WORKING PAPER 1

Modeling Water Allocation between Wetlands and Irrigated Agriculture

Case Study of the Gediz Basin, Turkey

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Hammond Murray-Rust

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The authors: K. de Voogt is a student at Wageningen University, Wageningen, the Netherlands. Peter Droogers and Geoff Kite are Hydrologists and Murray-Rust is Irrigation and Water Management Specialist, all of the International Water Management Institute (IWMI).

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Please send inquiries and comments to:

The Research Division
P O Box 2075
Colombo, Sri Lanka

or

iwmi-research-news@cgiar.org

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Acronyms

CKGM	Cevre Koruma Genel Müdürlügü (Turkish Council of Environmental Protection)
CROPWAT	Program to calculate irrigation requirement (a.o.), made by FAO
DSI	Devlet Su Isleri (State Hydraulic Works)
DHKD	Dogal Hayvanlari Koruma Dernegi (Turkish association for wildlife protection)
FAO	Food and Agriculture Organization
IBA	Important Bird Area
IWRB	Turkish council for bird preservation
LANDSAT	Land satellite (images)
MLB	Menemen left bank
MRB	Menemen right bank
RAC/SPA	Regional Activity Centre for Specially Protected Areas
SLURP	Semi-Distributed Land Use-Based Runoff Processes

Summary

The Kus Cenneti is a Class A wetland in the Gediz river delta in Turkey, which has its importance as a habitat for threatened bird species such as the Dalmatian Pelican, the Black Stork and several other birds. In the present situation, their survival is threatened by large water shortages, especially in summer, and the low quality of the available water. The decline of the freshwater area and the area covered with reed beds has drastically decreased the feeding, breeding and sheltering possibilities for the water birds.

This report investigates how much water is required to maintain (i) a constant water level and (ii) a constant salt concentration, as salt accumulation is believed to be lethal for the freshwater reed beds that are the main shelter and breeding place for the birds. Next, we look at the ability of the Gediz basin to fulfill this requirement and the effects of this requirement on irrigated agriculture, the major competitor for water in the Gediz basin. With SLURP, a semi-distributed hydrological basin model, these possible effects were simulated.

The water requirement is assumed to be that needed to satisfy the average daily evapotranspiration (ET) from the sanctuary area while maintaining desirable areas and (constant) depths of water. However, to maintain a constant salt level, a multiple of this demand is required. The demand increases strongly with increasing salt concentration of the inflowing water. Discontinuous supply results in fluctuating salt concentrations.

The Kus Cenneti water demand results in a conflict with agriculture during irrigation seasons when there is not sufficient water to satisfy both water users. The deliverable supply to the Kus Cenneti depends on the way the water is divided by water managers. If the Kus Cenneti gets a priority treatment, then simulations show that the deliverable supply outside the irrigation seasons depends on weather conditions only. In a wet year, the Gediz river can easily supply up to six times the evapotranspirative demand. Irrigation losses in a dry year were about a few percent as long as the minimum base flow was maintained at the downstream regulator only.

As operating rules for the three regulators in the Gediz basin are not synchronized, a distribution of the water demand to all irrigation areas will not result in a distribution of transpiration losses, but will increase reductions in transpiration. Three management options were evaluated in which water was diverted from all irrigation systems, varying the timing of water supply to the Kus Cenneti and varying the timing of closure of the canals of the several irrigation systems. The management options do not differ in yield loss significantly because in all three options the same amount of water was diverted to the Kus Cenneti, but they clearly show that even a high Kus Cenneti demand does not influence yields to a large extent. Selecting an alternative should be based on feasibility and on financial and organizational factors. The management alternative in which each canal supply is reduced by a few percent is recommended for dry years. In wet years, the Kus Cenneti should be supplied directly from the main reservoir. Further methods should be found to transport the Kus Cenneti demand into the freshwater reed beds.

CHAPTER 1

Introduction

1.1 The Importance of Wetlands

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal lives. They occur where the water table is at or near the land surface, or where the land is covered by shallow water. Wetlands are among the world's most productive environments. They are cradles of biological diversity, providing the water and primary productivity upon which many species of plants and animals depend for survival. They support high concentrations of birds, mammals, reptiles, amphibians, fish and invertebrate species. Of the 20,000 species of fish in the world, more than 40 percent live in freshwater. Wetlands are also important storehouses of plant genetic material. Rice, for example, which is a common wetland plant, is the staple diet of more than half of humanity.

