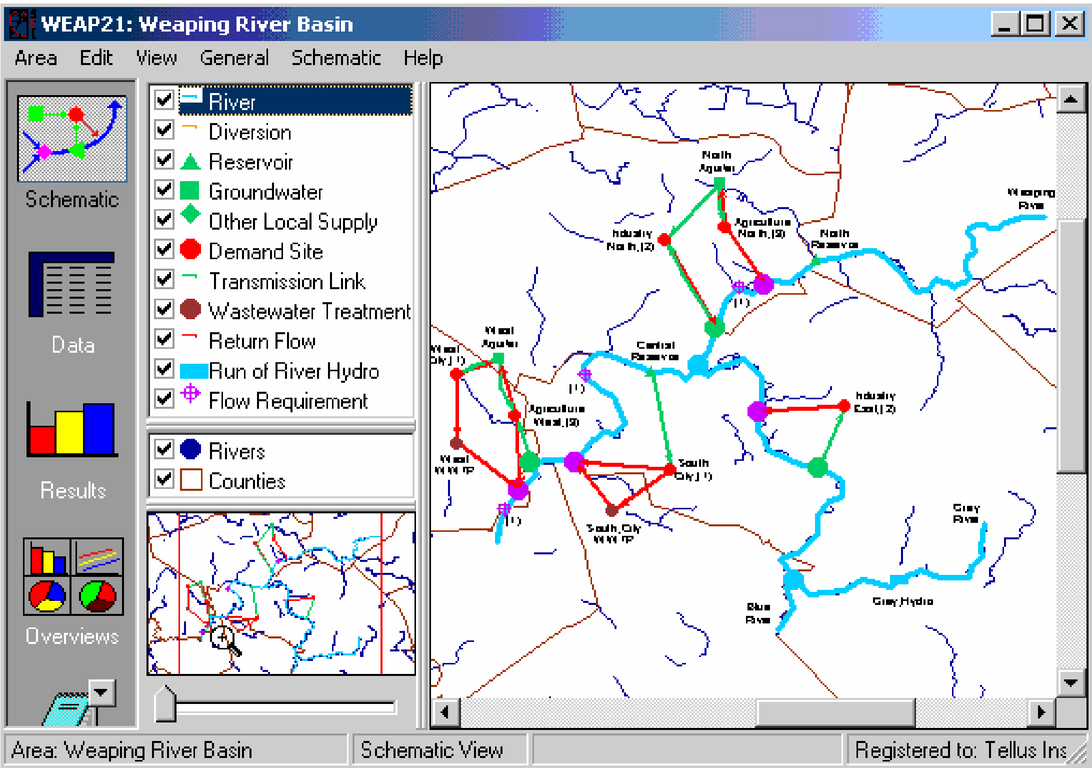


Figure 3.2 The schematic view of WEAP

The *Schematic View* aims to describe and visualize the physical features of the water supply and demand system. The user can build the network of nodes and links representative of the water resource system of the study area by dragging and dropping the desired types of nodes and transmission links from a window at the upper-left, which lists them to a specific position on the map. After the node type is dropped on the map, a pop-up window requests some minimum general information about the new node, e.g., the name of the node, and asks whether the node will be simulated in the default scenario. Further information to be filled in depends on the specific element type. The available network elements include rivers, diversions, reservoirs, groundwater pumping stations, demand sites, wastewater treatment plants, hydropower stations, and flow requirements. Nodes are linked by transmission links and return flows. The former carry water from the water supply nodes to the demand nodes, and the latter exit the demand nodes towards treatment plants or river locations.

The *Data View* is the place where the data structures, models and assumptions are created. In this view, the hierarchical tree panel is used to create and organize data structures under six major categories: *Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Water Quality, and Other Assumptions*.

The *Key and Other Assumptions* are user-defined intermediate variables that can be referenced in any expression or function used in data and scenario definition. Examples of assumptions are variables such as the crop coefficients (K_c), irrigation efficiencies, transmission lost rates, gross domestic product (GDP).

The *Demand Sites* are cities, industries and irrigation districts demanding water and are described in terms of annual water use, monthly share of annual demand among all the sites of the same category, the loss and re-use rates within the demand site, and the costs and savings accruing from demand management.

The *Hydrology* category refers to future time series of inflows to supply nodes, specified via mathematical expressions (models) or pre-defined monthly data.

The *Supply and Resources* category groups all the water sources and network links. The latter are featured by the maximum loss rate and cost per unit of water delivered whilst each kind of source has its own specific variables.

The *Water Quality* category concerns the generation of pollutants, their concentrations, and removal within treatment plants.

In each category, a *data entry table* is used to edit data and create modeling relationships in respect of data trends over time. The user has to specify the parameters of the relationships so as to define the variable behavior. Examples of functions are the *Growth* and the *Interp,* which compute a value in any given year, using respectively a growth rate from the base year value and a linear interpolation of year/value time-series. Variable trends can be also built through dedicated wizards for monthly and yearly time-series construction. Once the user has filled-in the data, he can convert and display them in different measurement units and scales. The list of units depends on the category of network elements they refer to. The *data entry tables* are also used to manage scenarios. The default one-year scenario is called *Current Accounts,* and the corresponding data represent the status of the system in the specified year as a the starting point for all the simulated and alternate scenarios for the following years. As noted before, the behavior of variables is built through mathematical expressions which can be constant or which can generate time-series of values. These expressions can be exported from one scenario to another to allow minimizing the amount of data entries and to facilitate scenario editing and management.

The *Results View* displays a wide variety of charts and tables covering each aspect of the system: demand, supply and resources, water quality, and financial data. Customizable reports can be viewed for one or more scenarios. The user can also use the "Favorites" option to bookmark the most useful charts for the analysis. Furthermore, he can choose the variables to plot, display a specific month or the entire time-series, plot information associated to just one network node or to all the nodes of the same type. Moreover, he can choose and change the graph type, select the scenario, and select/change the measurement units. The data table can be exported to Excel by clicking the dedicated button, and graphs can be copied and printed. The graphs previously saved as favorite can be viewed all together in the *Overview* so as to compare different aspects of the river basin, such as water demand and coverage, storage levels, pollutant generation and costs.

The *Notes View* is just a word processor to write notes about the network elements, scenarios built or mathematical expressions used; this feature is very useful for further detailed studies.

3.2.2 Computational Algorithms

WEAP operates on a monthly time step, starting from the first month of the *Current Accounts* year and continuing up to the last month of the last scenario year; it computes water mass balance for every node and link in the system for the simulation period. Each month is independent of the previous month, except for reservoir and aquifer storage. Thus, the water entering the system in a month (e.g., headflow, groundwater recharge, or runoff into reaches) is either stored in an aquifer or reservoir, or it leaves the system by the end of the month (e.g., outflow from the end of the river, consumption at a demand site, or transmission and return flow losses. In other words, a demand site can withdraw water from the supply source, consume some and return the rest to a specified route. This return flow is available for use in the same month by downstream demand sites.

Since this study deals with the water resources management model that is developed only for the agricultural use of water in term of surface water quantity and excludes water quality assessments, the extensive computational algorithms of WEAP are selected and described herein so as to comply with the requirements of this study. Accordingly, three main algorithms, i.e., the computation of agricultural demand, determination of the available supply and allocation of water, are briefly introduced below. The detailed features and explanations to set up the analysis in WEAP can be found in the user guide of the model (SEI, 2007).

Computation of Agricultural Demand

Here, "agricultural demand" refers to water needs for irrigation purposes. It is driven by meteorological factors such as precipitation and evapotranspiration, as well as by the types of cultivated crops, which are characterized by crop coefficients. The FAO crop coefficient method, presented by The Food and Agriculture Organization of United Nations (FAO), is the demand estimation approach employed. The following successive equations, (Eq. 3.1-3.5), are used to implement this approach, where the subscript *LC* refers to land cover, and *HU* to the hydrologic unit. Here, *HU* refers to the area where the agricultural water demand is calculated. The precipitation and evapotranspiration data are obtained from the meteorological stations that demonstrate the climate conditions of the HU.

$$PAET_{LC} = P_{HU} * A_{LC} * 10^{-5} * P_{e_{LC}} \tag{3.1}$$

$$ET_{c_{LC}} = ET_{o_{HU}} * K_{c_{LC}} * A_{LC} * 10^{-5} \tag{3.2}$$

$$PS_{LC} = Max\,(0, ET_{c_{LC}} - PAET_{LC}) \tag{3.3}$$

$$SR_{LC} = (1 / IE_{LC}) * PS_{LC} \tag{3.4}$$

$$SR_{HU} = \Sigma_{LC} SR_{LC} \tag{3.5}$$

The units and definitions for variables for the above equations are given below:

A	: Area of land cover (ha)
P	: Precipitation (mm)
P_e	: Percentage of precipitation that can be used for evapotranspiration (%)
$PAET$	: Precipitation available for evapotranspiration (10^6 m^3)
K_c	: FAO crop coefficient
ET_o	: Reference evapotranspiration (mm)
ET_c	: Crop evapotranspiration (10^6 m^3)

PS : Evapotranspiration deficit due to precipitation shortfall (10^6 m^3)

IE : Irrigation efficiency (%)

SR : Crop irrigation demand (10^6 m^3)

The above equations are used to determine the additional amount of water (in addition to the available precipitation) needed to meet the evapotranspiration demand of the land cover (and the total hydrologic unit) while taking into account irrigation efficiencies.

Determination of Available Water Supply

WEAP has four methods for projecting the surface water hydrology over the study period: *Water Year Method, Expressions, Catchment Runoff, and Read From File Method*. These methods may be used to project the inflow to every surface and groundwater inflow point in the system for every month within the study period. The inflows include river and tributary headflows, surface water inflows to river reaches, groundwater, local reservoirs and other supply inflows.

The *Water Year Method* (WYM) allows the user to use historical data in a simplified form and to easily explore the effects of future changes in hydrologic patterns. The WYM projects future inflows by varying the inflow data from the *Current Accounts* according to the *Water Year Sequence* and *Definitions*. In WYM, hydrologic fluctuations are entered as variations from a Normal Water Year. The WYM requires data for defining standard types of water years (Water Year Definition; e.g., Normal, Very Wet, Wet, Dry, and Very Dry), as well as defining the sequence of those years for a given set of scenarios (Water Year Sequence; e.g., 3 very dry years occur after 3 very wet years).

Inflows can also be specified with a mathematical *expression*. Typical expressions include: constants, a specified value for each month, or some other relationship.

Catchment Runoff can be directed to rivers and groundwater nodes using a Runoff/Infiltration Link. These flows can be specified directly (for the Rainfall Runoff method), or WEAP can simulate, using the Soil Moisture Method, the amounts of runoff, soil moisture, and base flow generated by the catchment. Here, it should be noted that, since groundwater resources are not incorporated to the analyses, the soil moisture method that requires more extensive soil and climate parameterization is not used in this study.

If the users have monthly data on inflows to the rivers and local supplies, the *Read From File Method* allows modeling the system using this sequence of inflows. The user can export gauged inflow data from many conventional hydrologic databases and then edit these files into the required format. The monthly inflow data are not restricted to historical values. Projected monthly surface water estimates can be based on historical data, or on projections from some external model, or a mixture of both. With this method, the user can modify historical flows to account for projected changes due to climate change or can use outputs from a climate model to project future inflows.

Water Allocation

In WEAP, water allocation is based on the concepts of *Supply Preferences* and *Demand Priorities* as well as on a schematized water scheme. The *Supply Preferences* are attached to the transmission links in case the demand sites are connected to more than one resource, and they establish the order of water supply service. In other words, each demand site with multiple sources can specify its preference for a source (e.g. groundwater exploitation can be preferred to reservoir water withdrawals) due to economic, environmental or political reasons. The *Demand Priorities* can range from 1 to 99, with 1 representing the highest priority and 99 the lowest. These priorities have a particular importance during water shortage conditions because the demand sites with the highest priorities are assumed as the primary sites to access water that fully covers their water demands. The allocation process includes computation of withdrawals from supply nodes (groundwater resources or reservoirs) to meet the demand. This step is solved by linear programming (LP), where the objective is to meet the demand and in-stream flow requirements, subject to demand priorities, supply preferences, mass balance and other constraints.

The LP constraint set foresees the supply of an equal percentage of water to the members of each equity group that is constituted by demand sites with the same priority. This is done by adding to the LP for each demand site: 1) a percent demand coverage (% of requirement met) variable, which is the percent of the total demand satisfied at the given time step; 2) an equity constraint that equally satisfies all demands within an equity group in terms of the percentage of satisfied demand; and 3) a demand coverage (% of requirement met) constraint which ensures that an appropriate amount of water is supplied to a demand site or to meeting of an in-stream flow requirement. In addition, the user can constrain the flow through any transmission link to a maximum volume or a percentage of demand, to reflect physical (e.g., pipe or pump capacities) or contractual limits, or preferences on mixing of supplies. Details of this allocation algorithm can be found in Yates et al. (2005).

Another important point in water allocation is reservoir operation. Reservoirs represent a special object in the WEAP model in that they can be configured to store water that becomes available either from the solution of the physical hydrology module or from a user-defined time series of stream flows. The operation rule of a reservoir determines how much water is available in the current time step for release to satisfy downstream demand and in-stream flow requirements, hydropower generation, and flood control requirements and how much, if any, should be carried over until a later time-step. If the priority assigned to storing water in a reservoir is less than the downstream demands or in-stream flow requirements, WEAP will release only as much of the available storage as is needed to satisfy the demand and in-stream flow requirements, taking into consideration releases from other reservoirs and withdrawals from rivers and other sources.

In WEAP, a reservoir is stratified according to water storage volumes as shown in Figure 3.3, where: 1) the flood control storage (S_F) defines the zone that can temporarily hold water but must be released before the end of the time step. In effect, this volume is always vacant, as additional flows that would lead to reservoir storages above the flood control storage are spilled; 2) the conservation storage (S_C) is the storage available for downstream demands at full capacity, where all water in this zone can be drawn from; 3) the buffer storage (S_B) is a storage that can be controlled to uniquely meet water demands during shortages; when reservoir storage falls within the buffer storage, water withdrawals are effectively conserved via the buffer coefficient, B_c, which determines the fraction of storage available for reservoir release; and 4) the inactive storage (S_I) is the dead storage that cannot be utilized.

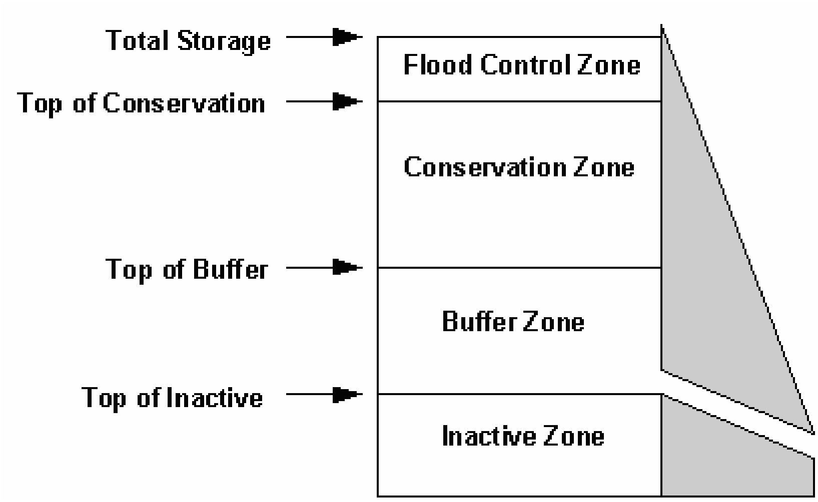


Figure 3.3 The reservoir storage volumes used to describe operation rules

All these storage parameters can vary in time and can be used to define water conservation and flood storage/release targets. The amount available for release from the reservoir, S_R , is the total amount in the conservation and flood control zones and a fraction (defined by B_c) of the amount in the buffer zone (Eq. 3.6).

$$S_R = S_C + S_F + (B_c * S_B) \tag{3.6}$$

3. 3 Scenario Formulation

An important aspect of modeling a water system is to understand how it operates under a variety of hydro-meteorological conditions. This task is also a stepping stone for formulation of the strategies to solve water problems. However, natural variations in hydrology, as well as in meteorology, can have major effects not only on water resources, but also on water demand. Under this context, scenario formulation should be based on forecasts of water supply and water demand.

3.3.1 Water Availability

The purpose of the water availability module is to generate monthly time series of water quantity for each river in the network; accordingly, historical river flow data constitute the most valuable component for this task. Within these data, three plausible ways can be proposed to build up scenarios:

1) repeating the historical data for the entire duration of the scenario,
2) defining a total decrement (or increment) over the entire period, either annual or monthly,
3) building up a sequence of defined water years by the Water Year Method that is implemented in WEAP.

Furthermore, the scenarios must consider the climatic changes that may have significant impacts on water availability. The *Intergovernmental Panel on Climate Change* (IPCC) warns that "projected climate change could further decrease stream flow and groundwater recharge in many water-stressed countries" (IPCC, 2007). At river basin scale, however, the direction of such changes is not certain. Accordingly, formulating various water availability scenarios under the light of research studies which downscale climate change impacts to basin level seems as the best way to constitute future time series of river flows.

3.3.2 Demand Forecasting

As previously mentioned, the demand here refers to the irrigation water requirement which is calculated by the FAO crop coefficient approach (Eq. 3.7). In this approach, crop evapotranspiration, ET_c, is calculated by multiplying the reference evapotranspiration, ET_o, by a crop coefficient, K_c.

$$ET_c = K_c * ET_o \tag{3.7}$$

The evapotranspiration from a reference surface, not short of water, is called the reference evapotranspiration, and is denoted as ET_o. The reference surface is a hypothetical grass reference crop with specific characteristics. Owing to the difficulty of obtaining accurate field measurements, ET_o is commonly computed from meteorological data. On the other hand, the effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient, K_c, which incorporates crop characteristics and averaged effects of evaporation from the soil.

The ET_o is generally defined and calculated by the FAO Penman-Monteith equation (Allen et al., 1998). Apart from the location information of a site (identified with longitude and latitude), the FAO Penman-Monteith equation requires air temperature, humidity, radiation and wind speed data for evapotranspiration calculations. Since it is difficult to derive all the required data, the CROPWAT computer program is developed by the Land and Water Development Division of FAO for computation of the reference evapotranspiration. This software enables to compute the ET_o and effective precipitation (P_e), as well as the crop coefficients (K_c), practically by the aid of country databases incorporated to the software package or by user-defined hypothetical conditions.

In this study, the demand scenarios are based on assessments of ET_o since current climate change reports indicate that temperatures (t) show an increasing trend in the region studied (SUMER, 2006). Although projections on precipitation are also provided in these reports, the effects of precipitation variations are neglected in the demand scenarios because the case study region already experiences droughts in the summer season when the demand peaks.

3.3.3 Reference Scenarios

Although numerous scenarios can be generated, those which refer to the *worst*, *normal* and the *best* hydro-meteorological conditions can be reasonably selected not only to consider the basic boundary conditions, but also to increase the number of scenarios to a manageable size. In accordance with the formulation approaches explained above, three different *reference scenarios* which consider both the water availability and the demand scenarios are developed. The *Business as Usual* (BAU) scenario refers to the repeating of historical stream flows as well as the stable irrigation demand. The *Pessimistic* scenario combines low water availability and increasing demand scenarios. High water availability and stable demand scenario combination demonstrates the *Optimistic* scenario, that allows to infer on whether the water problems still exist in better hydro-meteorological conditions. Here, it should be noted that the reference scenarios represent the changes likely to occur in the future in terms of hydro-meteorological variations. However, if there are the definite projects to be realized in the future (e.g., construction of new dams), they should also be incorporated to the analyses within the reference scenarios while setting up the simulation model.

3. 4 Evaluation

3.4.1 Management Alternatives

In water resources development and management practices, policy makers and water managers propose variable options according to the problem encountered while taking into account technical feasibility as well as the economic effectiveness of possible investments. A large number of alternatives can be proposed to cover construction of new dams, groundwater exploitation, desalination, recycling and reuse, water importing, irrigation methods improvements, crop pattern change, network improvements and enhancements, and water pricing. These management options are generally grouped under three major categories. The *supply enhancement measures* represent the new structural interventions to increase water supply. The *demand management measures* aim to improve water use efficiencies as well as to decrease water demands. The *socio-economic measures* are needed to mitigate unfavorable impacts by means of socio-economic instruments, such as water pricing and education. Moreover, another category can also be defined to produce management strategies through combinations of the above options in seeking efficient solutions.

However, all alternative management plans may not be compatible with basin features, and the acceptability of an alternative depends on the socio-economic realities of the country. Thus, proposed alternatives differ for each country and more specifically for each river basin or management unit.

The alternative management plans analyzed in this study are outlined in Table 3.1 with brief descriptions. Here, the alternatives are proposed in accordance with the purpose of the study; that is, the main objective of the management alternatives is to increase the water supply for irrigation and the irrigation efficiency and decrease the demand. The detailed structures and attributes of these alternatives are introduced in the next chapter.

