IMPACT OF LARGE-SCALE IRRIGATION ON A CLOSED BASIN WETLAND: WATER FLOW ALTERATIONS AND PARTICIPATORY IRRIGATION MANAGEMENT EFFECTS ON THE SULTAN MARSHES ECOSYSTEM IN TURKEY

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Patrick L. Brezonik, Heinz G. Stefan, Advisors

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ABSTRACT

This dissertation analyzes alterations in a closed-basin wetland system resulting from the construction of a large-scale irrigation project in its catchment. The study was conducted at the Sultan Marshes ecosystem (Develi Basin, Turkey), which has been severely degraded within the last 20 years due to diversion of its major water sources for agricultural irrigation.

Spatial changes in the Sultan Marshes from 1980 to 2003 were analyzed using satellite remote sensing. Changes in the areal coverages of lakes, marshes, agricultural, and steppe areas determined by unsupervised classification of four Landsat images showed that both lakes and marshes became smaller after construction of the irrigation project. Steppe areas expanded onto wetlands. Significant portion of northern (Kepir) marshes were converted to agriculture.

Hydrologic changes in the Sultan Marshes were analyzed statistically and used to develop a dynamic hydrologic model of the system. Water levels dropped more than one meter in the lakes and marshes from 1993 to 2003, and decreases were observed in ground-water levels and spring flows, although precipitation and evaporation rates remained mostly stable. Simulations with the hydrologic model showed that even if surface water continues to be used for irrigation, reductions in appropriations from ground water and springs would restore and protect water levels in the marshes.

Agricultural and environmental changes in the Develi Basin were analyzed after the irrigation management was transferred from state to “irrigation associations” in 1994. The analyses showed that irrigated areas and water use in the Develi Basin showed significant fluctuations. The area allocated to production of high water-consuming plants increased. Water fee collection rates were lower than 100%. Although soil and water quality in the Develi Basin did not change significantly, ground-water levels, flow rates from springs and water levels in the Sultan Marshes all dropped. Four recommendations were developed that would help to resolve the conflict between agricultural and wetland water requirements: (1) a basin-wide approach water planning, (2) more realistic water pricing, (3) demand-based irrigation scheduling, and (4) rehabilitation of the irrigation system.
Economic costs and benefits associated with water diversions from agriculture to the wetlands were estimated, and the optimum or economically-efficient amount of water diversion was determined. When only direct-use values of the wetland (reed cutting, animal grazing and ecotourism) were included, the annual optimum amount of water diversion to the wetlands was found to be 5.2 million m$^3$ yr$^{-1}$ (165 L s$^{-1}$) compared to about 62 million m$^3$ yr$^{-1}$ (1,957 L s$^{-1}$) used in irrigation. Diversion of 5.2 million m$^3$ yr$^{-1}$ water would be sufficient to restore the conditions in the marshes. The analysis showed that economically-efficient restoration of water levels in the Sultan Marshes is feasible with moderate amounts of water diversion.
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OVERVIEW

Wetland ecosystems provide many hydrologic, biological and ecological functions (Heimlich et al. 1998). They recharge/discharge ground water, maintain or improve water quality by sediment and nutrient retention, reduce erosion and floods by water storage, and provide habitat for numerous plant and animal species. They also regulate local climate and have important roles in carbon sequestration. Wetlands offer products for human use and opportunities for observation of nature.

Human activities have seriously affected wetlands in the twentieth century. More than 50% of the world’s wetlands have been lost since 1900s, and significant portions of the remaining wetlands have been seriously degraded (Mitsch and Gosselink 1993). Although wetland loss and degradation are caused by drainage, dredging, pollutant discharge, and grazing, socio-economic factors are often important determinants of wetland destruction. Therefore, wetland conservation is possible only if we understand both the physical processes responsible for the degradation of wetlands and the social and economic processes at the root of the degradation. This dissertation combines approaches from the physical and social sciences to improve our understanding of the nature and extent of alterations in wetlands and to explore measures that can mitigate adverse impacts.

Turkey is among the countries that have lost almost half of their original wetland areas during the last century (Özesmi and Özesmi 2001). The Sultan Marshes are the focus of the research described in this dissertation. Located at the center of the Develi Basin in central Anatolia, they are one of the most important wetland systems in Turkey. The marshes consist of two salt-water lakes (Yay and Çöl) and two freshwater wetlands (Örtülüüakar and Kepir) covering a total of 17,200 ha. The Sultan Marshes provide critical habitat for a variety of plant and animal species, including 301 species of birds (Karadeniz 2000). Two bird species (pygmy cormorant (Phalacrocorax pygmeus), and white-headed duck (Oxyura leucocephala)) that breed in the marshes were classified as endangered by the Council of Europe (Karadeniz 2000). The Sultan Marshes have been recognized for their significance in ecological conservation. They were first designated as a “Nature Conservation Area”, then as a “Ramsar Site” (Ramsar Convention on Wetlands
of International Importance especially as Waterfowl Habitat), and recently as a “National Park” by the Turkish Government. Despite this recognition, the Sultan Marshes have undergone a rapid degradation in recent years, particularly due to the construction of an irrigation project in their catchment. The Develi Irrigation Project, planned and constructed by the State Hydraulic Works (Devlet Su İşleri or DSI, in Turkish) to increase agricultural productivity and income in the region, has altered the natural hydrologic flow regime of the Sultan Marshes by diverting almost all the surface water inflows from wetlands to irrigation. Together with increased ground-water pumping, water diversion has caused more than a one-meter drop in water levels in the marshes and has caused alterations in the biological characteristics of the wetlands.

The five chapters in this dissertation examine the Sultan Marshes from several disciplinary perspectives and establish multi-disciplinary relationships. The multi-disciplinary tools and results are presented in the following order: remote sensing, i.e., information obtained by analysis of satellite imagery; hydrology, i.e., analysis of water availability based on climate and water use in the Develi Basin; socio-political analysis of water management in the Develi Basin; and economic analysis of the value of the Sultan Marshes.

Each chapter is written in the style of a separate paper, and each has been prepared for submission to an appropriate journal. Several chapters have been published or are “in press” already. An overview of the contents of these five chapters is as follows.

The first chapter analyzes spatial changes in the Sultan Marshes after the expansion of irrigated agriculture in their catchment. Satellite (Landsat) images from 1980, 1987, 2000, and 2003 were used in this analysis. An ‘unsupervised classification technique’ was devised and applied to transform the satellite images into five information (land-use) classes (water, marsh, agriculture, dry lake, and steppe), and a ‘post-classification change detection method’ was applied to identify observable changes. The analysis showed that after 1980 lake surface areas decreased by 93% and the marshes receded more than 50% in area from 1980 to 2003. Yay Lake, which covered 3,650 ha prior to the Develi Irrigation Project, was almost completely dry in 2003. Significant portions of the Kepir Marshes were converted to agriculture. Analysis of weather
conditions in the same years showed that the changes in the Sultan Marshes are extraordinarily large and cannot be attributed to fluctuations in weather.

Water diversions and increased use of ground water were considered the most likely causes of land-cover changes. The second and third chapters thus analyze observed changes in the hydrologic characteristics of the Sultan Marshes on a monthly timescale over a period of several years. In chapter 2, relationships between water-level changes in the marsh, and inflows and outflows of surface water and ground water are examined using graphical and statistical methods. In chapter 3, a dynamic hydrologic model is described for the Örtülüakar Marsh that quantifies changes in water budget components that have led to the observed changes in water levels. The model also was used to explore potential remediation options. Substantial declines in water levels were observed in the Sultan Marshes from 1993 to 2003. In the same time period, decreasing trends were observed in the ground-water levels and spring flow rates. Precipitation and evaporation rates, however, remained mostly stable. These results confirmed that decreases in surface and ground-water inflows to the Sultan Marshes are responsible for water level changes, rather than climatic factors. Simulations with the Örtülüakar Marsh hydrologic model showed that it is necessary to reduce water use from ground water and springs to maintain pre-1995 marsh water levels. A 50% reduction in ground-water and spring-water use for irrigation showed promising results for the Sultan Marshes. It may not be necessary to reduce surface water use for irrigation of farmland to save the Sultan Marshes if ground-water use is reduced.

In chapter 4, I explored how irrigation management in the Develi Basin has affected the extent of alterations in the Sultan Marshes. The participatory approach has become popular in irrigation management since the 1980s. Turkey is one of the first countries that implemented this approach. The Turkish government transferred management responsibilities of irrigation projects to farmers, who mostly are organized as “irrigation associations”. In this chapter, I show the contradictions between participatory irrigation management and wetland conservation in watershed basins, like the Develi Basin, where both irrigated agriculture and wetlands compete for a limited amount of water. I evaluated the practices of the Kovalı and Ağcaasår Irrigation
Associations (which have been responsible for management of the Develi Irrigation Project since 1995) and analyzed the agricultural and environmental changes after irrigation management was transferred from the government to the associations. Data for these analyses were obtained by interviews with farmers and irrigation association officials and reports prepared by DSI and irrigation associations. The analyses showed that irrigated areas and water use in the Develi Basin were not stable; i.e., they showed significant fluctuations from 1995 to 2003. The area allocated to production of high water-consuming plants, such as fruits, increased, while the area allocated to low-water consuming plants, such as cereals and legumes, decreased. Successful maintenance of irrigation canals has become dependent on water fee collection rates, but water fee collection rates have been much lower than 100%. Although soil and water quality in the Develi Basin have not changed significantly, ground-water levels, flow rates from springs and water levels in the Sultan Marshes have all dropped. Based on the analysis of the data, I developed four recommendations that the irrigation associations and the government could adopt to increase the efficiency of agricultural water use and simultaneously meet basic water requirements of the Sultan Marshes on a sustainable basis: (1) adopt a basin-wide approach in water planning, (2) develop a more realistic water pricing structure, (3) practice demand-based irrigation scheduling, and (4) in the longer term, rehabilitate the irrigation system.

In chapter 5, I analyzed how economic benefits from agricultural crops and simultaneously from the wetlands would be affected if limited amounts of surface water were diverted from agricultural use back to the wetlands in the Develi Basin. Only direct economic benefits (i.e., reed cutting, animal grazing, ecotourism) and one major indirect benefit (wastewater assimilation/treatment) provided by the Sultan Marshes were included in the analysis. Total and marginal costs and benefits associated with water diversions were estimated (Table 1). The optimum or economically-efficient amount of water diversion was determined as the point where marginal costs became equal to marginal benefits. When only direct-use values of the wetland were included, the annual optimum amount of water diversion to the wetlands was found to be 5.2 million m³ yr⁻¹ (165 L s⁻¹) compared to about 62 million m³ yr⁻¹ (1,957 L s⁻¹) used in irrigation.
Diversion of 5.2 million m$^3$ yr$^{-1}$ water would be sufficient to restore the conditions in the marshes. When wastewater treatment benefits were added, the amount rose to 7 million m$^3$. The economic analyses showed overall that economically-efficient restoration of water levels in the Sultan Marshes is feasible with moderate amounts of water diversion/restoration compared to water use for irrigation.

**Table 1. Total and marginal costs and benefits associated with water restoration/diversions to the Sultan Marshes. (All values are in millions per year)**

<table>
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<tr>
<th>Annual Water Diversion (m$^3$ yr$^{-1}$)</th>
<th>Agricultural Costs (USD yr$^{-1}$)</th>
<th>Wetland Benefits (USD yr$^{-1}$)</th>
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</table>

Overall the analyses conducted in this dissertation showed that the Sultan Marshes have been negatively affected by expansion of the irrigated agriculture in their catchment. Although a government agency (DSI) carried out the Develi Irrigation Projects, local support from affected villagers was apparent. Both the state and most of the rural people preferred short-term economic welfare resulting from increased agricultural production to long-term natural resource sustainability. However, hydrologic analyses and modeling, supported by social and economic analyses conducted in this dissertation, show that Sultan Marshes can be restored hydrologically and economically with only moderate changes in water management policies and practices. Development of a basin-wide water planning approach that incorporates the required moderate wetland water allocation into
the planning process, and increasing the efficiency of agricultural water use by pricing and water allocation can ensure that the Sultan Marshes can fulfill its functions, which are themselves of significant economic value to the region. These actions also can assure that the Sultan Marshes remains a sustainable, functioning wildlife habitat and Turkish National Park in the future.

LITERATURE CITED


CHAPTER 1 : CHANGES IN THE SULTAN MARSHES ECOSYSTEM (TURKEY) IN SATELLITE IMAGES 1980 – 2003

ABSTRACT

Sultan Marshes, an important ecosystem and wildlife refuge in the Develi Basin in Turkey, originally included two lakes and two freshwater marshes, with a total surface area of 176 km², surrounded by wet meadows and salt steppes. The Develi Irrigation Project changed the Sultan Marshes severely starting in 1988 by diverting surface and ground-water flows from the wetlands. Water diversions caused more than 1 m decline in water levels in the lakes and marshes. Spatial changes in the Sultan Marshes ecosystem with time were analyzed using Landsat images from 1980, 1987, 2000, and 2003 that were transformed into five information classes (water, marsh, agriculture, dry lake, and steppe) by unsupervised classification. Changes were identified by a post-classification change detection method. Classification accuracies were 89% to 93%, and accuracies of the change maps were 80% to 85%. The analysis showed that lake surface areas decreased by 93% from 1980 to 2003. Yay Lake was almost completely dry in 2003. The marshes receded more than 50%, and the surrounding steppe expanded into the lakes and marshes. Agriculture expanded in the western and eastern parts (Kepir Marshes) of the study area. Although the years 2000 and 2003 had lower than average annual precipitation, and lower annual precipitation than in 1980 and 1987, the changes in Sultan Marshes are so large that they cannot be solely attributed to weather fluctuations. Surface water diversions and increased use of spring waters and ground water are responsible for the changes.

Key Words: ecosystems, hydrology, irrigation, Landsat, water, wetlands, Sultan Marshes

INTRODUCTION

Sultan Marshes is a wetland ecosystem located at the center of the Develi Basin, in Central Anatolia, Turkey (Figure 1.1). It is one of the twelve Ramsar Sites in Turkey according to the “Ramsar Convention on Wetlands of International Importance” (an
intergovernmental treaty signed in 1971 for the conservation of wetlands). Sultan Marshes was recently declared a National Park by the Turkish government. Sultan Marshes consists of two salt-water lakes (Yay Lake and Çöl Lake) and two freshwater marshes (Örtülüakar and Kepir Marshes), which in 1980 covered an area of 176 km². The lakes and marshes are surrounded by wet meadows, salt steppes, and agricultural areas (Figure 1.1). Sultan Marshes is a critical habitat for a variety of plant and animal species, including 301 species of birds (Karadeniz 2000). It is located on two bird migration routes connecting Europe and Asia to Africa. Two bird species, pygmy cormorant (Phalacrocorax pygmeus) and white-headed duck (Oxyura leucocephala), classified as endangered by the Council of Europe breed in these marshes (Karadeniz 2000).

Major changes have been observed in the Sultan Marshes in the last two decades. Hydrologic, physical, and biological characteristic of the marshes have been altered by a major irrigation project in the Develi Basin. The Develi Irrigation Project was designed and constructed by the Turkish government through the State Hydraulic Works (in Turkish, Devlet Su İşleri or DSI) to the benefit of a farming population of about 17,000 people (2000 census). This project includes two major dams and over 250 km of principal irrigation canals to provide flood irrigation for 28,000 ha of farmland.

Prior to the Develi Irrigation Project, the Sultan Marshes were fed by water flowing from streams, springs, and ground water. Five small streams with a total average annual flow of 128 million m³ and five major springs with a total annual average flow of 40 million m³ were discharging most of their water into the wetlands — only a small portion of water was used in irrigation. After completion of the irrigation project in 1988, major streams feeding the Sultan Marshes were diverted into two reservoirs with water capacities of 62 million m³ and 25 million m³. Although no flow measurements are available to calculate the reduction in surface water flows to the Sultan Marshes, Özesmi and Gürer (2003) roughly estimated that the decrease was about 86 million m³ yr⁻¹. Ground water and springs have also been increasingly used for irrigation after 1988 as crop pattern changed to include more high water consuming varieties such as corn and orchards (Dadaser-Celik et al. 2008). Reductions in surface and ground-water flows
affected both the timing and the magnitude of peak water levels in the lakes and marshes (Figure 1.2). The lakes and marshes even became completely dry in some years (e.g., in 2003 shown on Figure 1.2). Bird populations declined by up to 90% compared with the period prior to 1985 (Kiziroğlu et al. 1992).

Figure 1.1. Location and elements of the Sultan Marshes ecosystem in the Central Anatolia, Turkey (modified after Paşaoğlu (1994)). Components of the Develi Irrigation Project are also shown.

Few studies have been conducted in the Sultan Marshes ecosystem. Earlier studies focused on the description of biological characteristics of the Sultan Marshes (e.g.,
Özesmi et al. 1993, Gürpınar 1994, Karadeniz 1995). These studies pointed to the risks posed by the Develi Irrigation Project on the Sultan Marshes, but they were mostly qualitative. Karadeniz (1995) developed strategies for the conservation of the Sultan Marshes based on analysis of the characteristics of the natural environment and human activities in the Develi Basin. She concluded that the Develi Irrigation Project threatened the sustainability of the Sultan Marshes ecosystem. More recently, Gürer (2004) analyzed hydrologic conditions in the Develi Basin and the Sultan Marshes and found significant ground-water use in the basin and increases in salinity and pollutants (fertilizers) in the marshes. Dadaser-Celik et al. (in press) quantified hydrologic relationships between water inflow and water loss from the Sultan Marshes and climatic variables (precipitation and pan evaporation), ground-water levels, and spring flow rates for the period 1993-2003. Water levels in the Sultan Marshes dropped about 1 m from 1993 to 2003. While pan evaporation and precipitation rates remained stable over the same period, decreases in ground-water levels and spring flow rates were also observed. Water levels in the marshes were found to be strongly correlated to ground-water levels and spring flows, but poorly correlated to precipitation and pan evaporation. Dadaser-Celik et al. (2006) also developed a hydrologic simulation model for the Örtülüakar Marsh (a subsystem of the Sultan Marshes) to examine the relationships between all water budget components and strategies for the restoration of a viable water balance for the Sultan Marshes ecosystem. The model simulated the 1997-2003 period, when a major drop in water levels was observed. The analysis showed that ground water constituted about 50% of the water inflow to the Örtülüakar Marsh during the 1997-2003 period. Spring flows constitute 22-37% of the water inflow, and 10-27% of water inflow was provided by precipitation. There was almost no surface water inflow to the Sultan Marshes during this period except for irrigation return, which was only 2-3% of water inflows. Almost all water losses from the Örtülüakar Marsh were through evapotranspiration. The analysis led to the conclusion that a 50% decrease in water use from ground water and springs is necessary and sufficient to restore the water levels in the marsh, while surface water is continued to be used in irrigation. All previous studies agreed that large changes were observed in the hydrologic, chemical, and physical characteristics of the Sultan Marshes ecosystem, but
the spatial changes have yet to be characterized and quantified. Data limitations, particularly lack of historical hydrologic and climatic data, have prevented the study of the changes in a longer time frame. There also is uncertainty regarding the base condition of the Sultan Marshes; i.e., the condition of the wetland before major human impacts is not clearly defined.

Figure 1.2. Water levels in the Örtülüakar Marsh (A) and Yay Lake (B) in 1993, 1998, and 2003. The locations of the marsh and lake relative to the irrigation project are shown in Figure 1.1. Water levels declined about 1 m from 1993 to 2003.

In this study, my goal was to determine the physical changes in the Sultan Marshes in order to understand better how wetlands responded to flow alterations. The analysis covers the period 1980-2003. Because historical information related to the Sultan Marshes is very limited or unavailable, I used four Landsat images (Figure 1.3A) to identify changes in the lakes and marshes within the Sultan Marshes and surrounding steppe areas. Satellite imagery provided the potential to determine the magnitude of the changes, their areal extent, and spatial patterns (Zainal et al. 1993).
Figure 1.3. (A) Sultan Marshes in Landsat images (1980-2003) (B) Study area on Landsat ETM+ image acquired in June 2000.

BACKGROUND

Landsat imagery has been acquired repetitively since 1972. When historical information is unavailable, satellite imagery provides an opportunity to identify past land surface conditions and to follow changes over time (Hollis 1990). The digital format and large spatial coverage of such images provides a cost- and time-effective method for studying large wetlands.

Satellite imagery has been employed in wetland studies for inventory, classification and monitoring purposes (Özesmi and Bauer 2002). Wetland inventory and delineation are common objectives for using satellite images in wetland studies (e.g., Lee and Lunetta 1995, Lunetta and Balogh 1999, Lyon 2001). Frazier and Page (2000)
examined different classification methods to detect and delineate wetlands using Landsat MSS (Multispectral Scanner) and Landsat TM (Thematic Mapper) images. They concluded that the density slicing of Band 5 of Landsat TM images provides the best discrimination of water and non-water areas. Landsat images also have proven useful for monitoring wetlands and detecting changes over time (e.g., Zainal et al. 1993, Jensen et al. 1995, Haack 1996, Elvidge et al. 1998, and Munyati 2000). In this study, I analyzed changes in surface area of the saline lakes, freshwater marshes, and surrounding steppe areas of the Sultan Marshes wetland ecosystem from 1980 to 2003.

In change detection studies it is preferable to acquire images from the same sensor to minimize errors originating from spatial, spectral, and radiometric differences (Jensen 2005). In this study, however, I use Landsat MSS, TM, and ETM+ images. Even though other differences exist between MSS, TM, and ETM+ operating parameters, the most important to this study are spectral and spatial resolutions. Landsat MSS imagery has four multispectral bands compared to six multispectral bands and one thermal band in Landsat TM and ETM+ images. Landsat MSS images have a spatial resolution of 80 m, and Landsat TM and ETM+ images have spatial resolutions of 30 m (multispectral bands). Sensor characteristics can affect the accuracy of classifications and change detection. Sub-pixel mixing of signals from different cover types is a major problem in classifications of Landsat MSS images because of their lower spatial resolutions (Maingi and Marsh 2001). Capture of narrow wetland patches is particularly difficult when the images with lower spatial resolutions are used (Özesmi and Bauer 2002). The most important spectral range for wetland identification (i.e., 1.55-1.75 or Band 5 in Landsat TM/ETM+) (Özesmi and Bauer 2002) is not available in Landsat MSS imagery. Despite their differences, the use of images from different sensors is common in change detection studies particularly when earlier dates of images are needed. Although Landsat MSS images became available in 1972, Landsat TM and ETM+ images have been recorded only since 1982 and 1999, respectively. Previous studies which used datasets consisting of MSS, TM, ETM+ images showed that images from different sensors can be used in change detection studies with sufficient success (e.g., Munyati 1999, Tømmervik 2003).
Pre-classification and post-classification algorithms can be employed for detecting changes with satellite imagery. Pre-classification approach identifies the changes on a pixel-by-pixel basis using methods such as composite analysis, image differencing, principal component analysis, change vector analysis or spectral mixture analysis (Lunetta 1999). Post-classification approach requires independent classifications of images, followed by pixel-by-pixel comparison. Both methods have advantages and shortcomings. Post-classification approach minimizes the need for radiometric normalization and provide “from-to” change information (Lunetta 1999). On the other hand, the accuracy of the post classification comparisons is dependent on the accuracies of individual classifications (Singh 1989). Although the method used for change detection can significantly affect the results, a recent review of the previous literature showed that the choice was often driven by the characteristics and requirements of the study (Coppin et al. 2004).

**STUDY AREA**

The study area is shown in the Landsat image in Figure 1.3B. The study area was delineated by including the area surrounded by major irrigation and drainage channels and roads, and excluding the areas used for human settlement. The 388 km² study area includes open water, emergent marshes, dry lakes, steppes, and agricultural land. It is surrounded by large agricultural areas to the west, south, and southeast. Akköy, Kovalı, and Ağcaşar Reservoirs provide much of the surface water for irrigation of the farmland around the marshes. The two reservoirs are seen on the western and southeastern sides of Figure 1.3B, respectively, and a third reservoir, Kovalı Reservoir, is at the southwestern fringe.

The Sultan Marshes consist of four interconnected water systems (Figure 1.1). Yay Lake, located at the center of the study area, is a brackish water lake that had a depth of 0.4 to 1.5 m prior to the irrigation project. Saline Çöl Lake lies to the northwest of Yay Lake. The water level of Çöl Lake rose by up to 0.5 m in spring and dried up in summer prior to the project. Both Yay Lake and Çöl Lake have been almost dry since 1993. Two freshwater marshes, the Örtülüakar Marshes and Kepir Marshes (significant portion of
which was converted to agriculture in 1950s), lie to the south and northeast of Yay Lake, respectively. The marshes and lakes are surrounded by wet meadows and salt steppes. The total surface area of the Sultan Marshes was about 172 km\(^2\) but it expanded up to 200 km\(^2\) in wet years (Magnin and Yarar 1997). The Örtülüakar and Kepir Marshes are covered with reed communities (*Phragmites australis*). Several small ponds (< 0.01 km\(^2\)) lie within the Örtülüakar Marshes. Myriophyllum is the dominant submerged vegetation in the pond bottoms (Akçakaya et al. 1983). *Carex, Cyperus, Typha, Juncus,* and *Scirpus* also are found in the Kepir Marshes and northern side of Örtülüakar Marshes (Karadeniz 1995). Surrounding seasonally inundated areas support a variety of emergent plant species: *Carex, Consolida, Cynodon, Polygonum, Ranunculus, Rumex, Ceratophyllum, Chara, Potamegeton,* and *Utricularia* (Akçakaya et al. 1983). On the steppe areas around Yay and Çöl Lakes, salt-tolerant vegetation (*Salicornia* (dominant), *Alhagi, Lepidium, Limonium, Salsola, Astragalus,* and *Cynodon*) can be observed (Akçakaya et al. 1983). Agriculture is the main economic activity in the Develi Basin and includes both crop and fruit production. Major crops include cereals, beans, sugar beets, sunflower and maize.

**METHODS**

I followed four steps to analyze changes using Landsat images: 1) image acquisition, 2) preprocessing (geometric and radiometric), 3) application of a change detection algorithm, and 4) accuracy assessment. I also analyzed weather data from a nearby station to identify climatic conditions at the time of image acquisition.

**Image Acquisition**

The study area is entirely contained within Landsat path 33, row 175. Four cloud-free, late-spring/early summer Landsat images were acquired to monitor changes in the Sultan Marshes (Figure 1.3A). Water levels in the Sultan Marshes are highest during that period (Figure 1.2), and thus spring/summer images provide the most contrast between wetland and upland areas (see also Jensen et al. (1995)).

In this study, images from different sensors were used to obtain data from the earliest dates and with the highest spatial, spectral, and radiometric resolutions possible.
Images used in this study included a Landsat MSS image acquired on 13 June 1980, a Landsat TM image acquired on 7 July 1987, and two Landsat ETM+ (Enhanced Thematic Mapper Plus) images acquired on 13 June 2000 and 5 May 2003. The earliest (1980) and the latest (2003) images shown in Figure 1.3A show striking differences in areal coverage of wetlands. The irrigation project in the Develi Basin began operations in 1988. The 1980 and 1987 images thus represent conditions before the irrigation project, and the 2000 and 2003 images represent conditions after the irrigation project was underway.