The interactions of physical, biological and chemical components of a wetland, such as soils, water, plants and animals, enable the wetland to perform many vital functions, for example: water storage, storm protection and flood mitigation, shoreline stabilization and erosion control, groundwater recharge (the movement of water from the wetland down into the underground aquifer), groundwater discharge (the movement of water upward to become surface water in a wetland), water purification through retention of nutrients, sediments, and pollutants and stabilization of local climate conditions, particularly rainfall and temperature.

Wetlands provide tremendous economic benefits, for example: water supply (quantity and quality), fisheries (over two-thirds of the world's fish harvest is linked to the health of coastal and inland wetland areas), agriculture, through the maintenance of water tables and nutrient retention in floodplains, timber production, energy resources such as peat and plant matter; wildlife resources, transport; and recreation and tourism opportunities. In addition, wetlands have special attributes as part of the cultural heritage of humanity: they are related to religious and cosmological beliefs, constitute a source of aesthetic inspiration, provide wildlife sanctuaries, and form the basis of important local traditions. These functions, values and attributes can only be maintained if the ecological processes of wetlands are allowed to continue functioning. Unfortunately, and in spite of important progress made in recent decades, wetlands continue to be among the world's most threatened ecosystems, owing mainly to ongoing drainage, conversion, pollution, and overexploitation of their resources.

1.2 Ramsar Convention

The Convention on Wetlands is an intergovernmental treaty adopted at Ramsar, Iran on 2 February 1971. Thus, though nowadays the name of the Convention is usually written "Convention on Wetlands (Ramsar, Iran, 1971)," it has come to be known popularly as the "Ramsar Convention.” The Convention's mission is the conservation and wise use of wetlands by national action and international cooperation as a means to achieving sustainable development throughout the world.

The official name of the treaty—*The Convention on Wetlands of International Importance especially as Waterfowl Habitat*—reflects its original emphasis on the conservation and wise use of wetlands primarily to provide habitats for water birds. Over the years, however, the Convention has broadened its scope to recognizing wetlands as ecosystems that are extremely important for biodiversity conservation and for the well-being of human communities.

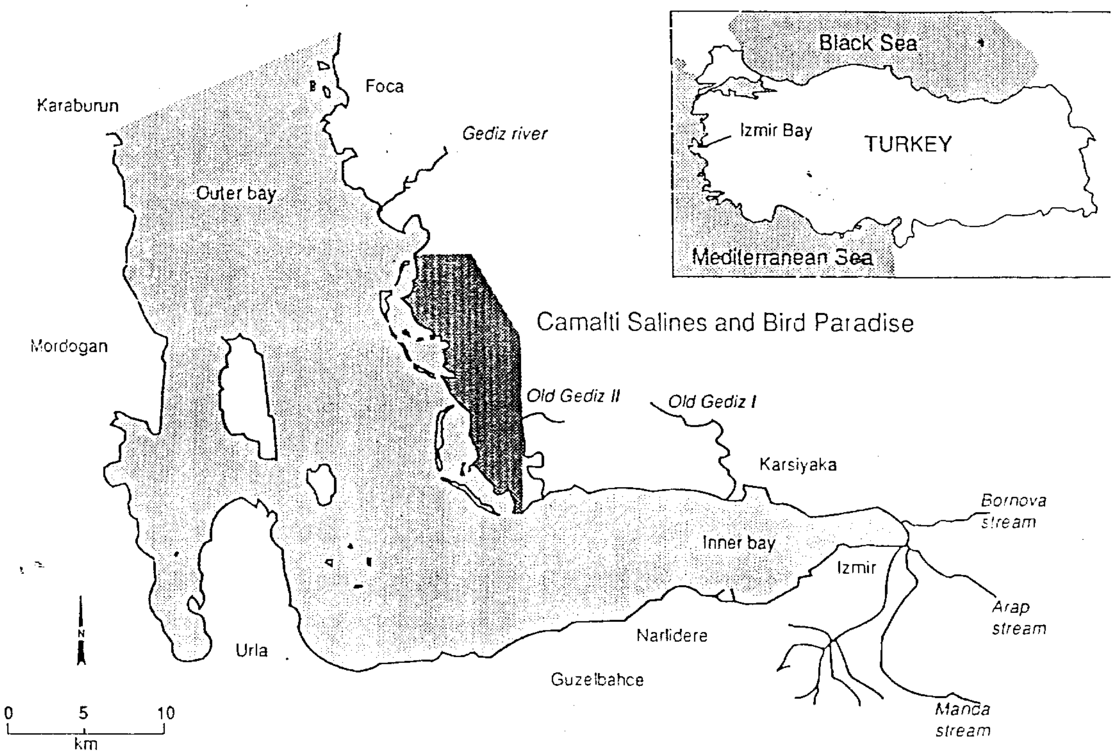
The Convention entered into force in 1975 and now has more than 110 Contracting Parties in all parts of the world. The Parties (the main decision-making body of the Convention, composed of delegates from all the member states) has further developed and interpreted the basic tenets of the treaty text and has succeeded in keeping the work of the Convention abreast of changing world perceptions, priorities, and trends in environmental thinking. Approximately 950 wetlands have been designated for inclusion in the List of Wetlands of International Importance, covering some 70 million hectares (Ramsar 1999).