Table 3.1 Management alternatives evaluated

Management alternatives	Description
Do nothing (A0)	No additional measures to the current system
Canal maintenance (A1)	Maintenance and replacement of irrigation networks in order to reduce the water losses
Crop pattern change (A2)	Substitution of existing crops by other crops that have lower irrigation water demand
Drip irrigation (A3)	Changes in the irrigation system (in favor of drip irrigation) in order to increase irrigation efficiency and reduce water losses
Pressured systems (A4)	Substitution of the existing open channel water distribution system by a pressured system
A2 + A1 = (A5)	Demonstrates the strategy constituted jointly by crop changing & canal maintenance alternatives
A2 + A3 = (A6)	Demonstrates the strategy constituted jointly by crop changing & drip irrigation systems
A2 + A4= (A7)	Demonstrates the strategy constituted jointly by crop changing and pressured distribution system

3.4.2 Evaluation Criteria

Agenda 21 (Chapter 40) states that “indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to the self-regulating sustainability of integrated environmental and development systems”. This has led to the acceptance of indicators as basic tools for supporting policy implementation. In order to evaluate the achievements of management alternatives, nine indicators that are relevant to environmental, social and economic sustainability are developed. It should be noted that since a simulation model is used, the focus is given to the numeric outputs of the model; in other words, the developed indicators are based on the quantitative assessments of alternatives while the qualitative side is ignored. The indicators used in this study to evaluate management alternatives are given in Table 3.2 with brief descriptions.

Table 3.2 The evaluation criteria and indicators

Criteria	Indicator	Unit	Description
ENVIRONMENTAL	Agricultural Sustainability Index (*ASI*)	[-]	The temporal aggregation of supply/demand ratio time series (only for irrigation) according to the performance measures where the satisfactory range is considered between 0.8 and 1.0
	Environmental Sustainability Index (*ESI*)	[-]	The temporal aggregation of supply/demand ratio time series (only for environmental needs) according to the performance measures where the satisfaction value is 1 (full coverage).
	Water Exploitation Rate (*WER*)	[-]	The percentage of surface water potential that is allocated for irrigation; (annual average is used in the evaluations)
SOCIAL	Yield Reliability (*YR*)	[-]	Average yield reliability of main cultivated crops (the satisfactory range is considered between 0.75 and 1.00 for all crops)
	Irrigation Water Deficit (*IWD*)	[10^6 m^3]	Represents annual unmet demand for irrigation; (annual average is used in the evaluations)
	Domestic Supply Reliability (*DSR*)	[-]	The supply reliability of transmission link to Izmir from Gordes dam
ECONOMIC	Benefit / Cost Ratio (*B/C*)	[-]	∑ Benefits / ∑ Costs of management alternatives for the simulation period
	Irrigation Water Use Efficiency (*IWUE*)	[€/m^3]	Production value (monetary) of agricultural practices per allocated water for irrigation; (annual average is used in the evaluations)
	Total Production Value (*TPV*)	[10^6 €]	Annual total production value of agricultural practices; (annual average is used in the evaluations)

The methodology for developing indicators is based on two approaches. The first one is the use of average values for indicator time series that is obtained annually during the simulation period. The *WER*, *IWD*, *IWUE* and *TPV* indicators are computed using this approach. Here, a differentiation is made for the *B/C* which is obtained by dividing the total benefits (overall cultivation revenue) to the total costs (the sum of capital and operational costs).

The second approach that has been recommended by the American Society of Civil Engineers and the International Hydrological Programme (working group of UNESCO) is the temporal aggregation of indicator time series using performance measures of *reliability*, *resilience* and *vulnerability* (ASCE, 1998).

This procedure can be illustrated by considering any selected indicator C, whose time series of values is denoted as C_t, where the simulated time period, t, extends to some future time, T (Figure 3.4). To define performance measures, the lower limit (LL) and the upper limit (UL) of satisfactory range should be identified. These limits may change within a year and over multiple years, and are based on the decision maker's judgements.

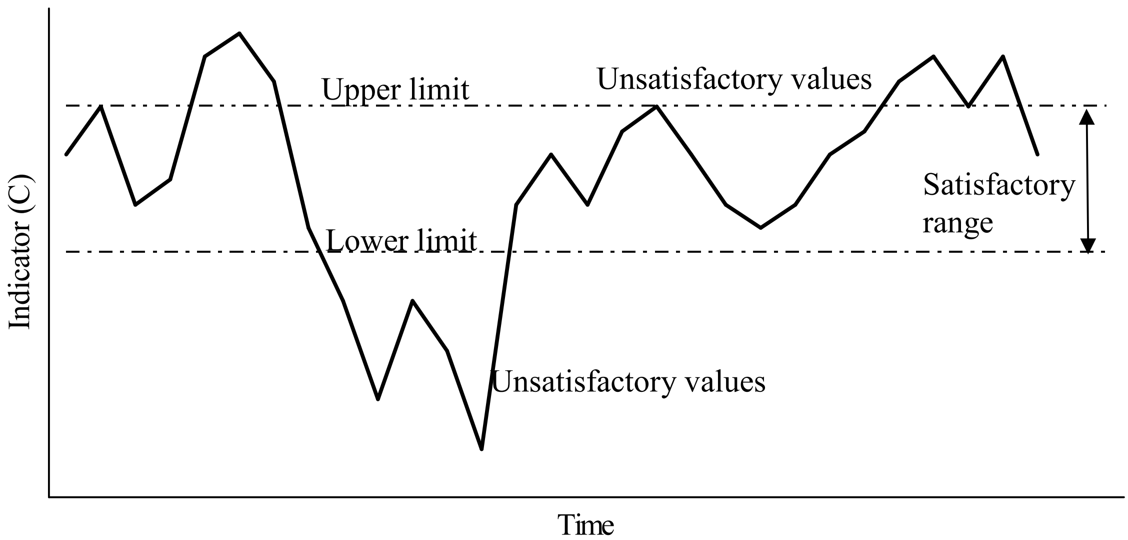


Figure 3.4 Indicator time series and range of satisfactory values

Reliability (RE) is defined as the probability that any particular C_t value will be within the range of values considered satisfactory (Eq. 3.8).

$$RE\ of\ (C) = \frac{Number\ of\ satisfactory\ C_t\ values}{Total\ number\ of\ simulated\ periods} \tag{3.8}$$

Resilience (RS) is an indicator describing the speed of recovery from an unsatisfactory condition. It is the probability that a satisfactory value C_{t+1} will follow an unsatisfactory C_t value (Eq. 3.9).

$$RS\ of\ (C) = \frac{Number\ of\ times\ a\ satisfactory\ C_{t+1}\ value\ follows\ an\ unsatisfactory\ C_t\ value}{Total\ number\ of\ unsatisfactory\ values} \tag{3.9}$$

Vulnerability (VU) is a statistical measure of the extent (magnitude) or the duration of failures in a time series. The extent (magnitude) of a failure is the amount that a value C_t exceeds the upper limit, $UL(C_t)$, of the satisfactory values or the amount that value falls below the lower limit, $LL(C_t)$, of the satisfactory values. In this study, vulnerability is defined as *expected extent-vulnerability* (Eq. 3.10), and the durations of failures are excluded.

$$VU\ of\ (C) = \frac{\sum\ individual\ extents\ of\ C_t\ failures}{Total\ number\ of\ individual\ extents\ of\ C_t\ failures} \tag{3.10}$$

Sustainability Index that ranges from 0, for its lowest and the worst possible value, to 1, as its highest and the best possible value, is computed by multiplying the reliability, resilience and (1-vulnerability) values since reliability and resilience are the maximizing while vulnerability is the minimizing criteria for sustainability. Thus, the *agricultural sustainability index* (*ASI*) and *environmental sustainability index* (*ESI*) are calculated with Eq. (3.11) and Eq. (3.12), respectively. The indicator used for *ASI* is the *supply/demand ratio* (*S/D*) of irrigation districts as well as of the environmental needs for *ESI*.

$$ASI = RE_{(S_i/D_i)} * RS_{(S_i/D_i)} * (1 - VU_{(S_i/D_i)}) \tag{3.11}$$

$$ESI = RE_{(S_e/D_e)} * RS_{(S_e/D_e)} * (1 - VU_{(S_e/D_e)}) \tag{3.12}$$

In this study, the satisfactory range of Fig. 3.4 is selected between 0.80 and 1.00 for irrigation purposes, which are the $LL(S_i/D_i)$ and $UL(S_i/D_i)$, respectively.

However, for environmental needs, it is desired to meet all the water demand; thus, the LL(S_e/D_e) and UL(S_e/D_e) are both fixed to 1.

The reliability (Eq. 3.8) is solely used to determine the *domestic supply reliability* (*DSR*), which indicates the percent of time the requirement (the expected amount of water from a transmission link to domestic uses, D_t) is fully met with water allocated to the transmission link, S_t, (Eq. 3.13). Here again, the LL(S_t/D_t) and UL(S_t/D_t) are both fixed to 1 while developing the indicator for this study.

$$DSR = \frac{Number\ of\ periods\ the\ requirements\ fully\ met\ (S_t / D_t = 1)}{Total\ number\ of\ periods\ the\ transmission\ link\ operated} \tag{3.13}$$

The *yield reliability* (*YR*) is another core social indicator that represents the probability of achieving at least α % of maximum yield. Here, α is a subjective constant and indicates the satisfactory level. The *YR* is formulated in Eq. (3.14), where the crop type and the number of crops are *i* and *n*, respectively.

$$YR = \frac{1}{n} \sum_{i=1}^{n} \frac{Number\ of\ satisfactory\ yield\ values\ for\ crop\ i}{Total\ number\ of\ simulated\ periods\ for\ crop\ i} \tag{3.14}$$

Here, it should be noted that, since the crop yield, or more generally agricultural productivity, is largely influenced by the irrigation water deficit, the response of yield to water deficit is quantified through the *yield response factor* (k_y) which relates relative yield decrease to relative evapotranspiration deficit (Eq. 3.15):

$$1 - \frac{Y_a}{Y_m} = k_y \left(1 - \frac{ET_a}{ET_c}\right) \tag{3.15}$$

where,

Y_a = actual yield

Y_m = maximum yield

ET_a = actual evapotranspiration

ET_c = crop (potential) evapotranspiration

k_y = yield response factor

The k_y values differ according to the crops as well as to the ET_a that differs according to the irrigation system. Accordingly, the *YR* indicator is a valuable indicator to address the performance of management alternatives with socio-economic aspects, and it is incorporated to the analyses with a reasonable satisfaction level (α=0.75).

3. 5 Defining Criteria Weights

3.5.1 The Performance Matrix

The major element of the decision making process is the *performance matrix* (PM), A, where the columns correspond criteria (C_1, C_2, …, C_m) and rows to alternatives (A_1, A_2, …, A_n), with the entries (a_{ij}) being the indicators for all alternatives across all criteria (Eq. 3.16). Once the matrix is set up, the next step for the decision process is to define the weights (w_1, w_2, …, w_m) of the criteria, which reflect of decision makers' (DM) subjective preferences:

$$A = \begin{array}{c c} & \begin{array}{cccc} w_1 & w_2 & \cdots & w_m \\ C_1 & C_2 & \cdots & C_m \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ . \\ A_n \end{array} & \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix} \end{array} \tag{3.16}$$

The criteria weights are usually assigned by the DMs, based on their own experiences, knowledge and perception of the problem. This assignment may be made via a preference elicitation technique such as the *analytic hierarchy process* (*AHP*), which will be discussed further in this chapter. However, the DMs involved in the decision process usually have different attitudes and can rarely reach an agreement on the relative importance of criteria. Another difficulty is the inconsistency problem in subjective weighting. These problems can be overcome by using an objective weighting process, which is carried out independently from the subjective preferences of the DMs. The logic behind such a weighting process is that each alternative is objectively described by its performance scores, and these scores in the performance matrix represent the sources of information provided to the DM (Srdjevic et al., 2004). Since recent studies show that no single weighting approach can guarantee a more accurate result, different criteria weights obtained from various approaches explained below are applied for the robust ranking of alternatives.

3.5.2 The Entropy Method

Entropy is generally understood as a measure of uncertainty in the information as defined by Shannon and Weaver (1947). It indicates that a broad distribution represents more uncertainty than does a sharply peaked one (Deng et al., 2000). To determine objective weights by the entropy value (e_j), the performance matrix in Eq. (3.16) needs to be normalized by Eq. (3.17). Then, a new matrix (Eq. 3.18) is derived, containing relative scores of alternatives across criteria.

$$r_{ij} = a_{ij}\left[\sum_{i=1}^{n} a_{ij}\right]^{-1}, \quad j = 1, 2,....., m \tag{3.17}$$

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{3.18}$$

The information contained in matrix R can be considered as the ‘emission power’ of each criterion C_j (j =1, 2,...., m) and is used to compute an entropy value e_j:

$$e_j = -k\sum_{i=1}^{n} r_{ij} \ln r_{ij}, \quad j = 1, 2,....., m \tag{3.19}$$

A constant k, k = 1/ ln n, is used to guarantee that $0 \leq e_j \leq 1$. The degree of divergence (f_j) of the average intrinsic information contained in each criterion is calculated as:

$$f_j = 1 - e_j\,, \qquad j = 1, 2, \ldots, m \tag{3.20}$$

It means that the more divergent the initial scores a_{ij} of alternatives A_i (i = 1, 2,..., n) are for a given criterion C_j, the higher is its f_j and the more important is the criterion C_j for the problem. Consequently, if all alternatives have similar scores for a given criterion, this criterion is less important for the specific problem, and if all scores against this criterion are the same, the criterion can be eliminated because it transmits no information to the DM (Zeleny, 1982).

If f_j is considered as the specific measure of inherent contrast intensity of the criterion C_j, the final relative weights for all criteria can be obtained by simple additive normalization:

$$w_j = f_j \left[\sum_{j=1}^{m} f_j \right]^{-1}, \quad j = 1, 2, \ldots, m \tag{3.21}$$

Because the criteria weights are obtained directly from the performance matrix, i.e., independently of the DM, this qualifies the entropy method (EM) as an unbiased evaluation procedure, and the same holds true for the results obtained with that criteria weight set (Srdjevic et al., 2004).

3.5.3 The CRITIC Method

In addition to the entropy method (EM), any other method of measuring the divergence in performance ratings can be used to determine the objective weights. Diakoulaki et al. (1995) has proposed the CRITIC (The CRiteria Importance

Through Intercriteria Correlation) method that uses correlation analysis to detect contrasts between criteria, as described below.

If we assume the normalized matrix, Eq. (3.18), by examining the jth criterion in isolation, we generate a vector r_j denoting the scores of all n alternatives considered (Eq. 3.22):

$$r_j = (r_{1j}, r_{2j}, \ldots., r_{nj}) \tag{3.22}$$

Each vector r_j is characterized by the standard deviation (σ_j), which quantifies the contrast intensity of the corresponding criterion. So, the standard deviation of r_j is a measure of the value of that criterion to be considered in the decision making process.

Next, a symmetric matrix is constructed, with dimensions m x m and a generic element l_{jk}, which is the linear correlation coefficient between the vectors $\boldsymbol{r_j}$ and $\boldsymbol{r_k}$. It can be seen that the more discordant the scores of the alternatives in criteria j and k are, the lower is the value l_{jk}. In this sense, Eq. (3.23) represents a measure of the conflict created by criterion j with respect to the decision situation defined by the rest of the criteria:

$$\sum_{k=1}^{m}(1-l_{jk}) \tag{3.23}$$

The amount of information C_j conveyed by the jth criterion can be determined by composing the measures which quantify the above two notions through the multiplicative aggregation formula (Eq. 3.24):

$$C_j = \sigma_j \sum_{k=1}^{m}(1-l_{kj}) \tag{3.24}$$

According to the previous analysis, the higher the value C_j is, the larger is the amount of information transmitted by the corresponding criterion and the higher is its relative importance for the decision making process. Objective weights are derived by normalizing these values to unity (Eq. 3.25):

$$w_j = C_j \left[\sum_{k=1}^{m} C_k \right]^{-1} \tag{3.25}$$

It is worth mentioning that Diakoulaki et al. (1995) and Deng et al. (2000) also recommended the *standard deviation* (SD) and *mean weight* (MW) methods to obtain objective weights. The SD method calculates the weights by Eq. (3.26), where σ_j is the standard deviation of the performance rating vector r_{ij}:

$$w_j = \sigma_j \left[\sum_{k=1}^{m} \sigma_k \right]^{-1} \tag{3.26}$$

The MW method derives objective weights by Eq. (3.27), where m is the number of criteria. Assignment of equal weights to the decision criteria reflects a completely neutral attitude of the decision maker, and it is often considered that such an attitude guarantees the objectivity of the evaluation process.

$$w_j = 1/m \tag{3.27}$$

3.5.4 Analytic Hierarchy Process

The *Analytic Hierarchy Process* (AHP) developed by Saaty (1980) is a method of converting subjective assessments to a set of weights by pairwise comparisons between all criteria. The pairwise comparisons are quantified by using a linear scale as in Table 3.3.

Table 3.3 Scales of relative importance according to Saaty (1980)

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective(s)
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgements	Where compromise is needed
Reciprocals of the above nonzero numbers	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

In accordance with Table 3.3, the decision maker is asked to define the pairwise comparison matrix, P, where the entries p_{ij} are described as the relative importance of the ith criterion with respect to the jth criterion (Eq. 3.28):

$$P = \begin{bmatrix} 1 & p_{12} & \cdots & p_{1m} \\ p_{21} & 1 & \cdots & p_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ p_{m1} & p_{m2} & \cdots & 1 \end{bmatrix} \tag{3.28}$$

In the comparison process, once the upper triangular matrix is determined, the lower triangular matrix can be defined by Eq. (3.29):

$$p_{ji} = \frac{1}{p_{ij}} \tag{3.29}$$

The normalized pairwise comparison matrix (X) is obtained by dividing each element in P by its column sum (Eq. 3.30). Then, the principal eigenvector (λ) that defines the criteria weight vector (W) is obtained by averaging across the rows of X (Eq. 3.31).

$$X = \begin{bmatrix} 1/\sum_{m=1}^{m} p_{m1} & . & . & p_{1m}/\sum_{t=1}^{m} p_{tm} \\ . & . & . & . \\ p_{m1}/\sum_{m=1}^{m} p_{m1} & . & . & 1/\sum_{t=1}^{m} p_{tm} \end{bmatrix} = \begin{bmatrix} x_{11} & . & . & x_{1m} \\ . & . & . & \\ x_{m1} & . & . & x_{mm} \end{bmatrix} \tag{3.30}$$

$$W = \frac{1}{m} \begin{bmatrix} \sum_{m=1}^{m} x_{1m} \\ . \\ . \\ \sum_{t=1}^{m} x_{mt} \end{bmatrix} = \begin{bmatrix} w_1 \\ . \\ . \\ w_m \end{bmatrix} \tag{3.31}$$

In the above, the w_j (j=1,.., m) shows the relative weights among the criteria that are compared, and the sum of criteria weights is 1.

On the other hand, the consistency of weights must also be checked (Triantaphyllou, 2000). Saaty (1980) expresses the inconsistency of pairwise comparison matrix in terms of the *consistency index* (CI), which is defined as in Eq. 3.32, where $\lambda_{\max}$ is the maximum eigenvector of the pairwise comparison matrix, and

n is the order of that matrix. Saaty (1980) also claims that one should find an eigenvector corresponding to λ_{max} as in Eq. (3.33), where $\lambda_{max} \geq n$.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3.32}$$

$$P * W = \lambda_{\max} * W \tag{3.33}$$

Then, the consistency ratio (CR), which is the comparison between the consistency index (CI) and the random consistency index (RI), is determined as in Eq. (3.34) to measure the inconsistency of subjective judgements of DMs.

$$CR = \frac{CI}{RI} \tag{3.34}$$

Here, RI (Table 3.4) denotes the average random consistency index obtained from a sample of size of 500 randomly generated reciprocal matrices with entries derived from the scale in Table 3.3. If this approach yields a CR value smaller or equal to 10%, the inconsistency is acceptable (Triantaphyllou, 2000).

Table 3.4 Random consistency index (RI)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The AHP method is relatively simple to determine the criteria weights; however, the DM needs to define a total of n (n-1) subjective judgements among n criteria. Since this process is not easy, the DM may be overburdened to obtain reliable weights. Thus, in this study, the AHP is used to determine the weights of a few numbers of criteria which relate to the main management objectives.

3. 6 Multi Criteria Decision Making Methods

3.6.1. Available Methods

Once the performance matrix (PM) and the criteria weights are created, numerous MCDM methods can be used to identify the most preferred alternative. Simple Additive Weighting (SAW), Compromise Programming (CP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can be cited as the methods that are directly use the PM to rank the alternatives. ELimination Et Choice Translating Reality (ELECTRE) and Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) are the other important MCDM methods in literature. Generally, the first group is known as the *distance type methods* (excluding SAW), and the second group is the *outranking type methods*. However, the outranking type methods, which are based on the pairwise comparison between alternatives via selected criteria, need more subjective judgements like indifference, preference and veto thresholds to be determined by the DMs. Since an objective evaluation of management alternatives is foreseen, the two distance type methods (CP and TOPSIS) and SAW method are applied in the decision making process of this study.

It is worth mentioning here that *Data Envelopment Analysis* (DEA) is a special method that does not use the PM directly. While standard MCDM methods are used to select the best alternative, DEA evaluates the efficiency of a group of alternatives but does not indicate a clear winner. DEA has a multi criteria concept to minimize all inputs and maximize all outputs. The connection between DEA and MCDM can be built by defining the *maximizing criteria* as *outputs* and the *minimizing criteria* as *inputs.* The standard version of DEA does not use DM's preferences over inputs and outputs; however, this can be done. There are several weight restrictions related to criteria that lead to various versions of the method (Sarkis, 2000). Yilmaz et al. (2009) adopted this methodological connection in their DEA evaluation model for ranking the efficiency of the irrigation districts in Buyuk Menderes River Basin in Turkey. Another application of DEA as a MCDM tool can be cited in the paper of

Srdjevic et al. (2005) which evaluates reservoir system performance for various operation scenarios.