**Image Preprocessing**

All images except the 1980 image were rectified to the Universal Transverse Mercator (UTM), Zone 36 projection (WGS84 spheroid) using at least 30 well-distributed ground control points consisting of road and irrigation/drainage canal intersections. Most of the nearest roads and irrigation/drainage channels were not present on the 1980 image, and other ground-control points could not be identified. The 1980 image was therefore registered to the 2000 image using AutoSync function in ERDAS Imagine, version 9.1. A nearest neighbor algorithm was used for resampling of all images to retain original pixel values. The root mean square errors in image rectification were less than 0.25 pixel (7.5 m) for all four images.

**Image Classifications and Change Detection**

An unsupervised classification algorithm using the ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering method was used to classify the images (Tou and Gonzales 1974). Unsupervised classification (i.e., no a priori training required) provided the best approach for this study, due to the lack of historical reference data for the area of interest. ISODATA clustering identifies spectral clusters from Landsat data using a minimum spectral distance to assign a cluster for each candidate pixel. The analyst-assigned variable of the number of classes (clusters) is the most important input into the ISODATA algorithm. The number of classes affects the capture of spectral-radiometric variability and provides more homogeneous classes (Yang and Lo 2002). A
large number of classes, however, can increase the time required to assign initial classes to appropriate information classes.

In this study, the images were classified initially into 150 classes that then were assigned into one of the five classes (water, marsh, dry lake, steppe, agriculture) (Table 1.1). During class assignment, signature characteristics were examined using signature mean plots and location of the classes in the feature space. Plots of Band 3 versus Band 5 and Band 4 versus Band 5 provided the most discrimination among the classes for Landsat TM and ETM+ images. This was consistent with Frazier and Page’s (2000) study, which indicated that density slicing of Band 5 in Landsat TM provided the best discrimination between water and non-water classes. The plot of Band 2 versus Band 4 was helpful in classification of the Landsat MSS image. During class labeling information from the original images and the knowledge of the study area was used.

Table 1.1. Information classes and their descriptions.

<table>
<thead>
<tr>
<th>Information Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Open water such as lakes or ponds</td>
</tr>
<tr>
<td>Marsh</td>
<td>Marsh with <em>Phragmites, Juncus</em> and <em>Scirpus</em> as dominant species, drainage canals covered with vegetation and wet meadows</td>
</tr>
<tr>
<td>Dry Lake</td>
<td>Dry lake bottom with no vegetation cover</td>
</tr>
<tr>
<td>Steppe</td>
<td>Sparse pasture and shrub land where majority of the cover is barren soil</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Crop fields, orchards and poplar fields</td>
</tr>
</tbody>
</table>

Post classification processes were applied to reduce classification errors between 1) agriculture and wetland and 2) agriculture and steppe classes. Agricultural areas and marshes were easily recognizable from the images because of their distinct patterns.
Therefore, pixels classified as agriculture within marshes and pixels classified as marsh within agricultural areas were reclassified into marsh and agriculture classes, respectively. The agricultural areas were also digitized from the images and reclassified areas classified as steppe within these areas into the agriculture class. Finally single pixels classified as agriculture within steppe areas, which created a “salt and pepper effect”, were reclassified. The mixing between agriculture and other classes was most probably due to the time of the year the images were acquired. In spring/early summer, crops do not yet fully cover the soil. Therefore signatures from agricultural areas include the signatures of bare soil, which are similar to signatures for steppe areas with sparse vegetation cover. The mixing between agriculture and wetland classes is probably due to the overlap of wetland and agricultural area signatures (Özesmi and Bauer 2002).

After post classification processes, areal coverages for all classes were determined for each image and then compared with each other. The changes between two successive images (e.g., 1980 and 1987) and between 1980 and 2003 were identified using a post-classification change detection algorithm. I selected this approach because I wanted to obtain from-to change information. Post classification change detection approach also reduced the problems originating from the use of images from different sensors. In the change detection step, agriculture and steppe classes were combined to make a new class called steppe/agriculture because agriculture was only a small part of the study area and was highly mixed with other classes.

**Accuracy Assessment of Individual Classifications**

The accuracy of the classifications was analyzed using 150 random points. Points were selected using stratified sampling (the images were stratified based on 150 classes) by taking at least 20 points from each class. Reference data were extracted from the images. I also collected ground reference information for the 2003 image in summer 2005. Two hundred sites initially were selected using a stratified sampling strategy; the sampling scheme was revised in the field because of difficulties in reaching some sampling points. A total of 157 points were collected. These data were used to test the accuracy of the 2003 classification.
A standard error matrix (confusion matrix), which reported producer’s, user’s, and overall classification accuracies, and Kappa chance correction statistic were prepared for each image to determine the accuracy of the classifications (Congalton and Green 1999). Producer’s accuracy of a class was calculated as the ratio of correctly classified pixels to the total pixels assigned to that class in the reference data. User’s accuracy of a class was calculated as the ratio of correctly classified pixels to the total pixels assigned to that class in the classified map. Overall accuracy is the ratio of correctly classified pixels to the total pixels in the images. The Kappa statistic measures the agreement between classified image and reference data. Accuracies of the change maps were estimated by multiplying the accuracies of the individual classifications (Lunetta 1999).

Analysis of Climate Data

Precipitation and pan evaporation data for the study area were obtained from the DSI. The trends in precipitation and pan evaporation data from 1974 to 2003 were analyzed and precipitation and pan evaporation rates for years 1980, 1987, 2000, and 2003 were calculated.

RESULTS

Classification Accuracy

Overall accuracies of the 1980, 1987, 2000, and 2003 classifications (using reference data from the images) were 90%, 89%, 93%, and 91%, respectively (Table 1.2). Producer’s and user’s accuracies of individual classes ranged from 77% to 100%. Kappa statistic values for the same classifications were 0.87, 0.86, 0.91, and 0.88, respectively. The accuracy of the 2003 classification calculated using ground reference information was 88%, which is very close to the classification accuracy calculated using 150 random points and the image as the reference data source.

Post classification processing significantly affected the accuracy of agriculture and wetland classes and overall accuracies of the classifications. Overall accuracies of the classifications increased between 4% and 9% (Table 1.2), while producer’s and user’s accuracies of the agriculture class increased up to 72% and 30% and those of the wetland
class increased up to 8% and 11%, respectively. There was a significant change in the accuracies of the agriculture class after post-processing because of the mixing between agriculture and other classes, explained earlier. Multiplication of accuracies of individual classifications provided overall accuracies of 80%, 83%, and 85% for the for the change maps for the periods 1980-1987, 1987-2001, 2001-2003, respectively, and 82% for the 1980-2003 change map.

**Analysis of Individual Classification and Changes**

Areal coverage of individual land-cover classes in 1980, 1987, 2000, and 2003 is shown graphically in Figure 1.4 and numerically in Table 1.3. The percent changes between successive years and from 1980 to 2003 are presented in Tables 1.4 and 1.5, respectively. Agriculture expanded by 9 km2 or 82% in the study area from 1980 to 2003. Expansion was mostly in the western and eastern parts of the study area. Agricultural areas in the southern and southeastern parts remained more or less the same. Although the study area covers only a small portion of the agricultural areas in the Develi Basin (less than 1%), the change in the eastern part (Kepir Marshes) is worth mentioning. The major reason for expansion on this side is the drainage of Kepir Marshes for conversion to agriculture in 1950s. The areas converted to agriculture in the Kepir (northern) Marshes can be seen clearly in Figure 1.3 from the year 2000 by their mostly rectangular patterns. In other years (1980, 1987, 2000), probably because of temporary wetting of these areas, they were classified as marsh.
Table 1.2. Producer’s, user’s and overall accuracies (%) and Kappa statistics for the 1980, 1987, 2000, and 2003 classifications.

<table>
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<tbody>
<tr>
<td></td>
<td>Producer’s</td>
<td>User’s</td>
<td>Producer’s</td>
<td>User’s</td>
</tr>
<tr>
<td>Water</td>
<td>96</td>
<td>86</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>Marsh</td>
<td>85</td>
<td>100</td>
<td>84</td>
<td>93</td>
</tr>
<tr>
<td>Dry Lake</td>
<td>94</td>
<td>77</td>
<td>100</td>
<td>83</td>
</tr>
<tr>
<td>Steppe</td>
<td>89</td>
<td>89</td>
<td>91</td>
<td>89</td>
</tr>
<tr>
<td>Agriculture</td>
<td>91</td>
<td>95</td>
<td>76</td>
<td>80</td>
</tr>
<tr>
<td>Overall accuracy</td>
<td>90</td>
<td>89</td>
<td>93</td>
<td>91</td>
</tr>
<tr>
<td>Overall accuracy before post processing</td>
<td>86</td>
<td>81</td>
<td>89</td>
<td>86</td>
</tr>
<tr>
<td>Overall Kappa statistics</td>
<td>0.87</td>
<td>0.86</td>
<td>0.91</td>
<td>0.88</td>
</tr>
</tbody>
</table>
According to the land-cover classification results (Tables 1.3-1.5), the areal coverage of water and marsh decreased from 1980 to 2003, while areal coverage of dry lake increased. Water surface area decreased by 58 km² (94%), and marsh surface area decreased by 60 km² (53%). Dry lake area increased by 30 km² or 136%. The changes in water surface and dry lake area can be attributed mostly to the drying of the major water body, Yay Lake, in 2003. A total of 34 km² of water surface in 1980 were converted to dry lake area in 2003, and only 2 km² remained as water surface (Table 1.5). Another 21 km² were converted to steppe/agriculture, and 5 km² of water surface area appeared to be converted to marsh (Table 1.5). This can be due to the drying out of vegetated water bodies. The decrease in marsh area (Figure 1.5) is due mainly to recession of Örtülüakar Marsh and conversion of portions of Kepir Marsh to agriculture. Örtülüakar Marsh became smaller from 1980 to 2003 (Figure 1.5), due to the conversion of emergent vegetation to steppe vegetation; 66 km² of marsh area were converted to steppe/agriculture (Table 1.5). In addition, 2 km² of marsh area in 1980 were classified as water in 2003, and 1 km² of marsh area in 1980 was classified as dry lake (Table 1.5).

Table 1.3. Areas (km²) of individual land-cover classes in 1980, 1987, 2000 and 2003.

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<tbody>
<tr>
<td></td>
<td>Area</td>
<td>%</td>
<td>Area</td>
<td>%</td>
</tr>
<tr>
<td>Water</td>
<td>62</td>
<td>16</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>Marsh</td>
<td>114</td>
<td>29</td>
<td>74</td>
<td>19</td>
</tr>
<tr>
<td>Dry Lake</td>
<td>22</td>
<td>6</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>Steppe</td>
<td>179</td>
<td>46</td>
<td>230</td>
<td>59</td>
</tr>
<tr>
<td>Agriculture</td>
<td>11</td>
<td>3</td>
<td>17</td>
<td>4</td>
</tr>
</tbody>
</table>
Figure 1.4. Land-cover classifications in 1980, 1987, 2000, and 2003.
Table 1.4. Percentage change in area of land-cover classes in successive periods between 1980 and 2003.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>-43</td>
<td>-26</td>
<td>-85</td>
<td>-94</td>
</tr>
<tr>
<td>Marsh</td>
<td>-35</td>
<td>-30</td>
<td>4</td>
<td>-53</td>
</tr>
<tr>
<td>Dry Lake</td>
<td>45</td>
<td>0</td>
<td>63</td>
<td>136</td>
</tr>
<tr>
<td>Steppe</td>
<td>28</td>
<td>8</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>Agriculture</td>
<td>55</td>
<td>82</td>
<td>-35</td>
<td>82</td>
</tr>
</tbody>
</table>

Table 1.5. “From-to” changes (km²) in the Sultan Marshes from 1980 to 2003.

<table>
<thead>
<tr>
<th></th>
<th>1980 to 1987</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1980</td>
<td>1987</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>33</td>
<td>2</td>
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<tr>
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<tr>
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<td>5</td>
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<tr>
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<tr>
<td>Total</td>
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<td>247</td>
<td>32</td>
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<td>42</td>
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<td>74</td>
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<td>7</td>
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<tr>
<td>Water</td>
<td>25</td>
<td>52</td>
<td>279</td>
<td>32</td>
<td>388</td>
</tr>
</tbody>
</table>
These minor changes may reflect classification errors. The small ponds in the Örtülüakar Marsh were classified as marsh areas in the 1980 classification, but as water (lake) or dry lake areas in the 2003 classification. Nine km² of dry lake in 1980 were converted to steppe/agriculture probably due to expansion of steppe vegetation towards the lake (Table 1.5).

Steppe increased by 79 km² or 44% from 1980 to 2003. The increase in steppe is mainly due to the recession of Örtülüakar Marsh. Four km² of steppe/agriculture apparently were converted to marsh (Table 1.5); but this result may be due to classification errors. In 2003, temporary wetting of agricultural areas caused agricultural fields to appear as marsh.

<table>
<thead>
<tr>
<th></th>
<th>1980</th>
<th>2003</th>
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<tbody>
<tr>
<td>Water</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Marsh</td>
<td>1</td>
<td>45</td>
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<td>0</td>
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<tr>
<td>Total</td>
<td>4</td>
<td>54</td>
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<table>
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<tr>
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<tr>
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<td>Dry Lake</td>
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<td>0</td>
</tr>
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<td>Total</td>
<td>4</td>
<td>54</td>
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</tbody>
</table>

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Figure 1.5. Change in the extent of Örtülüakar Marsh from 1980 to 2003.

RELATIONSHIP BETWEEN WETLAND CHANGES AND CLIMATE/WEATHER

Wetland ecosystems are dynamic hydrologic systems, and weather changes can cause seasonal and annual fluctuations in water levels (Mitsch and Gosselink 1993). I conducted an analysis to determine whether the large areal declines in marshes and lakes of Sultan Marshes from 1980 to 2003 found from the Landsat images could be attributed to observed weather variations or climate change.

Analysis of precipitation records from the Musahacılı weather station for the period 1974-2003 showed that annual precipitation had an average of 294 mm yr-1 with a negligible decreasing trend of -0.0715 mm yr-1 (Figure 1.6). The Musahacılı climate station is the closest station to the Sultan Marshes and also has the longest weather records in the region. The periods 1986-1988 and 1991-1993 were exceptionally wet periods, followed by exceptionally dry years (1989-1990 and 1994). In all other years, precipitation was approximately average (Figure 1.6).
Pan evaporation from May to September (months with the highest evaporation rates) showed a decreasing trend of -16.2 mm yr⁻¹ for the same period (1974-2003). Average pan evaporation for May-September was 1059 mm (Figure 1.6). As a first step in the analysis I compared precipitation and evaporation data for the four years for which Landsat images were analyzed. Precipitation and pan evaporation values deviated somewhat from average values in the years included in this study. The last two years (2000 and 2003) had lower than average annual precipitation, but also lost substantially less water than the annual average amount by evaporation (Table 1.6). With a pan coefficient of 0.6, the balance between precipitation and evaporation comes out in favor of higher-than-average water availability for these years (Table 1.6). Therefore, the years 2000 and 2003 cannot be considered exceptionally dry. In the first year (1980), when pan evaporation was highest, the balance between precipitation and evaporation comes out in favor of less than average water availability. This means that 1980 cannot be considered an exceptionally wet year. These results suggest that water availability, as defined in terms of the difference between precipitation and evaporation, did not decrease from 1980 to 2003.
Table 1.6. Precipitation and evaporation data and water availability for an average year and for years 1980, 1987, 2000, and 2003. Pan coefficient (the fraction of pan measured evaporation that actually was evaporated from the water surface) was accepted to be 0.6.

<table>
<thead>
<tr>
<th>Years</th>
<th>Precipitation (1)</th>
<th>Pan Evaporation (2)</th>
<th>Actual Evaporation (3) = (2) * pan coefficient</th>
<th>Water Availability (4) = (1) – (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>294</td>
<td>1059</td>
<td>635</td>
<td>-341</td>
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<tr>
<td>1980</td>
<td>323</td>
<td>1291</td>
<td>775</td>
<td>-452</td>
</tr>
<tr>
<td>1987</td>
<td>473</td>
<td>932</td>
<td>560</td>
<td>-87</td>
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<tr>
<td>2000</td>
<td>296</td>
<td>954</td>
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<tr>
<td>2003</td>
<td>270</td>
<td>911</td>
<td>547</td>
<td>-277</td>
</tr>
</tbody>
</table>

Results from two previous investigations suggest that the changes in the Sultan Marshes derived from the Landsat images are not related to weather variations or climate change. I previously analyzed the relationships between hydrologic parameters in the Develi Basin and changes in the Sultan Marshes ecosystem for the 1993 to 2003 period, in which a rapid change in water levels was observed (Dadaser-Celik et al., in press). The results showed that precipitation and pan evaporation data were not correlated with the water levels in the Örtülüakar Marsh and in Yay Lake. Instead, ground-water levels and spring flow rates showed a strong correlation with water levels. These results suggest that after 1993 changes in surface and ground-water flows had more significant impacts on the hydrology of the Sultan Marshes ecosystem than climatic factors.

I also used a hydrologic model (Dadaser-Celik et al. 2006) to study the effect of increases or decreases in annual precipitation rates on the Sultan Marsh water levels. With this model, water levels in the Örtülüakar Marsh, a subsystem of the Sultan Marshes, were simulated for a seven-year period (1997-2003). Average precipitation for this time period was 284 mm, which is 4% lower than long-term average precipitation.
between 1974 and 2003. Three simulations, with 20%, 40% and 60% higher precipitation than actual values, were run. Results (Figure 1.7) show that water levels in the Örtülüakar Marsh would have dropped even if precipitation had been 60% higher than the observed value. This simulation result suggests that actually observed weather variations in the Develi Basin were not large enough to cause the decline in water levels in the marsh.

Figure 1.7. Water levels in the Örtülüakar Marsh simulated with 20%, 40% and 60% higher precipitation values than those of the base simulation (with observed precipitation).

**SUMMARY & CONCLUSIONS**

The land-cover changes in the Sultan Marshes ecosystem were analyzed using Landsat images for June 1980, July 1987, June 2000, and May 2003 and an unsupervised ISODATA classification method that classified surface areas to five information classes: lakes, marshes, steppes, dry lakes, and agriculture. The classified images were compared using a post-classification change detection algorithm. Although the post-classification change algorithm was the best approach, given the spatial, radiometric, and spectral differences between Landsat images used in this study, the errors in registration and
classification of the individual images and quality of the reference data affected the accuracy of the change maps. Accuracies of individual classifications were in the range of 89%-93%, but accuracies of the change maps were between 80% and 85%.

The results showed that both lakes and marshes became significantly smaller from 1980 to 2003. Yay Lake, where water levels had risen over 1 m prior to 1988, was completely dry in 2003. Örtülüakar Marsh lost almost 50% of its area. The Örtülüakar Marsh is an ecologically important subsystem of the Sultan Marshes and necessary to sustain large waterbird populations. Steppes expanded 44% from 1980 to 2003. The major changes in Yay Lake and the Örtülüakar Marsh are clearly evident in the Landsat images. Precipitation and evaporation records in the Sultan Marshes, and results from previous statistical and modeling studies indicate that variability in weather or climate change cannot be the cause of the observed changes in the Sultan Marshes. The changes are related to the intensification of irrigated agriculture in the Develi Basin, which has deprived the Sultan Marshes of its natural water source. Diversion of stream flows and increased use of ground water and spring flows have significantly reduced the amount of water reaching the marshes. A water allocation plan for the Sultan Marshes is urgently needed if the Sultan Marshes are to be saved as a Ramsar site and National Park. Other studies have shown that the amount of water required is moderate (Dadaser-Celik et al. 2006) and that the water allocation to the Sultan Marshes would not adversely affect crop yields from irrigated agriculture in the Develi Basin.

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CHAPTER 2 : HYDROLOGIC SUSTAINABILITY OF THE SULTAN MARSHES IN TURKEY

ABSTRACT

Hydrologic changes in the Sultan Marshes ecosystem, a closed-basin wetland in the semi-arid Develi Basin in south-central Turkey, are analyzed and related to intensification of irrigated agriculture in the catchment. Relationships between water-level changes in the marsh, and inflows and outflows of surface water and ground water are examined. Since the 1980s, surface runoff from the surrounding mountains into the Develi Basin has been captured in three major reservoirs and used for flood irrigation. Substantial declines in seasonally-fluctuating water levels were recorded in the Sultan Marshes from 1993 to 2003. The analysis shows that these trends are related to decreases in inflows from ground water and springs, not to climatic changes. Simulations with a deterministic hydrologic model for the Örtülüakar Marsh, a sub-system of the Sultan Marshes, as well as statistical analyses, showed that it is necessary to reduce water use from ground water and springs to maintain pre-1995 marsh water levels. Alternative ground-water management scenarios to sustain both the wetland and irrigated agriculture in the Develi Basin were tested. A 50% reduction in ground-water and spring-water use for irrigation showed promising results for the Sultan Marshes. Irrigation in the basin uses 66% surface water and 34% ground water. A 50% reduction in ground-water use for irrigation therefore represents less than 20% of total irrigation water used. Reduction in ground-water use is, however, linked to social and economic conditions in the Develi Basin, and incentives that encourage farmers to adopt sustainable ground-water use practices need to be developed.

Key Words: Environmental impact, irrigation, Sultan Marshes, sustainability, wetland, water allocation
INTRODUCTION

The Sultan Marshes, a closed basin wetland in Central Anatolia, Turkey (Figure 2.1), is one of twelve internationally important wetlands in Turkey (according to the “Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat”). It also was declared a “Nature Conservation Area” and recently a “National Park” by the Turkish Government. Sultan Marshes’ complex structure, consisting of interrelated fresh and salt-water ecosystems, has provided habitat for many organisms, including 25 species of mammals, 25 species of mollusks, 40 species of hymnoptera, 5 species of fish, 301 species of birds, and 125 species of algae (Karadeniz 2000).

Intensification of irrigated agriculture in the Develi Basin around the Sultan Marshes started in 1970s with a large-scale irrigation project financed and constructed by the Turkish State Hydraulic Works (DSI - Devlet Su İşleri). This project aimed to increase economic welfare in the region through irrigated agriculture. Many changes occurred in the Sultan Marshes after the project went into operation in 1988. The entire wetland dried up in 1990-1991 (Özesmi et al. 1993) and 2000-2001, an event not observed previously. Also, bird populations declined up to 90% compared with the period prior to 1985 (Kiziroğlu et al. 1992). In this study, I explored hydrologic alterations in the Sultan Marshes after the intensification of irrigated agriculture in its catchment. In addition to analyzing the water balance of the marshes, I also examined alternative water management scenarios that may reverse the impairment of the wetland.

Intensive agriculture, which is needed to feed ever-growing human populations, has well-known impacts on natural ecosystems, including wetlands. In developed countries, the deterioration of natural ecosystems due to agricultural practices occurred a long time ago, but it is continuing in developing countries, where governments and rural people prefer short-term economic welfare resulting from increased agricultural production to long-term natural resource sustainability.

Effects of irrigation and agriculture on wetlands have received considerable attention in recent years (Zalidis et al. 1997, Gerakis and Kalburtji 1998, Davis and Froend 1999, Sanz 1999, Lemly et al. 2000). Alterations in wetland hydrologic flow regimes and changes in biodiversity have been described (Kingsford and Thomas 1995,
Davis and Froend 1999), and changes in water quality including alterations in salinity or nutrient concentrations have been demonstrated (Portnoy 1999). Wetlands have become partially or completely dry due to changes in hydrologic flows (Davis and Froend 1999). Irrigation development has negatively affected wetland uses for ecotourism and plant harvesting, both of which can provide considerable income for local people (Hollis 1990, Thompson and Polet 2000).

Figure 2.1. Geographical setting of the Sultan Marshes ecosystem and water use elements of the Develi Irrigation Project (modified after Paşaoğlu 1994)

Sultan Marshes provides an example to examine the conflict between ecosystem conservation and irrigated agriculture. Changes have been observed in the Sultan Marshes in the last 15 years, but the factors leading to these changes have not been sufficiently explored, and the role of the irrigation project in causing these changes is still
unknown. The complexity of the hydrologic system and the limited availability of hydrologic and hydrogeologic data pose a challenge to characterize the past and present hydrology of the Sultan Marshes. In this study, I first analyzed available hydrologic and climatic data to identify and quantify relationships between wetland changes and these variables using graphical and statistical methods. I then developed a deterministic hydrologic simulation model for the Örtülüakar Marsh, a sub-system of the Sultan Marshes. The model was used to determine whether process-based hydrologic relationships led to the same conclusions as statistical analyses of hydrologic data. Because agreement was found, the model was used to test alternative water management scenarios for irrigation water use. My ultimate goal is to develop water management strategies that can contribute to the sustainability of both the wetland and irrigated agriculture in the Develi Basin.

**GEOGRAPHICAL AND HYDROLOGIC SETTING**

**Location**

Sultan Marshes (Sultan Sazlığı, *in Turkish*) is located in central Anatolia, southwest of the city of Kayseri (38.05-38.40 N, 35.00-35.35 E) (Figure 2.1). This complex wetland lies at the center of the Develi Basin. Develi Basin covers an area of about 800 km² and has a drainage area of 3190 km² (DSI 1995). Develi Basin is a semi-arid closed basin surrounded by hills and mountains that rise up to 3916 m. Average altitude of the basin is 1100 m; the lowest elevation is 1070 m at which Sultan Marshes is located. The human population in the basin is approximately 140,000 (2000 census), of which 23,000 people live in the region directly affected by the Develi Irrigation Project. Crop (cereals and sugar beets) and fruit production are the most important economic activities followed by animal husbandry and reed cutting.

**Climate**

The regional climate is continental with a mean annual temperature of 11°C and a large difference between summer and winter temperatures. Hottest months are July and August (maximum recorded daily temperature is 38°C), and coldest months are
December and January (minimum recorded daily temperature is -20°C) (OGM 1993). The dominant wind direction is from the north on the east side of the basin and from the east on the north side of the basin (Somuncu 1988). Annual rainfall is 330 mm, and average annual pan evaporation rate is 1660 mm (DSI 1995). This large water deficit makes Develi Basin a semi-arid region. The bulk of precipitation occurs in April and May, and evaporation is highest in July and August (Figure 2.2).

![Figure 2.2. Average recorded monthly precipitation and pan evaporation in the Develi Basin from 1993 to 2003. Values the average of the data collected at Musahaci and Yay Lake weather stations.](image)

Hydrogeology

The Develi Basin has a closed ground-water system (Figure 2.3). According to DSI (1970, 1994) water-bearing formations are composed of gravel, sand, and silty gravel. Three interconnected aquifers with different lithologies occur on the eastern side of the plain (DSI 1995). The thicknesses of the aquifers were estimated by DSI (1970) based on a few test drillings. The thickness of the eastern aquifer layer has been estimated as 200-250 m. On the south side, the estimated aquifer thickness is 150 m; in the southwest, it is 100-150 m; and in the west, the estimated thickness is 150-200 m.
Towards the Sultan Marshes, the aquifer becomes thinner, and the particle size of aquifer material becomes smaller (DSI 1995).