1.3 Kus Cenneti

The Izmir Bird Paradise (Kus Cenneti, figure 1.1) is a Class A wetland, which means it can offer refuge and food to over 25,000 birds. The Kus Cenneti, with 8,000 hectares, is part of the Gediz river delta, 25 km to the west of Izmir harbor, and forms the main feeding and breeding location within the delta, although the birds use the entire delta as a habitat.

The delta (20,400 ha) is one of the largest on the Turkish coastline. The running waters meet the sea in four lagoons, which function as habitats for thousands of organisms, especially fish and birds. The former riverbeds now form an extensive salt marsh. Due to its favorable climatic conditions and function as a stopover for migrating birds, the Gediz delta is ecologically one of the most important wetlands in Turkey. Since 1863, 3,300 hectares have been managed as salt pans, which produce 500,000 tons of salt per year. In the north there are three main freshwater marshes, and further there are wide salt marshes, meadows, orchards, arable land and low scrub, which are important as habitat. To date, researchers have found 308 different plant species, 20 species of fish and over 200 bird species. The Gediz delta is especially renowned for its birds, which include flamingos, pelicans, buzzards and storks.

Figure 1.1. The location of the Kus Cenneti and the Bay of Izmir in Turkey.



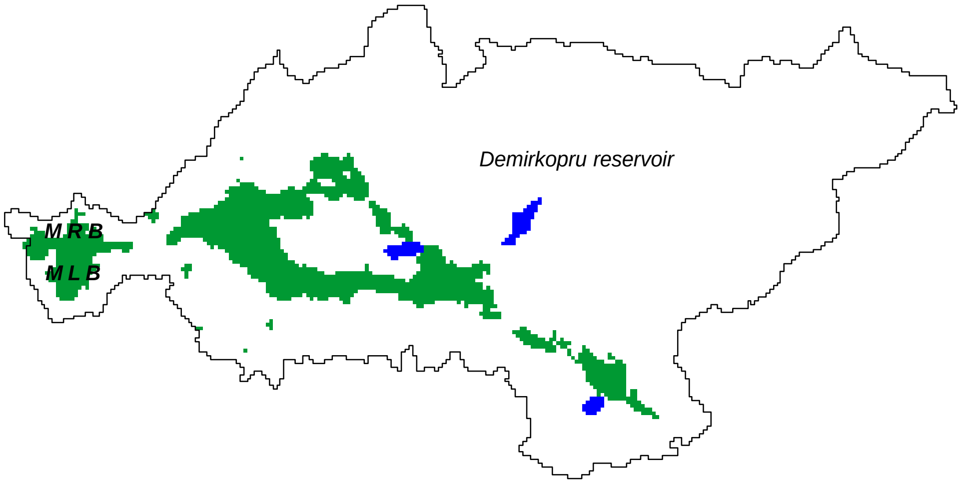
1.4 The Gediz Basin

The Gediz river is about 275 km long and drains an area of 17,220 km^2 (figure 1.2). The river network consists of one large reservoir (Demirköprü)—mainly used for irrigation and generating hydropower—and some smaller reservoirs (Lake Marmara, Afsar and Buldan). The water that is released by the reservoirs is diverted to irrigation systems on either side of the river by three regulators: Adala, Ahmetli and Emiralem. This part of Turkey is characterized by a Mediterranean climate consisting of hot and dry summers and mild and rainy winters. Annual precipitation is variable over the years and within the year (the annual average is 543 mm). The winter flow of the river is stored in the reservoirs for release in the summer irrigation period. The nonagricultural vegetation in the basin consists of mainly shrubland, *maki* (bay, myrtle, scrub oak and juniper trees, amongst others) and coniferous forest with large outcrops of barren limestone mountain.

The main crops grown in the basin are: cotton, grapes, cereals, vegetables, fruit trees, olives, tobacco and melons. The total extent of irrigated land supplied by Demirköprü is 125,000 hectares (figure 1.3) and there are many smaller schemes many of which depend on groundwater.

Figure 1.2. Topographical features of the Gediz basin: The regulators in the Gediz river (Gediz nehri) and the Izmir bird sanctuary (Kus Cenneti).

Figure 1.3. Irrigated areas (green) and reservoirs (blue) in the Gediz basin. The green spot on the left represents MLB and MRB.