3.6.2 Simple Additive Weighting (SAW)

The SAW method is a classic version of the multi-attribute value method. With a normalization procedure (Eq. 3.35) for each criteria j, the performance values ($a_{i,j}$) are transformed onto a commensurable scale between 0 and 1, where 1 represents the best performance. The selection of alternatives is made on the basis of u_i which is determined by Eq. (3.36):

$$r_{ij} = \frac{a_{ij}}{\max(a_{ij})} \quad , \qquad i = 1, 2, \ldots.., n \quad , \qquad j = 1, 2, \ldots.., m \tag{3.35}$$

$$u_i = \sum_{j=1}^{m} r_{ij}\, w_j \quad , \qquad i = 1, 2, \ldots.., n \tag{3.36}$$

The higher utility values, (u_i), correspond to better alternatives. In this method, a complete compensation among the criteria is possible. In addition, for the minimizing criteria, such as the “water exploitation rate”, lower values are better, and the reciprocals of $a_{i,j}$, ($1/a_{i,j}$), are to be used in the normalization procedure (Pomerol & Barba-Romero, 2000).

3.6.3 Compromise Programming (CP)

This technique ranks alternatives according to their closeness to the so-called ‘ideal’ point. The best alternative in a set of efficient solutions is the one whose location is at the least distance from the ideal point. The weighted distance measure used in CP is the family of L_i metrics (Eq. 3.37) defined in especial way by Zeleny (1982). A parameter p is used to implicitly express the DM’s intent to balance the criteria (p = 1), to accept decreasing marginal utility (p > 1), or to search for an absolutely dominant solution ($p = \infty$). Accordingly, the measurement of the distance is based on the p parameter, where $p = 1$, $p = 2$ and $p = \infty$ correspond to *Block distance*, *Euclidean distance* and *Tchebycheff distance*, respectively (Pomerol & Barba-Romero, 2000). The most common value is $p = 2$, where larger distances from the ideal solution are penalized more than the smaller distances from the ideal.

$$L_i = \left[\sum_{j=1}^{m} w_j^p \left| \frac{\max a_{i,j} - a_{i,j}}{\max a_{i,j} - \min a_{i,j}} \right|^p \right]^{1/p} \tag{3.37}$$

Whichever parameter value (p) is used, an alternative with the minimum L_i metric is considered as the best. It should be mentioned that (max $a_{i,j}$) refers to the ideal point whereas (min $a_{i,j}$) refers to an anti-ideal point. However, if the decision maker can define the specific points for each criterion as ideal and anti-ideal, the relevant values can be shifted with the recommended ones. Where no such points exist, as in this study, they may be drawn from within the performance matrix (Hajkowicz & Higgins, 2008).

3.6.4 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method developed by Hwang & Yoon (1981) is based on order preference by similarity to the ideal solution. It is a rational and relatively simple method where the underlying concept is that the most preferred alternative should not only have the shortest distance from 'ideal' solution, but also the longest distance from an 'anti-ideal' solution. As an illustration, Figure 3.5 shows five alternatives A, B, C, D and E with a choice of two criteria; it also shows the ideal and anti-ideal points. It is obvious that, if we use the usual Euclidean distance ($p = 2$) with equal weights, point C is the closest to the ideal and D is the furthest. TOPSIS solves this dilemma in the choice between the ideal and the anti-ideal. To apply the TOPSIS method, the performance matrix needs to be normalized by Eq. 3.38:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{n} (a_{ij})^2}} \quad , \qquad i = 1, 2, \ldots, n \quad , \qquad j = 1, 2, \ldots, m \tag{3.38}$$

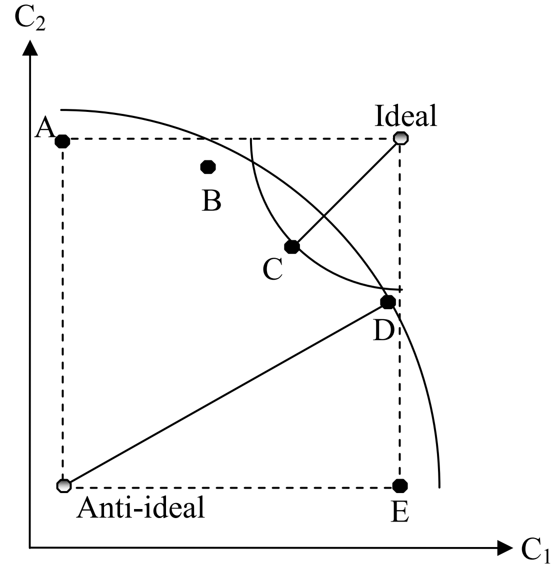


Figure 3.5 Illustration of the notations of distance to the ideal and the anti-ideal

For each alternative a_i, the weighted distances $d^M(a_i)$ and $d^m(a_i)$ corresponding to the ideal and the anti-ideal are computed by Eq. (3.39) and Eq. (3.40), respectively, according to the chosen metric *p:*

$$d^M(a_i) = \left[\sum_{j=1}^{m} w_j^p \left| \max(a_{ij}) - (a_{ij}) \right|^p \right]^{1/p} \tag{3.39}$$

$$d^m(a_i) = \left[\sum_{j=1}^{m} w_j^p \left| \min(a_{ij}) - (a_{ij}) \right|^p \right]^{1/p} \tag{3.40}$$

The *similarity ratio* (Eq. 3.41) can be computed, using the above equations, and this varies from $D(\min(a_i))=0$ for the anti-ideal point to $D(\max(a_i))=1$ for the ideal point. The alternative with the highest ratio is the best option.

$$D(a_i) = \frac{d^m(a_i)}{d^M(a_i) + d^m(a_i)} \tag{3.41}$$

CHAPTER FOUR
APPLICATION OF METHODS TO GEDIZ RIVER BASIN

4. 1 Gediz River Basin

The Gediz River, with a length of 275 km, drains an area of some 18,000 km^2 and flows from east to west into the Aegean Sea just north of Izmir in western Turkey. The river originates up in the Murat Mountain on the east at an elevation of 2224 m. The main tributaries of Gediz River are Deliinis, Selendi, Demirci, Nif, Kumcay and Alasehir creeks (Figure 4.1). The Gediz River Basin (GRB) is surrounded by mountains at an elevation of about 2000 m in the north, south and east directions, and is located geographically at the interval of 38° 01′- 39° 13′ northern latitude and 26° 42′-29° 45′ eastern longitude. The GRB has a typical Mediterranean climate with hot, dry summers and cool winters. The mean annual temperature is 15.6°C. Mean annual precipitation in the basin ranges from almost 800 mm at high elevations to below 500 mm near the Aegean coast with an average of 635 mm. The rainfall is concentrated in winter months. January and February are the wet, and July and August are the driest months. 75% of the total annual precipitation is observed between November and March.

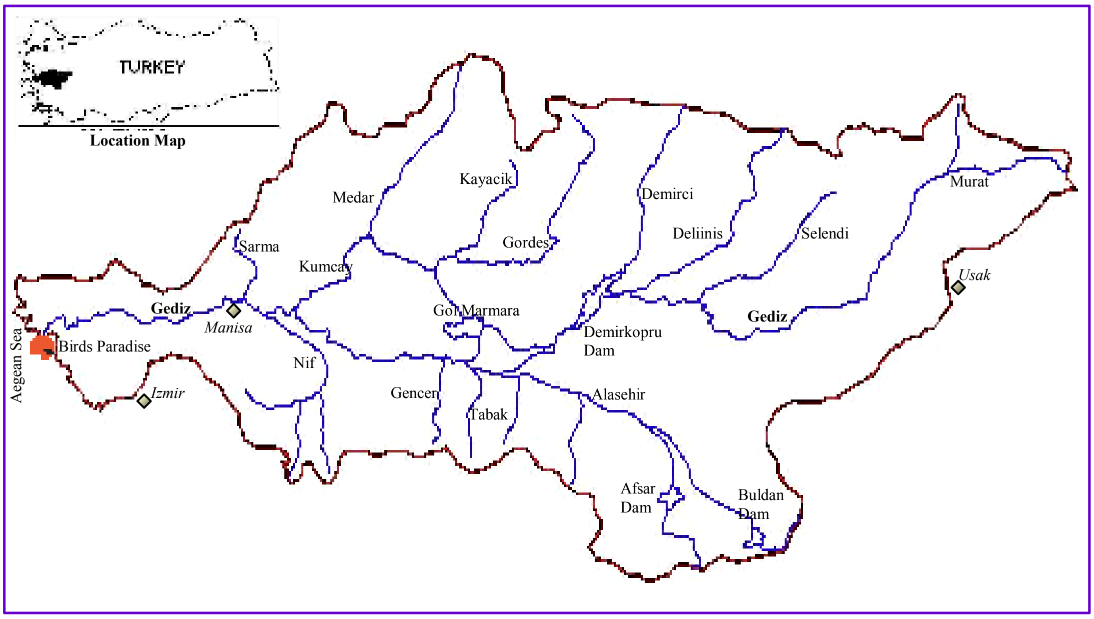


Figure 4.1 The Gediz River Basin with the main river and its tributaries

In the Upper Gediz Basin, small plains exist along the tributaries of the river; then the river valley widens close to the town of Gediz to eventually form the fertile plains. Lower Gediz Basin thus involves the large plains of Adala, Ahmetli, Menemen, Akhisar, Manisa and Alasehir, which are subject to extensive agricultural practices with large irrigation schemes covering an area of about 110,000 hectares. The main crops cultivated are cotton, maize, grape, vegetables and cereals. Due to climatic conditions, irrigation is the most important requirement of agriculture which is the main economic activity in the basin. As in many other ‘agriculture dominant’ basins, a great portion of surface water resources, i.e., 75%, is allocated to irrigation.

The first investments in modern irrigated agriculture began in 1945 with the construction of two large regulators to tap the flow of the Gediz River. The Adala regulator serves some 20,000 ha of land in the middle portion of the basin, whereas Emiralem regulator commands 22,000 ha in the Gediz delta. In the 1960’s, a second set of investments were made, that included the construction of Demirkopru Dam, a few kilometers upstream of Adala, a third regulator at Ahmetli, and the regulation and raising of the natural lake of Gol Marmara. Ahmetli Regulator commands some 50,000 ha of land. The final surface water developments took place in the Alasehir Valley with the construction of Buldan and Afsar dams (Svendsen et al., 2005). The Gordes Dam, which will supply domestic water to Izmir as well as irrigation water to the new agricultural lands and the Yigitler Dam, which aims to supply water to the Kemalpasa industrial area are still under construction (Figure 4.2).

The population of the GRB was about 1.7 million in 2000, with an annual growth rate of 1.5%. However, the internal migration from rural to urban areas (especially to Izmir) and the rapid urbanization in the major cities exert pressure on domestic water demand, which increases at an annual rate of 2% (SMART, 2005). Izmir is the third largest city in Turkey and consumes a significant portion of the groundwater resources of the basin. Actual consumption data are not available, but Izmir has extracted as much as 108 MCM/year from the two well fields, Goksu and Sarikiz. In addition, the projected withdrawal from the Gordes Dam to Izmir is 60 MCM/year. Since the amount of surface water that is allocated to irrigation will decrease in favor of domestic water supply, in fact, this new plan for Izmir disturbs the farmers as well as the irrigation associations (IAs) who are responsible for distributing irrigation water to the farmers under State Hydraulic Works's (DSI) authority.

Figure 4.2 The regulators and the irrigated areas (green) in Gediz River Basin

The growth of the industrial demand is even more drastic with an annual rate of 10%, due to the rapid industrialization in the basin, where the main industries are ceramics, leather, food processing, metal works and textile. The groundwater resources supply water for industrial use; however, no reliable and consistent data are available about the amount of water usage. On the other hand, industrial activities generate pressures on the environment, such as untreated waste water discharges and emission of pollutants.

The seaward fringe of the Gediz delta is an important nature reserve and has been designated as a Ramsar site to protect rare bird spices. The Izmir Birds Paradise (Kus Cenneti) is a Class A wetland, which means it can offer refuge and food to over 25,000 birds. The Birds Paradise, with 8,000 hectares, is part of the Gediz river delta and forms the main feeding and breeding location within the delta, although the birds use the entire delta as a habitat (De Voogt et al., 2000). In fact, the area receives excess water from the Gediz River for much of the year, but since 1990, with restrictions on irrigation releases, it suffers from water shortages. The summer months are the critical times for providing water specifically to the nature reserve due to the intensive irrigation practices. As presented in the working paper of International Water Management Institute (IWMI), the water demand of Birds Paradise is 14.2 MCM and 7.9 MCM in a dry and a wet year, respectively (De Voogt et al., 2000). To preserve the bird habitat, a number of groundwater pumping stations have been constructed to deliver water to Birds Paradise; moreover, a water transmission link extends from the irrigation system into the nature reserve since 1997. This environmental water demand is also incorporated into the analyses with an average annual demand of 12 MCM, and the coverage of this water demand also constitutes an important criterion to identify the 'best' satisfactory management alternative.

The total estimated water extraction by different users in the basin is replicated from Svendsen et al. (2005), and is shown in Table 4.1.

Table 4.1 Estimated water use by sector in Gediz River Basin

Water user	**Estimated Consumption**		**Notes**
	MCM	Share of total	
Surface water			
Large-scale irrigation	550	62%	From Demirkopru and Gol Marmara
Small-scale irrigation	60	7%	Alasehir valley
Hydropower	50	6%	
Birds Paradise	4	-	Current releases only; needs more
Groundwater			
Pump irrigation groups	30	3%	Only those outside surface irrigation area
Private irrigators	5	1%	18% of extraction, remainder is return flow
Urban within the basin	26	2%	Trans-basin transfer, no return flow
Transfer to Izmir city	108	12%	Estimated by DSI
Industry	50	6%	

MCM, million cubic meters

It is obvious that irrigation uses a large share of the surface water resources of the basin, and withdrawals total about 660 MCM, with 83% of that going to large-scale irrigation systems comprising the Adala, Ahmetli and Menemen irrigation districts.

Due to the antiquity of water conveyance systems (open channel) which lead to high water losses, non-adapted type of crops, lack of maintenance of irrigation systems and farmer's lack of knowledge about appropriate irrigation practices, it is certain that the current use of water for irrigation purposes is inefficient. The canal loses are approximately 32%, and the irrigation efficiency is 60%. Therefore, the modernization of irrigation techniques should be encouraged, and more productive use of water should be a fundamental objective, not only for agriculture but also for other water demanding sectors.

4. 2 Modeling Gediz River Basin in WEAP

The *Schematic View* is the starting point for all activities in WEAP. For a detailed analysis, supply (i.e., rivers, reservoirs, groundwater withdrawal points) and demand site nodes (i.e., cities, irrigation districts, industry areas), as well as the transmission/return flow links, in other words, all the physical features of the water supply and demand system should be presented in a schematic. It is also possible to locate stream gauging stations on this schematic for the calibration process. The Gediz River network with primary tributaries, meteorological stations, stream gauging stations and reservoirs can be seen in Figure 4.3.

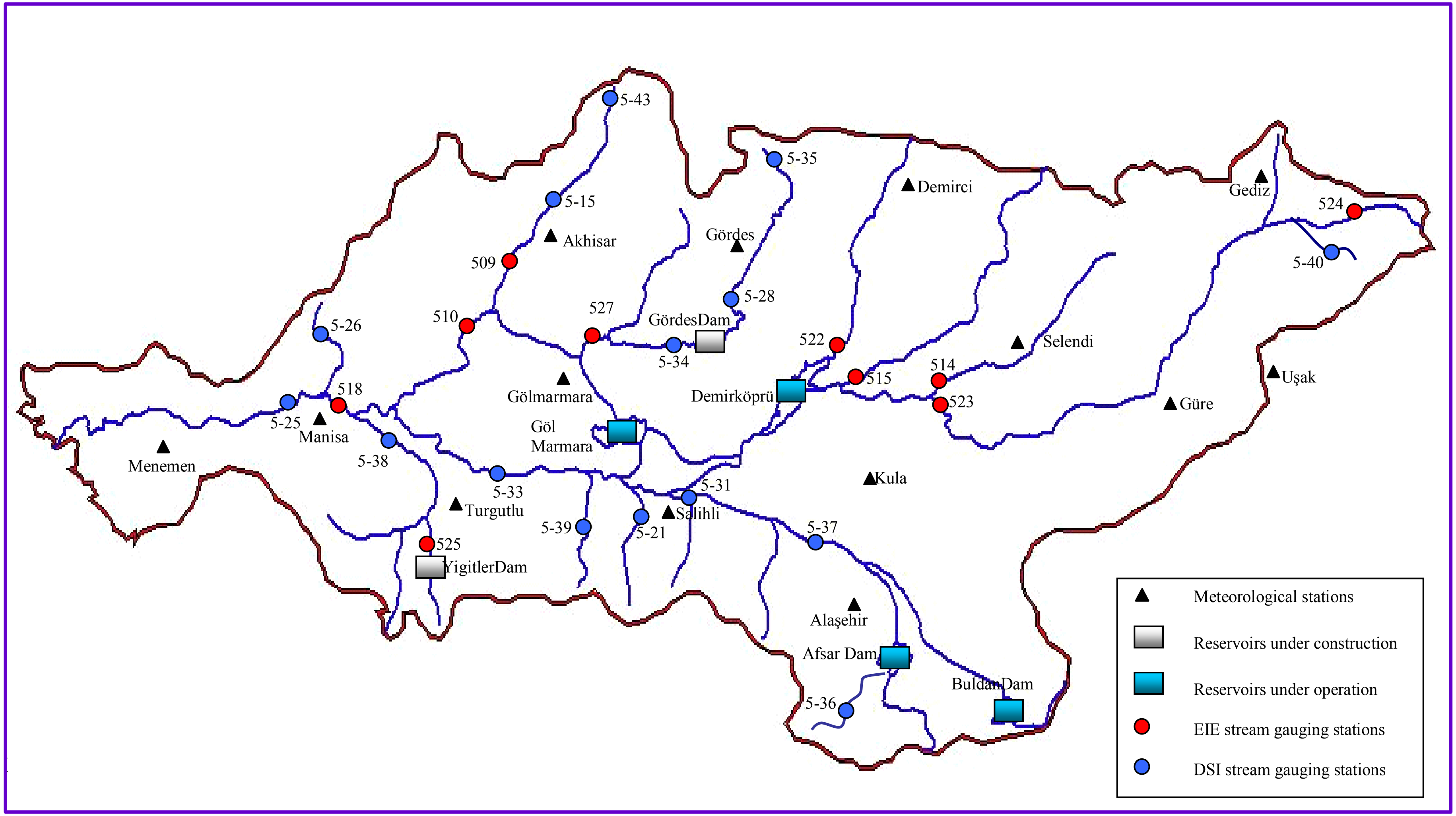


Figure 4.3 The Gediz River network, reservoirs, and stream gauging and meteorological stations in the basin

4.2.1 The River Network

In Turkey, streamflow gauging networks are operated by two state organizations, Electrical Works Authority (EIE) and the State Hydraulic Works (DSI). Each organization has its own independent network of streamflow gauging stations (SGS) in the Gediz River Basin. The first monitoring application in the basin was initiated in 1938 by EIE in order to obtain data for the planning and construction of the Demirkopru Dam. At present, 10 SGS of EIE are under operation. DSI started its streamflow monitoring network in 1968 at Muradiye, 9 km away from the city of Manisa. Since 1968, DSI has operated a large number of SGSs in Gediz River Basin, most of which are closed at present. Table 4.2 provides a list of all SGSs (12) in the basin, where the data records used in this study are highlighted. The monthly runoff data of the stations obtained from the streamflow discharge annals (7 under EIE's operation and 5 under DSI's operation) are used to represent the river headflows in the analysis, excluding 518 which is used for the calibration process.

In the study, Gediz River and its four main tributaries (Medar, Gordes, Nif and Alasehir) are taken into account. The Gencer, Tabak and Sarma creeks are also added to the main river as lateral flows. Although the Demirkopru Dam collects the four reaches (Selendi, Deliinis, Demirci and Murat) from upstream catchments, they are all considered as a single inflow to the reservoir for purposes of simplification. So the inflow to the Demirkopru Dam is the summation of the monthly flows observed at SGS of 522, 515, 514 and 523.

Another simplification is made for the Gordes inflows. Since Gordes inflows are diverted to feed the Gol Marmara lake via Comlekci weir and the operation rule of that weir is irregular, Gol Marmara (which is operated for the additional supply for the irrigation districts in the summer season) is considered as a natural reservoir on the Gordes River, where the station 527 represents the headflows.