![Figure 2.3. Topographic and observed ground water table elevations in the Develi Basin (DSI 1995).](image)

Ground water is fed by infiltration from rainfall and overland flow, as well as underflow from tuffs in the northeast, limestone in the south and southeast, and alluvial cones in the west. Ground-water recharge in the Develi Basin has been estimated as 92.3x10^6 m^3 yr^{-1} (DSI 1970) and 160x10^6 m^3 yr^{-1} (DSI 1995). There is no indication of ground-water discharge from the basin. Because the region is a closed basin, ground
water is either pumped for irrigation or discharges into the lakes and marshes and subsequently is lost to the atmosphere through evapotranspiration.

Soysallı and Çayırözü springs (Figure 2.1) originate from magmatic rocks on the north side of the plain and have average annual flows of $18.6 \times 10^6$ and $5.1 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$, respectively ($10^6 \text{ m}^3 \text{ yr}^{-1} = 0.032 \text{ m}^3 \text{ s}^{-1}$). To the south, Karaboğa ($12.9 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$), Yerköy ($1.9 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$) and Kurbağalık ($1.6 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$) and Akçakoca springs ($2.5 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$) (Figure 2.1) originate from Paleozoic limestones (Karadeniz 1995). Flows from these springs form freshwater marshes (i.e., Örtülüakar and Kepir Marshes) in the center of the Develi Basin.

### Surface Water Hydrology

There are no large rivers in the Develi Basin (Figure 2.1), but small streams drained into the Sultan Marshes prior to 1988. Since completion of Develi Irrigation Project, the streams are captured in reservoirs (Ağcaşar and Kovalı) with annual storage capacities of 62 million m³ and 25 million m³, respectively, and do not reach the marshes. Yahyalı stream and Ağcaşar stream (annual flows of $64.5 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$ and $12 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$, respectively) discharge into Ağcaşar Reservoir. Dündarlı stream (annual average flow of $29.6 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$) flows into Kovalı Reservoir. Yeşilhisar stream (average annual flow of $17.6 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$) has discharged into Akköy Reservoir since 1967. Develi stream has a small flow ($4.4 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$) and is used for irrigation. It disappears before reaching the Sultan Marshes (Akçakaya et al. 1983). Construction of reservoirs has most likely increased the evaporation losses in the Develi Basin and ground-water recharge in the vicinity of the reservoirs.

The Sultan Marshes consists of four interconnected water systems (Figure 2.1). Yay Lake (3,650 ha) is a brackish water lake that had a depth of 40-150 cm before the irrigation project but now is dry for most of the year. Çöl Lake (2,600 ha), a saline lake north of Yay Lake, rises up to 50 cm during the year but usually dries up in summer. Two freshwater marshes, Örtülüakar (3,300 ha) and Kepir (1,900 ha), lie to the south and northeast of Yay Lake, respectively. The marshes and lakes are surrounded by wet meadows and salt steppes. Prior to dam construction, streams and springs in the Develi
Basin fed the Sultan Marshes. Ağcaásar, Yahyalı and Dündarlı streams and Akçakoca, Karapınar, Yerköy, and Kurbağalık springs flowed into the Örtülüakar Marsh; the rest fed the Kepir Marsh. When water levels in the marshes rose above a specific level, excess water spilled into Yay Lake; when Yay Lake became full, water spilled into Çöl Lake (Özesmi et al. 1993, Gürpinar 1994). Water flow from the marshes to Yay Lake continued for ~1.5 months (in May and June) in typical years and was mostly sheet flow (Gürpinar 1994). Some water from Çayırözü and Soysallı springs still discharge into the Kepir Marsh. Almost all the water from the Akçakoca, Karaboğa, Yerköy, and Kurbağalık springs currently is used for irrigation from June to November.

**Irrigation and Other Water Uses**

Surface-water and ground-water uses for irrigation in the Develi Basin were estimated to be 129 and 65 million m$^3$/yr, respectively (DSI 1993, Gurer 2004). Irrigation in the basin increased significantly after completion of the Develi Irrigation Project. Prior to the project, 926 ha had been irrigated by flows from Akköy Reservoir, which was constructed in 1967. Two reservoirs constructed in the first phase of the irrigation project now provide water to another 28,000 ha of farmland. Irrigation return water, collected in drainage channels, is discharged into the Örtülüakar Marsh or Yay Lake. The second, uncompleted phase of the irrigation project includes plans to transfer 111-150 million m$^3$/yr of Zamantı River water through a 12-km channel from a basin to the south to double the irrigated area in the Develi Basin. This phase has been underway for more than ten years, but funding limitations have delayed its completion.

Irrigation from the Ağcaásar and Kovalı reservoirs is managed by irrigation associations (IAs). Each IA controls one reservoir. The IAs assumed responsibility for managing the irrigation system in 1994. Their activities include irrigation planning, water distribution, maintenance of irrigation and drainage structures, and fee setting and collection. Farmers who use surface water for irrigation become members of the IAs and have the right to elect managerial committees that are responsible for implementing association activities.
Irrigation with ground water is generally on a village scale and managed by farmer cooperatives. Ground water is priced by volume (in contrast to areal pricing of irrigation water from reservoirs). Because of this difference, the cost of irrigation with ground water is much higher than irrigation with surface water. Ground-water pumping is practiced in the east, west and southeast parts of the Develi Basin.

Drinking water is also supplied from ground water in most villages and municipalities. No wastewater treatment facilities exist in the region for treatment of domestic wastewater. Although some industries have wastewater treatment plants, they are not fully operational. Domestic wastewater and industrial discharges from a few leather and textile factories eventually flow into the marshes. Discharge of wastewater and irrigation return to the marshes are probably responsible for increases in salinity and pollutant concentrations, and decreases in oxygen concentrations in the Sultan Marshes in recent years (Demirezen and Aksoy 2004, Gürer 2004)

**METHODS OF ANALYSIS**

In this study, three methods were used: 1) Trend analysis 2) Correlation analysis, and 3) Hydrologic modeling.

I analyzed available hydrologic and climatic data to evaluate the effects of shifting water from the Sultan Marshes to irrigation. The temporal patterns in water levels were examined in the Örtülüakar Marsh and Yay Lake in relation to climatic conditions, spring flow rates and ground-water flow rates from 1993 to 2003. The non-parametric Mann-Kendall test was used to identify the trends in water levels, climatic and hydrologic parameters. Data were obtained from DSI. The 1993-2003 period was selected because water-level observations in the Örtülüakar Marsh and Yay Lake were available only for this period. Precipitation and pan evaporation data used in the analysis were from Yay Lake and Musahacılı weather stations, which are the closest stations to the wetland.

To explore the causes of water-level changes in the Örtülüakar Marsh and Yay Lake, I calculated correlation coefficients using monthly and annual averages of recorded hydrologic and climatic data. The Kolmogorov-Smirnov test was used to check whether the distribution of data differs significantly from a normal distribution. If the data showed
a normal distribution, the Pearson correlation coefficient was calculated. Otherwise, the Spearman correlation coefficient was selected (Einspruch 1998).

A deterministic, process-based hydrologic simulation model was developed for the Örtülüakar Marsh to examine whether cumulative interactions of several hydrologic processes can explain observed water levels in the marsh. The Örtülüakar Marsh was selected because it is one of the most important sub-systems of the Sultan Marshes and sufficient historical hydrologic data were available. The model uses a monthly timescale and solves the unsteady water balance equation using Euler’s method. It was developed using the software package MATLAB. The timeframe of the simulation is seven years (1997 to 2003).

TRENDS IN HYDROLOGIC AND CLIMATIC DATA

Water Levels

Water levels in both water bodies decreased after 1993 (Table 2.1 and Figure 2.4). The 11-year record was divided into three sub-periods based on water levels (Table 2.2). In the first sub-period, 1993-1994, average water elevations were 1071.52 m in the Örtülüakar Marsh and 1071.41 m in Yay Lake. In the second sub-period, 1995-1999, average water elevations were 1071.32 m in the Örtülüakar Marsh and 1070.99 m in Yay Lake. In the period 2000-2003, average water elevations were 1070.53 m in the Örtülüakar Marsh and 1070.41 m in Yay Lake (Table 2.2). Average water levels decreased by about 1 m between the first and last sub-period.

Precipitation

Mean annual precipitation was 270 mm ± 28 mm (standard deviation-SD) at Musahacılı and 264 mm ± 40 mm (SD) at Yay Lake from 1993 to 2003. There was little variation in precipitation over the period of analysis (Figure 2.5). The maximum monthly precipitation was observed in May 2001 at Musahacılı (126 mm) and May 2000 at Yay Lake (127 mm). Average monthly precipitation for sub-periods 1-3 were 19, 23, and 21 mm, respectively (Table 2.2). While water levels decreased in the wetland from the first
to the third sub-period, precipitation actually increased (Table 2.1). Water level declines thus were not caused by decreased precipitation.

Figure 2.4. Monthly recorded water levels in the Örtülüakar Marsh and in Yay Lake (1993 to 2003).

Table 2.1. Trend analysis of water levels, hydrologic and climatic variables

<table>
<thead>
<tr>
<th>Water Levels</th>
<th>Z Statistics</th>
<th>Climatic Variables</th>
<th>Z Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ortuluakar Marsh</td>
<td>-2.96**</td>
<td>Precipitation</td>
<td>1.79+</td>
</tr>
<tr>
<td>Yay Lake</td>
<td>-3.58***</td>
<td>Pan Evaporation</td>
<td>-0.72</td>
</tr>
<tr>
<td>Springs</td>
<td></td>
<td>Ground-Water Levels</td>
<td></td>
</tr>
<tr>
<td>Akçakoca</td>
<td>-2.33*</td>
<td>W1</td>
<td>-3.58***</td>
</tr>
<tr>
<td>Karaboğa</td>
<td>-2.86**</td>
<td>W2</td>
<td>-3.43***</td>
</tr>
<tr>
<td>Yerköy</td>
<td>-1.43</td>
<td>W3</td>
<td>-3.43***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W4</td>
<td>-2.34*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W5</td>
<td>-3.74***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W6</td>
<td>-2.02*</td>
</tr>
</tbody>
</table>

1 Positive values show a positive trend and negative values show a negative trend.
+ Significant at the 0.1 level
** Significant at the 0.01 level
* Significant at the 0.05 level
*** Significant at the 0.001 level
Table 2.2. Average values (standard deviations) of water levels, climatic and hydrologic parameters in sub-periods 1 to 3 (1993-2004, 1995-1999, 2000-2003).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sub-Period 1</th>
<th>Sub-Period 2</th>
<th>Sub-Period 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Levels (m amsl)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Örtülüükar Marsh</td>
<td>1071.52 (± 0.23)</td>
<td>1071.32 (± 0.31)</td>
<td>1070.53 (± 0.38)</td>
</tr>
<tr>
<td>Yay Lake</td>
<td>1071.41 (± 0.31)</td>
<td>1070.99 (± 0.34)</td>
<td>1070.41 (± 0.27)</td>
</tr>
<tr>
<td>Precipitation and Pan Evaporation (mm/month)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation (Jan-Dec)</td>
<td>18.5 (± 12.6)</td>
<td>23.0 (± 15.2)</td>
<td>23.3 (± 21.2)</td>
</tr>
<tr>
<td>Pan Evaporation (Apr-Oct)</td>
<td>217 (± 73.8)</td>
<td>212 (± 68.7)</td>
<td>197 (± 72.2)</td>
</tr>
<tr>
<td>Spring Flow Rates (m³/s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Akçakoca</td>
<td>0.12 (± 0.05)</td>
<td>0.07 (± 0.04)</td>
<td>0.05 (± 0.13)</td>
</tr>
<tr>
<td>Karaboğa</td>
<td>0.44 (± 0.05)</td>
<td>0.44 (± 0.09)</td>
<td>0.31 (± 0.10)</td>
</tr>
<tr>
<td>Yerköy</td>
<td>0.11 (± 0.06)</td>
<td>0.07 (± 0.04)</td>
<td>0.04 (± 0.02)</td>
</tr>
<tr>
<td>Çayıroğlu</td>
<td>0.42 (± 0.06)</td>
<td>0.43 (± 0.10)</td>
<td>0.37 (± 0.06)</td>
</tr>
<tr>
<td>Soysallı</td>
<td>--</td>
<td>0.50 (± 0.08)</td>
<td>0.43 (± 0.11)</td>
</tr>
<tr>
<td>Ground-Water Levels (m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>7.19 (± 1.09)</td>
<td>7.68 (± 1.14)</td>
<td>2.43 (± 1.29)</td>
</tr>
<tr>
<td>W2</td>
<td>20.12 (± 0.66)</td>
<td>24.75 (± 0.67)</td>
<td>18.48 (± 0.69)</td>
</tr>
<tr>
<td>W3</td>
<td>22.30 (± 1.49)</td>
<td>25.55 (± 1.38)</td>
<td>18.31 (± 1.82)</td>
</tr>
<tr>
<td>W4</td>
<td>21.81 (± 1.15)</td>
<td>26.82 (± 0.56)</td>
<td>20.45 (± 1.40)</td>
</tr>
<tr>
<td>W5</td>
<td>13.65 (± 0.18)</td>
<td>15.98 (± 0.42)</td>
<td>12.75 (± 0.53)</td>
</tr>
<tr>
<td>W6</td>
<td>26.99 (± 0.69)</td>
<td>32.05 (± 0.74)</td>
<td>26.54 (± 0.77)</td>
</tr>
</tbody>
</table>

Pan Evaporation

There is no significant annual trend in pan evaporation rates during the 1993-2003 period (Table 2.1). Mean annual pan evaporation rates were 1296 mm (± 129 mm SD) at Musahacılı and 1492 mm (± 166 mm SD) at Yay Lake. Monthly pan evaporation values at the Yay Lake and Musahacılı weather stations (Figure 2.5) averaged 217 mm for sub-period 1, 212 mm for sub-period 2, and 197 mm for sub-period 3 (Table 2.2). The slight
decline in pan evaporation values does not explain the observed decline in water levels of
the marsh and lake.

![Graph showing precipitation and pan evaporation rates from 1993 to 2003.]

**Figure 2.5.** Monthly recorded precipitation and pan evaporation rates in the Develi Basin (1993 to 2003).

**Spring Flows**

Four springs (S1-S4) flow into the Örtülüakar Marsh, and two spring (S5, S6) flow into Kepir Marsh (Figure 2.1). Monthly flow rates for the five available spring flow records (Figure 2.6) show a trend of decreasing flow in all cases. Trend lines show the largest decrease in Karaboğa Spring and similar decreases in Yerköy and Akçakoca springs. Flow rates from the springs decreased from sub-period 1 to sub-period 3 (Table 2.1 and 2.2).
Flow characteristics of the springs can be indicators of ground-water levels. Ground water is mostly fed by rainfall and snowmelt in the Develi Basin. Therefore, it is likely that ground-water levels and also spring flows become highest in summer after the highest monthly rainfalls, particularly in April and May. Karaboğa Spring had peak flows in July, and Akçakoca and Yerköy Springs had peaks in June. A lag of 1- to 3 months between rainfall and spring flows is reasonable. Two exceptions are Soysallı Spring, which had peak flow in spring, and Kurbağalık Spring, which had peak flow in winter, possibly because these springs are located closer, and are better connected to the recharge areas.

Figure 2.6. Monthly estimated flow rates of major springs in the Develi Basin (1993 to 2002).
Ground Water

Water levels in six observation wells (W1-W6, Figure 2.1) generally decreased between 1993 and 2003 (Table 2.1 and Figure 2.7); water levels also fluctuated seasonally, more strongly in some wells, e.g., in W6 and W3 than in others, e.g., in W5. A large fluctuation in water levels could be caused by intermittent water withdrawal from nearby irrigation wells. In most of the observation wells, maximum water levels were reached in May, near the beginning of the irrigation season, and lowest water levels occurred in August, near the end of irrigation season. An exception is W2 where water level was highest in July and lowest in October.

Water levels in all wells were highest in sub-period 2 and lowest in sub-period 3 (Table 2.2) indicating that ground-water levels have decreased since 1993. The increase in water levels in the second sub-period may be due to favorable precipitation conditions in the first sub-period. The decrease in ground-water levels is a possible cause of the decrease in spring flows and water levels in the Sultan Marshes.

Trends in well-water levels also provide information about the gap between ground-water recharge and pumping rates. The trend line for W1 has the largest slope (-0.056 m yr⁻¹), and W3 shows the second largest decrease (-0.042 m yr⁻¹) indicating that these wells are affected by ground-water pumping more than the other wells. This also suggests that ground-water pumping rates in the western and southern parts of the Develi Basin are higher than ground-water recharge rates. This conclusion is reasonable because these two wells are located in an area of intensive agriculture. On the east side of the Develi Basin, where W4, W5 and W6 are located, seasonal fluctuations are larger, but water levels declined less between 1993 and 2003. In W6 and W5, water levels dropped during summer and recovered during spring. Although water levels in observation wells on the east side have been affected by ground-water pumping, recharge on the east side apparently is high enough to allow recovery.
Summary of Trends in Hydrologic and Climatic Data

Ground-water levels and spring flows have decreased since 1993. In contrast, the synoptic precipitation and pan evaporation rates have remained stable. These trends suggest that the observed decrease in water levels in the Sultan Marshes most likely is related to the changes in ground-water and spring inputs and not changes in climate.

CORRELATIONS BETWEEN WATER LEVELS AND CLIMATIC DATA

I analyzed the correlations of Örtülüükar Marsh water levels with (1) precipitation and pan evaporation data from Musahacılı climate station, (2) flows of three springs (S2-S4), and (3) static water level measurements in six observation wells (W1-W6). Monthly data for static water levels measurements showed a normal distribution except the data for W4. Monthly data for other variables did not follow a normal distribution Annual data showed a normal distribution except the data for marsh water levels.
Results for monthly data (Table 2.3) indicate no significant correlations between marsh water levels and rainfall or evaporation, but strong correlations of marsh water levels with spring flows and static water-level measurements in the wells. Correlation coefficients calculated using annual data (Table 2.3) support the findings from the monthly data. Overall, the results indicate that spring flows and ground-water levels are more important factors affecting water levels in the Örtülüakar Marsh since 1993 than rainfall and evaporation.

I also analyzed the correlations of Yay Lake water levels with (1) precipitation and pan evaporation data from Yay Lake weather station, and (2) static water-level measurements in the six observation wells (W1-W6). Monthly data show a strong correlation between water levels in the lake and water levels in the wells (Table 2.3). There was a weak correlation between lake water level and precipitation and no statistically significant correlation between water level and pan evaporation. These results indicate that both ground water and precipitation influence monthly water levels in Yay Lake, but the role of ground water appears stronger than that of precipitation. Correlation coefficients calculated with annual average data (Table 2.3) show an even stronger correlation between lake water level and ground water. The relationship between lake level and precipitation was not significant when annual averages were used. In the long-term, ground water appears to be the most important factor controlling water levels in Yay Lake.
Table 2.3. Correlation coefficients of water levels in the Örtülüakar Marsh and in Yay Lake with climatic and hydrologic parameters using monthly and annual data.

<table>
<thead>
<tr>
<th></th>
<th>Örtülüakar Marsh</th>
<th></th>
<th>Yay Lake</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monthly</td>
<td>Annual</td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td><strong>Climate Parameters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation*</td>
<td>0.13</td>
<td>-0.58</td>
<td>0.20***</td>
<td>-0.47</td>
</tr>
<tr>
<td>Pan Evaporation*</td>
<td>0.16</td>
<td>0.21</td>
<td>0.07</td>
<td>0.38</td>
</tr>
<tr>
<td><strong>Spring Flow Rates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Akçakoca (S2)</td>
<td>0.50**</td>
<td>0.72***</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Karaboğa (S4)</td>
<td>0.45**</td>
<td>0.66***</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Yerköy (S3)</td>
<td>0.47**</td>
<td>0.75***</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Ground-Water Levels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>0.67**</td>
<td>0.50</td>
<td>0.67**</td>
<td>0.70***</td>
</tr>
<tr>
<td>W2</td>
<td>0.61**</td>
<td>0.86**</td>
<td>0.58**</td>
<td>0.82**</td>
</tr>
<tr>
<td>W3</td>
<td>0.62**</td>
<td>0.90**</td>
<td>0.52**</td>
<td>0.80**</td>
</tr>
<tr>
<td>W4</td>
<td>0.54**</td>
<td>0.55</td>
<td>0.58**</td>
<td>0.63***</td>
</tr>
<tr>
<td>W5</td>
<td>0.69**</td>
<td>0.80**</td>
<td>0.69**</td>
<td>0.90**</td>
</tr>
<tr>
<td>W6</td>
<td>0.44**</td>
<td>0.58</td>
<td>0.45**</td>
<td>0.62</td>
</tr>
</tbody>
</table>

*Used Musahacılı weather station for Örtülüakar Marsh and Yay Lake weather station for Yay Lake

**Correlation is significant at the 0.01 level (2-tailed)

*** Correlation is significant at the 0.05 level (2-tailed)

**HYDROLOGIC SIMULATION MODEL FOR THE ÖRTÜLÜAKAR MARSH**

**Model Description**

A deterministic, dynamic water balance model operating on a monthly timescale was developed for the Örtülüakar Marsh for two principal purposes: (1) to test if the recorded water levels in the marsh could be derived/simulated from the inflow and outflow components of the marsh, and (2) to use such a model, if successful, to explore
the potential responses of the marsh to different water management alternatives. A schematic of inflows and outflows contributing to the water balance of Develi Basin and the embedded Sultan Marshes system is shown in Figure 2.8. This figure also shows the inflows and outflows of the Örtülüakar Marsh, which is a major part of the Sultan Marshes (Figure 2.1). Inflows to the Örtülüakar Marsh include direct precipitation on the marsh surface (P), irrigation return (IR), flows from springs (SP), overland flows from dry lands and smaller basins surrounding them (OF1, OF, respectively) and net groundwater flow ($\Delta GW$; ground-water inflow minus ground-water outflow). Outflows are evapotranspiration (ET) and surface flow to Yay Lake (SF) when the water level is higher than 1.3 m in the Örtülüakar Marsh.

Figure 2.8. A schematic of inflows and outflows contributing to the water balance of the Develi Basin and the embedded Sultan Marshes ecosystem.
In the model the total ‘active’ water volume of the marsh at any time consists of a surface water volume and a subsurface (soil) water volume. There is a close relationship between soil water and surface water in wetlands. The water volume in the soil zone equals the soil volume multiplied by available water content (AWC), which varies between field capacity and permanent wilting point. AWC is expressed as a fraction of the soil volume. The surface area of the marsh was related in the model to the total water volume and topographic relationships.

### Table 2.4. Parameter values used in the water budget components

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Used</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root depth (m)</td>
<td>≥1m</td>
<td>1</td>
<td>(Cross and Fleming 1989)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Wheeler and Shaw 1995)</td>
</tr>
<tr>
<td>Available Water Content (%)</td>
<td>15-25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Runoff Coefficient (%)</td>
<td>5-18</td>
<td>5</td>
<td>(Mitsch and Gosselink 1993)</td>
</tr>
<tr>
<td>Irrigation Return Coefficient (%)</td>
<td>0-15</td>
<td>1</td>
<td>(Paşaoğlu 1994)</td>
</tr>
<tr>
<td>Pan Coefficient</td>
<td>0.67-0.93*</td>
<td>0.67-0.93</td>
<td>(Allen et al. 1998)</td>
</tr>
<tr>
<td>Crop Coefficient</td>
<td>1.1-1.3*</td>
<td>1.1-1.3</td>
<td>(Allen et al. 1998)</td>
</tr>
<tr>
<td>Weir Coefficient</td>
<td>1.44-1.7</td>
<td>1.7</td>
<td></td>
</tr>
</tbody>
</table>

* Monthly calibration parameters were calculated based on the method proposed by Allen et al (1998).

Irrigation return was estimated from monthly volumes of irrigation water distributed to farmland from the reservoirs. An irrigation return coefficient (Table 2.4), denoted as the percentage of irrigation water that becomes return flow, was used to estimate the amount of return flow reaching the marshes (Paşaoğlu 1994). It is expected that the coefficient would be small because irrigation return is reused in the Develi Basin during the periods of water scarcity.
Overland flow was assumed to be generated from the area bounded by drainage canals to the west, south and east and by the Yay Lake drainage basin to the north. A runoff coefficient (Table 2.4) was used to define the fraction of precipitation that becomes overland flow. Overland flow generated in agricultural areas and drylands in Develi Basin was ignored because it is very small under semi-arid conditions.

Ground-water inflow to the Sultan Marshes was estimated by using average monthly water-level data in observation wells W1 to W6. It was assumed that ground-water discharge occurs to the Sultan Marshes at a water elevation of 1070 m, which is the lowest elevation of the lakes and marshes. Annual flows from the eastern, western and southern parts of the plain were calculated separately using water-level data from wells W1, W2-W3 and W4-W6, respectively (DSI 1994). Aquifer widths were estimated from a hydrogeologic map (DSI 1994). Average transmissivities (T) were estimated to be 500 m$^3$ m$^{-1}$ d$^{-1}$ on the eastern side, 3000 m$^3$ m$^{-1}$ d$^{-1}$ on the southern side, and 1500 m$^3$ m$^{-1}$ d$^{-1}$ on the western side (DSI 1994). Because the observation wells are located at higher elevations than irrigation fields, the amount of ground water pumped from the aquifers for irrigation was subtracted from the overall value to find annual ground-water recharge to the Sultan Marshes. In this calculation, it was assumed that the effect of ground-water pumping on water levels in the observation wells was minor on an annual timescale.

Annual ground-water pumping rates were taken from previous studies. DSI (1995) estimated that water pumping in the eastern and southern sides of the basin was $47 \times 10^6$ m$^3$ yr$^{-1}$, but the amount of water extraction on the west side of the basin could not be calculated. The total amount of ground-water pumping in the Develi Basin also was estimated recently as $65 \times 10^6$ m$^3$ yr$^{-1}$ (Gürer 2004). Most of the ground-water development in the Develi Basin occurred after 1980; therefore the above values can be used to represent ground-water withdrawal through pumping over the modeling period. It was estimated that ground-water flow to the Örtülüakar Marsh is one-third of the total ground-water recharge to the Sultan Marshes because the area of Örtülüakar Marsh is approximately one-third of the area of the Sultan Marshes. It was also assumed that monthly flow is distributed around a mean annual value and varies similarly to monthly fluctuations in the observation wells.
Model input included precipitation and pan evaporation data from the Musahacılı weather station. Pan evaporation measurements were converted to evapotranspiration following FAO 56 guidelines (Allen et al. 1998). First, pan evaporation data were converted to a reference evapotranspiration, which is the evapotranspiration from a reference crop that has a height of 0.12 m, surface resistance of 70 m s\(^{-1}\), and albedo of 0.23 (Allen et al. 1998), using pan coefficients. The reference evapotranspiration then was multiplied by plant coefficients to calculate evapotranspiration from marsh plants. Örtülüakar Marsh is covered with emergent vegetation (dominantly *Phragmites australis* (Cav.) Trin. ex Steud. or common reed), which is rooted deep in the soil water zone (~1 m) and emerges above the surface water zone. The marsh is surrounded by a zone which is seasonally flooded and covered with vegetation that has a height of up to 40 cm (Akçakaya et al. 1983). Evapotranspiration from the marsh and the surrounding zone were calculated separately using appropriate coefficients. In the first phase of model formulation, I assumed that the wetland boundary (i.e., edge of wetland vegetation) did not change. Evapotranspiration was allowed to occur only in areas where the roots were able to reach ground water, and the ground-water level next to the wetland was assumed to be the same as the wetland surface water level in each simulation time-step.