Industries in the basin are textile factories, weaving, salt production and leather works. Urban areas in the basin are expanding at an expected annual average of 11 percent for the period 2000–2030 (International Office for Water 1999) and groundwater pumping is therfore expected to increase as well. The city of Izmir, located just outside the basin in the southwest, pumps a lot of groundwater from the basin area. As a result of the increasing use of water, many problems like water shortage, falling water tables, pollution, salinity, waterlogging and competition for water between farmers, urban users and industrial users arise in the basin.

1.5 Statement of the Problem

The Kus Cenneti bird sanctuary is a wetland located at the outlet of the Gediz basin. Many other users, including agriculture, urban areas and industries, take water from upstream in the Gediz basin. The concern is that there may not be enough water left to maintain the wildlife sanctuary in a healthy condition under present circumstances.

The main objectives of this study are therefore:

? to determine which criteria can be used to express the wetland quality

? to determine the hydrological demand of the Kus Cenneti bird sanctuary in terms of quantity and timing

? to determine to what extent the Kus Cenneti requirements are being satisfied and how the water allocations within the basin could be changed to satisfy the wildlife requirements

? to investigate the effect of such changes on irrigation systems in the basin

1.6 Structure of This Report

Chapter 2 will start with a description about what wetlands are, about the Kus Cenneti in particular, and about its place and function in the Gediz basin. After this the criteria for wetland quality are discussed. In chapter 3 the water requirements of the Kus Cenneti bird sanctuary will be established. Chapter 4 will give an outline of the characteristics of the SLURP model and the way it calculates the various terms of the water balance. For SLURP, the water requirement computed in chapter 3 acts as a sort of boundary condition for the simulations of the Gediz basin, and the effects on the Gediz basin and several management options will be dealt with in chapter 5. In chapter 6 conclusions about all chapters are combined to assess if, and to what extent, the objectives were achieved. Based on these conclusions some recommendations will be made.

CHAPTER 2

The Kus Cenneti

2.1 History of the Kus Cenneti

The Gediz river has its sources in the Murat and Saphane mountains, which are located in the inner parts of Western Anatolia. Over a period of several thousand years it has frequently changed its bed and has now formed a delta of 40,000 hectares. Until 1886, the river had its delta about 50 km west of Izmir. In 1886, the river was diverted to prevent silting up of the Izmir harbor. In 1963, the course of the river was again changed by human interference and, as a result, the wetland changed partly from sweet to salt water. This was believed to cause a decrease in the number of bird species and a change of bird species. An overall decrease of precipitation from 1963 onwards has worsened the situation.