Table 4.2 The SGSs in the Gediz River Basin

Station No	River Name	Station Name	Elevation (m)	Drainage Area (km^2)	Opening Year	Max Flow and Date (m^3/s)	Coordinates N	Coordinates E	Annual Average Flow (m^3/s)
5-25	Gediz	Muradiye Koprusu	17	15848.00	1968	600 (17.12.1981)	38 40 57	27 20 03	37.21
5-37	Alasehir	Baklaci	141	1691.00	1984	18 (10.01.1985)	38 23 25	28 32 25	1.16
5-39	**Gencer**	**Dereköy**	**125**	**95.00**	**1987**	**30.2 (29.12.1989)**	**38 29 36**	**27 56 33**	**0.60**
5-21	**Tabak**	**Caltili**	**137**	**81.10**	**1969**	**78 (15.12.1981)**	**38 27 55**	**28 03 01**	**1.07**
5-31	**Alasehir**	**Taytan Koprusu**	**91**	**2513.00**	**1981**	**270 (11.02.1984)**	**38 30 38**	**28 11 31**	**3.30**
5-40	Cancurt	Kucukler	1230	41.40	1987	4.47 (08.04.1992)	38 52 00	29 36 00	0.21
5-43	Cemal	Kayganlı	290	64.00	1990	20.4 (31.03.1995)	39 07 30	28 00 19	0.42
5-36	Derbent	Uluderbent	420	420.00	1984	40 (08.01.1986)	38 10 58	28 32 25	1.19
5-33	Gediz	Urganli	58	9587.00	1982	380 (11.02.1984)	38 33 41	27 50 23	13.73
5-28	Gordes	Hacihidir	305	808.20	1977	380 (15.12.1981)	38 40 26	28 11 51	3.46
5-34	Gordes	Maden Cesmesi	129	1444.00	1983	520 (11.02.1984)	38 45 44	27 57 57	4.00
5-35	Inderesi	Gunesli	598	88.00	1983	31 (09.02.1984)	39 03 17	28 22 00	0.58
5-15	Medar	Medar Koprusu	106	512.30	1970	360 (15.12.1981)	38 57 10	27 49 40	1.83
5-38	**Nif**	**Hacihaliller**	**31**	**854.00**	**1986**	**44 (01.10.1986)**	**38 34 46**	**27 34 31**	**3.63**
5-26	**Sarma**	**Sarma**	**117**	**52.30**	**1969**	**91 (29.22.1971)**	**38 46 10**	**27 23 58**	**0.31**
509	Medar	Kayalioglu	77	901.60	1951	433 (15.12.1981)	38 53 25	27 46 09	2.93
510	**Kumcay**	**Killik**	**54**	**3188.60**	**1951**	**1494 (08.02.1952)**	**38 46 11**	**27 40 02**	**4.06**
514	**Selendi**	**Derekoy**	**345**	**689.60**	**1960**	**860 (15.12.1981)**	**38 41 58**	**28 41 55**	**2.26**
515	**Deliinis**	**Topuzdamlari**	**376**	**739.60**	**1960**	**1025 (15.12.1981)**	**38 43 24**	**28 33 18**	**3.13**
522	**Demirci**	**Borlu**	**245**	**818.80**	**1970**	**890 (15.12.1981)**	**38 45 11**	**28 28 48**	**3.11**
523	**Gediz**	**Acisu**	**348**	**3272.40**	**1969**	**1290 (11.2.1984)**	**38 38 26**	**28 43 13**	**9.75**
518	**Gediz**	**Manisa Koprusu**	**23**	**15616.40**	**1962**	**812 (31.01.1963)**	**38 38 41**	**27 26 30**	**30.49**
524	Murat	Sazkoy	790	176.00	1972	100 (15.12.1981)	38 57 29	29 30 44	1.53
525	Yigitler	Yigitler	158	64.00	1974	153 (15.12.1981)	38 24 44	27 36 47	0.69
527	**Gordes**	**Daribuku**	**128**	**1430.50**	**1978**	**1555 (15.12.1981)**	**38 46 40**	**27 57 58**	**4.56**

The main irrigation districts namely Sarigol and Alasehir, which are in the southeastern part of the basin, use groundwater as well as supplies from Afsar and Buldan dams for irrigation. On the other hand, there are no sufficient and reliable stream flow data for the rivers that feed the Afsar and Buldan dams, which essentially are relatively small dams with respect to Demirkopru and Gol Marmara. Since the present study focuses on surface water balance in the basin, the Sarigol and Alasehir irrigation districts are not taken into account; however, to account for Adala Irrigation return flows and the other lateral flows of the Alasehir tributary, this tributary is added to the schematic. The observed monthly flows of Taytan streamflow gauging station (5-31), which is at the end of the Alasehir tributary, is taken as the headflow of that tributary.

The Medar tributary headflows are taken into account through the observed monthly discharges at station 510. Thus, the residual water downstream of Comlekci diversion and the inflows of the Medar tributary are used in the analysis.

The monthly flows observed at Hacihaliller stream flow gauging station (5-38) are used to represent Nif headflows; while 5-39 Derekoy, 5-21 Caltili and 5-26 Sarma flows are used to describe Gencer, Tabak and Sarma headflows, respectively.

4.2.2 Demand Sites

In the analyses, the Adala, Ahmetli and Menemen irrigation districts (IDs) are taken into account as demand sites. Each of these districts is disaggregated into two sub-irrigation districts, since the namesake regulators divert water to right bank (RB) and left bank (LB) irrigation schemes. This segregation is a must to compute the water demand reasonably, due to the different crop patterns as well as the variation in growing seasons of crops in the two schemes. The irrigated areas in each ID for the period between 1995 and 2003, and the ID command area (in brackets) are given in Table 4.3. The data are obtained from the DSI II.Regional Directorate in Izmir.

Table 4.3 Irrigated areas of irrigation districts

ID	Menemen RB (6365 ha)	Menemen LB (16500 ha)	Ahmetli RB (27213 ha)	Ahmetli LB (23028 ha)	Adala RB (9101 ha)	Adala LB (13696)
1995	4950	13200	15335	10900	5869	8384
1996	5717	13350	16484	10864	6291	8397
1997	5481	13322	13662	10069	6121	7273
1998	5870	14141	15659	10175	6335	7648
1999	5725	13438	15719	10271	5448	7890
2000	5413	12997	15243	10312	6000	9110
2001	5414	13359	16501	11061	5867	8109
2002	5800	13607	17638	10972	6301	9183
2003	5551	13989	17170	11060	6590	9383
I.R.	87	82	59	46	67	61

ha, hectares

I.R., average irrigation ratio as percentage of the command area

As observed in Table 4.3, quite a large portion of IDs are irrigated with the surface water supplied by Demirkopru and Gol Marmara. No significant increase or decrease in the size of irrigated lands has occurred in recent years. The reasons for this stability should be investigated further under different perspectives, such as the presence of fallow land, urbanization effects and the year to year variation of water supply (i.e. groundwater) in the relevant areas; however, this is beyond the scope of this study. In accordance with Table 4.3., the irrigated areas are taken as constant with mean areas; in other words, any increment or decrement in the irrigated areas is considered only in the simulated years.

The crop pattern is also an important factor to determine the irrigation water demand. Although the main crops in the GRB are cotton, maize, grape and vegetables, their cultivation area differs within the IDs. In addition, the increasing cultivation of maize and the decreasing cultivation of cotton is a noticeable response against water scarcity in the basin, especially after the major drought between 1989 and 1994 (SMART, 2005). Therefore, the crop patterns of each ID in recent years (Table 4.4) are obtained from DSI II.Regional Directorate, not only to compute the water demand, but also to build the demand management alternative. It should also be mentioned that, although a large number of crop types is cultivated in GRB, the present study focuses on four main crops, and the other crops are aggregated into the main crops in accordance with the cultivation percentages of main crops.

Table 4.4 Percent share of main crops at the demand sites

ID	Crops	Years								
		1995	1996	1997	1998	1999	2000	2001	2002	2003
Menemen RB	Cotton	74	73	71	74	69	58	63	64	60
	Grape	14	13	13	11	13	15	13	12	13
	Maize	3	5	5	4	8	11	9	11	15
	Vegetables	9	9	11	11	10	16	15	13	12
Menemen LB	Cotton	76	74	73	75	71	64	71	72	69
	Grape	12	11	10	9	10	11	9	8	10
	Maize	6	7	11	11	13	17	13	13	14
	Vegetables	6	8	6	5	6	8	7	7	8
Ahmetli RB	Cotton	71	70	70	66	65	61	61	54	48
	Grape	25	28	28	31	32	36	35	35	38
	Maize	0	0	0	0	0	2	3	5	12
	Vegetables	4	2	2	3	3	1	1	6	2
Ahmetli LB	Cotton	51	51	50	46	47	31	35	37	42
	Grape	39	39	41	43	37	47	46	45	45
	Maize	1	1	2	1	0	6	7	8	10
	Vegetables	9	9	7	10	16	16	12	10	3
Adala RB	Cotton	59	55	53	53	49	38	52	50	46
	Grape	26	27	27	24	26	29	30	32	32
	Maize	8	8	16	14	19	26	12	14	19
	Vegetables	7	10	4	9	6	7	6	4	3
Adala LB	Cotton	29	28	21	24	20	13	19	19	15
	Grape	65	61	66	63	66	62	68	65	68
	Maize	1	4	6	5	7	11	8	10	13
	Vegetables	5	7	7	8	7	14	5	6	4

Since the water demand computation in WEAP uses the FAO crop coefficient approach, the crop coefficient (K_c) is another data requirement for the analysis. K_c is crop specific and varies by the length of the crop development stages and climatic conditions. The development of K_c is exemplarily depicted in Figure 4.4.

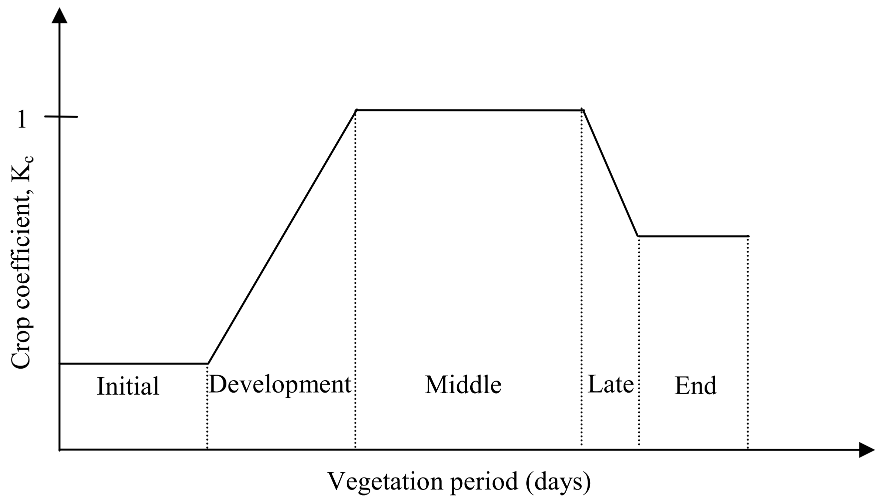


Figure 4.4 Variation of the crop coefficient over the vegetation periods

The CROPWAT computer program developed by FAO is an essential tool to develop K_c values, not only with its predefined crop types, but also with the country data bases including regional climatic conditions. Although the K_c values are determined within this program, the smaller K_c values that are used by DSI to compute the irrigation demand are incorporated to the analysis (Table 4.5). This is considered as a reasonable approach to simulate the reality, and also to calibrate the model, because the primarily water allocation to the regulators from Demirkopru Dam and Gol Marmara are managed by DSI. In Table 4.4, where the IDs cover both the RB and the LB of namesake irrigation districts, the K_c values are given for the main crops that have different growing seasons due to the climatic conditions of the regions.

Table 4.5 K_c values of main crops in Gediz irrigation districts

ID	Crop & Growing Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Menemen	Cotton May,1 - Oct,31	-	-	-	-	0.42	0.50	0.87	0.88	0.71	0.38	-	-
	Grape Apr,1 - Aug,21	-	-	-	0.24	0.56	0.82	0.62	0.20	-	-	-	-
	Maize May,1 - Aug,31	-	-	-	-	0.50	0.81	0.92	0.93	-	-	-	-
	Vegetables May,1 - Sep,23	-	-	-	-	0.42	0.67	0.80	0.78	0.56	-	-	-
Ahmetli	Cotton May,1 - Oct,31	-	-	-	-	0.42	0.50	0.87	0.88	0.71	0.38	-	-
	Grape Apr,1 - Aug,21	-	-	-	0.24	0.56	0.82	0.62	0.20	-	-	-	-
	Maize Apr,10 - Sep,9	-	-	-	0.49	0.60	0.85	0.92	0.85	-	-	-	-
	Vegetables May,1 - Sep,23	-	-	-	-	0.42	0.67	0.80	0.78	0.56	-	-	-
Adala	Cotton Apr,15 - Sep,30	-	-	-	0.41	0.43	0.67	0.87	0.76	0.40	-	-	-
	Grape Apr,1 - Aug,21	-	-	-	0.24	0.56	0.82	0.62	0.2	-	-	-	-
	Maize May,1 - Sep,15	-	-	-	-	0.49	0.74	0.92	0.94	-	-	-	-
	Vegetables May,1 - Sep,23	-	-	-	-	0.42	0.67	0.80	0.78	0.56	-	-	-

The climatic conditions for the Menemen, Ahmetli and Adala IDs are demonstrated by the long term monthly average temperature and precipitation data of the Menemen, Manisa and Salihli meteorological stations (Figure 4.3), respectively. The potential evapotranspiration (ET_o) in each hydrological unit is computed by CROPWAT, which also enables the computation of effective precipitation (P_e) to identify the irrigation water demand. The relevant data for the computation and the outputs such as ET_o and P_e for Menemen, Ahmetli and Adala regions are given in Tables 4.6, 4.7 and 4.8, respectively.

Table 4.6 The meteorological data used for Menemen IDs

Meteorological station: Menemen Altitude: 10 m Latitude: 38.37 N Longitude: 27.05 E											
Month	**Mean temperature (°C)**	**Maximum temperature (°C)**	**Minimum temperature (°C)**	**Air humidity (%)**	**Wind speed (@ 2 m) (km/day)**	**Daily sunshine (hrs)**	**Solar radiation ($Mj/m^2/d$)**	**Mean precipitation (mm)**	**Effective precipitation (mm)**	**ET_o (mm/day)**	**ET_o (mm/month)**
Jan	7.8	12.0	4.5	57.7	241.9	4.4	7.6	90.3	77.3	1.84	57.04
Feb	8.7	13.5	4.8	55.7	233.3	5.2	10.6	70.8	62.8	2.28	63.84
Mar	10.9	16.7	6.2	56.4	224.6	6.1	14.4	62.6	56.3	2.99	92.69
Apr	15.0	21.5	9.2	54.8	155.5	7.4	18.9	42.5	39.6	3.79	113.70
May	20.0	26.9	12.8	50.3	146.9	9.3	23.2	25.6	24.6	5.09	157.79
Jun	24.5	31.5	16.4	43.2	164.2	10.7	25.7	5.5	5.5	6.40	192.00
Jul	26.9	33.7	19.4	40.2	172.8	11.3	26.2	2.7	2.7	6.92	214.52
Aug	26.2	33.3	19.2	42.6	164.2	11.3	24.5	3.1	3.1	6.28	194.68
Sep	22.2	29.8	15.4	47.9	146.9	9.5	19.4	11.8	11.6	4.60	138.00
Oct	17.6	24.5	12.1	51.1	146.9	7.3	13.3	30.7	29.2	3.08	95.48
Nov	13.0	18.6	8.9	56.2	172.8	5.3	8.9	79.2	69.2	2.10	63.00
Dec	9.6	13.6	6.4	60.1	216.0	3.7	6.5	108.7	89.8	1.70	52.70

Table 4.7 The meteorological data used for Ahmetli IDs

Meteorological station: Manisa			**Altitude: 71 m**		**Latitude: 38.37 N**	**Longitude: 27.26 E**					
Month	**Mean temperature (°C)**	**Maximum temperature (°C)**	**Minimum temperature (°C)**	**Air humidity (%)**	**Wind speed (@ 2 m) (km/day)**	**Daily sunshine (hrs)**	**Solar radiation ($Mj/m^2/d$)**	**Mean precipitation (mm)**	**Effective precipitation (mm)**	**ET_o (mm/day)**	**ET_o (mm/month)**
Jan	6.7	10.8	3.1	71.9	168.2	3.6	7.0	122.2	98.3	1.17	36.27
Feb	7.9	12.1	3.3	67.8	195.4	4.7	10.0	106.6	88.4	1.71	47.88
Mar	10.4	15.7	5.1	67.8	173.5	5.9	14.2	78.7	68.8	2.39	74.09
Apr	15.1	21.5	9.2	61.2	155.5	7.3	18.7	56.3	51.2	3.64	109.20
May	20.3	27.1	13.6	55.5	157.5	9.1	22.8	37.6	35.3	5.06	156.86
Jun	25.2	32.5	18.1	47.5	162.8	10.6	25.5	13.9	13.6	6.43	192.90
Jul	27.9	34.9	21.2	45.0	164.0	11.1	25.9	6.5	6.3	6.86	212.66
Aug	27.4	35.0	21.0	46.4	163.0	11.1	24.2	4.4	4.4	6.40	198.40
Sep	23.2	31.2	16.7	50.6	160.8	9.7	19.6	16.5	16.1	4.87	146.10
Oct	17.7	24.2	12.1	60.7	150.2	7.2	13.2	47.0	43.5	2.87	88.97
Nov	12.1	16.4	7.0	68.8	140.9	4.8	8.5	91.9	78.4	1.50	45.00
Dec	8.2	11.5	4.2	75.5	146.9	3.2	6.1	142.0	109.7	0.98	30.38

Table 4.8 The meteorological data used for Adala IDs

Meteorological station: Salihli	**Altitude: 111 m**		**Latitude: 38.32 N**	**Longitude: 28.09 E**							
Month	**Mean temperature (°C)**	**Maximum temperature (°C)**	**Minimum temperature (°C)**	**Air humidity (%)**	**Wind speed (@ 2 m) (km/day)**	**Daily sunshine (hrs)**	**Solar radiation ($Mj/m^2/d$)**	**Mean precipitation (mm)**	**Effective precipitation (mm)**	**ET_o (mm/day)**	**ET_o (mm/month)**
Jan	7.0	11.2	1.9	74.1	95.7	3.6	7.0	74.1	65.3	0.93	28.83
Feb	8.5	12.4	2.3	70.9	108.3	4.7	10.1	68.6	61.1	1.39	38.92
Mar	10.5	15.9	4.3	70.9	113.6	5.9	14.2	61.4	55.4	2.14	66.34
Apr	15.5	21.8	8.5	61.8	122.3	7.3	18.7	42.3	39.4	3.48	104.40
May	20.6	28.3	12.6	57.5	131.6	8.8	22.4	34.2	32.3	4.91	152.21
Jun	24.8	32.5	16.3	51.8	142.9	10.6	25.6	17.0	16.5	6.11	183.30
Jul	26.8	35.0	18.6	54.6	159.5	11.1	25.9	11.6	11.4	6.58	203.98
Aug	26.2	35.0	18.4	57.0	147.5	11.1	24.3	7.6	7.5	5.99	185.69
Sep	22.4	31.1	14.3	58.5	114.3	9.7	19.6	16.8	16.3	4.24	127.20
Oct	16.3	24.2	9.9	65.1	91.1	7.2	13.3	34.7	32.8	2.36	73.16
Nov	12.4	16.4	5.7	70.5	83.1	4.8	8.5	58.0	52.6	1.20	36.00
Dec	9.2	12.1	3.3	76.1	85.1	3.2	6.1	81.8	71.1	0.80	24.80

Birds Paradise is another demand site where the water requirement is calculated with the evapotranspiration (ET_o) and precipitation (P) data of the Menemen region. As mentioned by Voogt et al. (2000), the ideal water depth is 15 cm in the bird sanctuary where the area of the freshwater beds is about 1,100 hectares. The monthly water requirement for maintaining a constant water level, $Q_{(ETo-P)}$, is computed in Table 4.9. The calculations show that the additional water requirements occur from March to October, and the annual water requirement (12 MCM) is quite less than the annual average irrigation demand in the basin (660 MCM).

Table 4.9 Estimated minimum water requirement for Birds Paradise

Month	**ET_o (mm/month)**	**P (mm/month)**	**ET_o-P (mm/month)**	**Q $_{(ETo-P)}$ ($10^6 m^3$/month)**	**Monthly variation**
January	57.0	90.3	-33.3	0.00	
February	63.8	70.8	-7.00	0.00	
March	92.7	62.6	30.1	0.33	0.03
April	113.7	42.5	71.2	0.78	0.07
May	157.8	25.6	132.2	1.45	0.13
June	192.0	5.5	186.5	2.05	0.18
July	214.5	2.7	211.8	2.33	0.21
August	194.7	3.1	191.6	2.11	0.19
September	138.0	11.8	126.2	1.39	0.12
October	95.5	30.7	64.8	0.71	0.06
November	63.0	79.2	-16.2	0.00	
December	52.7	108.7	-56.0	0.00	
TOTAL	1435.4	533.5		11.16	1.00

4.2.3 Hydraulic Structures

Demirkopru Dam and Gol Marmara are the two reservoirs that supply water for the downstream irrigation demands. Demirkopru Dam can supply water for all the six irrigation districts while Gol Marmara is operated for the Ahmetli and Menemen irrigation systems to fulfill the gaps in supply. In WEAP, the physical data requirements of the reservoirs are the storage capacity, volume-elevation curve, leakage and evaporation losses as well as the data relevant with the operation rule, such as the initial storage, the dead storage and the buffer coefficient. The volume-elevation curves of the reservoirs are given in Table 4.10.