Flow to Yay Lake from Örtülüakar Marsh was estimated using an overflow (weir) equation when water level exceeded 1.3 m in the Örtülüakar Marsh. Weir width was estimated from available maps and satellite images. A detailed model description including the equations used is given by Dadaser-Celik et al. (2006).

**Model Calibration/Validation/Uncertainty**

The model was calibrated to fit monthly water level measurements in the marsh from 1997 to 2003. This period includes both dry and wet periods. Values of selected model parameters were varied iteratively with reasonable variations from literature values (Table 2.4) until satisfactory agreement was obtained between observed and simulated water levels. Root mean square error (RMSE) of marsh water level was used to test simulation accuracy.
The best fit (RMSE = 0.28 m) between simulated and observed water levels for 1997-2003 (Figure 2.9) was obtained with parameter values reported in Table 2.4. The theoretical error range of the measurements (±10 cm), defined according to Winter (1981), is also shown in Figure 2.9.

Figure 2.9. Simulated and observed monthly water levels in the Örtülüakar Marsh (1997-2003).

The model was able to simulate multi-year trends in water levels, especially decreases in water levels after 1999. It also could simulate seasonal fluctuations in water levels for most years. Both the model and measurements show that water levels became highest during spring (March-May), started to decrease in late spring or summer, and became lowest during autumn (September-November). Moreover, the model predicted the timing of minimum and maximum water elevations accurately. Annual magnitudes of simulated water inflows and outflows for 1997-2003 (Figure 2.10) show that total outflow (evapotranspiration and flow to Yay Lake) was greater than total inflow in every year, which explains the drop in water level during the simulation period. Largest inflows were ground-water and spring flows. On average they constitute 51 and 27% of total inflows, respectively; 95-100% of outflow is due to evapotranspiration. Simulation
results fit better for Period 1 (RMSE = 0.23 m) than Period 2. After 1999, the difference between simulated and measured levels remained about the same, except that a simulated seasonal filling and depletion cycle (October 2001-August 2002) is not found in the observed data. As a result RMSE in Period 2 rose to 0.32 m.

![Figure 2.10. Simulated water inflows and outflows for the Örtülüakar Marsh (million m³ yr⁻¹)](image)

In contrast, the model did not capture dry periods sufficiently. Although it predicted zero water levels in 1999 and 2002, there are large differences between simulated and measured seasonal water levels in these years. Simulated water level is 0.52 m higher than measured level in October 1999. The model also did not predict sharp decreases and increases in water levels in 1999, 2000 and 2001, which created a 0.15 m average difference between measured and predicted extreme values. For example, between August and September 1999, there was a 0.69 m-drop in observed water level, but the model predicted only a 0.19-m drop. Similarly, water level rose 0.48 m between January and February 2000 but the model predicted only a 0.13-m increase.

The model deficiencies probably can be attributed to the various factors. Poor data quality is one of the major causes. Another factor can be estimation of ground-water...
inflow on an annual timescale, and use of the information in the hydrologic model which runs on monthly timescale. The real ground-water system is likely more dynamic than the simulated system. Ground-water pumping for irrigation use was assumed to be constant in the simulations, but it may fluctuate rapidly when farmers turn pumps on and off. Another cause for model deficiencies is the crude estimation of spring flows. Monthly spring-water diversion was estimated based on secondary sources of information and has not been measured. A third cause is that percentages of irrigation water return to the system were assumed to be constant in the simulations. Nevertheless, the model was able to simulate the general hydrologic characteristics of the Örtülüakar Marsh for 1997-2003 despite high uncertainties in hydrologic inputs and model parameters.

An uncertainty analysis of the results (Örtülüakar Marsh water levels) was conducted by sequentially changing ground-water flow, rainfall, spring flow and evapotranspiration components by various percentages (Winter 1981, LaBaugh 1986). The uncertainty analysis showed that water levels in Örtülüakar Marsh are highly sensitive to inflows from ground water and springs and water loss by evapotranspiration. For example, decreasing evapotranspiration by 20%, increased the RMSE of marsh water levels by 147%, and increasing evapotranspiration by 20%, increased RMSE by 52%. Without water inputs from springs, RMSE would rise by 78%. In contrast, if there were no diversion from springs for irrigation, RMSE would increase by 97%. Doubling ground-water inputs to the marsh would increase RMSE by 153% and raise marsh water levels. Without any ground-water input to the marsh, RMSE would rise by 125% and marsh water levels would drop to zero every year.

Overall, model results and results from the statistical data analysis are in agreement. Both show high sensitivity to ground-water and spring flows. The model, therefore, can be used for a rough exploration of various water management scenarios.

**Water Management Options**

I simulated alternative management scenarios to determine whether agricultural and wetland water requirements can be met at the same time in the Develi Basin. Because analysis of climatic and hydrologic data suggested that ground-water and spring flows are
the most important inputs to the Sultan Marshes system, the scenarios focused on these two components. Reducing ground-water pumping rates by 50% increased average water level from 0.65 m to 1.11 m (Figure 2.11). Average water level, however, would rise up to 0.99 m when there was no water use from springs. Decreasing ground-water use by 50% and using only 50% of summer flows from the springs would stabilize water levels in Örtülükär Marsh (Figure 2.11) and halt the drop observed in water level of the Sultan Marshes after 1995. Details of water management scenarios examined are given by Dadaser-Celik et al. (2006).

![Figure 2.11. Sensitivity of water levels (m) in the Örtülükär Marsh to water use scenarios.](image)

Increasing irrigation efficiency is a prerequisite for any water management alternative in the Develi Basin. Flood irrigation is currently the primary method of surface water irrigation in the Develi Basin. Irrigation with ground water uses either flood or sprinkler irrigation techniques. Drip irrigation systems are used by only a small number of farmers. High water loss rates have been reported due to the deterioration of the channels (Dadaser-Celik 2005). Conversion of the traditional open channel conveyance system and flood irrigation method to a pressurized conveyance system and sprinkler/drip irrigation methods would help save water and increase the availability of
surface and ground water for the Sultan Marshes. Conveyance loss in open channels can be as high as 60% (Van Tuijl 1993). The loss is much smaller in pressurized systems. Water-use efficiency in sprinkler and drip irrigation systems is 70% and 90%, respectively, in contrast to 40% efficiency in flood irrigation systems (Seckler 1996).

A major question regarding irrigation system rehabilitation is by whom and through what mechanisms should the construction works be funded. Neither farmers nor state organizations want to take on the complete responsibility. Interviews with the farmers in the Develi Basin showed that the high investment requirement has prevented farmers from adopting sprinkler or drip irrigation technologies (Dadaser-Celik 2005). One possible way to overcome this problem is to offer long-term and low-interest loans to farmers who want to convert to new irrigation technologies and to irrigation associations that want to modernize their conveyance systems (Wichelns et al. 1996, Playán and Mateos 2004). Water pricing is another tool to promote the adoption of water saving technologies (Wichelns et al. 1996).

Land management is another important factor affecting irrigation system rehabilitation. Increases in irrigation efficiency may lead to the expansion of irrigated lands or cultivation of high-water consuming crops (Howell 2001). Basin-wide cropping plans need to be prepared with input from farmers and state officials to balance irrigation and other water requirements (i.e., ecosystem water requirements). Short- and long-term monitoring mechanisms need to be developed to evaluate the success of these plans. Demand-based irrigation scheduling and laser leveling of the land are some methods that can help increase the efficiency of irrigation (Playán and Mateos 2004). Although the amount of drainage water would be reduced, it is still necessary to ensure proper drainage of fields and proper disposal of drainage water. Reuse of drainage water in the Develi Basin must not lead to salinization of fields.

SUMMARY & CONCLUSIONS

Hydrologic changes in the Sultan Marshes wetland in south-central Turkey were analyzed after intensification of irrigated agriculture in the Develi Basin. Statistical analysis of available hydrologic and climatic data shows that the observed water level
decline in the Sultan Marshes after 1993 is strongly related to decreases in groundwater levels and spring flows. For the same period, precipitation and pan evaporation rates remained stable, suggesting that climatic factors are not responsible for water level changes in the marshes.

A hydrologic simulation model for the Örtülüakar Marsh, a sub-system of the Sultan Marshes, was used to explore alternative water management scenarios that could maintain water levels in the marsh, as well as maintain some level of irrigation in the Develi Basin. The analysis focused on the use of ground water and spring flows in irrigation. Simulation results showed that a 50% reduction in water use both from ground water and springs would effectively halt water level declines in the wetland. Application of this management alternative, however, would require understanding of socio-economic conditions in the Develi Basin and development of incentive mechanisms to encourage farmers to reduce their water use.

Representatives from farmers’ and non-government organizations should be included in the decision-making process regarding irrigation activities. This analysis shows that with proper water management, irrigated agriculture can continue in the Develi Basin without causing further degradation of the Sultan Marshes wetland.

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CHAPTER 3 : DYNAMIC HYDROLOGIC MODEL OF THE ÖRTÜLÜAKAR MARSH IN TURKEY

ABSTRACT

A dynamic hydrologic model was developed for the Örtülüakar Marsh in Turkey to investigate the causes of water-level decreases observed since the 1990s and to explore potential remediation and sustainability options. Örtülüakar Marsh is a sub-system of the Sultan Marshes ecosystem, a large wetland complex consisting of freshwater marshes and salt-water lakes in the Develi Basin of south-central Turkey. The wetland has experienced significant seasonal and long-term water-level changes after the construction of an irrigation project in the catchment. The model uses a monthly time scale and solves the unsteady water-balance equation. Inputs from precipitation, overland flow, springs and ground water, and outputs due to evapotranspiration and surface flow are represented in the model. The model was calibrated to fit monthly water-level measurements from 1997 to 2003. Sensitivity analyses showed that the model is highly sensitive to evapotranspiration and ground-water inflow. Simulations of several water allocation options suggest that ground-water use should be reduced in the Develi Basin to halt the decline in water level in the Örtülüakar Marsh.

Key Words: marsh, water budget, Sultan Marshes, Turkey, water allocation, sustainability

INTRODUCTION

Wetlands are shallow, dynamic aquatic systems where water levels and the associated surface areas often show short-term and long-term fluctuations (Gilman 1994). This dynamic hydrologic regime is responsible for unique properties that characterize different wetland types (Mitsch and Gosselink 1993). In a closed basin, freshwater marshes appear when precipitation, ground-water and/or surface-water inflows exceed evapotranspiration. Alterations of wetland hydrologic regimes (e.g., by water diversion) affect not only the physical and chemical characteristics of wetlands but also their

Water budgets are useful in describing changes in wetland hydrology because they quantify water inputs and outputs and the relative importance of each component in system behavior during different time intervals. Changes in the hydrologic regime of a wetland can be characterized by analyzing measured water-budget components or by simulating them (Smakhtin and Piyankarage 2003). The lack of historical hydrologic data often poses a challenge in constructing wetland water budgets. When long-term hydrologic data are not available, hydrologic models can provide a useful alternative approach; scarce observations and data may then serve for model calibration (NAP 1995). Models can be used to explore the sensitivity of a wetland system to water inputs and outputs and to predict wetland responses to management options.

Hydrologic models often have been used to analyze wetland changes and management options. For example, Sutcliffe and Parks (1987) developed a water-balance model to analyze the hydrologic behavior of the swamps of Sudd (Sudan) and to examine the effects of water diversion on the extent of the wetlands. Thompson and Hollis (1995) developed a water-balance model of the Hadejla-Nguru wetlands (Nigeria) to examine changes in the ground-water recharge and extent of inundated areas after an upstream irrigation development. Leconte et al. (2001) used a numerical hydrodynamic model to evaluate the role of flow regulation and hydroclimatic conditions on water levels of major lakes in the Peace–Athabasca River Delta (Canada). Smaklin and Piyankarage (2003) developed a model to examine the effects of upstream irrigation development on the lagoon hydrology in Sri Lanka.

In this study, a dynamic hydrologic model was developed to identify the effect of irrigation development on the hydrology of a freshwater marsh in Turkey. Hydrologic models of inland freshwater marshes are much more constrained by data requirements and temporal and spatial scales than other wetland types. Existing models of freshwater marshes also differ from each other because these marshes may have very different characteristics depending on geologic origin, hydrology, and size (Mitsch and Gosselink
The analysis conducted in this study uses (and provides) information typical of the hydrology of inland freshwater marshes in agricultural basins.

The Sultan Marshes are important wetlands in Turkey and were declared a Ramsar site (according to the Ramsar Convention on Wetlands of International Importance) and a Nature Conservation Area and National Park by the Turkish government. They comprise a large wetland complex including two salt-water lakes (Yay Lake and Çöl Lake) and two freshwater marshes (Örtülüakar and Kepir Marshes) surrounded by salt steppes and wet meadows. The wetlands have provided habitat for many organisms, including 25 species of mammals, 25 species of mollusks, 40 species of hymnoptera, 5 species of fish, 301 species of birds, and 125 species of algae (Karadeniz 2000). The Sultan Marshes have experienced a major decrease in seasonal and long-term water levels in recent years. Changes have occurred both in the timing and magnitude of peak water levels, and the wetland now become completely dry in some years (Figure 3.1). Wetland biodiversity has also been negatively affected. A significant decline in bird populations was reported during water-short periods (Kiziroğlu et al. 1992). Discharge of agricultural drainage to the wetland has disrupted the natural salinity and chemical composition of the wetland. These changes have been attributed to an irrigation project (Develi Irrigation Project) completed in the 1988 (Özesmi et al. 1993, Gürpinar 1994, Karadeniz 1995), which includes two reservoirs constructed on major streams feeding the marshes. A recent study showed that marsh water levels and precipitation/evaporation rates in the Develi Basin (Figure 3.2) were not significantly correlated, suggesting that climatic changes are not responsible for changes in water levels (Dadaser-Celik et al., unpublished data). No study, however, has been conducted to explore the factors that led to hydrologic changes in the Sultan Marshes. The complexity of hydrologic processes in the wetland and lack of hydrologic, climatic, and topographic data are major factors preventing a detailed hydrologic analysis.
Figure 3.1. Monthly water depths observed in Yay Lake in 1993, 1995 and 2001 and during the 1969-1972 period.

Figure 3.2. Monthly precipitation and pan evaporation rates at the Musahacılı weather station from 1993 to 2003.
In this study, a dynamic hydrologic model was developed for the Örطبیکار Marsh using limited available information in an effort to understand the causes of observed alterations in the Sultan Marshes. Örطبیکار Marsh was selected because it is located on the upstream end of the Sultan Marshes and some hydrologic observations that could be used to calibrate the model were available. The model simulates dominant hydrologic processes to explore the causes of fluctuations in water levels in the wetland after 1997. Model simulations were used to investigate how marsh water levels would change under various management scenarios.

**TOPOGRAPHY, CLIMATE AND HYDROLOGY OF STUDY AREA**

The Örطبیکار Marsh is part of the Sultan Marshes (Sultan Sazlıği, in Turkish) in central Anatolia, southwest of Kayseri (38.05-38.40 N, 35.00-35.35 E) (Figure 3.3). The marsh lies at the center of the Develi Basin, which covers an area of 800 km² and has a drainage area of 3190 km² (DSI 1970). The average altitude of the basin is 1100 m. The basin is surrounded by mountains that reach an elevation of 3916 m. The lowest elevation in the basin, 1070 m, is where the Sultan Marshes are located.

The region has a semi-arid, continental climate. Annual rainfall is 330 mm, and annual pan evaporation rate is 1660 mm (DSI 1995). The bulk of precipitation occurs in spring (April and May), and most of the evaporation occurs in summer (July and August). The mean annual temperature is 11°C; mean monthly highs and lows are 22.6 °C (July) and -1.00 °C (January).

The major streams that formerly discharged surface water into the Sultan Marshes are now intercepted by three major dams, and water stored in the reservoirs is used to irrigate farmland. Major crops are sugar beet and cereals. Fruit production also has increased in recent years.

The Develi Basin has a closed ground-water system; there is no known ground-water outflow from the Develi Basin. Ground water discharges into the lakes and marshes and is lost through evapotranspiration. It also is withdrawn at increasing rates by pumping for irrigation. There are three interconnected aquifers composed of gravel, sand, and silty gravel (DSI 1995). Estimated aquifer thickness is 200-250 m on the eastern side.
of the basin (DSI 1995), 150 m on the southern side, 100-150 m in the southwest, and 150-200 m in the west. Towards the Sultan Marshes, the aquifer becomes thinner, and particle size of the aquifer material becomes smaller (DSI 1995). Ground water is fed by infiltration of rainfall and overland flow. Sub-surface recharge occurs from tuffs on the northeastern side, limestone on the south and southeast sides, and alluvial deposits on the west side. There are ten major springs and many minor springs where ground water emerges on the periphery of the Develi Basin (Karadeniz 1995).

Figure 3.3. Geographical setting of the Sultan Marshes ecosystem and water use elements of the Develi Irrigation Project (modified after Paşaoğlu (1994)).

The Sultan Marshes consist of four interconnected water systems (Figure 3.3). Yay Lake (3,650 ha) is a brackish water lake that had a depth of 0.4-1.5 m in the past but
now is completely dry for most of the year. Çöl Lake (2,600 ha) is a saline lake that lies to the north of Yay Lake. Çöl Lake reached a depth of 0.5 m during the year and mostly dried up in summer. Örtülüüakar Marsh covers 3,300 ha and Kepir Marsh covers 1,900 ha. The marshes and lakes are surrounded by wet meadows and salt steppes. Prior to construction of the irrigation project, the Sultan Marshes mainly were fed by stream and spring flows in the Develi Basin. Three major streams, Ağcaasår (12 x 10^6 m^3 yr^-1), Yahyalı (64.5 x 10^6 m^3 yr^-1), and Dündarlı (29.6 x 10^6 m^3 yr^-1), flowed into the Örtülüüakar Marsh, and four major springs, Karaboğa (12.9 x 10^6 m^3/yr), Yerköy (1.9 x 10^6 m^3/yr), Kurbağalıık (1.6 x 10^6 m^3/yr), and Akçakoca (2.5 x 10^6 m^3/yr), supplied additional water. Soysallı and Çayırözü springs (18.6 x 10^6 and 5.1 x 10^6 m^3 yr^-1) fed the Kepir Marsh. When water levels rose above a specific level in the marshes, excess water spilled into Yay Lake, and when Yay Lake became full, excess water spilled into Çöl Lake (Özesmi et al. 1993, Gürpınar 1994). Water flow from the marshes to Yay Lake typically continued for ~1.5 months in a given year and was mostly a sheet flow plus a number of small channels (Gürpınar 1994). Since the Develi Irrigation Project was completed, the streams have been captured in reservoirs (Ağcaasår and Kovalı) and do not reach the marshes. Some water from Çayırözü and Soysallı springs still discharges into the Kepir Marsh, but almost all the water from the Akçakoca, Karaboğa, Yerköy, and Kurbağalıık springs currently is used for irrigation from June to November. Irrigation return, collected by drainage channels, is discharged either into the Örtülüüakar Marsh or into Yay Lake.

**MODEL FORMULATION**

The time frame of the model is seven years (1997 to 2003). The model was developed using the software package MATLAB and a monthly timescale. This timescale sufficiently represents the dynamics of marsh hydrology with input data available for monthly intervals.

**Water-Budget Equation**

A schematic of water inputs and outputs affecting the water balance of the Sultan Marshes and specifically Örtülüüakar Marsh is shown in Figure 3.4. For the latter marsh,
precipitation \((P)\), irrigation return \((IR)\), spring flow \((SP)\), overland flow from dry lands and smaller basins surrounding them \((OF1, \ OF)\), and net ground-water flow \((GW)\) are inputs, and outputs are evapotranspiration \((ET)\) and flow to Yay Lake \((SF)\). Flow to Yay Lake occurs when the water level in Örtülüakar Marsh becomes higher than 1.3 m. A list of symbols used in the text is presented in Table 3.1.

![Diagram of water inputs and outputs](image)

Figure 3.4. A schematic of water inputs and outputs contributing to the water balance of the Sultan Marshes and the embedded Örtülüakar Marsh.

\(P\)=precipitation, \(SP\)=spring flow, \(IR\)=irrigation return flow, \(OF\) and \(OF1\)=overland flows, \(GW\)=ground-water flow, \(ET\)=evapotranspiration, \(SF\)=surface outflow.

**Table 3.1.** Symbols and their descriptions/definitions.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description (Unit)</th>
<th>Symbol</th>
<th>Description (Unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Inundated area (m²)</td>
<td>∆L</td>
<td>Horizontal distance from the observation well to the marsh (m)</td>
</tr>
<tr>
<td>A_d</td>
<td>Drainage area (m²)</td>
<td>N</td>
<td>Number of observations</td>
</tr>
<tr>
<td>A_{evp}</td>
<td>Evaporation area (m²)</td>
<td>OF</td>
<td>Overland flow from the surrounding area (m³ month⁻¹)</td>
</tr>
<tr>
<td>A_{WC}</td>
<td>Available water content</td>
<td>OF1</td>
<td>Overland flow from the dryland (m³ month⁻¹)</td>
</tr>
<tr>
<td>C_{ir}</td>
<td>Irrigation return coefficient</td>
<td>P</td>
<td>Precipitation (m³/month)</td>
</tr>
<tr>
<td>C_r</td>
<td>Runoff coefficient</td>
<td>P_m</td>
<td>Precipitation at Musahacılı weather station (m month⁻¹)</td>
</tr>
<tr>
<td>E_{pan}</td>
<td>Pan evaporation (m month⁻¹)</td>
<td>RH</td>
<td>Relative humidity (%)</td>
</tr>
<tr>
<td>ET</td>
<td>Evapotranspiration (m month⁻¹)</td>
<td>RMSE</td>
<td>Root mean square error (m)</td>
</tr>
<tr>
<td>E_{T ref}</td>
<td>Reference evapotranspiration</td>
<td>SF</td>
<td>Surface flow (m³ month⁻¹)</td>
</tr>
<tr>
<td>FET</td>
<td>Fetch (m)</td>
<td>SP</td>
<td>Spring flow (m³ month⁻¹)</td>
</tr>
<tr>
<td>GW</td>
<td>Ground-water flow (m³ month⁻¹)</td>
<td>∆t</td>
<td>Time step(month)</td>
</tr>
<tr>
<td>h</td>
<td>Simulated water depth (m)</td>
<td>T</td>
<td>Transmissivity (m³ m⁻¹ month⁻¹)</td>
</tr>
<tr>
<td>h_{obs}</td>
<td>Observed water level (m)</td>
<td>U_2</td>
<td>Average wind speed at 2 m elevation (m s⁻¹)</td>
</tr>
<tr>
<td>∆H</td>
<td>Hydraulic head (m)</td>
<td>V</td>
<td>Total water volume (m³)</td>
</tr>
<tr>
<td>IR</td>
<td>Irrigation return flow (m³ month⁻¹)</td>
<td>V_s</td>
<td>Soil volume (m³)</td>
</tr>
<tr>
<td>IW</td>
<td>Irrigation water flow released from the reservoirs (m³ month⁻¹)</td>
<td>V_{sw}</td>
<td>Soil water volume (m³)</td>
</tr>
<tr>
<td>K</td>
<td>Weir discharge coefficient</td>
<td>V_w</td>
<td>Surface water volume (m³)</td>
</tr>
<tr>
<td>K_{c}</td>
<td>Crop coefficient</td>
<td>w</td>
<td>Weir width (m)</td>
</tr>
</tbody>
</table>
The model solves the unsteady water-balance equation. The change in water volume \( V \) for each month \( i \) equals the difference between water inputs and outputs.

\[
\Delta V_i = V_i - V_{i-1} = P_i + IR_i + OF_i + OF1_i + SP_i + GW_i - ET_i - SF_i \quad (1)
\]

Equation 1 was solved by assigning a starting water volume for the first month. Subsequent water volumes were calculated monthly using monthly water inputs and outputs.

Unlike other studies that neglect the connection between surface water and underlying soil/pore water, we assume that the total water volume in the marsh at any time \( V_i \) consists of surface water \( V_w \) and soil water \( V_{sw} \):

\[
V_i = (V_w)_i + (V_{sw})_i \quad (2)
\]

It was necessary to consider the relationship between surface water and pore water because the marsh is covered with emergent vegetation, which is rooted deep in the soil water zone and grows up through the surface-water zone. Evapotranspiration uses water from the soil zone and continues as long as plant roots are able to reach ground water or sufficient soil moisture. The depth of the soil zone included in the model equals the root depth \( h_r \) of the marsh vegetation (Figure 3.5). The water volume in the soil zone \( V_{sw} \) equals the soil volume \( V_s \) multiplied by the available water content \( AWC \) (Eq. 3), which varies between soil field capacity and permanent wilting point. \( AWC \) is expressed as a fraction of the soil volume and depends on soil characteristics. Although there is no information about the soil composition in the marsh, the underlying layer most likely is mineral soil (probably clay) that is rich in organic material content (DSI 1995, Gilman 1994).

\[
V_{sw} = V_s \times AWC \quad (3)
\]

The area of water coverage in the marsh (i.e., the inundated area) \( A \) was calculated at each simulation step using total water volume and topographic relationships prepared by the State Hydraulic Works (in Turkish, Devlet Su İşleri) (DSI). The maximum surface area of the marsh, which refers to the areal coverage of wetland

<table>
<thead>
<tr>
<th>( K_{pan} )</th>
<th>Pan coefficient</th>
<th>W</th>
<th>Aquifer width (m)</th>
</tr>
</thead>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>


vegetation, was extracted from satellite images. The area beyond the water surface where evapotranspiration continues was also calculated. This “evapotranspiration area” ($A_{evp}$) can be calculated as the surface area over which the ground water is found at a depth less than the root depth plus the capillary rise below ground level (Figure 3.5). In this study, the depth of the capillary zone was ignored.