In 1982, the Kus Cenneti was declared a nature reserve by the Department of Forestry, and in 1986, it was declared a no-hunting area and most of its boundaries were fenced off. In 1989, the International Council for Bird Preservation earmarked it as an Important Bird Area (IBA) because it was used as a habitat by thousands of water-related birds; some of these birds were at risk of becoming extinct. In 1997, the Government of Turkey declared the delta as a Ramsar area. The Convention on Wetlands, signed in Ramsar, Iran, is an intergovernmental treaty, which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. The government has divided the area into sections, some operated by the state-owned salt company, the rest managed by the Departments of Forestry and Fishery.

2.2 Threats

The main problems of the Kus Cenneti are water shortage due to agricultural development, low quality of the water supplied, the physical impact of human presence and illegal hunting.

Agriculture

The first irrigation programs started in the early 1940s and have led to a gradual control of the river delta for irrigational purposes. Winter floods that previously flooded the Kus Cenneti are now stored behind the three dams in the Gediz basin and released mainly during the summer for hydroelectric purposes and to supply summer irrigation water. To drain the upstream cultivated areas a drainage canal was constructed by DSI (Devlet Su Isleri = State hydraulic works) through the middle of the reed bed in 1984. As this canal was believed to contribute to the severe drought conditions in the reserve in the following years, the Department of Forestry has blocked the canal with earthen dams at several locations. In 1991, the ground level adjacent to the wetlands was lowered and stabilized to convert it to cultivated land. In addition, many roads were constructed. This meant a loss of habitat and the authorities were, therefore, recommended to improve the situation of the wetlands as compensation. The present sources of water inputs are not sufficient to provide the necessary conditions for the reed beds, which are the main birdnesting areas. Since the drought period of 1989–1994 and the diversion of the remaining water, the reed beds have dried up and the area covered with reed has dramatically declined (RAC/SPA 1993).

Contamination and Salinization

With the growth of modern irrigated agriculture, the use of pesticides and fertilizers has increased. Wetlands are stagnant waters and, therefore, act as reservoirs in which pollutants accumulate. Pesticides are generally toxic to animals and many bird species have been decimated as a result of low birth rates and infertility. Even if the pesticides introduced into the Kus Cenneti ecosystem do not directly affect animals, there may still be an indirect future effect (Harmancioglu and Alpaslan 1998).

The Gediz river delta is considered to be polluted to the fourth degree, which means that the water should be used with care in terms of amounts of water used and specific purpose (table 3.1). Cities discharge their untreated effluent into the Gediz river while tanneries and leather industries further pollute the water. The drainage water bordering the Kus Cenneti was found to be highly saline (up to 8 kg m^{-3}), especially after the irrigation season (CKGM 1998). Salinity levels of 36 kg m^{-3} were measured by Pinar (1998) (for comparison, the salt concentration of the Aegean Sea is 36 kg m^{-3}). Inflowing water with high salinity or pollution will kill the reed beds entirely in the long term (RAC/SPA 1993).

Human Presence

The wildlife in the delta was already threatened because of its proximity to Izmir, the third biggest city of Turkey. Another serious threat was almost added to the existing threats. The Chamber of Commerce and Industry of Izmir planned to construct a large harbor and dockyard complex in the southern part of the delta. The construction site would involve more than 50 percent of the critical habitat for breeding of birds. The Chamber of Commerce and Industry of Izmir petitioned directly to the Minister for the Environment of Turkey for a suspension of the process of declaring the Gediz Delta as a Ramsar site. They suggested that the area had already lost its importance for the wildlife due to the pollution in the Bay of Izmir and they claimed that the project would dramatically improve the commercial capacity of Turkey. Although this plan has been rejected for now, another dockyard is planned to be built in the far northern part of the proposed Ramsar site, this time by a private company.

Hunting

Still another threat is overhunting and unregulated hunting. A center for visitors (the Kus Cenneti Centre) has been established on the site, which also serves as headquarters for the team of forestry guards who monitor the area closely and control hunting. This Centre sees itself undermanned and the guards have to deal with aggressive hunters while they are only allowed to impound hunting licenses and weapons. The regulations are strict but they cannot be strictly applied.