Table 4.10 The volume-elevation curves of the reservoirs

Demirkopru Dam		Gol Marmara	
Elevation (m)	**Volume (10^6 m^3)**	**Elevation (m)**	**Volume (10^6 m^3)**
198.00	0.27	72.00	0.03
202.00	11.11	72.50	2.81
206.00	32.83	73.00	10.92
208.00	48.72	73.50	23.83
210.00	68.51	74.00	41.00
212.00	92.10	74.50	61.47
214.00	119.35	75.00	84.28
216.00	150.20	75.50	108.60
218.00	184.11	76.00	133.60
220.00	220.99	76.50	159.54
222.00	261.17	77.00	186.68
224.00	304.98	77.50	215.00
226.00	352.79	78.00	244.46
228.00	406.83	78.50	275.33
230.00	467.46	79.00	307.88
232.00	533.24	79.50	342.03
234.00	602.74	80.00	377.71
236.00	676.08		
238.00	754.09		
240.00	836.93		
242.00	923.61		
244.00	1013.18		

With these curves, WEAP converts the monthly evaporation losses (mm) to volumetric units (m^3) and subtracts them from the storage. Since the evaporation data, which are taken from the annual operation reports of DSI II.Regional Directorate, are already reported in volumetric units, the water volume lost to evaporation is used as in Table 4.11, where the maximum and dead storage volume of the reservoirs are given. Although the net evaporation changes with precipitation and temperature, it is assumed constant overtime in the analyses. The leakage losses are assumed equal to zero in the computations.

Table 4.11 Net evaporation volumes of the reservoirs (10^6 m^3)

Month	**Demirkopru Dam**	**Gol Marmara**
January	0.85	0.55
February	0.83	0.69
March	1.75	2.66
April	3.13	4.47
May	5.58	7.24
June	6.58	9.96
July	6.94	11.59
August	6.06	9.31
September	3.63	6.2
October	1.81	3.84
November	0.83	1.51
December	0.49	1.13
TOTAL	38.48	59.15
STORAGE CAPACITY	1022	320
DEAD STORAGE	209	30

In WEAP, the monthly operation rule of the reservoir is introduced with the initial storage and the buffer coefficient which is the fraction of water in the reservoir available each month for release. In accordance with the monthly operation reports of the reservoirs, the buffer coefficients are determined through the calibration process.

Irrigation water is supplied from the Emiralem, Ahmetli and Adala regulators to Menemen, Ahmetli and Adala irrigation districts by the namesake irrigation canals that are subject to physical constraints such as maximum flow capacity (Table 4.12) as well as to the contractual constraints that are specified by the Irrigation Associations (IAs), who are responsible for arranging water releases in the irrigation districts. Since the water distribution scheme in tertiary canals is out of the scope of the present study, the conveyance losses only in the main and secondary canals, that occur due to the presence of old open channels and canalets, are accounted for in the analyses. These losses are quite important for water budget assessments and are reasonably not the same in all links. However, due to lack of reliable data, a general loss rate is used to describe the losses (including the evaporation and leakage losses) as a percentage of flow passing through the link. The descriptive transmission loss rate is determined within the calibration process, which assumes the same rate for all links.

Table 4.12 Basic features of regulators and irrigation canals in Gediz River Basin (DSI, 1996)

Regulator	**Initial Operation**	**Irrigation Canal**	**Max. Capacity (m^3/s)**	**Canal Length (km)**	
				Main	**Secondary**
Emiralem	1944	Menemen RB	8	39	57
		Menemen LB	20	11	304
Ahmetli	1966	Ahmetli RB	26	100	125
		Ahmetli LB	24	95	170
Adala	1944	Adala RB	30	20	70
		Adala LB	21	68	132

4.2.4 Model Calibration

The calibration of the WEAP model is based on the schematic (Figure 4.5), where the Gediz River Basin is demonstrated within a node-link network. The priority of each demand site (in brackets in Figure 4.5) is equally set to 1 to reflect the highest priority. The streamflow gauging station 518, which is in the downstream part of the basin, is used for calibration purposes as well as to delineate the storage volumes in Demirkopru and Gol Marmara reservoirs. Since the water volume in the reservoirs and the irrigation demand change from year to year, the calibration is executed individually with the relevant data for the years from 1995 to 2003, the latter being the last year of published data. In this time interval, 1999, 1996 and 2001 refer to the wet, normal and dry years, and the calibration graphs are given in Figures 4.6., 4.7 and 4.8, respectively.

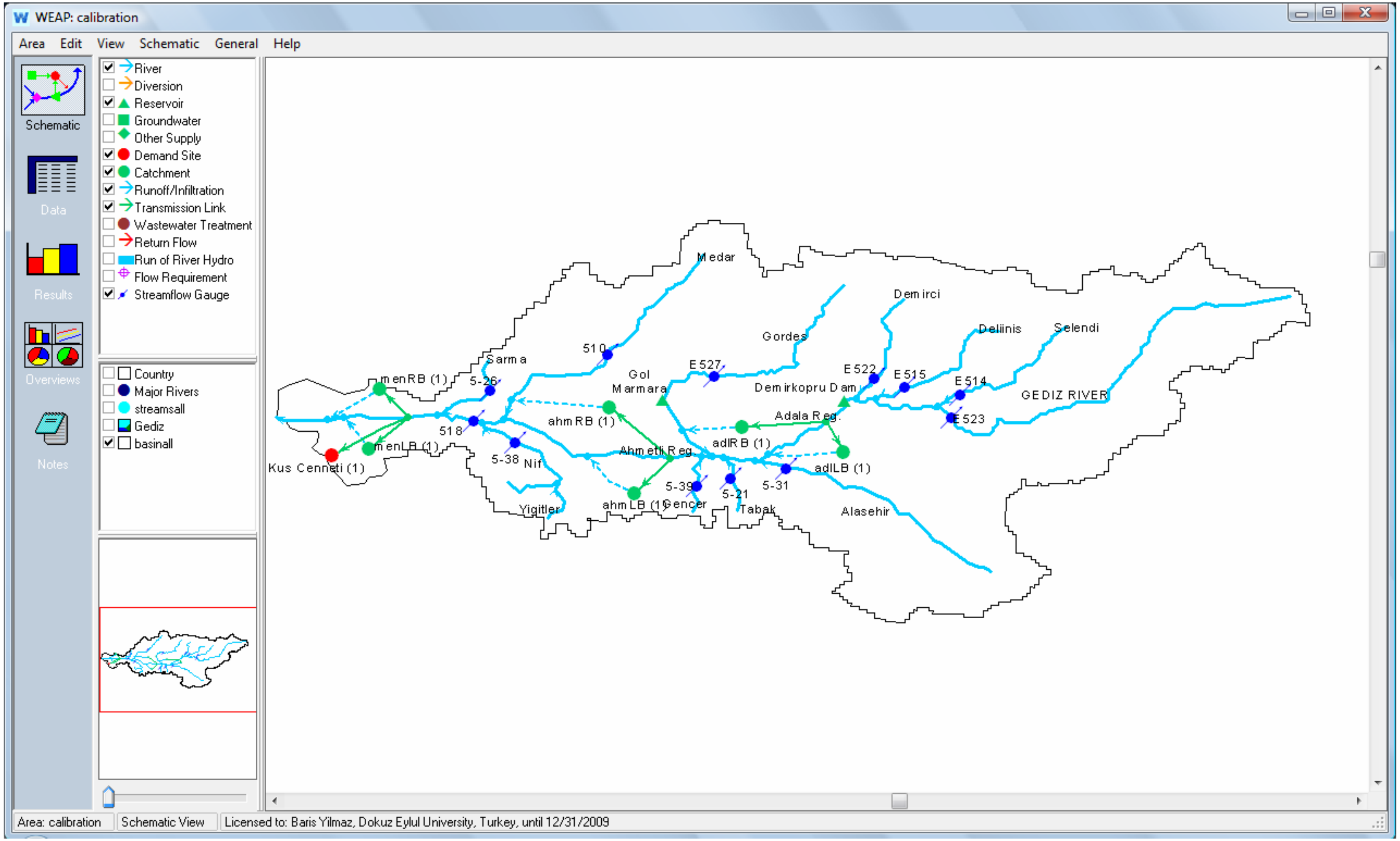
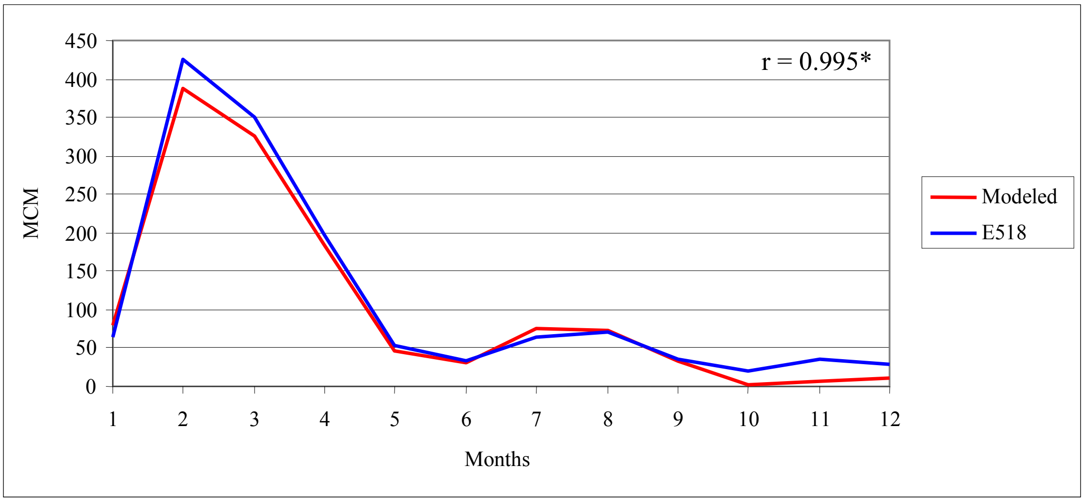
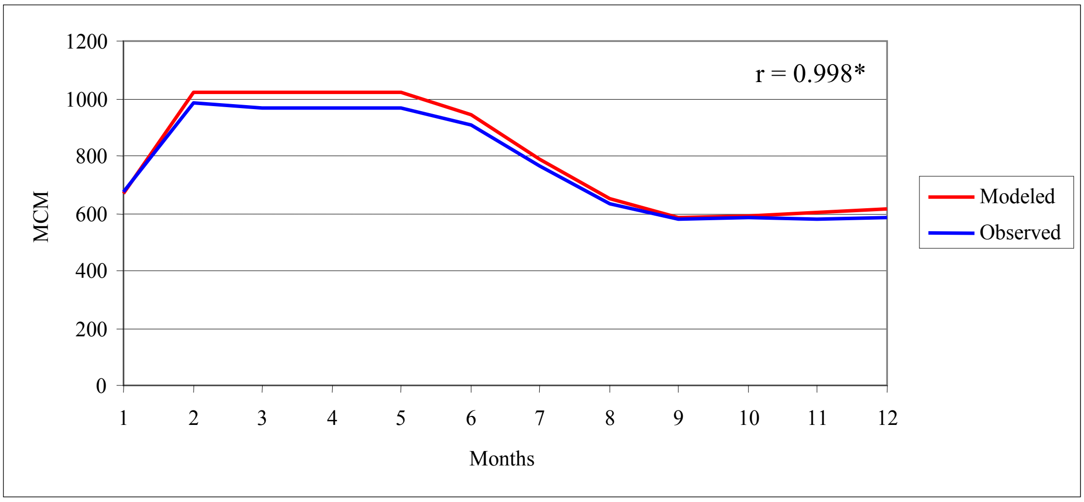


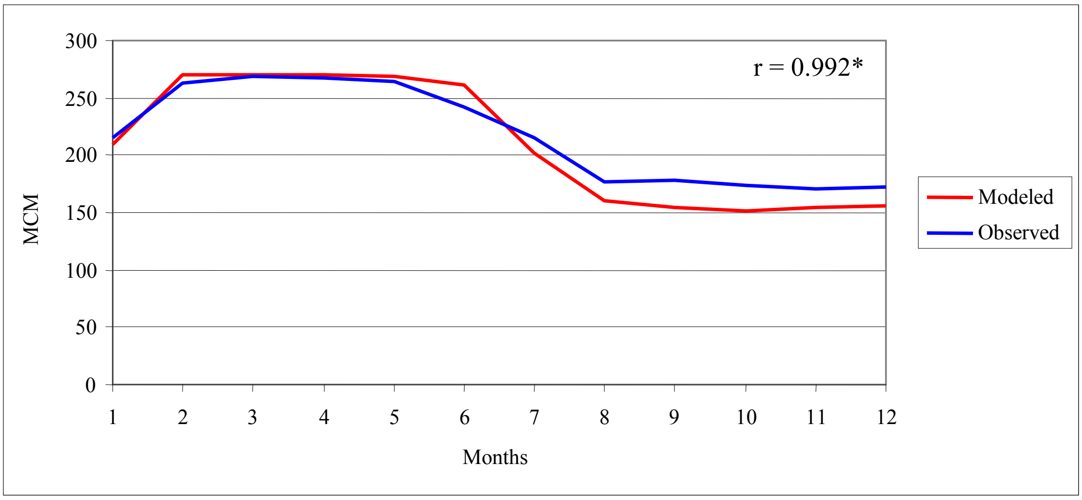
Figure 4.5 The simplified view of Gediz River Basin used as the schematic in WEAP



(a) Observed and modeled runoff series of station 518

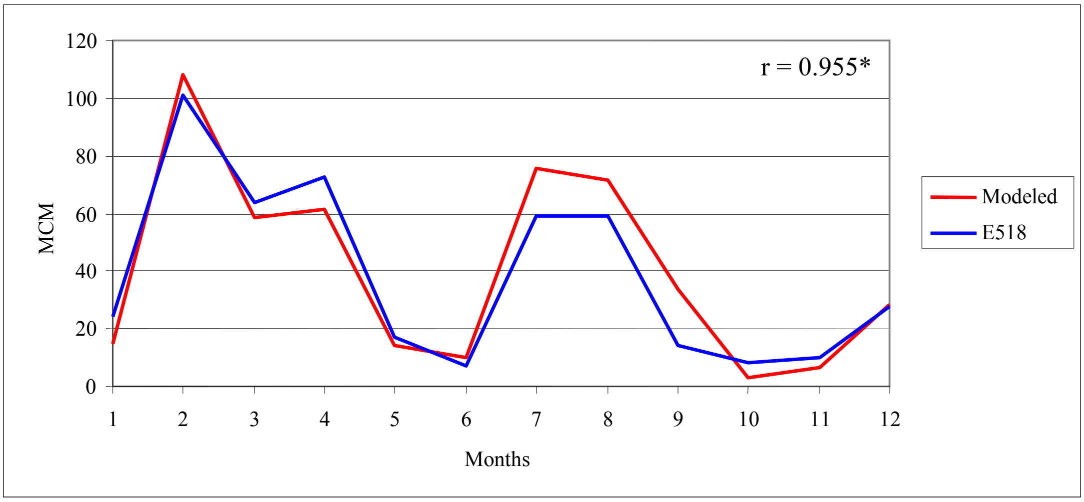


(b) Observed and modeled storage volumes in Demirkopru Dam

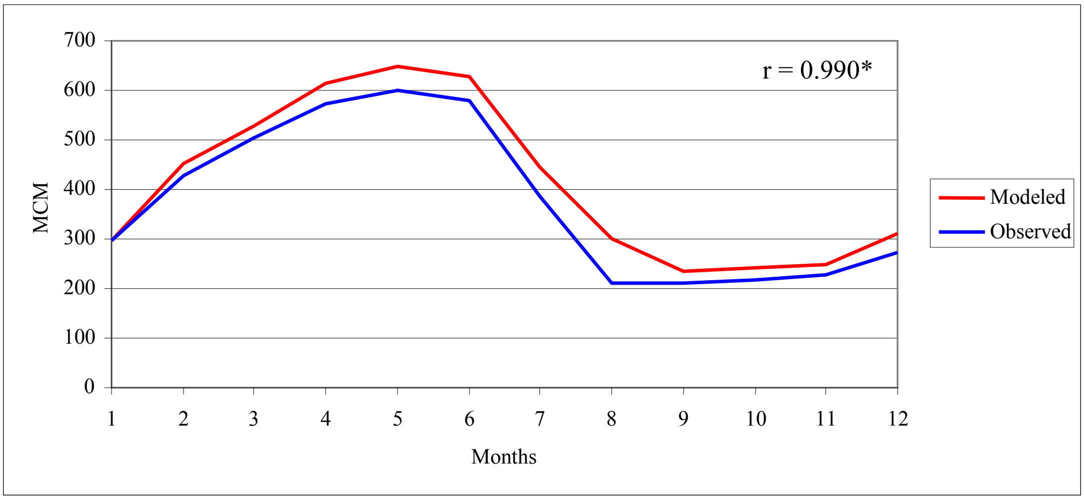


(c) Observed and modeled storage volumes in Gol Marmara

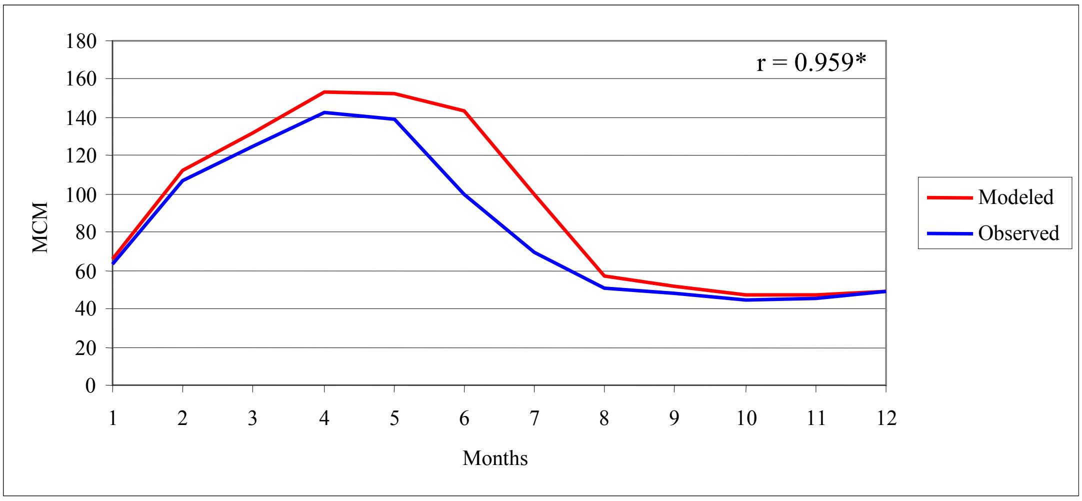
Figure 4.6 The calibration graphs for 1999 (wet year; MCM: million cubic meter; *: correlation is significant at 0.01 level)



(a) Observed and modeled runoff series of station 518

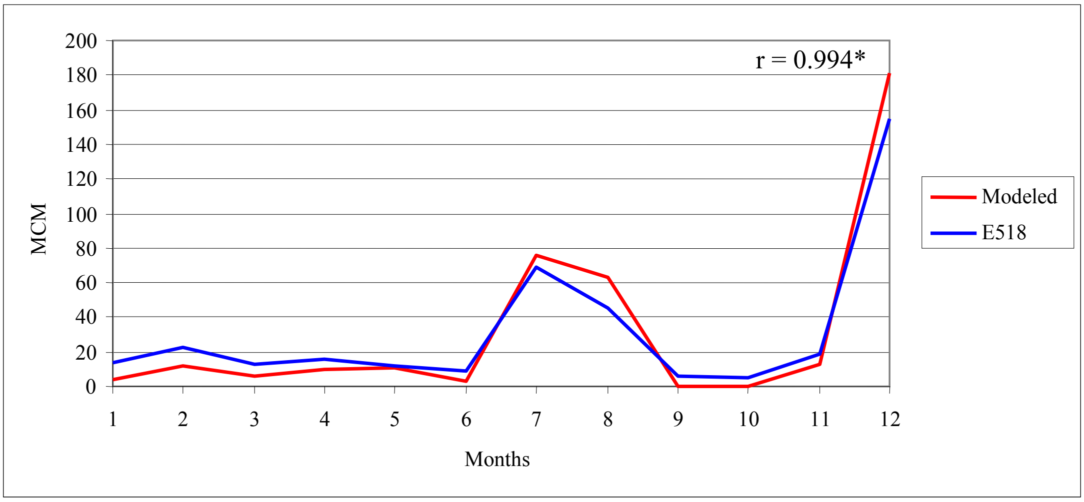


(b) Observed and modeled storage volumes in Demirkopru Dam

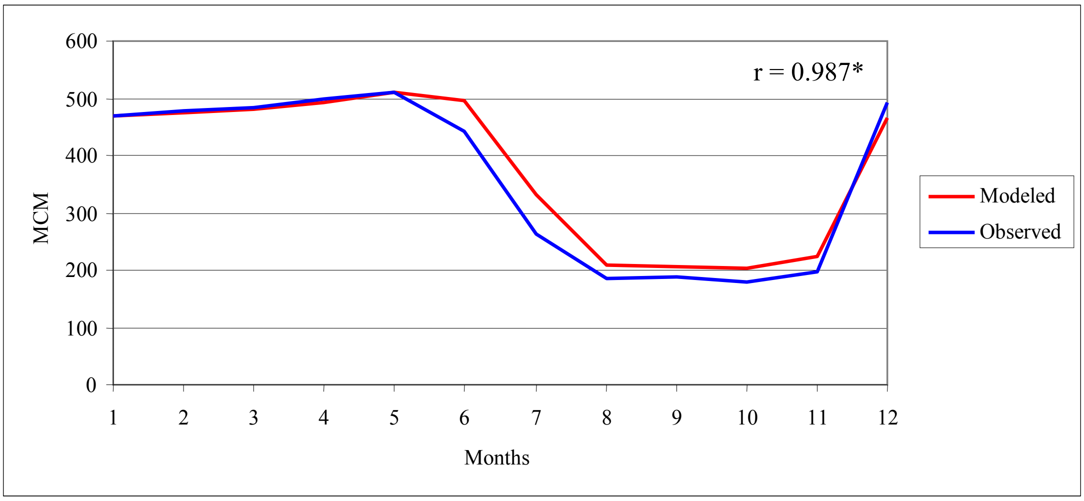


(c) Observed and modeled storage volumes in Gol Marmara

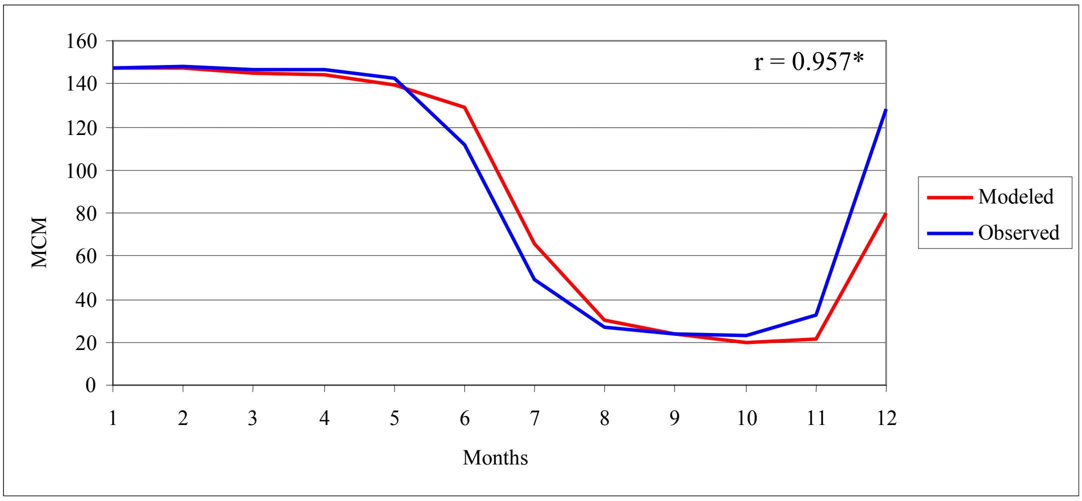
Figure 4.7 The calibration graphs for 1996 (normal year; MCM: million cubic meter; *: correlation is significant at 0.01 level)



(a) Observed and modeled runoff series of station 518



(b) Observed and modeled storage volumes in Demirkopru Dam



(c) Observed and modeled storage volumes in Gol Marmara

Figure 4.8 The calibration graphs for 2001 (dry year; MCM: million cubic meter; *: correlation is significant at 0.01 level)

The transmission link loss rate, irrigation efficiency, and the irrigation return flow rate are determined through the calibration as given in Table 4.13. These results agree with the rates mentioned by DSI engineers. (Silay & Gunduz, 2007).