![Figure 3.5. A schematic of vegetation distribution in the Örtülüükar Marsh. $h_r$ refers to the root depth.](image)

**Precipitation**

Precipitation ($P$) input to the marsh was calculated by multiplying monthly precipitation from Musahacılı weather station ($P_m$) by the inundated area for the previous month (Eq. 4). Musahacılı station is the closest weather station to the Örtülüükar Marsh. It is located less than 5 km away from the marsh at approximately 1075 m elevation.

$$P_i = (P_m)_i \times A_i \quad (4)$$

**Springs**

Monthly flow rates were available for Karaboğa, Yerköy, Akçakoca, and Kurbagalık springs, but no information was available on the amount of spring water used for irrigation. All spring flows were assumed to be diverted to irrigation during the irrigation season (from June to November) based on interviews with local people (Dadaser-Celik 2005).
Irrigation Return

Irrigation return ($IR$) was estimated (Eq. 5) from monthly volume of irrigation water distributed to the farmlands from the reservoirs ($IW$). An irrigation return coefficient ($C_{ir}$), which denotes the percentage of irrigation water that becomes return flow, was used to estimate the amount of return flow reaching the marshes (Paşaoğlu 1994).

$$IR_i = IW_i \times (C_{ir})_i$$

(5)

Overland Flow

Overland flow ($OF$) was assumed to be generated from the area ($A_d$) bounded by drainage canals to the west, south, and east and by Yay Lake drainage basin to the north. A runoff coefficient ($C_r$) was used to find the percentage of precipitation that becomes overland flow after infiltration and evapotranspiration. Overland flow from the agricultural areas and drylands in the Develi Basin was ignored because the flow should be very small under existing semi-arid climatic conditions.

$$OF_i = (A_d - A_t) \times (P_{\text{m}})_i \times (C_r)_i$$

(6)

Ground Water

Ground-water inflow to the Sultan Marshes was estimated from sparse field data using a site-specific approach. The relationship between the wetland and ground water is not well-known at present, and additional field exploration is needed to develop a ground-water model. In this study, ground-water flow was estimated using average monthly water-level data (Figure 3.6) in six observation wells, W1-W6 (Figure 3.3).
Figure 3.6. Mean annual water levels in wells W1-W6 from 1993 to 2003. Zero elevation corresponds to 1070 m.

The wells provide minimal information on ground-water levels in the western, southern, and eastern areas of the Sultan Marshes. No other long-term well logs could be located. It was assumed that ground-water discharge occurs to the Sultan Marshes when the wells have a water elevation of greater than 1070 m, which is the lowest observed elevation of the lakes and marshes. Annual flows from the eastern, western, and southern parts of the plain were calculated separately by equation 7 using water levels observed in wells W1, W2-W3, and W4-W5-W6, respectively (DSI 1995).

\[
\Delta L \times \Delta H_i \times W = GW_i
\]

In Equation 7, \( \Delta H \) is the hydraulic head, which equals to the difference between well elevation and 1070 m. The well logs showed ground-water elevations in the ranges 1082-1098 m in the east, 1085-1094 m in the south, and 1070-1080 m in the west. The horizontal distance from the wells to the edge of the Örtülüakar Marsh and Yay Lake (\( \Delta L \)) and aquifer widths (\( W \)) were estimated from a hydrogeologic map (DSI 1995). Average transmissivities (\( T \)) were estimated to be 500 m\(^3\) m\(^{-1}\) d\(^{-1}\) on the eastern side, 3000 m\(^3\) m\(^{-1}\) d\(^{-1}\) on the southern side, and 1500 m\(^3\) m\(^{-1}\) d\(^{-1}\) on the western side (DSI, 1995). Because observation wells are located at higher elevations than irrigation fields, the amount of ground water pumped from the aquifers for irrigation was subtracted from the
overall value to find annual ground-water recharge to the Sultan Marshes. In this
calculation, it was assumed that the effect of ground-water pumping on the water levels
in the observation wells is minor on an annual timescale, although seasonal variations
were observed in four of the wells. Annual ground-water pumping rates were taken from
previous studies. DSI (1995) estimated that water pumping in the eastern and southern
sides of the basin was $47 \times 10^6$ m$^3$ yr$^{-1}$, but the amount of water extraction on the west side
of the basin could not be calculated. The total amount of ground-water pumping in the
Develi Basin was estimated recently to be $65 \times 10^6$ m$^3$ yr$^{-1}$ (Gürer 2004). Most of the
irrigation development and ground-water pumping in the Develi Basin occurred after
1988; therefore, the above values can be used to represent ground-water withdrawal
through pumping over the modeling period. It was assumed ground-water flow to the
Örtülüakar Marsh is one-third of the total ground-water recharge to the Sultan Marshes
because Örtülüakar Marsh covers approximately one-third of the total wetland area. It
was also assumed that monthly flow is distributed around a mean annual value and shows
fluctuations similar to monthly fluctuations observed in the observation wells. Linear
relationships between ground-water flows and ground-water levels (piezometric slopes)
were used.

**Evapotranspiration**

Evapotranspiration in wetlands can be estimated in several ways: by
micrometeorological methods (e.g., Bowen ratio energy balance, eddy covariance), by
empirical equations (e.g., Priestley-Taylor), or by combination methods (e.g., Penman,
Penman-Monteith) (Drexler et al. 2003). However, these methods can provide
information only for short time periods (Peacock and Hess 2004). Pan evaporation data
are easy to collect and usually are available over long time periods. Moreover, pan
evaporation can be used to estimate reference evapotranspiration for periods of 10 days
and longer (Allen et al. 1998). Pan evaporation data collected at the Musahacılı weather
station was used to estimate evapotranspiration because climatic data (radiation, water
temperature, etc.) required by other methods were not available for the simulation period.
Pan evaporation ($E_{pan}$) data were converted to reference evapotranspiration ($ET_{ref}$) using pan coefficients ($K_{pan}$) calculated for each month using equation 8 (Allen et al. 1998). Reference evapotranspiration is the evapotranspiration from a reference crop that has a height of 0.12 m, surface resistance of 70 m s$^{-1}$, and albedo of 0.23 (Allen et al. 1998).

$$
(K_{pan})_i = 0.61 + 0.00341 \times RH_i - 0.000162 \times (U_2)_i \times RH_i \\
- 0.00000959 \times (U_2)_i \times FET + 0.00327 \times (U_2)_i \times \ln(FET) - 0.00289 \times (U_2)_i \times \\
\ln((U_2)_i) - 0.0106 \times \ln(86.4 \times (U_2)_i) \ln(FET) + 0.00063 \times [\ln(FET)]^2 \times \\
\ln(86.4 \times (U_2)_i) 
$$

(8)

Equation 8 calculates pan coefficients for a Class A type pan with dry fetch. In this equation, $U_2$ is average monthly wind speed in m s$^{-1}$; $FET$ is fetch distance in m; and $RH$ is the average relative humidity (%). $U_2$ and $RH$ were available from the Develi weather station. $FET$ was estimated to be 50 m. Average monthly $K_{pan}$ values (Table 3.2) were used to calculate a value for $ET_{ref}$ using Equation 9.

$$
ET_{ref} = (K_{pan})_i \times (E_{pan})_i 
$$

(9)

The reference evapotranspiration then was multiplied by crop coefficients ($K_c$) and areal coverage of plant within the evaporation area to calculate actual evapotranspiration (ET) from marsh plants. $K_c$ is related to crop type, climate, soil evaporation, and crop growth stages (initial stage, crop development stage, mid-season stage, and late-season stage) (Allen et al. 1998). Three separate values were required to specify $K_c$ for initial, mid-season, and late season growth stages of the crops. Reference values for $K_c$ were obtained from Allen et al. (1998) for wetland vegetation and corrected to account for climatic factors in the study area (Allen et al. 1998). The growth stage of marsh vegetation was considered in the calculation of the monthly $K_c$ values (Moro et al. 2004).

The marsh area was divided into three zones where different types of vegetation and therefore different evapotranspiration rates occur (Figure 3.7). Evapotranspiration was allowed only in areas where roots were able to reach ground water, and the ground-
water level next to the wetland was assumed to be the same as the wetland surface-water level in each simulation time-step. Ideally, an evapotranspiration model could be developed to estimate changes in evapotranspiration rates with changes in soil water content, as well as vegetation (Jacobs et al. 2002, Pyke 2004). However, data are not sufficient to prepare and run a model to follow changes in soil water content. Therefore, it was assumed that evapotranspiration rates were at maximum when plants could reach ground water and the boundaries of these zones did not change during the modeling period. The inner zone (Zone 1) contains hydrophytes (dominantly *Phragmites australis* (Cav.) Trin ex Steud or common reed) that can reach a height of 4 m (Karadeniz 1995) with roots that can extend as long as 1 m (Cross and Fleming 1989, Wheeler and Shaw 1995) (Figure 3.5). In the outer zone (Zone 3), xerophytes dominate (Figure 3.5). Zone 2 forms a transition from hydrophytes to xerophytes because depth to ground water increases. This zone is seasonally flooded (3-6 months) and covered with vegetation that has a height of up to 0.4 m (Akçakaya et al. 1983). Crop coefficients used for vegetation in Zones 1 and 2 are given in Table 3.2. Evapotranspiration in Zone 3 was ignored because shallow-rooted xerophytes are not able to reach ground water; thus, their evapotranspiration rates are very small compared to the evapotranspiration by hydrophytes.
Figure 3.7. Vegetation zones in the Örtülüakar Marsh shown on LANDSAT ETM+ image acquired on May 5, 2003. Zone 1 & Zone 3 are covered with hydrophytes and xerophytes, respectively. In Zone 2, the transition occurs from hydrophytes to xerophytes.

Surface Flow

Flow to Yay Lake from Örtülüakar Marsh was estimated when the water level exceeded 1.3 m in the marsh using a flow equation for broad-crested weirs (Mays 2001). Weir width ($w$) was estimated from available maps and satellite images to be 2.5 km. In Equation 10, $h$ refers to simulated water depth and $K$ is the weir discharge coefficient.
$SF_i = 0$ if $h<1.3$ m

$SF_i = K \times w \times (h_i - 1.3)^{3/2}$ if $h \geq 1.3$ m  \hspace{1cm} (10)

<table>
<thead>
<tr>
<th>Month</th>
<th>Average $K_{\text{pan}}$</th>
<th>$K_c$ for Zone 1**</th>
<th>$K_c$ for Zone 2***</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.64</td>
<td>1.10</td>
<td>0.8</td>
</tr>
<tr>
<td>February</td>
<td>0.62</td>
<td>1.10</td>
<td>0.80</td>
</tr>
<tr>
<td>March</td>
<td>0.60</td>
<td>1.10</td>
<td>0.80</td>
</tr>
<tr>
<td>April</td>
<td>0.59</td>
<td>1.10</td>
<td>0.80</td>
</tr>
<tr>
<td>May</td>
<td>0.61</td>
<td>1.31</td>
<td>1.26</td>
</tr>
<tr>
<td>June</td>
<td>0.59</td>
<td>1.31</td>
<td>1.26</td>
</tr>
<tr>
<td>July</td>
<td>0.57</td>
<td>1.31</td>
<td>1.26</td>
</tr>
<tr>
<td>August</td>
<td>0.58</td>
<td>1.31</td>
<td>1.26</td>
</tr>
<tr>
<td>September</td>
<td>0.59</td>
<td>1.11</td>
<td>0.80</td>
</tr>
<tr>
<td>October</td>
<td>0.60</td>
<td>1.10</td>
<td>0.80</td>
</tr>
<tr>
<td>November</td>
<td>0.60</td>
<td>1.10</td>
<td>0.80</td>
</tr>
<tr>
<td>December</td>
<td>0.63</td>
<td>1.10</td>
<td>0.80</td>
</tr>
<tr>
<td>Average</td>
<td>0.60</td>
<td>1.17</td>
<td>0.95</td>
</tr>
</tbody>
</table>

* $K_{\text{pan}}$ values for each month were calculated using Equation 8.

**$K_c$ for reed swamp under standing water conditions after adjustments for local climatic conditions (Allen et al., 1998). $K_c$ during non-growing periods was assumed to be $K_c$ for open water.

***$K_c$ for reed swamp under moist soil conditions after adjustments for local climatic conditions (Allen et al., 1998). $K_c$ during non-growing periods was assumed to be $K_c$ for barren soil.
MODEL CALIBRATION

The model was calibrated to fit monthly water-level measurements in the marsh from 1997 to 2003. This interval includes both dry and wet periods. Values of selected model parameters were varied iteratively with reasonable ranges from literature values (Table 3.3) until satisfactory agreement was obtained between observed and simulated water levels. Root mean square error (RMSE, equation 11) between simulated and observed water depths in the marsh was used to test the success of the simulations. In Equation 11, \( n \) is the number of observations, and \( h_{obs} \) is the observed water depth.

\[
RMSE = \sqrt{\frac{1}{n} \sum (h - h_{obs})^2}
\] (11)

The lowest RMSE (0.28 m) between simulated and observed water levels (Figure 3.8) for the 1997-2003 period was obtained with the coefficients reported in Table 3.3.

Table 3.3. Parameter values used in the model

<table>
<thead>
<tr>
<th>Parameter*</th>
<th>Range</th>
<th>Used</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root depth (m)</td>
<td>≥1</td>
<td>1</td>
<td>(Cross and Fleming 1989)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Wheeler and Shaw 1995)</td>
</tr>
<tr>
<td>Available water content (%)</td>
<td>15 - 25</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Runoff coefficient (%)</td>
<td>5 - 18</td>
<td>5</td>
<td>(Mitsch and Gosselink 1993)</td>
</tr>
<tr>
<td>Irrigation return coefficient (%)</td>
<td>0 - 15</td>
<td>1</td>
<td>(Pasaoglu 1994)</td>
</tr>
<tr>
<td>Weir discharge coefficient</td>
<td>1.44 - 1.70</td>
<td>1.70</td>
<td></td>
</tr>
</tbody>
</table>

*Values used for pan and crop coefficients are presented in Table 3.1.

The model successfully simulated seasonal fluctuations in observed water levels and predicted the seasonal timing of minimum and maximum peaks. It also was able to simulate the observed trend in water levels after 1999. However, it did not describe dry
periods sufficiently and could not predict the sharp decreases and increases in water levels observed in 1999, 2000, and 2001. These model deficiencies may be attributed to a number of causes. (1) Ground-water flow in the model is very rough and gives estimates on an annual timescale but does not have a monthly time resolution. The real ground-water system likely is more dynamic than the simulated system. (2) Ground-water pumping for irrigation use was assumed to be constant in the simulations, but it may fluctuate rapidly when farmers turn pumps on and off. No data were available on water levels in the irrigation wells, but it is likely that wells located close to the marsh can withdraw water from the marsh if well water levels become lower than the marsh water level. (3) Spring flows were estimated from average monthly values, and monthly spring-water diversion had to be estimated based on secondary sources of information, not from measured values. (4) The irrigation return coefficient was assumed to be constant in the simulations, but irrigation return is reused during periods of water shortage (Dadaser-Celik 2005). (5) There also are uncertainties in calculations of evapotranspiration, which was not measured but calculated from pan-evaporation data for a single station by using pan and crop coefficients. Evapotranspiration in wetlands is spatially and temporarily variable and depends on vegetation and soil moisture distribution (Lott and Hunt 2001).

The difference between simulated and observed water levels was largest in 1999 and 2002, although these years were not different from others in term of climatic conditions (Figure 3.2). One or more of the causes explained above could be responsible for this difference. Particularly for these years, poor data quality could be another factor because it was suspected that some water-level data were not properly referenced to the base elevation of the marsh.

Nevertheless, the model was able to simulate the general hydrologic characteristics and dynamics in the Örtülüakar Marsh for the 1997-2003 period despite high uncertainties in hydrologic inputs and model parameters.

MODEL RESULTS FOR PAST CONDITIONS

Simulated and observed water levels in the marsh (Figure 3.8) show seasonal fluctuations: they become highest during spring (March-May), start decreasing in late
spring or summer, and become lowest during autumn (September-November). These fluctuations coincide with fluctuations in water inputs and outputs. Maximum marsh water levels occur in months following the maxima in precipitation, spring flows, and ground-water flows. Minimum marsh water levels occur in autumn after highest evapotranspiration and ground-water pumping occur in summer (Dadaser-Celik et al, unpublished data).

Figure 3.8. Simulated and observed monthly water depths in the Örtülüakar Marsh with the estimated error range of the measurements (± 0.1 m).

Table 3.4 and Figure 3.9 show the magnitudes of simulated annual and monthly water inputs and outputs from 1997 to 2003, respectively. During this period, approximately half (48-53%) of the annual water inflow to the Örtülüakar Marsh was ground water, 22-35% was from springs, and 10-27% was from precipitation. Overland flow and irrigation return represented only 2-3% of total inflow to the marsh. Until 1999, water depths in the marsh remained around 1 m, suggesting that water inflow was fairly stable (Mitsch and Gosselink 1993).
Table 3.4. Total water inputs (million m³/year) and outputs (million m³/year) from 1997 to 2003

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total input</td>
<td>47.64</td>
<td>45.01</td>
<td>35.93</td>
<td>39.88</td>
<td>33.50</td>
<td>26.63</td>
<td>30.68</td>
</tr>
<tr>
<td>Total output</td>
<td>-52.37</td>
<td>-54.56</td>
<td>-49.38</td>
<td>-45.51</td>
<td>-35.99</td>
<td>-32.31</td>
<td>-28.26</td>
</tr>
</tbody>
</table>

Annual water loss from the marsh is mainly (95-100%) evapotranspiration. Water flow from the Örtülüükar Marsh to Yay Lake occurred only in spring of 1997 and 1998 when water levels were high. Total simulated output was greater than total input in all years, which explains the drop in water levels during the simulation period.

Trends for individual simulated water input and output components during the modeling period also were investigated (Figure 3.9). Slopes of the lines indicate that major decreases in inflow to the marsh occurred during the modeling period. The slope of the ground-water flow line in Figure 3.9 (-0.0102 m³/month per month) was derived from observation well data and suggests that a decrease in ground-water flow was the major cause for the drop in marsh water levels after 1999. Precipitation inputs also became lower as a result of the decrease in inundated area in the marsh (slope = -0.0112 m³/month per month). Inflows from springs and irrigation return decreased much less over the 1997-2003 period.
SENSITIVITY ANALYSIS

The sensitivity of marsh-water levels to different parameters was investigated. To study sensitivity, parameters were changed (increased or decreased) by 10%. Table 3.5 shows the results.
Table 3.5. Sensitivity of Örtüülükar Marsh water levels to changes in water-budget components. Averages for the simulation period 1997 to 2003 are given. The reference average water level for this period is 0.65 m.

<table>
<thead>
<tr>
<th>Water-budget component</th>
<th>Change</th>
<th>Average water level after change (m)</th>
<th>Change in average water level(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root depth</td>
<td>10% increase</td>
<td>0.68</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.66</td>
<td>1.6</td>
</tr>
<tr>
<td>Available water content</td>
<td>10% increase</td>
<td>0.66</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.65</td>
<td>-0.2</td>
</tr>
<tr>
<td>Runoff coefficient</td>
<td>10% increase</td>
<td>0.66</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.65</td>
<td>-0.4</td>
</tr>
<tr>
<td>Irrigation return coefficient</td>
<td>10% increase</td>
<td>0.66</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.65</td>
<td>-0.3</td>
</tr>
<tr>
<td>Weir discharge coefficient</td>
<td>10% increase</td>
<td>0.65</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.65</td>
<td>0.0</td>
</tr>
<tr>
<td>Transmissivity</td>
<td>10% increase</td>
<td>0.71</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.60</td>
<td>-8.7</td>
</tr>
<tr>
<td>Pan coefficient</td>
<td>10% increase</td>
<td>0.52</td>
<td>-20.9</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.83</td>
<td>27.6</td>
</tr>
<tr>
<td>Crop coefficient</td>
<td>10% increase</td>
<td>0.52</td>
<td>-20.9</td>
</tr>
<tr>
<td></td>
<td>10% decrease</td>
<td>0.83</td>
<td>27.6</td>
</tr>
</tbody>
</table>

Water levels in the marsh are most sensitive to pan and crop coefficients (Figure 3.10). Increasing pan or crop coefficients by 10% caused a decrease in average water level by 0.14 m or 21%. When pan or crop coefficients were decreased by 10%, average water level increased by 0.18 m or 28%. High sensitivity to evapotranspiration parameters was expected because evapotranspiration controls water loss from the marsh.

Water levels also are sensitive to transmissivity. Increasing or decreasing transmissivity by 10% changed the average marsh water level by +0.06 m or +9%. This
result is consistent with the strong correlation found previously in a statistical analysis of marsh- and ground-water levels (Dadaser-Celik et al, unpublished data).

Water levels in the marsh are not sensitive to root depth, available water content, runoff, irrigation return, and weir coefficients. Increasing root depth by 10% decreased water levels by 0.03 m or 4%. Decreasing root depth by 10% caused only 0.02 m or 1.6% difference in water levels. Decreasing or increasing other parameters caused less than 0.4% change in marsh water levels.

Figure 3.10. Sensitivity of water levels in Örtülüükar Marsh to evapotranspiration.

MODEL SIMULATIONS OF WATER ALLOCATION SCENARIOS

The Örtülüükar Marsh is embedded in the Sultan Marshes as the most upgradient element. I explored how changes in water use for irrigation would affect the Örtülüükar Marsh. Simulations were run to understand how a reduction in ground-water pumping for irrigation would affect marsh water levels. In these simulations, the connection between ground-water elevation and spring flows was ignored. As expected, a reduction in ground-water pumping led to higher water levels in Örtülüükar Marsh. For the 1993-2003 period, simulated average monthly water levels rose from 0.65 m to 0.79 m, 1.10 m, and 1.14 m when pumping rates were reduced by 20%, 50%, and 100%, respectively. A water-level decline still was present between 1993 and 2003 under the 20% reduction
scenario, but the annual rate of decline was smaller. With 50% and 100% reductions in ground-water pumping, the trend in marsh water levels was stabilized.

As a second scenario, I simulated how marsh water levels would respond if more flow from springs became available. Two sub-scenarios were developed. In the first, only 50% of the flow from springs was used for irrigation during summer. In the second, spring water was not used for irrigation at all, but left to flow into the marsh. The simulated average monthly water levels rose from 0.65 m to 0.79 m and 0.99 m under the first and second sub-scenarios, respectively. However, in both cases there still was a slight decline in water levels from 1993 to 2003.

I also ran simulations to evaluate how marsh water levels would be affected if reductions in water use both from ground water and springs were combined. In the first and second scenarios, ground-water pumping rates were reduced by 20%. The first scenario allowed a reduction in water use from the springs by 50% during summer; in the second scenario, all spring water use was disallowed. In the third and fourth scenarios, ground-water pumping was reduced by 50%, with spring water-use arrangements similar to the first and second scenarios. Simulation results indicate that reducing ground-water use by 50% and using only 50% of the summer flows from the springs would result in stable water levels in the Örtülüakar Marsh (i.e., water levels in the Sultan Marshes could be preserved) (Figure 3.11).
SUMMARY AND CONCLUSIONS

A water-budget model on a monthly time-scale was developed for Örtülüakar Marsh in the Develi Basin of Anatolia, Turkey. The marsh is the most upstream of four components of the Sultan Marshes, an internationally rated wildlife refuge. Water levels in Örtülüakar Marsh were simulated to evaluate factors contributing to the observed decrease in water levels since 1995.

Marsh water levels were found to be highly sensitive to ground-water use for irrigation and evapotranspiration from the marsh. The RMSE between the simulated and observed marsh water levels was 0.28 m. This large error is related to the uncertainties in topographic and hydrogeologic model inputs and poor availability of hydrologic and climatic data for the simulation period (1997-2003). More field data collection and analyses of evapotranspiration and ground-water components would be needed to refine the model. Nevertheless, the current model simulated marsh water levels sufficiently well to analyze the hydrologic sensitivity of the Örtülüakar Marsh to different water allocation scenarios. This analysis showed that ground-water use is a major factor affecting
fluctuations in the marsh water levels. Ground-water inflows to the marsh decreased between 1997 and 2003 due to ground-water pumping for irrigation. This can explain the observed decrease in marsh water levels after 1999. During the same period, a reduction in the marsh area caused direct inflow to the marsh from precipitation to decrease. Spring flows and irrigation return flows also decreased to a smaller extent than other water-budget components.

Despite its deficiencies, the model supports the conclusion that a reduction in ground-water use for irrigation in the Develi Basin would protect water levels in the Sultan Marshes. Reductions on the order of 50% in ground-water pumping and spring water use would maintain marsh water levels at their historical levels. Because the Develi Irrigation Project stores and uses all of the surface runoff for irrigation, ground-water represents only about 34% of the total use for irrigation. A reduction of 50% in ground-water pumping and spring water use would represent less than a 20% reduction in total water use for irrigation. Increases in irrigation efficiencies by crop rotation, water pricing, and use of other forms of irrigation techniques could compensate for the reduced water use. However, social and economic issues need to be resolved to implement hydrologic measures necessary to save the Sultan Marshes.

**LITERATURE CITED**


Problems Symposium). Kayseri Valiliği (Kayseri Governor's Office), Kayseri, Turkey.


CHAPTER 4: AGRICULTURAL AND ENVIRONMENTAL CHANGES AFTER IRRIGATION MANAGEMENT TRANSFER IN THE DEVELI BASIN, TURKEY

ABSTRACT

Develi Basin is a semi-arid basin in central Turkey where water sustains both irrigated agriculture and an internationally important wetland, the Sultan Marshes. Agricultural and environmental changes in the Develi Basin have occurred since irrigation management was transferred in 1994 from a state authority (DSI) to irrigation associations (Kovalı and Ağcaaşar IAs). In this paper the practices of the IAs were evaluated using extensive data from interviews with farmers and IA officials, as well as data from reports prepared by DSI and the IAs, using comparisons with case studies reported in the scientific literature. Irrigated areas and surface water use in the Develi Basin showed significant fluctuations from 1995 to 2003. The area allocated to high water-consuming plants increased. Maintenance activities became dependent on fee collection rates. Quality of the irrigation water did not change significantly. Groundwater levels, flow rates from springs, and water levels in the Sultan Marshes all dropped. Overall analyses indicate that the water requirements of the Sultan Marshes have not been met, while water use for irrigation has been effective but not efficient. To reconcile agricultural and wetland water requirements, a basin-wide approach in water planning is recommended. Amounts of water to be allocated to the IAs and wetlands need to be clearly defined. DSI has to monitor canal maintenance by the IAs more closely, and IAs need to be given more responsibilities for future rehabilitation of the canals. Realistic water pricing, increased reliability of irrigation scheduling, higher on-farm irrigation efficiency, and in the long-term, modernization of the irrigation system need to be considered.

Key Words: environmental impacts; irrigation management transfer; water management; wetlands; Turkey
INTRODUCTION

Irrigation policies and institutions in Turkey have undergone a dramatic change since 1993. Prior to then, state institutions, particularly State Hydraulic Works (in Turkish Devlet Su İşleri or DSI) primarily were responsible for the planning, construction, operation and maintenance of irrigation systems. In 1993, Turkey started an accelerated transfer program in which operation and management responsibilities for the irrigation schemes were transferred to farmers, who were mostly organized as ‘irrigation associations’ (IAs). By 1996, 61% of the irrigated area (approximately 1 million ha) that had been managed by DSI was transferred, and by 2001, over 80% of irrigated area was under the control of farmers (Svendsen & Murray-Rust 2001).

In this study, I explore the effects of irrigation management transfer (IMT) in the Develi Basin in south-central Turkey. Develi Basin (Figure 4.1) is a semi-arid closed basin where both irrigated agriculture and an important wetland, Sultan Marshes, are dependent on scarce water resources. In this analysis, I consider not only agricultural changes but also environmental changes, particularly changes in the Sultan Marshes ecosystem. Analysis of the Develi Basin can provide insights into irrigation management around important natural areas in Turkey and elsewhere in the world. To the best of my knowledge, this is one of the first case studies that explores the conflict between participatory irrigation management and environmental flow requirements of natural ecosystems.