2.3 Definition of Wetland Quality

Wetland quality can be expressed most clearly in terms of the number of bird, fish and plant species and the number within each species. While it is certain that the number of fish species (in the lagoons) has been decreasing during the last few years (RAC/SPA 1993), no information is available on vegetation or changes of vegetation species. The studies of bird expert, M. Siki of the Aegean University, show that in 1992, 190 bird species were present with 42 species being winter visitors, 48 summer visitors, 53 sedentary species and 24 migratory species recorded only on passage. Fifty-nine species were recorded as breeding. DHKD (Turkish association for wildlife protection) noticed however a decline in the number of bird species and the loss of reed-covered area has been confirmed by all sources. Until more accurate data are available, data on birds and vegetation cannot be used for the definition of a wetland-quality criterion.

As the wetland is a freshwater ecosystem, it seems logical to take the salt concentration as a quality criterion. The Kus Cenneti is surrounded by highly saline lagoons (40–90 kg m^{-3}), salt pans (40–200 kg m^{-3}) and saline drainage canals (2–36 kg m^{-3}) (Pinar 1998; CKGM 1998). Although salt levels have been monitored intensively in the last few years, the relation between salt level and wetland quality has not been quantified. In this study, the emphasis will be laid on fluctuations in the salt concentration when the Kus Cenneti is flushed constantly through the year. In this way, it is hoped that the salt concentration can be controlled to a certain extent. This will be discussed in chapter 3.

CHAPTER 3

Computing the Kus Cenneti Water Requirements

3.1 Hydrological Characteristics

The northern part of the Kus Cenneti consists of two reed beds (total area 950 ha, figure 3.1: green dashed border) while the southern part comprises flooded and abandoned evaporation pans, hills and cliffs. The DSI and the salt company have made low dykes around the reed bed to protect the area from the intrusion of salt water. Both the northern and the southern parts are freshwater areas (blue border). There are four sources, which should be able to provide freshwater. The water sources are also shown in figure 3.1.

1. *Rainfall* is about 540 mm each year but, although an indispensable term in the water balance, it is not sufficient to sustain the reed beds without additional water supply.

2. The Rama Camsuyu project (Rama freshwater project, red line) was involved in the installation of a pump that extracted freshwater from a shallow aquifer. The flow of 0.055 m^3 s^{-1} will never be sufficient to preserve or restore the reed-bed area. The pumped water has formed a pond and little water flows into the reed beds. Since the pumped water is slightly saline (1 kg m^{-3}) it brings about 1,700 tons of salt per year into the reed beds. Without adequate flushing, this will have serious long-term consequences for the reed beds.

3. The diversion weir in *the Gediz river* (not shown on the map) at Emiralem feeds 18 m^3 into the two irrigation systems near Menemen on either side of the river. The remaining river water bridges a hydraulic head difference of 10 m between the Emiralem regulator and the sea, which is too low to transport water into the reed beds. If it is to be used, it has to be pumped. At present, the reed beds are dependent both on rainfall and on diversions from the Menemen left bank irrigation system. The first irrigation period begins at the end of April and ends at the beginning of May. The second irrigation period is from the end of June/beginning of July until the end of August/beginning of September. In summer, the water is used for irrigation and is, therefore, unavailable for the Kus Cenneti. During the winter floods, the existing channels would allow the water to be transferred to within 3.75 km from the bird paradise with a maximum flow rate of 1.5 m^3 s^{-1}. One of the channels terminates in the s-47 tertiary irrigation canal (turquoise line), which was extended to supply the Kus Cenneti at a design flow rate of 0.200 m^3 s^{-1}. The DSI has made plans to replace this tertiary canal with another that has a full supply flow of 0.700 m3s-1. The quality of the irrigation water is low due to untreated sewage water, classified as level 4 (table 3.1) and, in the current situation, the Kus Cenneti receives whatever is left after diversions to the irrigated fields. It is uncertain if table 3.1 is valid for the Kus Cenneti as well as for irrigated fields but, if it is, this water is not recommended for use (RAC/SPA 1993).