Table 4.13 The calibration results

Transmission link loss rate	Irrigation efficiency	Return flow rate
32%	60%	16%

The buffer coefficients (Table 4.14) are also in agreement with the operation rules of reservoirs. Since the irrigators prefer to fulfill the irrigation demands in July and August, the buffer coefficients are set to 1 for these months However, if the storage volume of the Demirkopru Dam is available (e.g. equal or higher than 650 MCM in June and higher than 300 MCM in September), water releases are possible in early and late irrigation season.

Table 4.14 Buffer coefficients of the reservoir operation rules

Operation Month	Demirkopru Dam	Gol Marmara
June	0.05 or 0.10	0
July	1	1
August	1	1
September	0 or 1	0

4. 3 Scenarios

The scenarios developed are based on changing hydro-meteorological conditions, and simulations are run to identify the possible impacts of changing conditions on basin water budget in terms of water supply and demand.

4.3.1 Base Case

The Base Case, or Current Accounts in WEAP terminology, represents the basic definition of the water system in its present state and is also assumed to be the starting year for all scenarios. It includes the specifications of supply and demand data for the first year of the study on a monthly basis. Since the Current Accounts is inferred to as "the best available estimate of the system", the long term monthly averages of runoff (Table 4.15) as well as the monthly averages of temperature, precipitation and evapotranspiration (see Tables 4.6, 4.7, 4.8) are used to develop 'Current Accounts Year', that is set as 2003 in this study.

Table 4.15 Monthly average runoff representing river headflows (m^3/s)

Month	**Stream Gauging Stations**											
	510	**514**	**515**	**518**	**522**	**523**	**527**	**5-21**	**5-26**	**5-31**	**5-38**	**5-39**
Jan	9.67	5.52	7.90	53.67	7.60	19.33	10.47	2.39	0.85	6.36	8.43	0.88
Feb	9.53	5.98	7.76	60.46	8.22	22.43	11.90	2.44	0.81	8.86	9.19	1.54
Mar	7.48	4.02	5.80	46.44	5.88	17.09	9.27	2.16	0.53	6.54	7.56	1.31
Apr	6.46	3.46	5.01	39.06	4.91	18.05	7.58	1.81	0.33	6.21	5.64	1.05
May	3.65	1.85	2.51	22.24	2.14	11.42	3.27	0.96	0.12	2.18	2.52	0.54
Jun	1.49	0.54	0.64	14.19	0.61	4.34	0.82	0.40	0.02	0.84	1.09	0.23
Jul	0.57	0.20	0.24	21.02	0.14	1.69	0.20	0.20	0.01	0.60	0.57	0.08
Aug	0.27	0.12	0.22	22.01	0.08	1.03	0.10	0.15	0.01	0.64	0.50	0.06
Sep	0.47	0.13	0.18	17.95	0.12	1.20	0.07	0.16	0.02	0.61	0.35	0.09
Oct	0.80	0.29	0.36	14.54	0.32	2.40	0.28	0.21	0.03	0.55	0.64	0.17
Nov	1.46	0.95	1.21	18.63	1.17	4.95	1.31	0.37	0.24	1.42	1.23	0.36
Dec	6.93	4.09	6.02	35.69	6.04	13.09	9.34	1.63	0.73	4.81	5.83	0.89
AVERAGE	**4.06**	**2.26**	**3.13**	**30.49**	**3.11**	**9.75**	**4.56**	**1.07**	**0.31**	**3.30**	**3.63**	**0.60**

The crop pattern in 2003 (see Table 4.4) is assumed as the descriptive pattern of the demand sites. With respect to basic economic analysis, the other assumptions relevant to crops are given in Table 4.16. The cost and price data are estimated from the cost analysis reports published in the web site of the Turkish Chamber of Agricultural Engineers, and the maximum crop yields are assumed on the basis of the maximum yield in relevant irrigation districts, that are published in the crop production annuals of DSI. It should be mentioned that the price of the irrigation water is incorporated within the cultivation cost. The yield response factor (k_y), which refers to the relationship between the relative yield decrease and relative evapotranspiration, are obtained from FAO (1979). Although the yield response to water deficit differs with respect to the vegetation period, its values demonstrate the response of yield to overall water deficit for the total growing season.

Table 4.16 Main assumptions used for crops

Crop	Cost (€/ha)	Price (€/kg)	Max. Yield	Yield Response Factor (k_y)
Cotton	1424	0.43	5490	0.85
Grape	2106	0.56	7000	0.85
Maize	995	0.18	11340	1.25
Vegetables	4618	0.14	65000	1.15

The fixed operation and maintenance costs of supply nodes (Table 4.17) are obtained from the report of an EU project on Gediz River Basin (OPTIMA, 2006). The long term reservoir storages in January are assumed as the initial reservoir storages, which are 350 MCM and 90 MCM for Demirkopru Dam and Gol Marmara, respectively.

Table 4.17 Fixed operation and maintenance (O&M) costs

Supply nodes	O&M Cost (€/month)
Menemen RB	16040
Menemen LB	31406
Ahmetli RB	39963
Ahmetli LB	25537
Adala RB	11716
Adala LB	21091
Demirkopru Dam	64600

4.3.2 Reference Scenarios

The reference scenarios are selected on the basis of the assessments of the supply and demand side of the water system in the basin. Accordingly, three main reference scenarios are developed with combinations of water availability and demand scenarios. Here, it should be mentioned that the demand scenarios are based only on temperature increases leading to increases in crop irrigation water requirement due to higher potential evapotranspiration. Since the Gordes Dam will be in operation within the simulation period (2003-2030), the planned water withdrawal to Izmir (8.5 MCM/month) is also incorporated into the reference scenarios after January, 2010.

The Business as Usual (BAU) scenario foresees the preservation of long term averages with respect to water availability and water demand. In order to formulate the BAU scenario, the monthly average stream flows which were monitored between 1977 and 2003 are replicated for the simulation period (2003-2030). The water demand computations, where the monthly averages of temperature and precipitation are used, are carried out, considering constant irrigation areas as well as the same crop patterns for all irrigation districts.

The Pessimistic scenario (PES) focuses on low water availability and high demand. The project report dealing with the climate change effects in Gediz River Basin (SUMER, 2006) estimates the decreases in stream flows as well as in precipitation, and increases in the average monthly temperatures. In this report, the expected future variations in these hydro-meteorological parameters are determined, using different climate change scenarios for the years 2030, 2050 and 2100. The results for 2030 in the B2-SRES scenario, which emphasizes local solutions to economic, social and environmental sustainability with moderate population growth and economic development, are used to formulate the pessimistic scenario. Since the decrement in runoff is estimated to be about 23%, the monthly runoff time series used in the BAU scenario are decreased with this ratio to obtain pessimistic water availability conditions. Accordingly, the changes in precipitation and temperature with respect to the B2 scenario are used to set up the demand side of the water system. The decreases in percentage of the monthly total rainfall and the increases in monthly average temperature estimated for 2030 are given in Table 4.18. Since the estimations are given for 2030, a value in any given month within the simulation period is computed by linear interpolation.

The Optimistic scenario (OPT) foresees high water availability and stable water demand. In this scenario, the river headflows are represented by the monthly runoff data that are increased by 23 %. With so doing, the runoff series are considered not only as wet year averages, but also as the reversed conditions of the pessimistic scenario. Temperature and precipitation as well as the irrigation area are assumed constant in defining the stable water demand.

Table 4.18 Percent changes used in the pessimistic scenario (SUMER, 2006)

Month	Rainfall (%)	Temperature (%)
January	-3.3	13.5
February	-0.7	10.8
March	-0.2	7.7
April	-5.9	7.4
May	-12.4	6.8
June	-24.9	6.4
July	-35.2	5.6
August	-13.5	6.3
September	-9.9	6.3
October	-17.1	8.2
November	-6.2	9.2
December	-4.4	12.6

4.3.3 Comparative Assessment of Reference Scenarios

The water supply availability module developed within the three reference scenarios are depicted in Figure 4.9, where the water amount in 2003 is obtained from the long term average runoff of Gediz and its tributaries. In other words, the water potential described in 2003 (1,120 MCM) is the best estimation of the ‘normal’ conditions and does not refer to the cumulative runoff occurred in 2003.

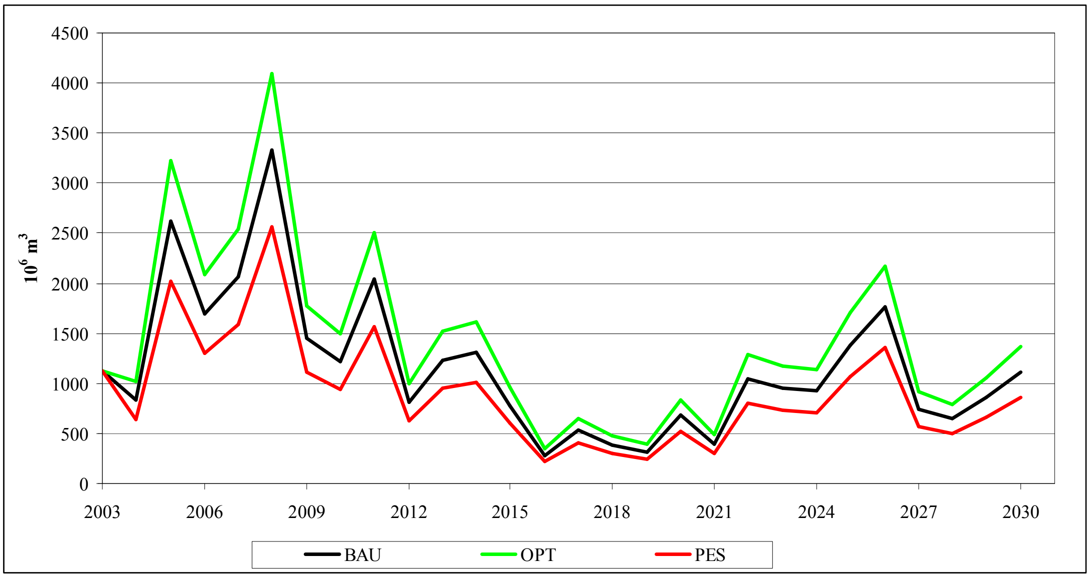


Figure 4.9 Total water supply used in the reference scenarios

However, the surface water that can be stored in the reservoirs (700 MCM), including Demirkopru and Gol Marmara, is quite less than the overall surface water potential (Figure 4.10). Since the reservoir storages are the main sources of irrigation water supply, it is reasonable to consider the stored water as the supply availability to meet the water demand in assessing the water budget of the basin. The water demand values computed within the reference scenarios are given in Figure 4.11.

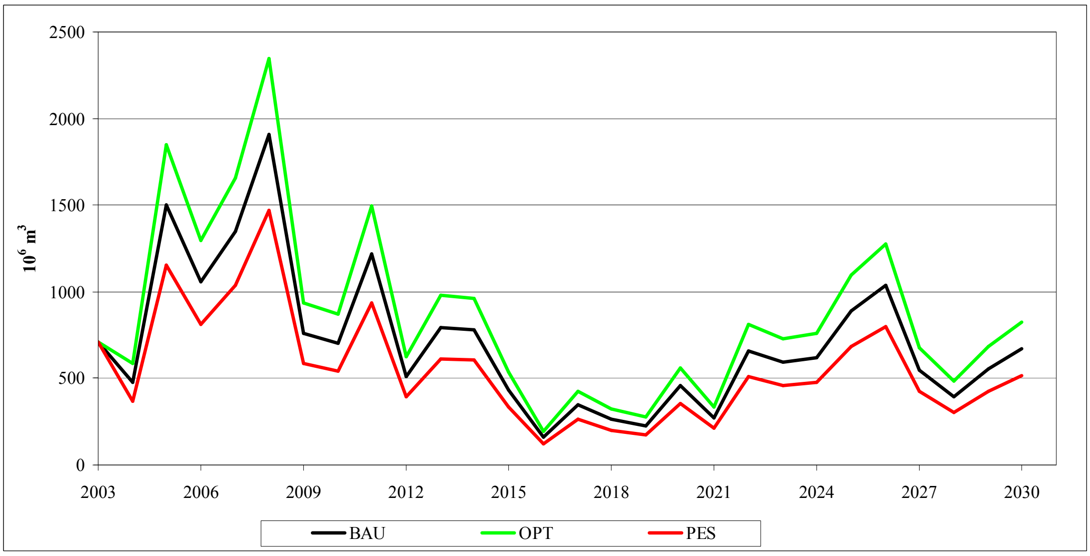


Figure 4.10 Total runoff into the reservoirs within the simulation period

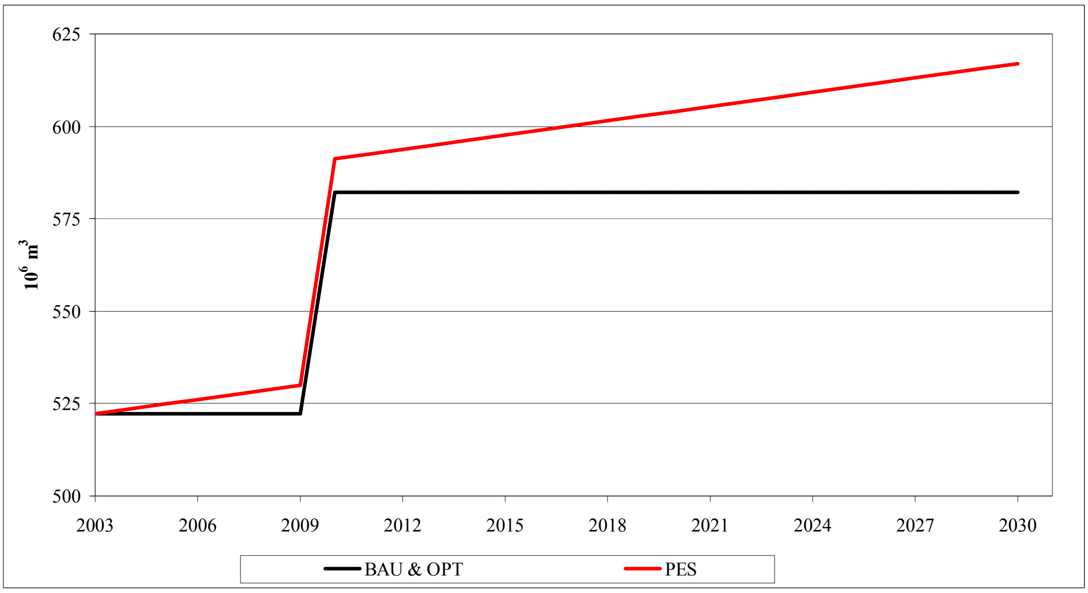


Figure 4.11 Total water demands in the reference scenarios

When the above two graphs are compared, it is obvious that the basin will suffer from water shortage especially in dry periods. However, the unmet water demand is more dramatic than that initially expected. If the basin experiences a drought period (for example 5 successive dry years), it is possible to encounter water deficits which range from 80 MCM to more than 500 MCM (Figure 4.12).

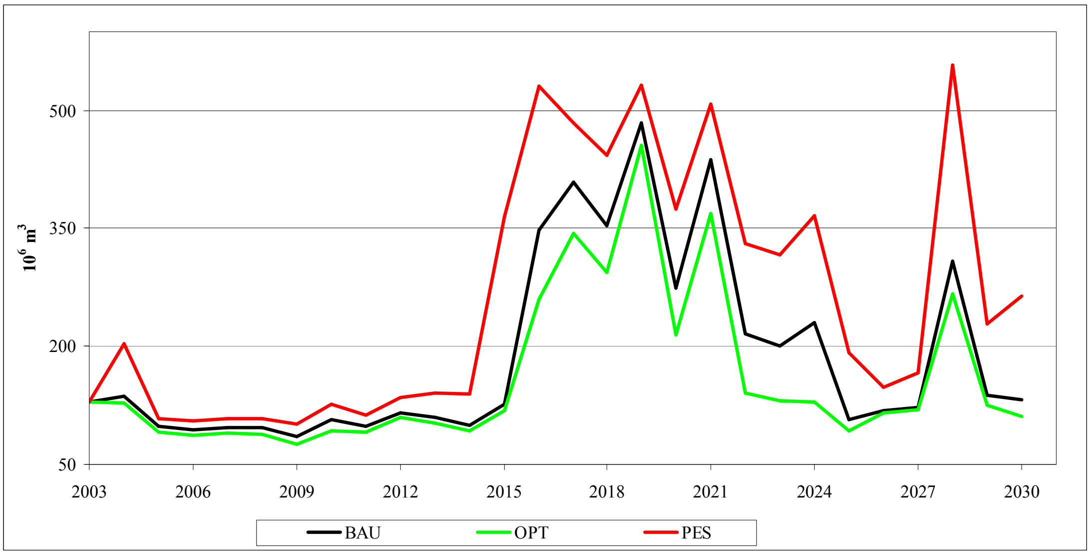


Figure 4.12 Total unmet water demands in the reference scenarios

The initial water budget analyses based on the reference scenarios prove that the irrigation demand coverage is quite sensitive to droughts. Moreover, it can be said that the basin will be under water stress even in the optimistic scenario unless significant measures are taken, that is when the “do nothing alternative, A_0” is in force (Figure 4.13).

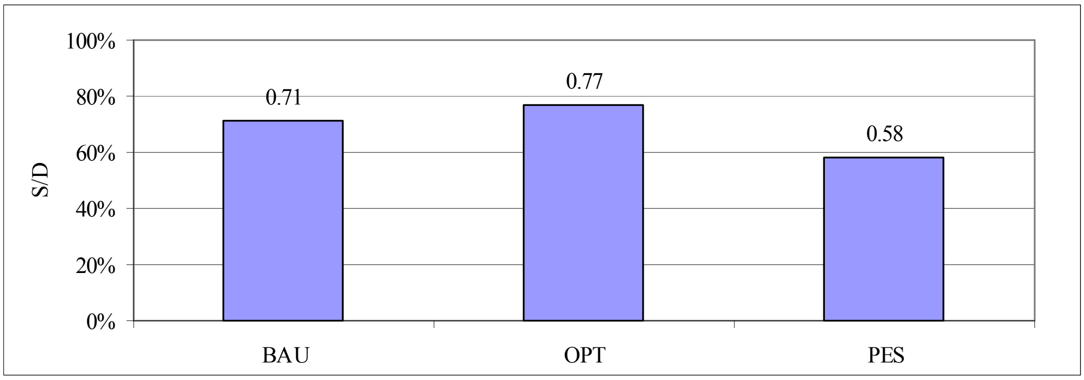


Figure 4.13 Supply/demand ratios as simulation period averages with respect to the reference scenarios

4. 4 Management Alternatives Evaluated

The management alternatives that are proposed in the previous chapter are explained in the following sections along with their main assumptions, schedules and their relevant areas of application. The performance of these alternatives differs with respect to changing hydro-meteorological conditions so that they are evaluated under each reference scenario of Section 3.4. The detailed results of this evaluation are presented in next chapter.