Participatory approaches have become popular in irrigation management all over the world as a means of increasing the economic efficiency and productivity of irrigation systems. There were three main drivers for decentralization in Turkey (Svendsen & Murray-Rust 2001; Yercan 2003). First, irrigation costs were not recovered because of low fee collection rates and high operation and maintenance costs. Second, privatization has been promoted in all sectors in Turkey for the last two decades. Third, farmer participation was expected to increase the efficiency and productivity of irrigation and sustainability of irrigation facilities. Until now, Turkey has been accepted as a “successful” example of IMT because of positive economic outcomes, particularly at the national scale (Svendsen & Murray-Rust 2001).
Turkey’s IMT program has received significant attention in the literature. Svendson and Murray-Rust (2001) reported that staffing intensity and operation expenses became lower and fee collection rates became higher since IMT. The performance of IMT in the Gediz River Basin in western Turkey, one of the first regions where IMT took place, has been analyzed in several studies. Murray-Rust and Svendson (2001) argued that although there was not a significant change in irrigation performance, IAs performed well by supporting increased agricultural productivity. Yercan (2003) and Yercan et al. (2004) reported increases in irrigated areas and fee collection rates and indicated that IAs were financially more self-sufficient compared to those in the pre-transfer period. Yercan (2003) found that farmers were satisfied with water availability, quality of the operation and maintenance activities, and irrigation scheduling, but were dissatisfied with water.
fees. In the Seyhan River Basin, Scheumann (2002) showed that operation and maintenance became better after IMT but salinization continued to be a problem.

Most of the previous studies of irrigation in Turkey used physical and economic performance measures to evaluate the outcomes of IMT and failed to analyze environmental impacts. Even in the participatory irrigation management literature that covers studies from many other countries, environmental impacts have not been sufficiently explored. A small number of (mostly qualitative) studies, such as Scheumann (2002) have focused on soil quality problems (Vermillion 1997). Effects of IMT on “downstream water uses” and “downstream ecosystems” generally have been ignored. Perry and Easter (2004) defined this conflict (i.e., the conflict between local and watershed-scale objectives) as the “scale incompatibility dilemma”.

In this study, I explore the outcomes of IMT in the Develi Basin. I analyze two IAs (Kovalı and Ağcaasår IAs) responsible for the management of almost 35% of irrigated area and 50% of surface water flows in the Develi Basin since 1994. This analysis draws on three primary sources of data: 1) interviews with farmers and staff of IAs, 2) reports prepared by DSI and IAs, and 3) scientific literature. We first explain the organizational structure and functions of the Kovalı and Ağcaasår IAs in the Develi Basin. Then we evaluate the changes in agricultural activities from 1995 to 2003 based on changes in irrigated areas, water use, cropping patterns, maintenance activities and water fees. Finally we evaluate the environmental changes in the same period, paying particular attention to changes in the Sultan Marshes ecosystem.

**STUDY AREA**

Develi Basin (Figure 4.1 & 4.2) is a semi-arid closed basin covering an area of about 800 km² with a drainage area of 3190 km² (DSI 1995). The regional climate is continental with a mean annual temperature of 11°C and a large difference between summer and winter temperatures. Annual rainfall is 330 mm, and average annual pan evaporation rate is 1660 mm (DSI 1995). The bulk of precipitation occurs in April and May, and evaporation is highest in July and August, coincident with the highest irrigation demand.
The human population in the basin is approximately 140,000 (2000 census). Develi Basin is located in the province of city of Kayseri, and Develi, Yahyalı and Yeşilhisar are the main towns in the basin. Crop (cereals and sugar beets) and fruit production are the most important economic activities, followed by animal husbandry and reed cutting from the Sultan Marshes. According to 2000 census, 47% of the working population in Kayseri was in the agriculture sector.

Irrigation has become more intense in the Develi Basin since completion of the Develi Irrigation Project in 1988. Prior to the project, 926 ha had been irrigated by flows from Akköy Reservoir, which was constructed in 1967. Ground water and surface water diverted from small streams had been used in other parts of the basin. The first phase of the Develi Irrigation Project, financed and constructed by DSI, included two irrigation reservoirs (Kovalı and Ağcaşar) and ground-water pumping facilities to irrigate 28,000 ha of farmland. The second, uncompleted, phase of the irrigation project includes plans to transfer 111-150 million m³/yr of Zamantı River water through a 12-km channel from a basin to the south to double the irrigated area in the Develi Basin. Current surface-water and ground-water uses for irrigation in the Develi Basin were estimated to be 129 and 65 million m³/yr, respectively (DSI 1993; Gürer 2004).

Management responsibilities for the Kovalı and Ağcaşar reservoirs were transferred to IAs in 1994. The command area for the Kovalı IA is 2,860 ha and covers seven villages and that for the Ağcaşar IA is 12,720 ha, covers 13 villages and one municipality. The areal coverage of various crop types cultivated in the region managed by the Kovalı and Ağcaşar IAs is summarized in Table 4.1 together with average crop productivity and income.

Ground-water use for irrigation is, generally on a village scale and managed by farmer cooperatives. Özaslan and Şeftalici (2002) estimated that 9,700 ha are irrigated from 187 wells distributed particularly in the western and southern parts of the basin. In Turkey, both surface and ground water are owned by the state. Although prior approval by the DSI is required for extracting deep (below 10m) ground water, surface water is open to all users but subject to the rights of prior users. Shallow ground water is also open to the public but requires notification of DSI. These laws, however, are not strongly
enforced. In the Develi Basin it is very common that wells are drilled without permits/notification.

![Figure 4.2. Geographic and hydrologic features of the Develi Basin and Sultan Marshes (modified after Paşaoğlu (1994))](image)

Drinking water in the Develi Basin is supplied from ground water at a rate estimated to be 15 million m$^3$/yr (DSI 1993). No wastewater treatment facilities exist in the region: domestic wastewater and industrial discharges from a leather and textile factory are carried to the Sultan Marshes at the center of the Develi Basin. Industrial water use is not significant.
Table 4.1. The crop types and cultivated areas, average productivity and average income in 2004 in the region managed by the Kovalı and Ağcaaaşar IAs (Ünlü 2005).

<table>
<thead>
<tr>
<th>Crop</th>
<th>area (ha)</th>
<th>average yield (kg ha⁻¹)</th>
<th>average income* (YTL ha⁻¹)</th>
<th>area (ha)</th>
<th>average yield (kg ha⁻¹)</th>
<th>average income* (YTL ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>633</td>
<td>3,250</td>
<td>1,110</td>
<td>2,444</td>
<td>4,100</td>
<td>1,560</td>
</tr>
<tr>
<td>Beans</td>
<td>20</td>
<td>1,200</td>
<td>1,100</td>
<td>112</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>250</td>
<td>40,000</td>
<td>4,000</td>
<td>1,716</td>
<td>50,000</td>
<td>5,500</td>
</tr>
<tr>
<td>Sunflower</td>
<td>165</td>
<td>1,750</td>
<td>1,930</td>
<td>1,711</td>
<td>2,500</td>
<td>3,250</td>
</tr>
<tr>
<td>Maize</td>
<td>65</td>
<td>40,000</td>
<td>4,800</td>
<td>633</td>
<td>40,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Fruit Plantations</td>
<td>301</td>
<td>-</td>
<td>-</td>
<td>148</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Vineyards</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>639</td>
<td>21,000</td>
<td>11,550</td>
</tr>
<tr>
<td>Fruits</td>
<td>1,360</td>
<td>23,000</td>
<td>14,950</td>
<td>43</td>
<td>36,000</td>
<td>11,520</td>
</tr>
<tr>
<td>Vegetables</td>
<td>51</td>
<td>32,000</td>
<td>17,600</td>
<td>8</td>
<td>26,000</td>
<td>10,660</td>
</tr>
<tr>
<td>Fodder</td>
<td>18</td>
<td>12,000</td>
<td>2,760</td>
<td>180</td>
<td>12,000</td>
<td>2,760</td>
</tr>
<tr>
<td>Poplar</td>
<td>1.5</td>
<td>30</td>
<td>2,640</td>
<td>2.9</td>
<td>30</td>
<td>2,250</td>
</tr>
<tr>
<td>Squash</td>
<td></td>
<td></td>
<td>23.4</td>
<td>29,000</td>
<td>9,860</td>
<td></td>
</tr>
</tbody>
</table>


The Sultan Marshes (Figure 4.2) are one of twelve internationally important wetland ecosystems Turkey (a Ramsar Site according to the Ramsar Convention on Wetlands of International Importance) and has been designated as a Nature Conservation Area and recently as a National Park by the Turkish government. The wetland consists of two salt-water lakes (Yay and Çöl Lakes) and two fresh-water marshes (Örtülüükar and Kepir marshes) covering 17,200 ha. The Sultan Marshes experienced a major adverse change after the construction of the Develi Irrigation Project (Dadaser-Celik et al. in press). Water levels in the wetland have dropped significantly, adversely affecting wetland biodiversity. An analysis of irrigation management in the Develi Basin can
provide a better understanding of these changes and help determine barriers and opportunities for the conservation of the Sultan Marshes.

METHODS

I first reviewed reports prepared by DSI and the Kovalı and Ağaçaşar IAs, and the scientific literature on Turkey’s IMT program to develop a general understanding of irrigation management in the Develi Basin and to identify data requirements for a more detailed analysis. In the summers of 2004 and 2005, I conducted extensive interviews with staff of the Kovalı and Ağaçaşar IAs (chairmen, general secretaries, members of the management committee, accountants) and with individual farmers who receive water from the Kovalı and Ağaçaşar reservoirs. The research was exploratory in nature and designed to obtain an in-depth understanding of IMT in the Develi Basin. Farmers were selected randomly from the villages or municipalities located in the IAs’ command areas. I interviewed at least one person from each village/municipality to capture the differences in crop patterns and water uses. A total of 42 interviews were conducted: 16 interviewees were selected from the command area of Kovalı IA, and 26 were selected from Ağaçaşar IA. All interviewees except the IA secretaries and an accountant defined their primary occupation as farming.

Interview data were collected and analyzed systematically using grounded-theory techniques (Glaser & Strauss 1967). Grounded theory provides advantages over questionnaire surveys because in the latter, researchers first need to develop a hypothesis (most probably a choice of anticipated answers) and then prepare the questions to test it. In the grounded theory, the hypothesis is developed and tested in the field. Therefore, it helps discover concepts or relationships, not defined or explained before. In this study, I chose grounded theory method because we aimed to explain the water-use practices of IAs in detail, and evaluate whether they are implicitly or explicitly related to the changes in the Sultan Marshes ecosystem. No previous studies were available in the scientific literature related to IMT in the Develi Basin.

Broad and open-ended questions were asked during interviews to capture as much detail as possible from the informants. The questions can be gathered in four groups: (1)
What are the characteristics and responsibilities of the IAs and how do they make decisions and plans regarding water use in the Develi Basin? (2) What factors affect the IAs decisions on water use, and how much do the water needs of the Sultan Marshes play a role in their decisions? (3) How much control do IAs have over water management in the Develi Basin? What kind of relationships is there between IAs and DSI? To what extent can IAs influence the farmers’ land-use or water-use decisions? (4) What are the main differences between participatory management and state management of irrigation systems? What are the agricultural, environmental and economic changes after IMT? A list of interview questions can be found in the Appendix.

After each interview, the responses were analyzed to separate information into several categories. The information from each interview then was compared with the information from previous interviews to identify common and conflicting points. New or modified interview questions were developed and asked in subsequent interviews to clarify any uncertainties. If necessary, I combined, divided or eliminated categories defined during the initial analysis. During this initial analysis, I noticed that the answers of IA staff and farmers did not differ from each other, probably because the majority of IA staff regard themselves as farmers rather than IA staff. I, therefore, analyzed all data together.

Data collection and analysis continued simultaneously, and interviews or data collection lasted until a saturation level was reached (Glaser & Strauss 1967). The saturation level is defined as the level after which further data collection does not provide new inputs regarding each category. It also means that each category is well-defined and well-connected with other categories (Strauss & Corbin 1990). Saturation level was realized when new interviews provided only a repetition of the data that had been collected before in each category. In the final analysis, we grouped all interview data in ten categories: 1) general IA characteristic, 2) organization and management of IAs, 3) responsibilities of IAs, 4) irrigation planning, 5) irrigation scheduling, 6) canal maintenance, 7) finances (including water fees), 8) cropping and irrigation decision-making process, 9) changes after IMT, and 10) Sultan Marshes. Results from the interview data were compared with information from government reports and literature.
Quantitative data on irrigated areas, crop patterns, water uses, water fees and other activities for the period 1995-2003 were extracted from reports of the IAs or obtained during interviews with IA staff. Historical hydrologic and climatic data for the Develi Basin and Sultan Marshes were obtained from the DSI. I analyzed quantitative data using statistical methods to identify trends in various variables and compare conditions before and after IMT.

CHARACTERISTICS AND RESPONSIBILITIES OF IRRIGATION ASSOCIATIONS

Irrigation associations have complete responsibility for the operation and maintenance of the Kovalı and the Ağcaaşar irrigation schemes, but the actual irrigation/drainage facilities and water rights are still owned by the State (Turkey). In other words, IAs provide all irrigation services and are responsible for the cost of providing those services.

Interviews showed that the majority of farmers think that IAs are better at irrigation management than the DSI (64%) or that there is no difference between IA and DSI management (24%). The reasons for farmers preference of IAs and DSI is provided in Table 4.2. It is apparent that there are some issues on which farmers provided conflicting opinions (e.g., canal maintenance and water conservation). These are most probably because of differences in farmers’ perception of changes in the Develi Basin.

The organizational structure and most important responsibilities of the IAs are explained in this section. Responsibilities are divided into: 1) general irrigation planning, 2) irrigation scheduling, 3) irrigation/drainage system maintenance, and 4) financial management.
Table 4.2. Farmers’ opinions regarding irrigation management by the IAs and DSI

<table>
<thead>
<tr>
<th>IAs are better, because;</th>
<th>DSI was better, because;</th>
</tr>
</thead>
<tbody>
<tr>
<td>farmers' water demands are met faster (35%)</td>
<td>water fees were lower (18%)</td>
</tr>
<tr>
<td>irrigation continues on weekends/at night (29%)</td>
<td>water distribution was more equitable (12%)</td>
</tr>
<tr>
<td>water conservation and financial management are better (24%)</td>
<td>canal maintenance was better (12%)</td>
</tr>
<tr>
<td>water distribution is more equitable (18%)</td>
<td>more water was available per unit area (12%)</td>
</tr>
<tr>
<td>canal maintenance is better (18%)</td>
<td>water conservation was better (6%)</td>
</tr>
<tr>
<td>ownership of the system is better (12%)</td>
<td></td>
</tr>
</tbody>
</table>

Organizational structure and management

The general assembly, the main governing body of IAs, is composed of three ( Ağcaasar IA) or four (Kovalı IA) members from each village and municipality. These members include village heads (in Turkish muhtar) and mayors and other two or three members selected by village heads or mayors, generally from among the members of local assemblies (in Turkish aza). General assemblies are renewed after general elections, which are held every five years. Representation of young generation and women are minimal in general assemblies because of land ownership and the traditional family structure. Most of the land titles are held by the oldest male members of the households. DSI is an observer member of the assembly. Major responsibilities of the general assemblies include electing the chair and the members of the management committee, approving plans/programs/reports and budgets/financial plans, formulating regulations, and dissolving the IA. The general assemblies meet two times a year.

A management committee, including the chair of the IA, three committee members, a general secretary and an accountant, meets at least semi-monthly. The management committee represents the IA and prepares annual programs, budgets and financial plans. The general secretary, who must be an “agricultural engineer”, implements IA activities and is responsible for the staff, which includes an accountant.
assistant, irrigation technicians (responsible for supervision of the irrigation labor force and field application of irrigation plans), irrigation laborers and machinery operators.

Farmers must become members of an IA to use water from the system, but they are not directly involved in IA management unless they are the members of the general assembly. They are indirectly involved in decision-making by electing local officials (such as village heads in villages and mayors in municipalities) during general elections.

**General irrigation planning**

General irrigation plans are prepared prior to the start of the growing season. Farmers report the areas to be irrigated and crops to be grown on water demand forms and IAs estimate water demands based on this information and crop water requirements calculated by DSI. A water allocation plan is prepared by comparing water demand with the reservoir supply. The calculated water demands generally are higher than the available supply. The shortage can be due to cultivation high water consuming crops, overestimation of water supply, or a combination of both conditions. It also suggests that the IAs’ influence on farmers’ cropping decisions is limited. In irrigation planning, other water uses in the Develi Basin (e.g., water needs of wetlands) are not considered.

**Irrigation scheduling**

Rotation scheduling is currently practiced by both IAs. In this system an amount of water is delivered to a certain point for certain duration at a pre-determined time. The water allocation for each tertiary canal is based on the crops and crop areas on the water demand forms. The rotation generally follows the order: cereals-fruits-sunflowers-sugar beets and corn. Irrigation schemes operate 24 h per day, but farmers reported discontent with night irrigation. When water storage in the reservoirs is sufficient, water flow to a field continues until water reaches the end of the field. During water-short periods, a 45-min or 1-h flow is applied per 1000 m² of irrigated area. Farmers are expected to prepare their field (e.g., leveling) prior to irrigation, and penalties are charged by the IAs to farmers who receive more water because of poor field conditions.
IAs respond to spontaneous water demands of farmers only if there is sufficient water in the reservoirs. The irrigation season usually starts in late April or early May and continues until available water in the reservoirs is distributed. In recent years, the Ağcaaaşar IA could complete only one rotation for all crops, while the Kovahı IA was able to complete at least four rotations for fruits and sugar beets and two rotations for other crops. This difference shows that in the Ağcaaaşar IA, water demand is much higher than supply, and water deliveries are not sufficient for most of the crops. Ground water or irrigation return is used widely in the region irrigated by the farmers in the command area of Ağcaaaşar IA because of this problem. Unlicensed wells are used commonly in the region to pump water when the quantity of water delivered by the IA is not satisfactory.

**Irrigation/drainage system maintenance**

IAs undertake canal maintenance prior to the start of the growing season by clearing of grass and weeds from the canals and repairing broken gates and cracks in canal linings. Canal maintenance also is undertaken during and after the irrigation season whenever a problem arises. Although IAs have become more self-sufficient since 1995 by obtaining the necessary machinery and equipment, some maintenance work still is undertaken with the help of DSI (maintaining service roads).

**Financial management**

IAs prepare annual budgets to balance income and expenditures. Income is provided from water fees, grants, attendance fees, penalties collected from members who do not obey instructions, revenue from purchasing-selling and renting of association goods (e.g., machinery), and interest on account balances. Water fees constitute the most important income for the IAs (e.g., 74% of the total income for the Kovahı IA in 2004). Fees are set by the IAs annually at a general assembly meeting based on expected expenditures in the following year. The fees are crop-specific and set on an areal basis. Therefore, water fees are not a direct measure of the amount of water use, and water itself is not priced.
Expenditures include expenses for the activities and management of the IAs. Most of the income in the IAs is used to sustain irrigation activities, which include maintenance of canals, salaries of maintenance staff, and equipment and machinery purchases. In 2004, these expenditures constituted 62% of the total expenditures of the Kovalı IA, and 24% of the expenditures were allocated to management expenses, such as salaries of management staff, office supplies, and electricity.

**AGRICULTURAL CHANGES AFTER IRRIGATION MANAGEMENT TRANSFER**

This section describes changes in agricultural activities in the Develi Basin after IMT. Most farmers perceived “positive” agricultural changes: 81% noticed an increase in high-water consuming crop varieties, and 51% noticed an increase in agricultural income. Other changes observed by the farmers were increases in crop yields (42%), cultivated areas (32%) and decrease in migration rates (29%). In this section, the changes on five variables were quantified based on statistical analysis of the data obtained from the IAs and DSI. The variables are: 1) irrigated areas, 2) water use and irrigation methods, 3) crop patterns, 4) water fees and fee collection rates, and 5) maintenance activities.

**Changes in irrigated areas**

The term “irrigated area” refers to the area irrigated from one of several reservoirs in a specific year. Although there has been an increase in irrigated areas since IMT, historical data show a large difference between planned and actual irrigated areas, particularly in the Ağcaaşar IA. From 1995 to 2003, only 28 to 62% of the planned irrigation area could be irrigated. Soil quality problems and water scarcity are the main reasons for this large difference. The Kovalı IA has been successful in meeting its goals for irrigated area; 91-122% of the planned irrigated area was irrigated by the Kovalı IA from 1995 to 2003.

The areas irrigated between 1995 and 2003 showed large annual fluctuations in the Ağcaaşar IA but were fairly constant in Kovalı IA. In the first two years after IMT, the irrigated area increased in both IAs reaching a maximum in 1997 (Figure 4.3). From
1997 to 1999, the irrigated area decreased sharply in the Ağcaasår IA. Precipitation in the water years 1997, 1998 and 1999 was 257mm, 320 mm and 289 mm, respectively, compared to an average of 294 mm, i.e. precipitation went from below average to above average and back to about average. The sharp drop in irrigated area from 1997 to 1999 was most likely triggered by the dry conditions in 1997, when farmers suffered economically due to water shortages. In 1998 and 1999, farmers left some fields uncultivated (by decreasing the area allocated to low-value crops, e.g., cereals) or used ground water instead of surface water (for high value crops, e.g., sugar beets) because of an expectation of another drought. Farmers started cultivating and using surface water again in 2000, and irrigated area increased gradually afterwards reaching the 1997 level in 2003. Overall, these results suggest that the Kovalı IA has been more reliable than that the Ağcaasår IA in meeting project goals after IMT, probably because the water resource is more stable, and the command area is smaller.

Figure 4.3. Irrigated areas (ha) in Kovalı and Ağcaasår IAs from 1995 to 2003.

Changes in water use and irrigation methods

Total surface water use for irrigation and surface water use per ha showed large fluctuations from 1995 to 2003 in both IAs (Figure 4.4) and were the lowest in 2001. In that year, surface water use per ha dropped significantly, particularly in the Ağcaasår IA,
because precipitation was below average (269 mm). The simultaneous increase in irrigated areas continued a trend started in 2000 (explained in the previous section). The crop pattern in 2001 reflects this situation: The area allocated to cereals was higher and the area of orchards irrigated from Ağcaasar reservoir was less compared to previous years. It is likely that most farmers served by the Ağcaasar IA used ground water to supplement surface water for high water-consuming crop varieties (e.g., fruits) in 2001.

Figure 4.4. Total surface water use and surface water use per ha in Kovalı and Ağcaasar IAs from 1995 to 2003.

The irrigation systems in the Develi Basin were designed as open canal and gravity distribution systems using the flood irrigation method, therefore, irrigation water requirements. In recent years, farmers developed positive attitudes toward modern irrigation technologies: 68% of the farmers mentioned that they would like to adopt drip and sprinkler irrigation. The major reason for this change in attitude is that more farmers have become aware of the positive impacts of new irrigation technologies on agricultural productivity and their incomes (64%). Another reason is that sprinkler and drip irrigation technologies provide more economical alternatives to flood irrigation when ground water is used (28%). In recent years, IAs have not been able to respond sufficiently to the water
demands of the farmers because of less than expected water accumulation in the reservoirs and ground-water use have become more common. According to farmers, these technologies also prevent soil erosion (8%), reduce labor cost (4%), and prevent distribution of diseases (4%). Nonetheless, sprinkler and drip irrigation methods are used only in 10% of the irrigated area because of high initial investment requirements (52%), unsuitable soil characteristics (12%), existing of the open-channel water distribution systems and operational needs (4%).

**Changes in crop patterns**

Crop types changed little in the Develi Basin from 1995 and 2003. A few new crops (e.g., corn, squash) were introduced, but they have not been widely accepted. Cereals (wheat and barley), legumes, sugar beets, sunflower, clover and vegetables have remained the principal crops cultivated in the area. Orchards, especially apple orchards, also have continued to exist. The land allocated to various plants, however, has changed since 1995. High water-consuming plants (fruits, sugar beets, sunflower, and clover) have become more widespread, and the area allocated to low water-consuming plants (cereals) has been shrinking gradually (Figure 4.5). For example, in the service area of the Kovalı IA, area allocated to orchards increased from 26% in 1995 to 46% in 2003. In the same time interval, the area allocated to legumes decreased sharply from 37% to 4%. The area allocated to sugar beets remained almost the same because of a government-determined quota for sugar beet production.

Interviews showed that the expectation of profits is important in crop selection for a majority of farmers (68%). Most farmers prefer to cultivate crops that are bought by the state (sugar beets and cereals) because the sale of those products is guaranteed, and for political reasons the prices are generally satisfactory. Another factor affecting crop selection (63%) is, of course, the availability of both ground water and surface water. Farmers who depend on water from the reservoirs (either due to the unavailability of ground water or the financial burden of pumping) usually select crops according to water availability in the reservoirs. Before irrigation season, DSI notifies the IAs (and IAs notify farmers), if a drought is expected. Crop selection by farmers who can obtain an
alternative water supply in the form of ground water (or drain water) probably are not affected by the notification. Tradition also plays an important role in crop selection for 11% of the farmers. Farmers generally are hesitant to accept new crops and wait for results from a small number of innovative farmers. Personal needs (11%) and amount of land owned (5%) also affect farmers’ cropping decisions.

Figure 4.5. Crops patterns in the Kovalı and Ağcaşar IAs in 1995 and 2003.

Changes in water fees and fee collection rates

The water fees became lower after IMT. In 2005 water fees set by the IAs were almost 50% lower than DSI charges in western and central Anatolia (Group 2) and almost 100% lower than fees charged by irrigation schemes that use ground water (Table 4.3). A reason for this difference is that operation and maintenance costs are generally lower in the IAs than in DSI because of low staffing levels. There is also a significant difference between the cost of irrigation from surface water and ground water because of high energy costs associated with ground-water pumping. Water fees also tend to be lower in
the IAs because farmers influence the decisions. The IA general assemblies approve decreases in fees during the irrigation season when climatic or other factors cause lower crop yields than expected. Despite the difference between water fees charged by the IAs and DSI, 35% of the farmers regard the current level of water fees as high and 47% of farmers regard it as normal. Only 18% of farmers think that water fees should be higher.