4. *Drainage water* from the nearby irrigation systems surrounds the borders of the Kus Cenneti (brown line) after which it flows to the Gediz river northwards. A sluice was constructed (discharge point on map) to allow water to be transferred to the reed-bed area along existing channels. Quality

measurements show, however, that this water is very saline (up to 9 kg m^{-3}) and highly polluted due to agrochemicals. This canal is currently not a part of the water balance due to a low hydraulic head difference between the canal and the bird paradise. The construction of a pump is being considered at the moment.

Table 3.1. Irrigation water quality criteria to be taken into consideration in classification of irrigation water. BOD_5 is the amount of oxygen needed to decompose biological pollutants (viruses, bacteria and algae) in 5 days.

Irrigation water quality criteria	1st Excellent	2nd Good	3rd Usable	4th To be used with care	5th Nonusable
Salt g m^{-3}	0–175	175–525	525–1,400	1,400–2,100	>2100
Cl^- g m^{-3}	0–142	142–249	249–426	426–710	>710
SO_4^{2-} g m^{-3}	0–192	192–336	336–576	576–960	>960
NO_3^-,NH_4^+ gm^{-3}	0–5	5–10	10–30	30–50	>50
Fecal coliform 1/100 ml	0–2	2–20	20–10^2	10^2–10^3	>10^3
BOD_5 g m^{-3}	0–25	25–50	50–100	100–200	>200

3.2 Data Availability and Assumptions

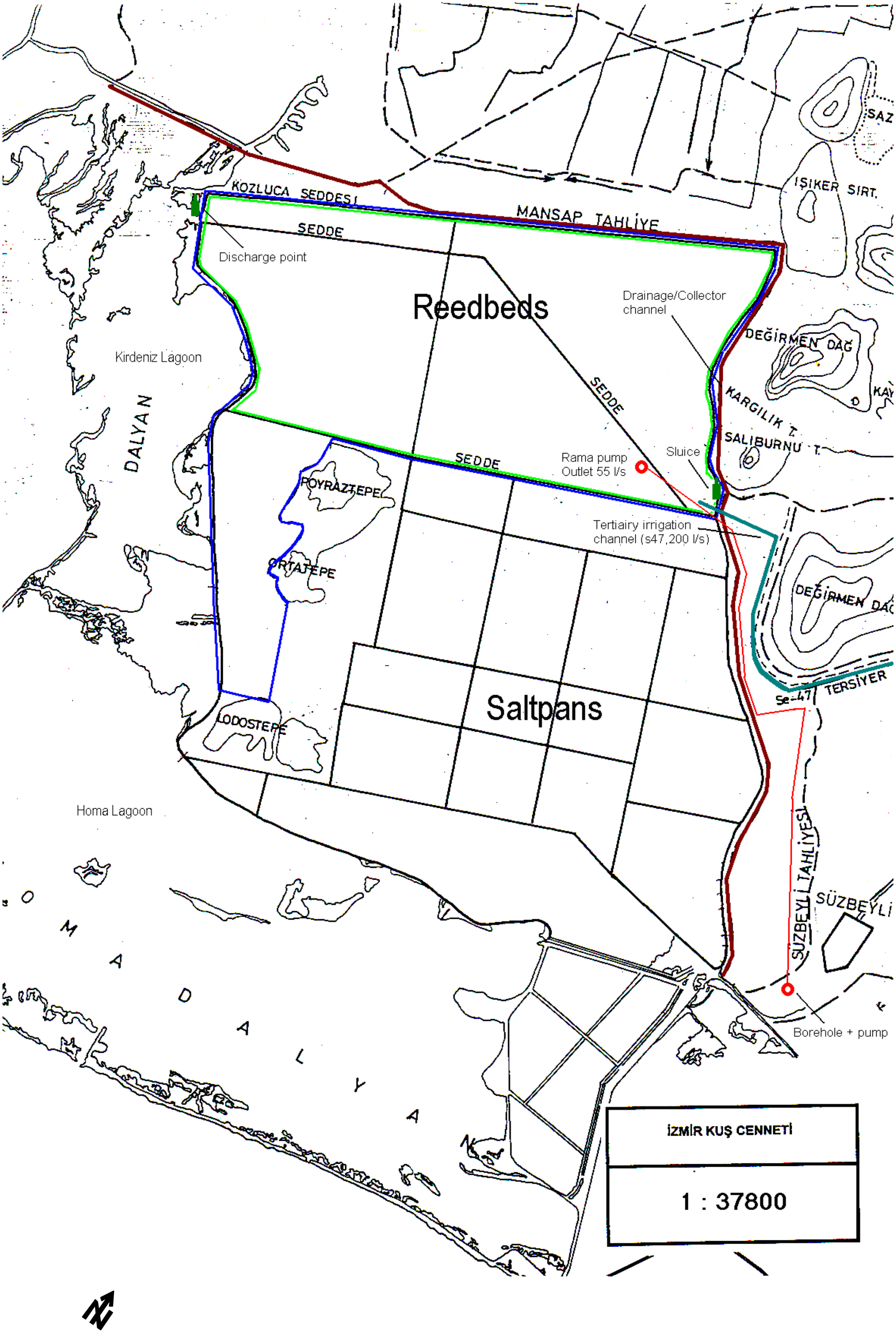
We had to make several assumptions to calculate the Kus Cenneti water requirements. Now we will discuss these to place the results in the correct framework.