4.4.1 Canal Maintenance (Scenario A1)

The current estimated level of conveyance losses in study area is approximately 32% of the water passing through the link. The canal maintenance alternative addresses the gradual reduction of losses from 32% to 15% in six years, with an even distribution of costs throughout this period. This alternative assumes that the interventions will be implemented evenly in all transmission links. This is a reasonable way to ensure the same investment priority. Since it is difficult to estimate the costs of such implementation, the recent bids for similar investments as well as the press releases of irrigation association managers are used to estimate the cost which is about 30,000 €/km. Accounting for the total lengths of the main and secondary canals within their total service areas, the cost of this management alternative is incorporated to the analyses as 400 €/ha, where the O&M costs are fixed.

4.4.2 Crop Pattern Change (Scenario A2)

After the severe drought between 1989 and 1994, cultivation of maize instead of cotton had been the only response of farmers to the water scarcity problem. On the basis of variations within the recent years, this response is assumed to continue as such. The crop pattern change alternative is designed to follow this trend and is applied separately to the irrigation districts. The main focus of the alternative setup is increasing the cultivation area of maize while decreasing the cotton cultivation. In addition, the slow increase of grape cultivation is also added to the analyses. As an illustrative example for Menemen RB, the crop pattern change alternative is shown in Figure 4.14. The estimated crop pattern changes in the irrigation districts are given in Table 4.19.

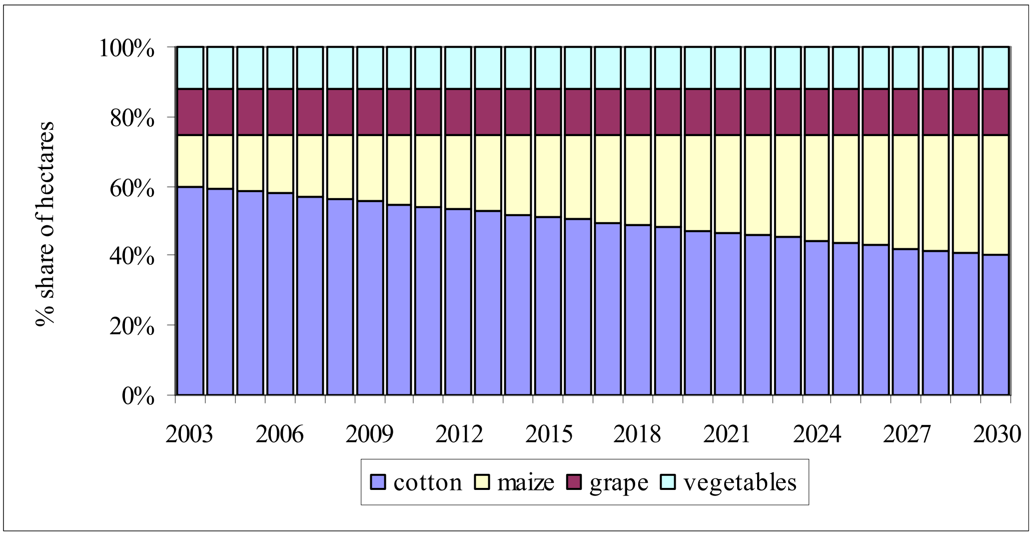


Figure 4.14 Crop pattern change for Menemen RB during the simulation period

Table 4.19 Crop pattern changes used in the analyses

Irrigation District	Crops	% share of hectares	
		2003	2030
Menemen RB	Cotton	60	40
	Grape	13	13
	Maize	15	35
	Vegetables	12	12
Menemen LB	Cotton	69	58
	Grape	10	10
	Maize	14	24
	Vegetables	8	8
Ahmetli RB	Cotton	48	28
	Grape	38	48
	Maize	12	22
	Vegetables	2	2
Ahmetli LB	Cotton	42	28
	Grape	45	52
	Maize	10	17
	Vegetables	3	3
Adala RB	Cotton	46	26
	Grape	32	36
	Maize	19	35
	Vegetables	3	3
Adala LB	Cotton	15	5
	Grape	68	68
	Maize	13	23
	Vegetables	4	4

4.4.3 Use of Drip Irrigation (Scenario A3)

Since agriculture is the major economic activity in the Gediz River Basin, it is vital to the local economy and social structure. All crops need to be irrigated in the summer season due to the prevailing climatic conditions. Although the farmers have been informed on how to improve irrigation efficiency, e.g., via drip irrigation where the irrigation efficiency is generally 90%, the existing water distribution system of open canals, as well as the economic capacity of the farmers, is a limitation in this regard. In recent years, the farmers are offered some significant incentives with subsidies to construct water saver irrigation technologies. The policy is to promote the irrigation efficiency, which is currently estimated to be in the range of 60%. However, unless the water distribution systems in the large irrigation districts are replaced by pressured lines, a decrease in the overall use of irrigation water does not seem to be possible.

The drip irrigation alternative that is evaluated for improvement of irrigation methods is developed in two parts. The first part is the replacement of the current water distribution network by a pressured (piped) system. Like in the canal maintenance alternative, the investments are scheduled to be implemented in six years (2004-2010); and the cost is incorporated into the analysis as 2500 €/ha, where the O&M costs are fixed. The water loss in the piped system is assumed to be 2% of water passing through the link. The second part refers to a transition from the currently used irrigation methods, which mostly involve furrow irrigation, to drip irrigation in all irrigation districts. The drip irrigation alternative is introduced to the model by assuming that the share of drip irrigation will be in the order of 80% of the irrigated area in 2030 and that the initial implementation will begin after 2010 (the operation year of the pressured system). The cost of the drip irrigation method is estimated to be 5,000 €/ha, and the annual O&M cost is evaluated as 10% of the capital cost.

4.4.4 Pressured Systems (Scenario A4)

This alternative evaluates only the first part of alternative A3 which considers the use of drip irrigation. That is, it focuses only on the replacement of the current water distribution network by a piped one without the option of a transition to drip irrigation methods. With so doing, it is possible to evaluate how the performance indicators improve if high conveyance losses are reduced to a negligible size. It is also a reasonable way to evaluate a lower cost alternative relative to A3.

4.4.5 Combined Alternatives

The alternative combinations, A5, A6 and A7, are also developed to evaluate the results of aggregated management plans. The crop pattern change alternative (A2) is considered together with canal maintenance (A1), drip irrigation (A3) and pressured systems (A4) alternatives to develop the A5, A6 and A7 alternatives, respectively.

CHAPTER FIVE
RESULTS AND DISCUSSION

5. 1 Performance Matrix

For the Gediz case, the performance matrix (PM) explained in Section 3.5.1 is set up with nine performance indicators versus eight alternatives (including A0, the do-nothing alternative). Since the entries of PMs differ with hydro-meteorological conditions, three PMs are obtained for three reference scenarios. The indicators are also grouped into three criteria category with respect to environmental, social and economic sustainability dimensions. The PMs not only permit indicator-based assessments but also constitute a stepping stone for the eventual decision making process.

In Table 5.1, where the best values are highlighted, performance evaluation under the BAU scenario is presented. A0 and A2 alternatives are not seen as feasible alternatives since they are dominated by the others; in other words, indicators of these alternatives are less than all other alternative's. Reasonably, A1, A4 and A7, which focus on the reduction of water losses in the conveyance system, as well as A3 and A6, which improve irrigation efficiency, are considered as the alternatives which are worth analyzing in depth. Since increased water availability is foreseen in the optimistic scenario, similar results with higher performance values are observed (Table 5.2). In the pessimistic scenario, the performance indicators are worse than those in BAU and OPT, as expected (Table 5.3). However, it is useful to evaluate the achievements of the alternatives under reference scenarios. In this regard, indicator based assessments are carried out on the basis of "percent improvement relative to the A0 alternative".

Table 5.1 Performance evaluation under the business-as-usual reference scenario

Alternative	*ENVIRONMENTAL*			*SOCIAL*			*ECONOMIC*		
	Agricultural Sustainability Index	**Environmental Sustainability Index**	**Water Exploitation Rate***	**Yield Reliability**	**Irrigation Water Deficit* (MCM)**	**Domestic Supply Reliability**	**Benefit/Cost Ratio**	**Irr. Water Use Efficiency (€/m^3)**	**Total Production (M€/year)**
	ASI	**ESI**	**WER**	**YR**	**IWD**	**DSR**	**B/C**	**IWUE**	**TPV**
A0	0.17	0.10	0.71	0.55	121.27	0.69	1.29	0.31	147.39
A1	0.22	0.20	0.66	0.67	80.16	0.73	**1.38**	0.36	159.98
A2	0.17	0.11	0.72	0.54	115.26	0.70	1.28	0.30	148.57
A3	0.41	**0.49**	**0.59**	0.87	**29.76**	**0.75**	1.21	**0.43**	**174.57**
A4	0.32	0.32	0.66	0.79	56.28	**0.75**	1.35	0.37	167.46
A5	0.24	0.22	0.67	0.71	74.64	0.73	**1.38**	0.35	161.25
A6	**0.47**	0.46	0.60	**0.88**	36.70	**0.75**	1.19	**0.43**	172.00
A7	0.38	0.31	0.65	0.79	57.34	**0.75**	1.34	0.37	166.61

*: minimizing criterion; MCM: million cubic meters; M€: million euros

A0: do nothing; A1: canal maintenance; A2: crop pattern change; A3: drip irrigation; A4: pressured systems; A5: crop+canal; A6: crop+drip; A7: crop+pressured systems

Table 5.2 Performance evaluation under the optimistic reference scenario

Alternative	*ENVIRONMENTAL*			*SOCIAL*			*ECONOMIC*		
	Agricultural Sustainability Index	**Environmental Sustainability Index**	**Water Exploitation Rate***	**Yield Reliability**	**Irrigation Water Deficit* (MCM)**	**Domestic Supply Reliability**	**Benefit/Cost Ratio**	**Irr. Water Use Efficiency (€/m^3)**	**Total Production (M€/year)**
	ASI	**ESI**	**WER**	**YR**	**IWD**	**DSR**	**B/C**	**IWUE**	**TPV**
A0	0.25	0.17	0.62	0.64	97.03	0.80	1.35	0.30	154.75
A1	0.33	0.28	0.57	0.78	57.65	0.83	**1.44**	0.35	167.03
A2	0.25	0.18	0.61	0.62	97.44	0.80	1.35	0.30	153.71
A3	0.69	**0.69**	**0.49**	**0.94**	**17.94**	**0.85**	1.25	**0.44**	**178.90**
A4	0.51	0.51	0.55	0.88	40.32	**0.85**	1.40	0.37	172.36
A5	0.36	0.33	0.56	0.78	57.38	0.83	**1.44**	0.35	166.49
A6	**0.72**	0.66	0.50	**0.94**	25.08	**0.85**	1.24	0.43	176.32
A7	0.54	0.46	0.54	0.88	41.93	**0.85**	1.40	0.37	171.51

*: minimizing criterion; MCM: million cubic meters; M€: million euros

A0: do nothing; A1: canal maintenance; A2: crop pattern change; A3: drip irrigation; A4: pressured systems; A5: crop+canal; A6: crop+drip; A7: crop+pressured systems

Table 5.3 Performance evaluation under the pessimistic reference scenario

Alternative	*ENVIRONMENTAL*			*SOCIAL*			*ECONOMIC*		
	Agricultural Sustainability Index	**Environmental Sustainability Index**	**Water Exploitation Rate***	**Yield Reliability**	**Irrigation Water Deficit* (MCM)**	**Domestic Supply Reliability**	**Benefit/Cost Ratio**	**Irr. Water Use Efficiency (€/m^3)**	**Total Production (M€/year)**
	ASI	**ESI**	**WER**	**YR**	**IWD**	**DSR**	**B/C**	**IWUE**	**TPV**
A0	0.07	0.04	0.78	0.33	180.72	0.53	1.13	0.35	129.58
A1	0.13	0.08	0.76	0.50	132.98	0.60	**1.24**	0.37	143.71
A2	0.08	0.04	0.78	0.33	176.71	0.54	1.13	0.34	128.95
A3	0.22	0.22	**0.71**	**0.65**	74.45	**0.62**	1.10	**0.44**	**157.67**
A4	0.17	0.13	0.76	0.55	107.54	**0.62**	1.23	0.39	151.18
A5	0.13	0.08	0.75	0.50	130.31	0.61	**1.24**	0.37	143.22
A6	**0.24**	**0.23**	**0.71**	**0.65**	**73.98**	**0.62**	1.10	**0.44**	157.00
A7	0.18	0.14	0.75	0.56	106.10	**0.62**	1.23	0.39	150.50

*: minimizing criterion; MCM: million cubic meters; M€: million euros

A0: do nothing; A1: canal maintenance; A2: crop pattern change; A3: drip irrigation; A4: pressured systems; A5: crop+canal; A6: crop+drip; A7: crop+pressured systems

The ASI, obtained through the reliability, resilience and vulnerability of irrigation demand coverage (supply/demand ratio), change between 0 and 1. It is not reasonable to strictly characterize the status of irrigation water budget; however, ASI values close to 1 refer to a "good position". If we consider the A0 alternative (or doing nothing), ASI is equal to 0.25, 0.17 and 0.07 in OPT, BAU and PES, respectively. This means that the irrigation water budget is already under stress, and under pessimistic conditions, it is not sustainable. Significant recovery in ASI can be obtained by the alternative policies. For example, ASI is equal to 0.24 in PES with A6 alternative, and this is almost equal to the ASI value with A0 in OPT (0.25). In other words, ASI can be increased by 243% (= (0.24 - 0.07) / 0.07 * 100) through the cumulative effects of drip irrigation methods and crop pattern change. The other alternatives also enhance ASI by different percentages (Table 5.4). It should be noted that the percent improvements in ASI under pessimistic conditions are larger than the ones in business-as-usual and optimistic conditions for all alternatives.

Table 5.4 Percent improvement of ASI with respect to the reference scenarios

Alternative	**OPT**	**BAU**	**PES**
A1	32%	29%	86%
A2	0%	0%	14%
A3	176%	141%	214%
A4	104%	88%	143%
A5	44%	41%	86%
A6	188%	176%	243%
A7	116%	124%	157%

Similar results are also valid for ESI, where A3 and A6 alternatives show significant improvements. A4 and A7 alternatives also increase ESI. Since the water requirement of the Birds Paradise in the summer season (12 MCM) is quite less than the seasonal irrigation demand (550 MCM), it is possible to fulfill the water demand of the bird sanctuary in the water conservative alternatives that serve to increase ESI.

The water exploitation rates (WER) are 0.62, 0.71 and 0.78 in OPT, BAU and PES, respectively. However, when A3 alternative is implemented, they sharply decrease to 0.49, 0.59 and 0.71 in the respective reference scenarios. Considering that the average water quantity stored in the reservoirs is almost 700 MCM, a 10%

decrease in WER leads to water savings in the order of 70 MCM. A3 and the coherent alternative A6 produce a 9% decrease in WER in the PES scenario and also over perform in BAU and OPT (Figure 5.1).

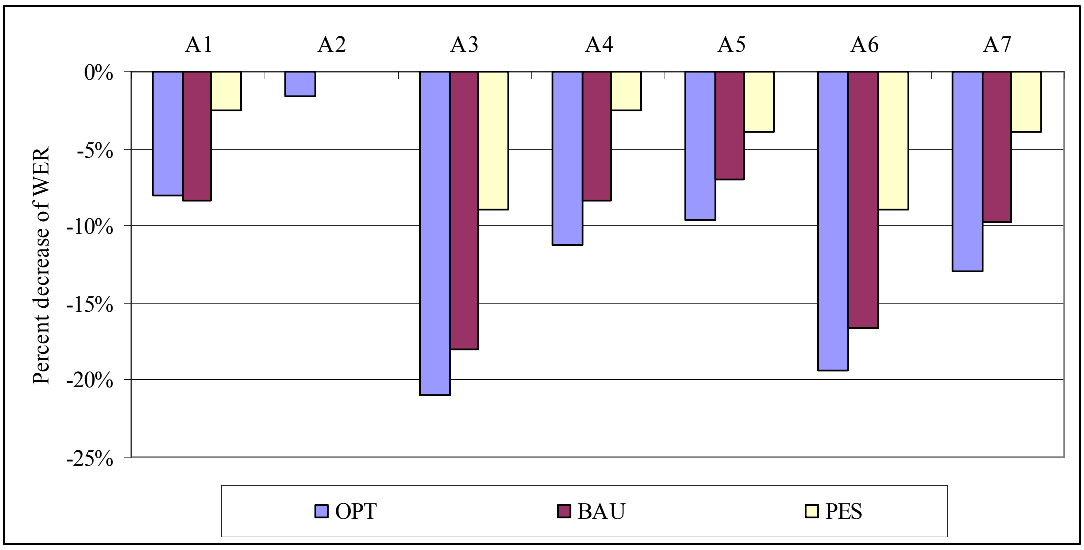


Figure 5.1 Percent improvements in WER with respect to the reference scenarios

Here, it should be mentioned that the water exploitation rate obtained via alternative A3 under the PES scenario is the same as that in A0 in the BAU scenario. Generally, all management alternatives reduce the exploitation rate at different percentages; however, the reduction is more noticeable in BAU and OPT scenarios due to the higher water availability conditions.

The yield reliability (YR), that represents the probability of achieving at least 75 % of the maximum yield, can be improved with the application of particular management alternatives excluding the crop pattern change alternative (A2). This can be explained by the yield response factors (YRF) of crops. The YRF of maize (1.25) is higher than the YRF of cotton (0.85). Therefore, the yield decrease in maize is expected to be higher than that in cotton if evapotranspiration deficit occurs. In addition, the water releases in June, when maize requires more water than cotton, are generally restricted to fully meet the irrigation demand in July and August. Accordingly, alternative A2 leads to a decrease in YR. On the other hand, an increase of 97% in YR in the PES scenario is achieved through the favorite alternatives A3 and A6. The other alternatives also increase this indicator value at significant rates, as depicted in Figure 5.2 where the alternatives show more effective responses to yield reliability under pessimistic conditions.

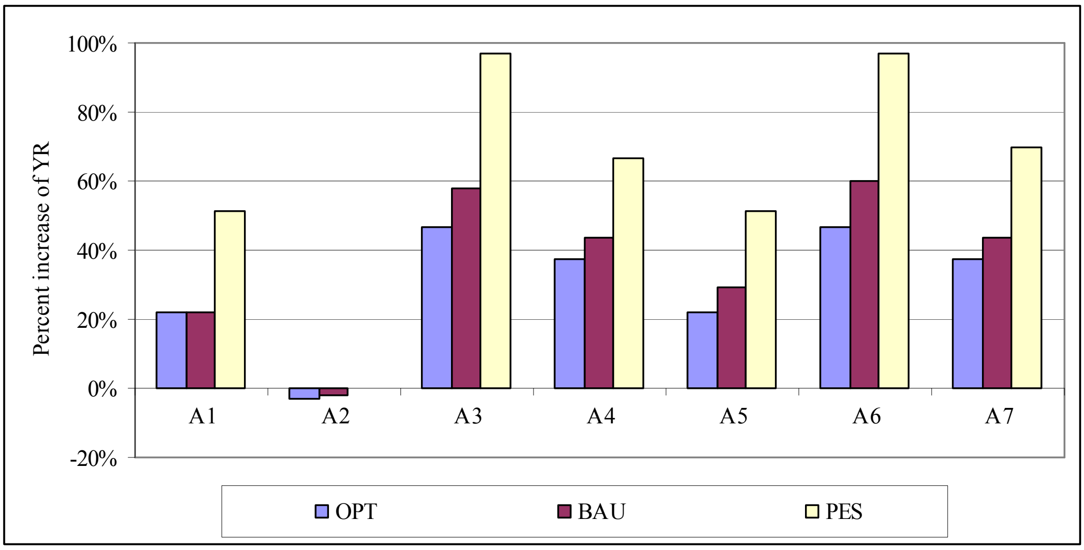


Figure 5.2 Percent improvements in YR with respect to the reference scenarios

Irrigation water deficit (IWD), or the average amount of water to meet the ET shortfall (ET_c - ET_{actual}), is a valuable indicator for the analyses. Although the total ET shortfall during the irrigation season is determined as 72.8 MCM, the indicator increases to 121 MCM in the BAU scenario due to low irrigation efficiency (0.60). IWD is equal to 97 MCM and 180 MCM in the OPT and PES scenarios, respectively. Considering the average annual crop water requirement in the system (300 MCM), which indicates an irrigation water demand in the order of 500 MCM, it is obvious that the deficit amounts presented above are enough to decrease the yield as well as the revenues of farmers. However, significant improvements of IWD can be achieved within the proposed alternatives (Figure 5.3). Accordingly, IWD can be improved by 59%; in other words, almost 100 MCM less deficit is possible with the A3 or A6 alternatives under pessimistic conditions. If we assume the BAU or the OPT scenarios, the alternatives produce more decreases in the irrigation deficit.