Water fee collection rates increased after IMT, but fee collection rates are still below 100%. In 2004, the Kovalı IA budgeted a shortfall of 24% of income from irrigation fees that could not be collected in 2003. The water-fee collection rate was as low as 40% for the Kovalı IA and below 80% for the Ağcaasăr IA in 2005. The majority of the water fees were collected through the Sugar Beet Cooperative, which pays all water debts of farmers directly to the IAs each year before paying the farmers. This method has increased the fee collection rates substantially. However, sugar beets are not cultivated as much in the service area of the Kovalı IA, and its fee collection rate thus is still low. Another problem is that water fees are collected after the irrigation season. That practice leaves IAs short of funds most of the year and prevents necessary maintenance activities and sometimes paying salaries. IA chairs and secretaries indicated their discontent with low water fee collection rates, but they admitted that IAs do not want to enforce legal procedures to collect late fees because of their sympathy for farmers. They said members of the management committee are also farmers and they do not want to create any difficulty for others.
Table 4.3. Water fees in YTL da\(^{-1}\) in Kovalı and Ağcaar IA's and under DSI management in 2005. Group 1 and Group 2 include surface water irrigation schemes (based on location) and Group 3 includes ground-water irrigation schemes.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Kovalı IA</th>
<th>Ağcaar IA</th>
<th>DSI Group 1</th>
<th>DSI Group 2</th>
<th>DSI Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits</td>
<td>16</td>
<td>18</td>
<td>21.22</td>
<td>31.45</td>
<td>83.57</td>
</tr>
<tr>
<td>Plantations</td>
<td>8</td>
<td>10</td>
<td>11</td>
<td>16.49</td>
<td>41.02</td>
</tr>
<tr>
<td>Cereals</td>
<td>6</td>
<td>8</td>
<td>6.82</td>
<td>10.23</td>
<td>25.95</td>
</tr>
<tr>
<td>Legumes</td>
<td>16</td>
<td>18</td>
<td>11</td>
<td>16.49</td>
<td>41.02</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>16</td>
<td>18</td>
<td>21.22</td>
<td>31.45</td>
<td>83.57</td>
</tr>
<tr>
<td>Clover</td>
<td>8</td>
<td>18</td>
<td>13.64</td>
<td>20.45</td>
<td>54.76</td>
</tr>
<tr>
<td>Corn</td>
<td>14</td>
<td>18</td>
<td>13.64</td>
<td>20.45</td>
<td>54.76</td>
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<td>Squash</td>
<td>10</td>
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<td>16.49</td>
<td>41.02</td>
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<tr>
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<td>16.49</td>
<td>41.02</td>
</tr>
<tr>
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<td>25.95</td>
<td>68.18</td>
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<tr>
<td>Poplar</td>
<td>16</td>
<td>13.64</td>
<td>20.45</td>
<td>54.76</td>
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</tr>
<tr>
<td>Potato</td>
<td>18</td>
<td>13.64</td>
<td>20.45</td>
<td>54.76</td>
<td></td>
</tr>
<tr>
<td>Mds**</td>
<td>4</td>
<td>10</td>
<td>6.82</td>
<td>10.23</td>
<td>25.95</td>
</tr>
</tbody>
</table>

YTL = Yeni Turk Lirası (New Turkish Lira). 1 USD = 1.33 YTL (July 2005).
1 da = 1 decar = 0.1 ha. ‘Decar’ is used as the unit area in Turkey by farmers and government institutions. ** Irrigation outside irrigation season

Changes in maintenance activities

In the Develi Basin, water loss rates higher than typical values (60%) have been reported because of the deterioration in irrigation and drainage channels. Most of the IA staff we interviewed indicated that the funds obtained through water fees are insufficient to cover operation and maintenance expenses at an adequate level, but they think water fees cannot be set higher than current levels because of farmers’ opposition to higher prices. The staff also confirmed that maintenance and purchase of equipment/machinery is reduced when there is a lack of money. Canal maintenance was listed by 18% of the
farmers as one of the tasks that IAs do better than the DSI due to availability of more field personnel, while 12% argued that DSI was better in canal maintenance due to the availability of more funds, machinery and equipment.

ENVIRONMENTAL CHANGES AFTER IRRIGATION MANAGEMENT TRANSFER

Irrigated agriculture can cause serious negative impacts on the natural environment. A report of the U.N. Food and Agriculture Organization (FAO) (Dougherty & Hall 1995) summarizes these impacts under four headings: 1) degradation of irrigation land; 2) degradation of water quality, 3) ground-water depletion, and 4) ecosystem degradation. Based on the interviews and previous studies, we can examine whether these impacts have appeared in the Develi Basin after IMT. Interviews showed clearly that most farmers did not acknowledge significant environmental changes. The changes listed by the farmers include decrease in ground-water levels (10%), drop in water levels in the Sultan Marshes (3%), and decrease in general environmental quality (3%).

Effects on irrigation land

Water logging and salinization are prevalent in most irrigated lands in the world including Turkey, e.g., in the Seyhan River Basin (Scheumann 2002). No study has been conducted to identify changes in soil characteristics in the Develi Basin. According to interviews with IA staff, there are no immediate threats from water logging and salinization in the service area of the Kovalı IA. Unlike the command area of Ağcaaslar IA, the water table in Kovalı region is deep enough and has a favorable gradient to allow proper drainage. Currently, DSI has approximately 300 observation wells in the project area and makes regular measurements to observe changes in the depth of the water table. If the water level rises higher than 1m below the land surface at a specific location, the IAs take the necessary steps to drain water (e.g., clean drainage canals).

It may be too early to see the effects of irrigation management changes on soil quality in the Develi Basin. Deterioration of irrigation and drainage canals, inadequate canal maintenance, excessive application of irrigation water, and water reuse from
drainage canals may create problems in the future. During interviews, many farmers indicated that they are aware of the problems created by excessive irrigation, but they also admitted that they irrigate more than necessary once water is available. Unreliable irrigation scheduling is the main reason for this behavior because farmers feel that there is no guarantee that water will be available in the future.

**Effects on irrigation water quality**

A significant change in irrigation water quality has not been observed in the Develi Basin because water accumulated in the reservoirs is generated within the basin and there are no users upstream. A threat to the quality of irrigation water could be the use of irrigation return water during periods of water scarcity, which can not only cause soil salinization but also increase pollutant concentrations in return water and pose a risk for the ultimate receiving area (Sultan Marshes). Ground-water pollution by irrigation return and untreated wastewater also could become a problem in the future.

**Effects on ground water**

Although the Kovalı and Ağcaşar IAs are responsible for managing surface water, their activities also affect the ground-water system. Most farmers start to pump ground water, when they are not satisfied by water deliveries from the reservoirs. In addition, the Ağcaşar IA owns approximately 100 wells and has operated 20 wells when surface water supply was insufficient.

Water levels in six observation wells (W1-W6) distributed over the Develi Basin (Figure 4.2) were analyzed for the 1993-2003 period to evaluate seasonal and long-term changes in ground-water levels (Dadaser-Celik et al. in press). The analysis showed that ground-water levels have been declining overall. Slopes of trend lines ranged from -0.0052 m month\(^{-1}\) for W6 to -0.0558 m/month for W1. Observation wells W2-W4 are located in the service areas of IAs and showed decreasing trends with slopes of -0.0161, -0.0422 and -0.0117 m month\(^{-1}\), respectively. The slope of the trend line for W5 was +0.0098 m month\(^{-1}\). For the same time period (1993-2003), precipitation showed a slightly increasing trend (with a slope of +0.039 mm month\(^{-1}\)), while pan evaporation
showed a decreasing trend (with a slope of - 0.173 mm month\(^{-1}\)). Ground-water level changes are therefore most probably related to increases in pumping rates rather than climatic changes. Spring flows also have been declining (Dadaser-Celik et al. in press) due to decline in ground-water levels. The slopes of the trend lines for S1 and S2 were -0.0007 and -0.0016 m\(^3\) s\(^{-1}\) month\(^{-1}\) respectively for the 1993-2003 period. The flow rates of S3-S5 showed a decreasing trend at a rate of 0.0009 m\(^3\) s\(^{-1}\) month\(^{-1}\).

**Effects on downstream ecosystems**

Excessive water use for irrigation has negatively affected the hydrologic regime of the Sultan Marshes. Figure 4.6 shows decreases in water levels from 1993 to 2003 in the Örtülüüakar Marsh and Yay Lake, two important subsystems of the Sultan Marshes. After the construction of the irrigation project, the major streams feeding the marshes were diverted to the Kovalı and Ağcaasăr reservoirs. Spring flows also have been diverted during the irrigation season. Irrigation return water discharges into the marshes at a very low rate because of water use from drainage canals, it is also highly polluted (Karadeniz 2000). A recent analysis showed that the decrease in water levels after 1995 is directly related to increased use of ground water and spring water for irrigation purposes (Dadaser-Celik et al. 2006). Alteration of the hydrologic regime of the Sultan Marshes has also adversely affected the biological and chemical characteristics of the wetland. It has caused a serious reduction in animal habitat, especially for birds and associated ecotourism, as well as plant harvesting. Irrigation return from agricultural areas also has been an increasing threat for the Sultan Marshes. Water quality measurements over 20-year period by Akçakaya et al. (1983), ENCON (1999) and recently by Gürer (2004) indicate that salinity and water pollutants have increased in the Sultan Marshes in recent years. Demirezen and Aksoy (2006) also showed that emergent vegetation in the Sultan Marshes, such as common reed, accumulated high concentrations of heavy metals.
SUMMARY

Agricultural and environmental changes were analyzed after IMT (irrigation management transfer) in the Develi Basin, Turkey. Operation and management responsibilities for the Kovalı and Ağcaasar reservoirs were transferred in 1994 from a government agency (DSI) to local irrigation associations (IAs) established and managed by farmers.

The analysis shows that IMT has not had significant impacts on agricultural activities. The size of irrigated areas fluctuated between 2,600 and 3,500 ha in Kovalı IA and 3,500 and 7,700 ha in Ağcaasar IA from 1995 to 2003. These fluctuations are related to water availability because total irrigation water use and surface water delivered per ha of agricultural land showed similar fluctuations. Analysis of crop patterns shows a trend toward the production of high water-consuming plants, which increases irrigation water requirements in the Develi Basin. The irrigation projects were designed by the DSI as flood irrigation systems, but farmers recently have developed a positive attitude toward modern irrigation systems. Drip and sprinkler irrigation systems became more popular during the period of water scarcity when farmers used ground water as a supplement to surface water. However, these irrigation systems are used in less than 10% of the basin. Water fees set by IAs are generally lower than those set by the government agency (DSI) because operation and maintenance expenses are lower in the IAs and farmers influence
decisions regarding water fees. Yet most farmers think that fees are higher than they can afford. Water fee collection was 40% in Kovalı IA and 80% in Ağcaüşar IA in 2005.

Although salinity, water logging and irrigation water quality have not become major problems in the Develi Basin, they may affect agricultural activities and environmental quality in the future. Poor maintenance of canals, excessive use of water and reuse of irrigation return pose risks for the sustainability of agriculture and the natural environment in the Develi Basin. Decreases in ground-water levels and spring flow rates provide evidence that ground-water pumping in the Develi Basin is above its sustainable yield. Excessive use of surface and ground water has lowered water levels in the Sultan Marshes to the point where its chemical water quality is impaired and the existence of the Sultan Marshes as a wildlife habitat is threatened.

**RECOMMENDATIONS**

The following strategies are recommended for consideration to simultaneously sustain agriculture and the Sultan Marshes in the Develi Basin:

**Basin-Wide Water Planning**

There is an urgent need for **basin-wide** water use planning in the Develi Basin to reconcile multiple sources and uses of water. Currently, there is no formal comprehensive water planning system in the Develi Basin. Although DSI holds water rights and can enforce water release to the Sultan Marshes, DSI does so only under extreme conditions (e.g., in the 2003 drought). Ground water, another water source for the Sultan Marshes, also has been mined extensively by farmers. Although ground-water use requires prior approval by DSI (or prior notification of DSI in the case of shallow ground water), the law is not enforced. The number of wells and amount of ground water extracted are unknown.

Water allocation problems can be solved only if alternative uses of water are coordinated. As Perry and Easter (2004) discussed, and as observed in the Develi Basin case study, IAs (or local institutions in general) make decisions to solve local problems and do not consider long-term or larger-scale impacts of these decisions. Therefore,
“institutional arrangements” are needed to coordinate the needs and activities of all water users (Perry and Easter 2004). In the case of the Develi Basin, government agencies (e.g., DSI and the Ministry of Environment and Forestry), IAs, and other stakeholders (e.g., non-government organizations) can form a regulatory body to review all water-use decisions and evaluate their broader impacts (e.g., impacts on the Sultan Marshes). There is also a need to define and legalize the water flow requirements of the Sultan Marshes and make it a high priority to release of that amount of water to the marshes.

**Water Rights and Ownership of Infrastructure**

The current delegation of management authority from DSI to the IAs creates no incentives for IAs to save water and to make improvements of the system. No water rights were transferred and no specification of water allocation is given to the IAs. This creates great uncertainty and insecurity for both IAs and the Sultan Marshes. The irrigation and drainage infrastructure is still owned by the state (DSI); ownership was not transferred to the IAs. This has caused improper maintenance by the IAs.

Development of a more appropriate water rights system is very important for the sustainability of the IAs and other water users in the Develi Basin. DSI needs to monitor and enforce infrastructure maintenance activities closely and ensure that maintenance is undertaken. In the long term, DSI can consider transferring the infrastructure ownership to the IAs or defining the role of IAs in the possible future rehabilitation of the infrastructure (e.g., cost sharing) (Svendsen and Nott 2002).

**Water Pricing**

The system used for pricing of irrigation water has an important influence on the efficiency of water use and the sustainability of the irrigation system (Le Gal et al. 2003). Use of a non-volumetric pricing method (areal pricing) and the current level of water fees do not create incentives for Develi Basin farmers to save water. Farmers do not want to increase water fees despite the fact that maintenance activities are not adequate due to funding limitations. The price elasticity of water demand (i.e., the responsiveness of water demand to changes in water fees) is low because total water cost is only a small
proportion of the farmers total production cost or income (Le Gal et al. 2003). It has been argued that water fees should be at least 20% of the net income to be able to cause a decrease in water demand (Cornish 2004). In the Develi Basin, water fees constitute less than 10% of the agricultural production costs and less than 5% of the agricultural income.

A new water pricing system should be developed in the Develi Basin to reflect the true value of water. Water fees need to cover not only operation and maintenance costs but also the cost of water (Ünver & Gupta 2003). Timely and full collection of water fees has to be enforced. Although volumetric pricing and market-based methods can effectively reduce water demand, they require significant initial investment and have high operational costs (Cornish 2004). They may therefore not be feasible in the Develi Basin. Modification of areal pricing, i.e., increasing the price difference between high- and low-water consuming varieties or setting different rates based on the technology used in irrigation (e.g., low rates for sprinkler/drip irrigated areas), would be options requiring less investment (Easter and Liu 2007).

Increasing the reliability of irrigation scheduling

In the Develi Basin, farmers have little influence on the amount and timing of water deliveries; they also have very little information available while they are making decisions on crop patterns. Current water use planning is based on short-term observations. Very few hydrologic and climatic data are collected. Water quality data are unavailable. These conditions show that the irrigation planning and scheduling is not reliable from the perspective of the farmers.

Uncertainties in irrigation scheduling coupled with low water fees cause farmers to use more water when water becomes available (Easter and Liu 2007). In India, a similar problem was solved when farmers were notified before the irrigation season about the amount of water to be delivered (Belsare 2001). Communication between farmers and the IAs and reliability of IAs related to irrigation scheduling should be increased. Irrigation scheduling should be done prior to the irrigation season and based on water availability. During droughts, IAs should provide more guidance on crop selection.
Increasing the efficiency of the irrigation system

Current trends in crop patterns show that farmers are moving toward more water-consuming varieties (such as orchards); therefore water shortage will likely be more severe in the near future. Therefore, it is necessary to increase irrigation efficiency in the Develi Basin.

Laser leveling of the land is one of the options to increase efficiency. Laser leveling can increase irrigation uniformity and reduce the amount of water use. Previous studies show successful applications of laser-leveling in developing countries such as Morocco and Egypt (Clemmens 1999). Repair of the canals can prevent water losses through seepage, thus save water in the Develi Basin.

Conversion of the traditional open-channel conveyance systems and flood-irrigation method to pressurized conveyance system and sprinkler/drip irrigation can be considered in the long-term. Despite positive attitude of farmers toward these technologies, high capital requirement was mentioned during the interviews as the major factor preventing the farmers from adopting them. The capital costs of drip and sprinkler irrigation systems were reported to be $2,000-4,500 per ha and $500-3,800 per ha in the U.S., respectively (Clemmens and Dedrick 1994). According to interviews, $1,000-3,000 per ha was thought to be sufficient for installation of drip irrigation equipment, but many farmers think that this is higher than they can afford. One possible way to overcome the funding problem is to offer incentives (such as long-term and low-interest loans) to farmers who want to increase on-farm irrigation efficiency and to IAs that want to modernize their conveyance/management systems (Playán and Mateos 2004). Another strategy can be cost-sharing between the state and farmers. In Yemen, closed conveyance system and drip irrigation equipment were installed successfully when the state covered 75% of the investment costs and 90% of the installation costs (Easter and Liu 2007). A study conducted in southeastern Turkey showed that it is necessary to subsidize irrigation equipment by at least 40% for low water tariffs and 60% for high water tariffs to make the transfer from furrow to drip irrigation acceptable (Luquet et al. 2005). Education activities and pilot studies can be effective in the interim to increase farmers’ awareness. For instance, in the last few years, use of drip irrigation on sugar beets is increasing as a
result of the promotion of this technique by the Sugar Beet Cooperative. It is important to ensure that water needs of the Sultan Marshes are not ignored once more water becomes available through improved irrigation practices.

APPENDIX: Interview Questions

Questions used as a guide in the interviews and in data analysis are listed below. The questions were placed in 11 information categories (A to K) created after combination or division of numerous subcategories created from interview data

Questions to Irrigation Association Staff:

A. General IA characteristics: 1) What is the area irrigated at present and area in design? If there is difference, what are the reasons? 2) Which irrigation techniques are used in your service area and what is the area irrigated by each technique?

B. Organization and management of IAs: 1) Can you describe the organizational scheme in the IA? 2) How are general assembly members, management committee (chairman, general secretary, other members) and other committees selected? 3) What are the responsibilities of general assembly, management committee, or other committees or each person in these committees? 4) What are the responsibilities of other IA staff 5) Can you explain the role of the individual farmers in the management of IA?

C. Responsibilities of IA: 1) What are the activities undertaken by the IA and what steps or procedures are followed while undertaking these activities? 2) What is the relationship of the IA with state institutions (particularly State Hydraulic Works?) Do state institutions provide any support to the IA (e.g., subsidies, education or training)?

D. Irrigation Planning in IAs: 1) What other institutions or individuals are involved in water-use decisions in the Develi Basin and what are their roles? 2) Are any hydrologic data collected or any hydrologic analyses (e.g. modeling, forecasting water availability) conducted to help with irrigation planning? If not, how do you make estimates on water availability? How do you ensure water quality is protected? How do you control the success of irrigation/drainage activities? 3) Does the availability of water influence the water-use by the association? If yes, how? 4) If water is not sufficient, how water is
shared during dry season? What kind of activities can be done to cope with drought by the association? 5) Is there a crop production plan in the Develi Basin?

E. Sultan Marshes: 1) Do the water requirements of the Sultan Marshes affect water-use decisions? Do you have to consider Sultan Marshes while making water-use decisions? If yes, how? 2) Is there any regulation/rule related to Sultan Marshes that you need to obey?

F. Irrigation scheduling in IAs: 1) How are water distribution plans prepared? 2) To what extent water distribution plans can be followed? What are the reasons for any deviation from these plans?

G. Canal Maintenance in IAs: What maintenance activities are undertaken by the IA?

H. Finances in IAs: 1) Can you explain the how the association’s budget is prepared? 2) Can you list all the incomes and expenditures in the budget? 3) What is the magnitude of each component? Are incomes and expenditures always equal? 4) How water fees are set? 5) What are the factors affecting the determination of water prices? 6) What percentage of the water fees can be collected? 7) Do you assess this level of water fee as suitable?

Questions to Farmers:

I. Cropping and irrigation decisions: 1) How do you decide what to cultivate? Which factors affect your decisions? 2) Would you like to adopt new irrigation technologies (drip and sprinkler irrigation)?

J. Water fees: 1) How do you regard the current level of water fees?

K. Agricultural, environmental and economic changes after irrigation management transfer: 1) What changes occurred in the Develi Basin in recent years? 2) Which one is better at irrigation management, DSI or IA? Why?

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CHAPTER 5: THE PROJECTED COSTS AND BENEFITS OF WATER DIVERSION FROM AND TO THE SULTAN MARSHES (TURKEY)

ABSTRACT

The Sultan Marshes in the Develi Basin, Anatolia, one of twelve internationally important wetlands of Turkey, have been severely affected by the construction of an irrigation project in 1988. Intensive use of surface and ground water in irrigation has caused more than a 1 m decline in water levels and has affected the wetlands’ ecological characteristics. Previous studies indicate that Sultan Marshes will need more water to restore viable ecological conditions. In this study, I analyze how economic benefits from agriculture and wetlands would be affected if moderate amounts of water were diverted from agriculture back to wetlands in the Develi Basin. By estimating total and marginal costs and benefits associated with water diversions, the optimum or economically-efficient amount of water diversion were determined. When only direct-use values of the wetland (animal grazing, plant harvesting, and ecotourism) were included in the analysis, the optimum amount of water diversion to the wetlands was found to be 5.2 million m$^3$ yr$^{-1}$ (165 L s$^{-1}$), which compares to about 62 million m$^3$ yr$^{-1}$ (1,957 L s$^{-1}$) used in irrigation. When wastewater treatment benefits (an indirect-use value) were added, the optimum amount rose to 7 million m$^3$ yr$^{-1}$. Overall, the analysis showed that water diversion from agriculture to the Sultan Marshes is economically feasible.

Key words: agriculture, economics, Sultan Marshes, Turkey, water diversion, wetlands.

INTRODUCTION

Wetlands are ecosystems with many hydrologic, biological and ecological functions (Heimlich et al., 1998). Wetlands recharge/discharge ground water, maintain or improve water quality by sediment and nutrient retention, reduce erosion and floods by water storage, and provide habitat for numerous plant and animal species. They regulate local climate and have important roles in carbon sequestration. Wetlands also offer products for human use opportunities for nature observation.
Intensification of irrigated agriculture has negatively affected wetlands worldwide in recent decades (Gerakis and Kalburtji, 1998; Lemly et al., 2000; Kingsford and Thomas, 2004). Water available for wetlands has diminished as more water is diverted for irrigation. Residues of fertilizers and pesticides used on agricultural lands have been transported as pollutants to wetlands. As a result, wetlands have become smaller or even completely dried out, and their chemical and biological characteristics have been altered. The conflict between agricultural intensification and wetland conservation has become more apparent as the value of wetlands has been recognized by the public. In this study, I provide an economic analysis of water use by irrigated agriculture and the Sultan Marshes wetlands in the Develi Basin, Anatolia, Turkey.

Irrigated agriculture has always existed in the semi-arid Develi Basin but became more intense after the completion of the first phase of the “Develi Irrigation Project”. Since 1988, almost all the surface water flows that formerly fed the Sultan Marshes have been collected in irrigation reservoirs. Ground water and flows from springs also have been used at an increasing rate for irrigation.

The Sultan Marshes are located at the center of the Develi Basin (Figure 5.1) and consist of two salt-water lakes (Yay and Çöl) and two freshwater marshes (Örtülüakar and Kepir) covering a total of 17,200 ha. The marshes were designated a Ramsar Site (according to the “Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat”), a “Nature Conservation Area”, and recently a “National Park” by the Turkish Government. Despite their strong conservation status, the marshes have undergone rapid degradation in recent years. Water levels have dropped significantly, and the marshes had several dry periods (Dadaser-Celik et al., 2006). Decreases in water levels, in turn, have affected the biological characteristics of the wetlands, particularly bird habitats (Özesmi et al., 1993). Previous studies have resulted in the recommendation that irrigation water use be reduced to restore the conditions in the Sultan Marshes. In this study, I evaluate possible economic outcomes of allowing water from agriculture to flow into the wetlands of the Develi Basin. In this analysis, I compare the changes in economic benefits from irrigation of agricultural lands to the changes in economic benefits from the wetlands.
There is a growing body of literature that evaluates the economic impacts of reductions in agricultural water use to sustain in-stream and wetland flow and prevent water quality degradation. Lee et al. (1997) estimated the economic impact of a hypothetical 25% cut in surface irrigation water supply to the Sacramento Valley in California. Effects on agricultural production and local economies were included. They concluded that a 25% water cut would cause a 32 million USD revenue loss from agriculture. Sundling et al. (1997) presented a methodological framework to analyze the impact of water supply reductions on agriculture. They developed three complementary impact models and estimated the economic effects of water diversions to improve the
water quality in the San Francisco Bay/Delta region of California. Barbier and Thompson (1998) and Barbier (2003) investigated the economic impacts of water diversions and ground-water extraction for agriculture on wetland goods and services (floodplain agriculture, forestry, and fishing) in the Hadejia-Jama’are wetlands, Nigeria. Their analysis showed that wetlands can provide overall economic benefits as large as those from agriculture.

This study addressed three questions. (1) How would water cuts affect agricultural income in the Develi Basin? (2) How would benefits from the Sultan Marshes be affected by water diversions? (3) What would be the optimum (or economically-efficient) amount of water diversion/restoration from agriculture to the wetlands? By answering these questions, I intend to provide an economical perspective to the water allocation problem in the Develi Basin. By comparing the value of water for different uses, this analysis can provide a foundation for better water allocation decisions in the Develi Basin.

**AGRICULTURAL PRODUCTION IN THE DEVELI BASIN**

Develi Basin is near the city of Kayseri and covers an area of about 100,000 ha (Özaslan and Şefalici, 2002). Agriculture is one of the main economic activities in Kayseri and in the Develi Basin; according to the 2000 census, 47% of the working population in Kayseri was employed in the agricultural sector (DPT, 2003). The area allocated to agriculture is approximately 78,000 ha, and almost half of this land is irrigated. A significant portion of the irrigated land was put in production after completion of the first phase of the Develi Irrigation Project in 1988. The three irrigation reservoirs in the Develi Basin (Akköy, Ağcaasar and Kovalı, with annual storage capacities of 7.5, 62, and 25 million m$^3$, respectively) irrigate 28,000 ha of farmland. Another 9,700 ha are irrigated by ground water (Özaslan and Şefalici, 2002). A second (uncompleted) phase of the Develi Irrigation Project includes plans to transfer 111-150 million m$^3$ yr$^{-1}$ of Zamanti River water through a 12-km channel from a basin to the south to irrigate an additional 34,000 ha in the Develi Basin.

Areas allocated to different crops and the economic benefits from agriculture (in 2005 USD) in the region irrigated by Kovalı and Ağcaasar Reservoirs are listed in Table
5.1. For the total cultivated area (approximately 10,000 ha), 36% was allocated to cereals, 25% to orchards, 16% to sunflower, and 15% to sugar beets. The highest income per unit area (ha) was obtained from vegetables, followed by potato, orchards, and sugar beets. Total agricultural income was 29.43 million USD in 2005.