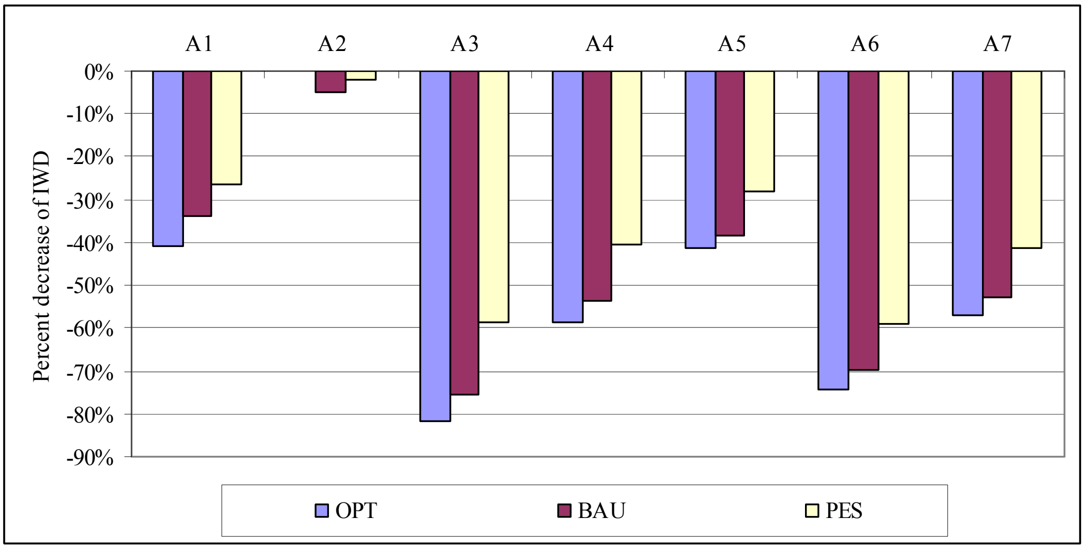


Figure 5.3 Percent improvement of IWD with respect to the reference scenarios

Izmir is the third largest metropolis in Turkey and significantly consumes groundwater resources. Due to the increases in the population and thus in the domestic water demand, it has been planned to deliver additional water (60 MCM/year) to Izmir via piped transmission link from Gordes Dam. The domestic supply reliability (DSR) refers to the satisfaction of this demand, which is determined as 5 MCM, considering the monthly share of the annual demand. The DSR is equal to 0.80, 0.69 and 0.53 in OPT, BAU and PES, respectively. The indicator value under optimistic conditions (0.80) means that the monthly demand will not be fully met approximately for 3 months in the summer season. Moreover, the risk of supply failure increases if we consider the pessimistic conditions. Again, improvement of DSR is possible through the management alternatives. As seen in Figure 5.4, DSR can be increased by more than 15% in the PES scenario, and the percent improvement of the indicator is relatively little for other scenarios. That is, the management alternatives produce better results under the pessimistic conditions.

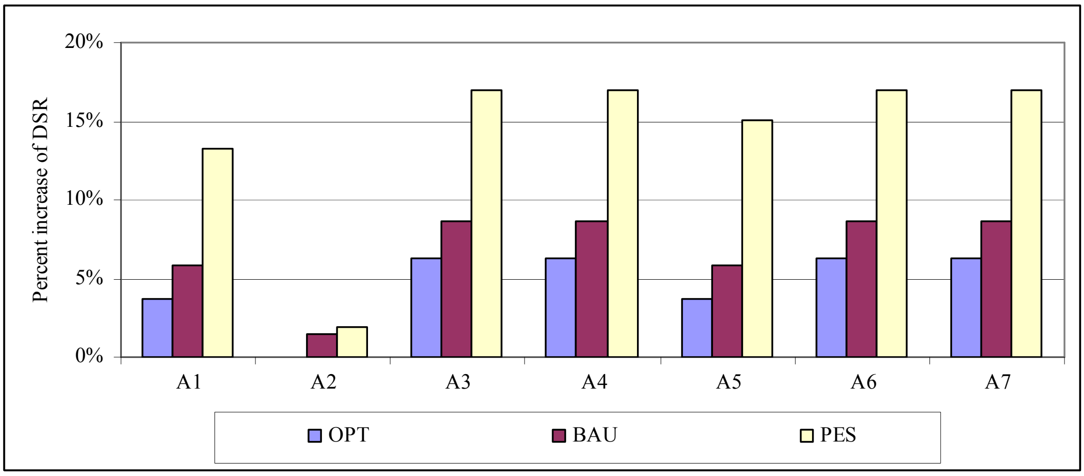


Figure 5.4 Percent improvements in DSR with respect to the reference scenarios

With respect to economic indicators, the alternatives reflect different results. Under the pessimistic scenario, the alternatives A1 and A5 are determined as the most beneficial ones, where the B/C ratios are the same and equal to 1.24. This is higher than 1.1 indicated by A3 and A6. Moreover, the alternatives A3 and A6 are under performed with respect to A0 in all reference scenarios.

In contrast to the B/C indicator, the alternatives A3 and A6 are better scored than the others with respect to irrigation water use efficiency (IWUE), which indicates the agricultural benefit per unit of irrigation water allocated (€/m^3) (see Tables 5.1-3). In the A3 and A6 alternatives, the percent improvement of IWUE in PES is determined as 26%, while A1 and A5 result in an increase of only 6%. This indicates improvements in the order of 22% and 11% in the total production value (TPV) if we consider the alternatives A3 (or A6) and A1 (or A5), respectively. The improvement of TPV in alternative A4 is 17% in the PES scenario and is also remarkable in other reference scenarios (Figure 5.5).

It is observed that, although drip irrigation methods increase benefits and decrease water consumption by efficient water use technologies, A3 and A6 do not appear to be beneficial in comparison with alternatives which have lower costs, such as canal maintenance (A1). It is also concluded that the alternatives including drip irrigation methods probably perform better if we extend the simulation period or implement the investments more rapidly than that specified in this study.

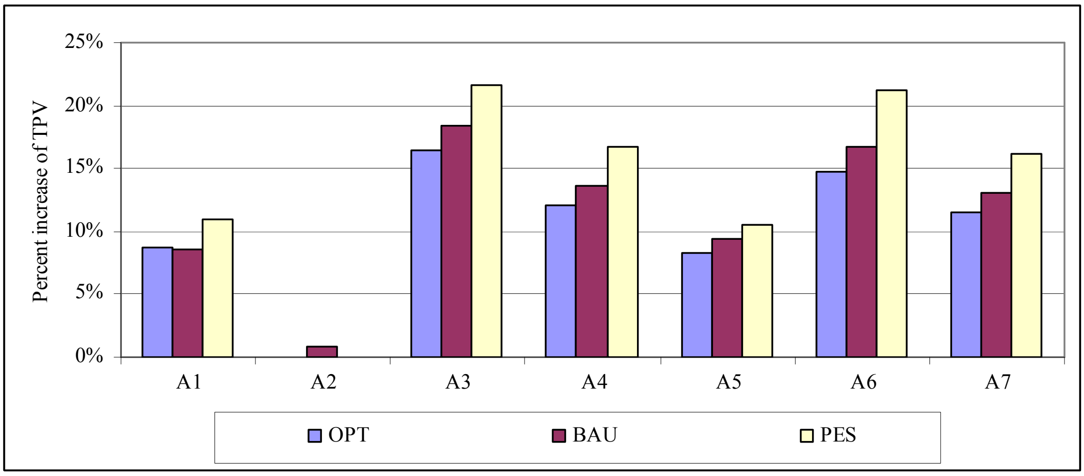


Figure 5.5 Percent improvements in TPV with respect to the reference scenarios

5. 2 Multi Criteria Decision Making

Once the performance matrix (decision matrix) is obtained, the next step in the decision making process is the determination of criteria weights. With respect to the methods explained previously, objective criteria weights are obtained by the performance matrix of each reference scenario as in Table 5.5, where EW, CW and SDW are the criteria weights derived by the entropy method, critic method, and the standard deviation method, respectively.

Table 5.5 Criteria weights assigned by objective weighting methods

Criteria	**OPT**			**BAU**			**PES**		
	EW	**CW**	**SDW**	**EW**	**CW**	**SDW**	**EW**	**CW**	**SDW**
ASI	0.201	0.172	0.199	0.192	0.177	0.193	0.229	0.167	0.209
ESI	0.300	0.196	0.241	0.387	0.220	0.271	0.494	0.299	0.312
WER	0.009	0.034	0.042	0.007	0.033	0.036	0.002	0.021	0.019
YR	0.029	0.055	0.075	0.045	0.070	0.093	0.086	0.093	0.127
IWD	0.427	0.317	0.304	0.335	0.259	0.263	0.157	0.168	0.178
DSR	0.001	0.010	0.012	0.001	0.013	0.016	0.006	0.035	0.035
B/C	0.004	0.140	0.028	0.004	0.150	0.028	0.004	0.140	0.028
IWUE	0.026	0.056	0.072	0.023	0.054	0.067	0.013	0.047	0.051
TPV	0.004	0.019	0.027	0.005	0.024	0.032	0.008	0.030	0.040

The above weights show that IWD, ESI and ASI are the most important criteria to assess the alternatives' overall performance, and the other criteria do not have a powerful impact on decision making. In other words, the alternative scores for the aforementioned criteria are more divergent and, consequently, are more important for the problem. It is interesting to note that, if we consider the worsening conditions (from OPT to PES), the ESI gain more importance; however, the sum of three criteria weights derived by entropy method is almost 0.90 for all scenarios. This is quite a large number when it is considered that the sum of all criteria weights is equal to 1.00. Therefore, it is concluded that the use of objective weighting methods, especially the entropy method, is required to determine the important criteria as well as unbiased criteria weights.

The criteria weight sets, namely W_{ENV}, W_{SOC} and W_{ECO}, are also developed to illustrate the subjective preference of the decision maker who is concerned with environmental, social and economic criteria. The weights are obtained by the AHP method. It should be noted that the AHP method is not fully arranged among all separate criteria but among the criteria (WER, DSR and B/C), which demonstrate the three criteria categories with respect to environmental, social and economic issues. With so doing, not only the number of required pairwise comparisons between the criteria (9*(9-1)/2=36) are reduced to a manageable size (3*(3-1)/2=3), but also the alternatives are evaluated by the criteria that are not considered important in the objective weighting methods.

To demonstrate the preference judgements in AHP, the three criteria are evaluated within a preference matrix through the use of Saaty's scale. With respect to the preference judgements of DMs who give priority to environmental effects, WER is regarded to have "strong importance" over DSR and "demonstrated importance" over B/C; and "equal importance" between DSR and B/C criteria is considered. In accordance with Saaty index (Table 3.3), the preference matrix is given in Table 5.6. The preference judgements are considered as "consistent", since the consistency ratio (CR) obtained by Eq. (3.34) is 0.01 ($\leq$ 0.10).

Table 5.6 Preference matrix used in the determination of W_{ENV}

	WER	DSR	B/C
WER	1	**5**	**7**
DSR	1/5	1	**1**
B/C	1/7	1/1	1

CR = 0.01 ≤ 0.10, consistent

In the preference matrix constituted according to the socially prioritized decision maker (Table 5.7), DSR is regarded to have "intermediate importance" over WER and "weak importance" over B/C, and again "weak importance" is considered between DSR and B/C.

Table 5.7 Preference matrix used in the determination of W_{SOC}

	WER	DSR	B/C
WER	1	1/4	**3**
DSR	**4**	1	**3**
B/C	1/3	1/3	1

CR = 0.04 ≤ 0.10, consistent

Considering the decision makers who give priority to economic criteria, B/C is regarded to have "strong importance" over WER and "demonstrated importance" over DSR, and "equal importance" is assumed between DSR and B/C. Table 5.8 summarizes the preference judgements converted to numeric numbers in accordance with Saaty index.

Table 5.8 Preference matrix used in the determination of W_{ECO}

	WER	DSR	B/C
WER	1	1/1	1/7
DSR	**1**	1	1/5
B/C	**7**	**5**	1

CR = 0.01 ≤ 0.10, consistent

Finally, the subjective criteria weights that are determined by AHP are presented in Table 5.9. Here, the MW also represents the idea of equal weighting, so the weight of each criterion is 0.111, the sum being 1.

The decision making process is conducted with the above subjective criteria weights in addition to the objective criteria weights. Moreover, the decision analyses are applied for each reference scenario individually, where the relevant objective weights are used. CP and TOPSIS, the two distance type methods in which the distance to the so called ‘ideal point’ (and also to the ‘anti-ideal’ point in TOPSIS) is measured by the Euclidean distance (p=2), and the SAW method are applied to rank the alternatives.

Table 5.9 Criteria weights assigned by subjective weighting methods

Criteria	**MW**	W_{ENV}	W_{SOC}	W_{ECO}
ASI	0.111			
ESI	0.111			
WER	0.111	0.746	0.221	0.120
YR	0.111			
IWD	0.111			
DSR	0.111	0.134	0.685	0.134
B/C	0.111	0.120	0.093	0.746
IWUE	0.111			
TPV	0.111			

Respectively, the alternative rankings with regard to CP, TOPSIS, and SAW methods are given in Table 5.10, which summarizes the results for the BAU scenario. It is also possible to compare the variations in alternative rank orders due to criteria weights.

Table 5.10 Ranking of alternatives with different criteria weights under the BAU scenario

Alternative	**EW**	**CW**	**SDW**	**MW**	W_{ENV}	W_{SOC}	W_{ECO}
A0	8,8,8	8,8,8	8,8,8	8,8,8	7,7,7	8,8,8	5,5,5
A1	6,6,6	6,6,6	6,6,6	6,6,6	4,4,4	5,5,5	1,1,1
A2	7,7,7	7,7,7	7,7,7	7,7,7	8,8,8	7,7,7	6,6,6
A3	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	7,7,7
A4	4,4,4	4,4,4	4,4,4	4,4,4	5,5,5	4,4,4	3,4,4
A5	5,5,5	5,5,5	5,5,5	5,5,5	6,6,6	6,6,6	2,2,2
A6	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	8,8,8
A7	3,3,3	3,3,3	3,3,3	3,3,3	3,3,3	3,3,3	4,3,3

If we consider EW, CW, SDW and MW, A3 is identified as the most preferred alternative for all MCDM methods, followed by A6 and A7. The worst alternatives are A0, A2 and A5, which is easy to see by reviewing the data in Table 5.1. Although the subjective weights, W_{ENV} and W_{SOC}, have similar ranks, this is not true for W_{ECO}, in which significant weight is assigned on B/C. A1 and A5 alternatives are identified as the most preferred alternatives according to the DM who is concerned with economic criteria, while the alternatives including the drip irrigation method (A3 and A6) appear to be the worst. Similar results are obtained when the optimistic conditions are considered (Table 5.11).

Table 5.11 Ranking of alternatives with different criteria weights under the OPT scenario

Alternative	**EW**	**CW**	**SDW**	**MW**	**W_{ENV}**	**W_{SOC}**	**W_{ECO}**
A0	8,8,8	8,8,8	8,8,8	8,8,8	8,8,8	8,8,8	5,5,6
A1	6,6,6	6,6,6	6,6,6	6,6,6	6,6,6	6,6,6	2,2,2
A2	7,7,7	7,7,7	7,7,7	7,7,7	7,7,7	7,7,7	6,6,5
A3	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	7,7,7
A4	3,3,3	3,3,3	3,3,3	4,3,3	4,4,4	4,4,4	4,4,4
A5	5,5,5	5,5,5	5,5,5	5,5,5	5,5,5	5,5,5	1,1,1
A6	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	8,8,8
A7	4,4,4	4,4,4	4,4,4	3,4,4	3,3,3	3,3,3	3,3,3

Regarding the pessimistic scenario, the rank of alternatives is, again, consistent with respect to not only the MCDM methods but also to criteria weights considered. The only noticeable difference is seen in the ranking obtained by W_{ECO}. If we consider the last column in Table 5.12, opposite to the previous results based on W_{ECO}, A0 and A2 alternatives are seen as the two worst alternatives, at least when TOPSIS and SAW methods are used. So, even if the DMs highly prioritize economic criteria, A0 (doing nothing) and A2 (crop pattern change) alternatives are seen as the two worst alternatives when the pessimistic scenario assumed.

Table 5.12 Ranking of alternatives with different criteria weights under the PES scenario

Alternative	EW	CW	SDW	MW	W_{ENV}	W_{SOC}	W_{ECO}
A0	7,7,7	7,7,7	7,7,7	8,7,7	8,8,8	8,8,8	6,8,8
A1	6,6,6	6,6,6	6,6,6	6,6,6	5,5,6	6,6,6	2,2,2
A2	8,8,8	8,8,8	8,8,8	7,8,8	7,7,7	7,7,7	5,7,7
A3	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	2,2,2	7,6,6
A4	4,4,4	4,4,4	4,4,4	4,4,4	6,6,5	4,4,4	4,4,4
A5	5,5,5	5,5,5	5,5,5	5,5,5	3,3,4	5,5,5	1,1,1
A6	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	1,1,1	8,5,5
A7	3,3,3	3,3,3	3,3,3	3,3,3	4,4,3	3,3,3	3,3,3

Following from the above discussions, the major results derived from the scenario analyses of possible hydro-meteorological variations in the Gediz River Basin and those evaluated on the basis of the proposed management alternatives can be summarized as the following:

1) The Basin is already under water stress and is also quite sensitive to drought conditions. If the pessimistic conditions, which lead to decreased water supply and increased water demand, occur, the resulting successive water deficits will significantly affect the agricultural sector. Moreover, even when the optimistic scenario is assumed to occur, it is not possible to observe a significant improvement in the water budget. Accordingly, efficient water management policies are crucial to solve water problems and to ensure sustainable development in the Gediz River Basin.

2) Considering environmental, social and economic sustainability, replacement of the water conveyance system by pressured lines coupled with the application of water saver technologies, such as drip irrigation methods, is determined as the most efficient and satisfactory management strategy for the Basin. With this strategy, it is not only possible to minimize the negative impacts of droughts, but also to stabilize or improve the current performance indicators.

3) According to the decision making process based on MCDM, the above recommended strategy should be supported further by additional measures, such as

crop change applications, even if the conditions are worse than expected, in other words, even when the pessimistic scenario occurs.

4) Since water transfer from Gordes Dam to Izmir is inevitable, the proposed alternative should be implemented as early as possible. This will ensure early benefits and will lead to economic investments.

5) Although they are easy and/or cheap, the traditional measures such as change of crop pattern and reduction of losses in the current water conveyance system are not considered as adequate and efficient responses for sustainable use of water resources.

6) The MCDM methods used in the study pinpoint the same alternative as the best choice. Thus, it is possible to say that the decision on the "best" alternative is basically independent of the MCDM method used, but it strictly depends on the weights assigned to the criteria as well as the data used in the analyses. Availability of accurate and adequate data is imperative for reliable and robust decisions.

CHAPTER SIX
CONCLUSION

In the study presented, a water resources management model that facilitates indicator-based decisions with respect to environmental, social and economic dimensions in a multiple criteria perspective is developed for the Gediz River Basin. The model has been applied under three different hydro-meteorological scenarios that reflect baseline as well as better and worse conditions of water supply and demand, not only to evaluate the impacts of proposed management alternatives under different conditions, but also to help the decision maker(s) make better informed choices for an uncertain future.

The results have indicated that the Gediz River Basin is quite sensitive to drought conditions, and the agricultural sector is significantly affected by irrigation deficits that increase sharply in drought periods. Even if the optimistic scenario is assumed to occur, it is not possible to observe a significant improvement in the water budget; however, the negative impacts of climate change can possibly exacerbate the water crisis. Therefore, efficient water management policies are crucial to ensure the sustainable use of water resources.

The maintenance of old open canals used in the water conveyance system and also crop pattern change applications are not considered as adequate measures for coping with water scarcity. The management alternative that combines the replacement of the current water distribution network by piped systems to decrease water losses and the use of 'water saver' technologies such as drip irrigation to improve irrigation efficiency is determined as 'best' alternative with respect to environmental, social and economic dimensions through the use of a multi criteria approach. It should be noted that the proposed alternative is the only way to overcome the water budget deficits under pessimistic conditions. It should also be the basic and long term policy for socio-economic development in the Gediz River Basin. On the other hand, the recommended alternative can increase the reliability of water supply for domestic and environmental uses and can reasonably decrease the risk of groundwater over exploitation.

The MCDM methods have identified the same rankings among the management alternatives when objective weights are assigned to the criteria. A different ranking is obtained only with the weight set which heavily prioritizes economic indicators. Hence, criteria weighting is a much more important process in decision making, and the use of the entropy method, which directly exploits the information contained in indicators, is recommended for robust and unbiased decisions. Equal weighting is also another method that is proposed for decision makers dealing with a large set of alternatives to minimize their efforts for the weighting procedure.

An interesting point achieved with case study is the remarkable consistency recognized between the current water management policies in the Gediz River Basin and the results of economy weighted analyses. In other words, canal maintenance is observed to be the most preferred alternative for both. This implies that a special emphasis is devoted to the cost of the alternative in real life applications. However, economic efficiency and environmental sustainability also need to be satisfied in management strategies. In this regard, the developed methodology is a valuable tool for the assessment of water resources systems and illustrates an efficient implementation of integrated water resources management approach for the Gediz River Basin. In particular, the WEAP model is a potentially useful tool for planning and management of water resources, and it provides a comprehensive, flexible and user friendly framework for evaluation of management strategies.

The approach presented in this study has been widely used in developed countries but has not yet been effectively implemented in other river basins of Turkey. It is recommended to increase the number of similar studies that will also incorporate groundwater resources, water quality, industrial and domestic water demand into the analyses provided that adequate data are available.

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