**Table 5.1. Crops cultivated in the region irrigated from Kovalı and Ağcaaşar reservoirs (Data obtained from Ünlü (2005)).**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area (ha)</th>
<th>Average Yield (kg ha(^{-1}))</th>
<th>Average Income (USD kg(^{-1}))</th>
<th>Average Income (million USD)</th>
<th>Average Income per ha (USD ha(^{-1}))</th>
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<td>3,750</td>
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</tr>
<tr>
<td>Sugar Beets</td>
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<td>5.74</td>
<td>3,878</td>
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<td>0</td>
<td>53.07</td>
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<tr>
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<td><strong>29.43</strong></td>
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</tbody>
</table>

**ECONOMIC VALUE OF THE SULTAN MARSHES**

Wetlands provide both use (direct, indirect, option and quasi-option) values and non-use (existence) values (Barbier et al., 1997). In Table 5.2, direct and indirect use values, and non-use values of the Sultan Marshes are listed.
Table 5.2. Use and non-use values of the Sultan Marshes

<table>
<thead>
<tr>
<th>USE VALUES</th>
<th>NON-USE VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Use</td>
<td>Indirect Use</td>
</tr>
<tr>
<td>Plant harvesting</td>
<td>Waste elimination/nutrient retention</td>
</tr>
<tr>
<td>Animal grazing</td>
<td>Ground-water discharge</td>
</tr>
<tr>
<td>Recreation/ecotourism</td>
<td>Micro-climate regulation</td>
</tr>
<tr>
<td></td>
<td>Carbon sequestration</td>
</tr>
</tbody>
</table>

The direct use value of the Sultan Marshes is derived from plant harvesting, animal grazing and ecotourism/recreational uses. Reed (*Phragmites australis* (Cav.) Trin. ex Steud.) and other plants are harvested in the Sultan Marshes by local people for commercial and domestic uses. Reed harvesting is a particularly important activity in the villages and municipalities adjacent to the Sultan Marshes (Dadaser and Özesmi, 2002). Harvested reeds are exported as thatch or insulation material and used locally for thatching houses and animal barns, as well as for fodder production. Local people also harvest cattails (*Typha angustifolia*) for weaving mats or baskets, bulrush (*Scirpus validus*) for making traditional cushions, and salt cedar (*Tamarix sp.*) as an energy source (Karabaş, 2001).

Animal grazing takes place on pasture areas surrounding the water bodies in the wetland. In 2002, around 9,000 cattle (cows and water buffalo) used the pastures around the Sultan Marshes (Şarkışla, 2002).

With a wide range of habitats, the Sultan Marshes are an important breeding and wintering site for 301 bird species. Moreover, they are located 50 km away from Cappadocia (in Turkish, Kapadokya), and close to Erciyes Mountain, which has become
a popular winter sport center. Because of these characteristics, the Sultan Marshes are potentially important for national and international tourism.

The indirect use value of the Sultan Marshes is derived from current wetland services, including waste elimination and nutrient retention, micro-climate regulation, and carbon sequestration, and potential uses in the future. The Sultan Marshes have received and assimilated untreated (raw) domestic and industrial wastewater (from municipalities Develi, Yahyalı and Yeşilhisar and many villages within their jurisdiction) and agricultural drainage for many years. Although the efficiency of treatment processes taking place in the marshes has not yet been explored, it is known that wetlands can remove organic matter, suspended solids, metals and nutrients from wastewater through physical (sedimentation, filtration, adsorption), chemical (precipitation, adsorption, decomposition) and biological processes (microbial and plant metabolism, plant adsorption, natural dieoff) (Hammer and Bastian, 1989; Watson et al., 1989). Emergent (e.g., cattail, bulrush, reeds), floating (e.g. water hyacinth) and submerged (e.g. watermilfoil) wetland vegetation, which are present in the Sultan Marshes, can play important roles in the treatment processes (Reed et al., 1995). Through waste storage and treatment functions, Sultan Marshes contribute to a variety of other services in the Develi Basin. First, Sultan Marshes prevent the contamination of the ground water, which is used for drinking and irrigation purposes. Second, by storing wastewater, Sultan Marshes prevent the distribution of many diseases that could develop due to improper disposal of wastewater. Third, Sultan Marshes minimize the cost of wastewater treatment and disposal.

The Sultan Marshes also transfer large amounts of water to the atmosphere through evapotranspiration, which may have significant impact on the local climate. Wetlands are sinks for carbon and may have role in global carbon sequestration, but this value of Sultan Marshes is yet unexplored.

The Sultan Marshes also have option and quasi-option values because of their potential uses in the future. Some services that the wetlands could provide (e.g., ecotourism) are not used at present. Information for the assessment of future uses of the Sultan Marshes is currently insufficient.
Non-use or existence values of the Sultan Marshes are derived from biodiversity, culture and heritage and bequest values. The Marshes sustain a rich biodiversity consisting of 25 species of mammals, 25 species of mollusks, 40 species of hymnoptera, five species of fish, 301 species of birds, 125 species of algae and 401 species of plants (Karadeniz, 2000). Many civilizations have lived around and used the Sultan Marshes since the early ages of mankind; the Sultan Marshes therefore are an important place in the region’s history and culture. Finally, the Sultan Marshes have a bequest value as important ecosystems that should be preserved for the future generations.

METHODS

This study was conducted in two stages. First a hydrologic analysis was performed to identify the amount of water required to restore the water levels in the Sultan Marshes. Then, an economic model was constructed to analyze the economic impact of water diversions on agricultural production and wetland uses.

Hydrologic Analysis

A deterministic, process-based hydrologic simulation model of the Örtülüakar Marsh (a subsystem of the Sultan Marshes) (Dadaser-Celik et al., 2006) was used for the hydrologic analysis. The model used a monthly timescale and covered a timeframe of seven years (1997-2003). Simulations were made with water diversions to the Sultan Marshes of 10,000 - 90,000 m³ day⁻¹ for five months (May to September) every year. These amounts represent 1.5-13.5 million m³ yr⁻¹, respectively, compared to 62 million m³ yr⁻¹ of water used for irrigation. The May-September period coincides with the irrigation season in the Develi Basin. Minimum water levels in the Örtülüakar Marsh recommended by the Ministry of Environment of Turkey (2002) were used as targets.

Simulation results (Figure 5.2) showed that 1.5 million m³ yr⁻¹ would be enough to obtain minimum water levels in the Sultan Marsh. For the complete restoration of water levels (i.e., to obtain historical (unaltered) water levels), 7.5 million m³ yr⁻¹ of water would be sufficient.
Economic Model Description

The economic model was developed using the software package STELLA. In STELLA, the model is constructed by various blocks categorized as stocks, flows and converters (Figure 5.3). Stock variables represent quantities that accumulate in the system. Flow variables describe processes that change stock variables. Converter variables are used for transformations and catalytic effects. The connectors (represented by the line with an arrow in Figure 5.3) represent the cause and effects within the model structure. For example, in a hydrologic system, the volume of a water body is modeled as a “stock”, while precipitation is modeled as a “flow”.

The economic model had two sub-models. A wetland sub-model simulated the increase in wetland benefits with increase in water diversion; an agriculture sub-model simulated the increase in agricultural costs with an increase in water diversion. Economic values were expressed in 2005 USDs; the exchange rate used was 1 USD = 1.35 YTL (in Turkish, Yeni Türk Lirası – New Turkish Lira).
Wetland sub-model

Only direct-use values of the Sultan Marshes were considered in the wetland sub-model (Figure 5.4) because of insufficiency or unavailability of data regarding other wetland values. Direct-use values are also important, because they represent the amount of direct cash flow. Included were changes in a) grazing benefits, b) reed extraction benefits, c) ecotourism income.
Change in Grazing Benefits: The substitute cost approach was used to estimate the change in grazing benefits from the Sultan Marshes. It was assumed that water diversion to the wetland would affect pasture productivity, but not pasture area. In Central Anatolia, where the Sultan Marshes are located, pastures on average produce 450 kg dry matter ha\(^{-1}\) yr\(^{-1}\) (DPT, 2001). The productivity of pastures around the Sultan Marshes was assumed to be lower than this value because of drought and overgrazing (300 kg dry matter ha\(^{-1}\) yr\(^{-1}\)). A direct relationship can be established between ground-water levels and plant density on pastures (Liu et al., 2005). I assumed that pasture productivity would increase linearly up to 500 kg dry matter ha\(^{-1}\) yr\(^{-1}\) as water diversion to the wetlands (and hence the groundwater level) increases. The animal carrying capacity of the pastures was calculated based on the average dry matter requirement of animals (Equations 1 and 2).
where $CCC$ is current pasture carrying capacity (animals yr$^{-1}$), $PA$ is pasture area (ha), $CPP$ is current pasture productivity (300 kg dry fodder ha$^{-1}$ yr$^{-1}$), and $AFR = \text{animal feed requirement (12.5 kg dry matter day}^{-1} \text{(Anonymous, 1998) multiplied by 365 days yr}^{-1}$).

$$
CCC = \frac{PA \times CPP}{AFR}
$$

where $ECC$ is estimated pasture carrying capacity (animals yr$^{-1}$) and $EPP$ is estimated pasture productivity (kg dry matter ha$^{-1}$ yr$^{-1}$).

The difference between current and estimated carrying capacity was multiplied by the amount of alternative feed required by animal ($AFR$; kg dry matter ha$^{-1}$ yr$^{-1}$), and the cost of the alternative feed ($CAF$; USD kg$^{-1}$) to find the change in grazing benefits ($GB$) (Equation 3). During non-grazing periods, animals are fed with a variety of other feed such as cultivated forages (e.g., clover, maize silage, trefoil, fig, hay), concentrates, cereal and grain legume straw, agro-industry by-products and residues in the Develi Basin. In this study, I assumed that alternative feed cost 0.15 USD kg$^{-1}$ in 2005. This number was reported during interviews with farmers in the Develi Basin and corresponds to the cost of “hay” (Dadaser-Celik, unpublished field data, 2006).

$$
GB = (ECC - CRC) \times AFR \times CAF
$$

Change in reed extraction benefits

The market price method was used to estimate the changes in reed extraction benefits (Mmopelwa, 2006). I assumed that reed area would expand in relation to the amount of water diverted to the system, but average reed density (128 bundles ha$^{-1}$) would remain the same. Because the economic benefits from harvesting plants other than exported reed are not significant (Karabaş, 2001), I considered only the benefits from reed harvesting.

Data on harvested reed quantities and prices were obtained from a 2001 study conducted by the General Directorate of National Parks and Game Wildlife in Turkey (Özesmi, 2002; Şarkışla, 2002). No information was available, however, about costs associated with reed harvesting; therefore, I made several assumptions regarding costs. First, I assumed that the capital requirement for the harvesting equipment is 5% of the
gross income. This assumption is reasonable because reed is harvested with sickles and carried to the shore with shared wooden boats (locally produced). Although I do not have the exact prices for this equipment, it is most likely that they cost less than 5% of gross income. Second, I assumed that the opportunity cost of labor (the income that could have been generated if the labor had been employed elsewhere) was 86 YTL month\(^{-1}\) (71 USD month\(^{-1}\)) in 2001. This is the statutory minimum wage payable to laborers in small businesses (Anonymous, 2004). Third, I assumed that one person harvests 75 bundles per day. The number of bundles that can be harvested in a day depends on the density of the reeds in an area and ranges between 25 and 150 bundles (Karabaşa, 2001). Finally, I assumed that cost of maintenance is 5% of the capital requirement (Mmopelwa, 2006). Results of the calculations are in Table 5.3. Variable cost in Table 5.3 refers to the transportation cost, but the transportation cost is zero because local businesses buy reeds at the shore and provide their own transportation. Fixed overhead costs include labor and maintenance costs and a fee of 0.025 YTL (0.02 USD) per bundle paid by reed harvesters to the General Directorate of National Parks and Game Wildlife. All values were converted to 2005 YTLs (USDs) using consumer price indices in 2001 and 2005. The change in reed extraction benefits was calculated with Equations 4 and 5.

\[
CBE = (ERA - CRA) \times RD \tag{4}
\]

where CBE is the change in number of bundles extracted, ERA is the estimated reed area (ha), CRA the current reed area (ha) and RD is density of reeds (bundles ha\(^{-1}\)).

\[
REB = CBE \times RI \tag{5}
\]

where REB is the change in reed extraction benefits and RI is the income obtained per bundle of reed (USD bundle\(^{-1}\)).
Table 5.3. Costs and benefits of reed harvesting in the Develi Basin.

<table>
<thead>
<tr>
<th></th>
<th>USD yr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital requirements</td>
<td>14,285</td>
</tr>
<tr>
<td>Gross value</td>
<td>285,690</td>
</tr>
<tr>
<td>Variable costs</td>
<td>0</td>
</tr>
<tr>
<td>Gross margin</td>
<td>271,406</td>
</tr>
<tr>
<td>Fixed overhead costs</td>
<td>129,275</td>
</tr>
<tr>
<td>Depreciation</td>
<td>714</td>
</tr>
<tr>
<td>Annual net income</td>
<td>141,417</td>
</tr>
<tr>
<td>Number of bundles</td>
<td>413,870</td>
</tr>
<tr>
<td>Net benefit per bundle</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Change in ecotourism benefits: Change in ecotourism benefits was projected by estimating the change in number of tourists visiting the site. Bird watching is the most important activity for the tourists. Therefore, I established a relationship between number of tourists visiting the site and number of birds present. I defined an index, called “habitat suitability index or HSI”, to explain the degree of suitability of the marsh for birds. This index was calculated by taking the ratio of the amount of water diversion in a year (WD in terms of million m³ yr⁻¹) to optimum amount of water diversion (OWD or 7.5 million m³ yr⁻¹)(Equation 6).

\[
HSI = \frac{WD}{OWD}
\]  

In this analysis, greater flamingo (*Phoenicopterus ruber*) was taken as the key species, because greater flamingo numbers were found to be correlated with water levels in other locations (Cezilly et al., 1995) and in the Sultan Marshes (Gürpınar, 1994). I assumed a direct relationship between habitat suitability index and number of flamingos observed in the site. Maximum and minimum number of flamingos observed at the site were 70,000 and 20, respectively (Gürpınar, 1994).

I also assumed that the number of tourists visiting the site was related to the number of flamingos observed. I could not find any data related to number of tourists visiting the Sultan Marshes in a year. Therefore, I made very conservative assumptions
about tourist numbers. The number of tourists visiting the site currently (CNT) was assumed to be 1,000 per year. This is about 3 percent of the international tourists who visited Kayseri in a year between 1996 and 2001 (Özaslan and Şeftalici, 2002). I also assumed that this number would rise up to 5,000 with water diversion (estimated number of tourists or ENT) (Equation 7). No data were available related to the economic benefits obtained from ecotourism (TI in terms of USD person−1 yr−1) in the Sultan Marshes. A literature review showed that the value of bird watching activity in the U.S. was 29.6 (± 8.35) USD cap−1 day−1 with a range of 5.80-78.46 USD cap−1 day−1 (Loomis, 2005). Another study conducted in Turkey (Pak and Türker, 2006) estimated the value of a forest recreation site in 22.1 USD person−1 visit−1. In this study, I assumed that the economic income per tourist is 20 USD.

\[ TB = (ENT - CNT) \times TI \]  

(7)

Indirect-use benefits: Waste water treatment: I added wastewater treatment benefits to the direct-use benefit model. Without data related to the degree of wastewater treatment taking place in the marshes, I considered three treatment levels corresponding to preliminary (i.e., screening), primary and secondary treatment in wastewater treatment plants. I assumed that as water diversion to the marshes increases, the treatment level in the marsh will also increase. This assumption is based on the fact that vegetation density and area in the marsh is directly related to amount of water diversion. Vegetation density and area improves treatment efficiency by increasing water residence times and potential surfaces for nutrient intake (Kjellin et al., 2007). As shown in many studies, reed is responsible for the treatment processes.

The substitute cost approach was used to estimate wastewater treatment benefits for various treatment levels. Wastewater treatment costs were obtained using the relationships established among wastewater quantities, wastewater treatment levels and construction/operation costs of treatment plants for Turkey (Öztürk et al., 2005). Annual investment requirement was estimated by adding annualized construction costs (calculated assuming that a wastewater treatment plant operates for 30 year) and operation/maintenance costs (Table 5.4).
Table 5.4. Construction and operation costs of preliminary, primary and secondary treatment plants.

<table>
<thead>
<tr>
<th>Treatment Option</th>
<th>Construction Cost (million USD)</th>
<th>Annual O&amp;M Costs (million USD yr(^{-1}))</th>
<th>Annual Investment Requirement (million USD yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Preliminary treatment</td>
<td>2.97</td>
<td>0.11</td>
<td>0.52</td>
</tr>
<tr>
<td>2. Primary treatment</td>
<td>5.47</td>
<td>0.24</td>
<td>1.02</td>
</tr>
<tr>
<td>3. Secondary treatment</td>
<td>11.01</td>
<td>0.45</td>
<td>2.01</td>
</tr>
</tbody>
</table>

Agriculture sub-model

The agriculture sub-model estimates the losses in agricultural production based on the amount of water allocated to the wetlands instead of agriculture. I assumed that farmers first divert water from low value crops. Based on this assumption, water cuts are projected to be made in the following order: wheat, legumes, sunflower, maize, and sugar beets. To represent the decrease in crop yield with respect to water diversion, the crop yield response factor \((k_y)\) defined by Stewart et al. (1977) was used.

\[
\frac{Y}{Y_m} = 1 - k_y \left(1 - \frac{ET}{ET_m}\right)
\]  

(8)

In Equation 8, \(Y_m\) is maximum crop yield, \(Y\) is crop yield with deficit irrigation, \(ET_m\) is maximum evapotranspiration, and \(ET\) is the evapotranspiration under deficit irrigation. According to Equation 8, relative crop yield is a function of relative evapotranspiration deficiency. The crop yield response factor \((k_y)\) varies depending on crop species, variety, irrigation method, and growth stage when deficit evapotranspiration occurs (Kirida, 2000). The \(k_y\) values were obtained from the literature (Table 5.5) and assumed that the evapotranspiration deficit occurred all season.
Table 5.5. Crop yield response factor (k_y) values for crops cultivated in the Develi Basin.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Ky</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>0.32</td>
<td>Erzurum, Turkey</td>
<td>(Kırdal et al. 1999)</td>
</tr>
<tr>
<td>Legumes</td>
<td>1.04</td>
<td>Trakya, Turkey</td>
<td>(Erdem et al. 2006)</td>
</tr>
<tr>
<td>Maize</td>
<td>1.02</td>
<td>Eskişehir, Turkey</td>
<td>(Ögretir 1993)</td>
</tr>
<tr>
<td>Sunflower</td>
<td>0.91</td>
<td>Kırklareli, Turkey</td>
<td>(Karaata 1991)</td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>1.27</td>
<td>Kırklareli, Turkey</td>
<td>(Yakan and Sabuncuoğlu 1991)</td>
</tr>
</tbody>
</table>

Potential evapotranspiration (ET_m) values and evapotranspiration values that have to be met by irrigation were provided by DSI (DSI) for the Develi Basin. DSI estimated ET_m values using the Braney-Criddle method and calculated irrigation water requirements based on average effective rainfall values. Using cereals as an example, the water saving/economic losses due to deficit irrigation were calculated as follows.

In Figure 5.5, IWU denotes the amount of irrigation water used by cereals, and PPT denotes the effective precipitation or precipitation used by cereals in a given year. IWUD is the amount of irrigation water used by the cereals under deficit irrigation, and WS (amount of water saving) denotes the difference between IWU and IWUD divided by irrigation efficiency (IE) (Kırdal, 2000) (Equation 9). In Turkey field application efficiency for flood irrigation is around 50% (Van Tuijl, 1993).

\[ WS = (IWU - IWUD) / IE \] (9)

With the assumption that changes in water use would not affect production costs, yield loss (YL) and economic loss (EL) were calculated from Equations 10 and 11.

\[ YL = Y \left( Y \cdot \frac{1 - k_y}{IQ + PPT} \right) \frac{1 - (IWUD + PPT)}{IWU + PPT} \] (10)

where Y refers to current yield (kg ha\(^{-1}\)) and A refers to the areal coverage of cereals (ha).

\[ CEL = YL \times CI \] (11)

where CI refers to crop income (USD kg\(^{-1}\))
Figure 5.5. Agriculture sub-model including calculation of water saving from cereals and its STELLA components.

Total economic losses from agriculture and total economic benefits from wetlands for various amounts of water diversion were obtained using the economic models. Marginal (or incremental) costs and marginal benefits then were calculated by using total costs and benefits. Marginal costs (benefits) can be defined as the cost of (benefit from) diverting 1 unit (m$^3$) of water from agriculture (to the wetlands). I accepted that optimum (or economically-efficient) amount of water diversion occurred when marginal costs became equal to the marginal benefits.

RESULTS

Total and Marginal Benefits and Costs

Total costs and benefits and marginal costs and benefits of water diversions are given in Table 5.6 and Figure 5.6. Total benefits were higher than total costs until 6 million m$^3$ of water yr$^{-1}$ were diverted. Above 6 million m$^3$ of water yr$^{-1}$, total costs became higher than total benefits.
Table 5.6. Total and marginal costs and benefits associated with water diversions.

<table>
<thead>
<tr>
<th>Water Diversion (million m³)</th>
<th>Agricultural Costs (USD yr⁻¹)</th>
<th>Wetland Benefits (USD yr⁻¹)</th>
<th>Marginal Costs (USD yr⁻¹)</th>
<th>Marginal Benefits (USD yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>0.041</td>
<td>0.064</td>
<td>0.041</td>
<td>0.064</td>
</tr>
<tr>
<td>2</td>
<td>0.082</td>
<td>0.128</td>
<td>0.041</td>
<td>0.064</td>
</tr>
<tr>
<td>3</td>
<td>0.124</td>
<td>0.191</td>
<td>0.042</td>
<td>0.064</td>
</tr>
<tr>
<td>4</td>
<td>0.171</td>
<td>0.255</td>
<td>0.046</td>
<td>0.064</td>
</tr>
<tr>
<td>5</td>
<td>0.217</td>
<td>0.319</td>
<td>0.046</td>
<td>0.064</td>
</tr>
<tr>
<td>6</td>
<td>0.354</td>
<td>0.383</td>
<td>0.137</td>
<td>0.064</td>
</tr>
<tr>
<td>7</td>
<td>0.609</td>
<td>0.447</td>
<td>0.255</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Total benefits include the benefits from ecotourism, grazing and reed cutting. The increases in grazing benefits were always the largest, followed by ecotourism and reed cutting (Table 5.7). Grazing benefits constituted 57% of the total benefits, while ecotourism and reed cutting provided 17% and 16% of the total benefits, respectively.

Figure 5.6. Total benefits and costs associated with water diversions
Figure 5.7. Marginal costs and benefits associated with water diversions.

Table 5.7. Total benefits provided by ecotourism, grazing and reed cutting

<table>
<thead>
<tr>
<th>Water diversion (million m(^3) yr(^{-1}))</th>
<th>Ecotourism (USD yr(^{-1}))</th>
<th>Grazing (USD yr(^{-1}))</th>
<th>Reed Cutting (USD yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>0.011</td>
<td>0.043</td>
<td>0.010</td>
</tr>
<tr>
<td>2</td>
<td>0.021</td>
<td>0.086</td>
<td>0.020</td>
</tr>
<tr>
<td>3</td>
<td>0.032</td>
<td>0.129</td>
<td>0.030</td>
</tr>
<tr>
<td>4</td>
<td>0.043</td>
<td>0.172</td>
<td>0.041</td>
</tr>
<tr>
<td>5</td>
<td>0.053</td>
<td>0.215</td>
<td>0.051</td>
</tr>
<tr>
<td>6</td>
<td>0.064</td>
<td>0.258</td>
<td>0.061</td>
</tr>
<tr>
<td>7</td>
<td>0.075</td>
<td>0.301</td>
<td>0.071</td>
</tr>
</tbody>
</table>

Marginal costs were constant until 5 million m\(^3\) yr\(^{-1}\) of water were diverted (Table 5.6 and Figure 5.7). After 6 million m\(^3\) yr\(^{-1}\) of water diversion, marginal costs showed a rapid increase. Marginal benefits, however, were constant for all amounts of water diversion.

Marginal benefits were equal to the marginal costs at 5.19 million m\(^3\) yr\(^{-1}\) of water diversion. This amount is almost equal to the amount of irrigation water used for cereal and legume production. This result suggests that water cuts from other crops (maize,
sunflower, sugar beets) are not economically feasible. Here I have to emphasize that the benefits from wetlands were estimated based on very conservative assumptions and included only direct-use benefits. The real benefits from the wetlands are most probably much higher than values calculated here.

**Sensitivity Analysis**

A sensitivity analysis (Figure 5.8) was conducted by sequentially changing ecotourism, grazing and reed cutting benefits and total cost by 20%. The results showed that the system was not sensitive to the increases and decreases in ecotourism and reed cutting benefits. Increasing (or decreasing) ecotourism and reed cutting benefits by 20%, increased (or decreased) total benefits by only 3%. Optimum water diversion (where marginal benefits equal to the marginal costs) moved from 5.19 million to 5.22 (5.17) million m³ with 20% increase (20% decrease) in both of them. Animal grazing benefits had more effect on the system compared to the other components. Changing animal grazing benefits by 20% caused a 14% change in total benefits. Optimum water diversion was 5.29 (5.10) million m³ with 20% increase (decrease). Increasing (decreasing) total costs by 20% moved optimum water diversion to 5.08 (5.37) million m³.
I analyzed the effect of uncertainty in the input parameters of the grazing benefits sub-model using Monte Carlo simulation (Figure 5.9). The change in grazing benefits was determined as the difference between current and estimated grazing capacities, which were defined by the grazing productivity function. In the Monte Carlo simulation I randomly selected values of two parameters from a feasible range and calculated the change in grazing benefits for a constant amount of water diversion (5 million m³ yr⁻¹). This process was repeated 10,000 times. The parameters were 1) pasture productivity at current conditions (or before water diversion) and 2) rate of increase in pasture productivity with water diversion. Because specific ranges for these parameters were not available from the literature, I accepted that the parameters varied by ±20%. Results showed that grazing benefits changed from 0.17 to 0.26 USD yr⁻¹ for 5 million m³ yr⁻¹ of water diversion. The mean value was 0.22 USD yr⁻¹. The probability of obtaining a value for grazing benefits smaller than or equal to 0.22 (model estimated value) was 54%.
Figure 5.9. Distribution of grazing benefits estimated using Monte Carlo simulation

Wastewater Treatment Benefits

Costs associated with preliminary, primary and secondary wastewater treatment are provided in Table 5.4 and results of the economic analysis with wastewater treatment benefits included are given in Figure 5.10. Results show that if the lowest (preliminary) treatment benefits are included in the analysis, the optimum water diversion would be 5.96 million m$^3$ yr$^{-1}$. With primary treatment, optimum water diversion would rise to 6.53 million m$^3$ yr$^{-1}$. With secondary treatment, optimum water diversion would be higher than 7 million m$^3$ yr$^{-1}$. These results show that inclusion of indirect and non-use benefits from the Sultan Marshes change the results significantly and make the diversion of more water to the wetlands not only feasible, but desirable.
SUMMARY & CONCLUSIONS

In this study, I calculated the total and marginal costs and benefits of allocating a fixed flow of water to the wetlands in the Develi Basin. This water is currently used for irrigation – but not very efficiently. The economic losses in agricultural production due to the reduced water allocation have been determined and included in the cost/benefit analysis. This analysis shows that an economically-efficient amount of water allocation is 5.2 million m$^3$ yr$^{-1}$ when direct benefits from the wetlands are considered. Inclusion of indirect benefits, particularly that raw wastewater discharged to the wetlands receives “natural assimilative” treatment and non-use values of the wetlands increase this amount even further. These results suggest that diversion of water from agriculture to the wetlands is economically feasible and preferable to the demise of the Sultan Marshes in the Develi Basin.

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