Engineers and wildlife experts working in the Kus Cenneti think that it should be functional as a feeding or breeding area throughout the year. This seems to contradict the fact that wetlands are naturally subject to annual fluctuations in water supply. However, the Kus Cenneti needs extra protection for two reasons. It will dry out in an early stage because it does not receive sufficient water in winter to form a buffer for drier periods because of the upstream storage in reservoirs. Second, the Kus Cenneti birds need the shelter of the reed beds from the moment they lay their eggs (late spring) till the time the youngsters are able to fend for themselves. They do not have the same chance of survival as they would have in a more isolated region due to hunting and the physical impact of nearby human presence.

To guarantee a continuous quality of the Kus Cenneti for birds in terms of feeding, breeding and shelter area, a constant water level is required in the freshwater area throughout the year. Sutcliff and Parks (1993) and Jones, Desmond, and Lemeshewsky (1998), however, used a different approach towards wetland management. They assumed a seasonal variation in the wetland water supply.

In this research, we assume the freshwater area to be 1,100 hectares, while other sources assume it to be 1,150 or 1,000 hectares or only mention the northern reed beds with areas varying between 500 and 800 hectares, which would reduce the water requirement considerably. As a detailed map with boundaries was not found we used a LANDSAT image to estimate the scale of the available unscaled map in figure 3.1 and in this way we determined the freshwater area.

Figure 3.1. The hydrological characteristics of the Kus Cenneti. The scale is estimated.



The Kus Cenneti was assumed to be a well-mixed reservoir although, in practice, salt will accumulate more in some locations than in others depending on shade and water depth. Salt accumulations could be excavated rather than flushed, which would reduce the water requirement by an unknown amount, but it may have other environmental consequences that are beyond the scope of this report.

The assumption of a homogeneous distribution and constant water level does not take into account elevation differences and obstacles on the flats. Thus, a homogeneous distribution of water and salt inflow is a simplification of reality but this will not change the water requirement to any significant extent.

Seepage is generally an important term in the water balance of wetlands because of recharge of groundwater storage. Including seepage in the calculation of the water balance could increase the water requirement as calculated in the next section and affect the salt balance, but these effects could not be included due to a lack of accurate data. Including such data would involve detailed soil processes and, consequently, more detailed and complex calculations. An appropriate small-scale hydrological model would be required but such an approach is beyond the scope of this research. Seepage fluxes are probably small owing to the small difference in hydraulic head difference between the Kus Cenneti and its surroundings. Nevertheless, the results of this chapter should be used with care.

3.3 Calculation of the Water Requirements

To study the effect of water diversions on the Gediz basin, the water requirement of the Kus Cenneti has to be determined. First, a constant water level in the entire freshwater area has to be maintained. Second, to maintain a constant (minimal) salt level we have to supply more water into the freshwater area to compensate for the increase in salt concentration due to evaporation.

To keep the volume of water constant in the Kus Cenneti, a balance has to be maintained between inflow (Q_{IN}), outflow (Q_{OUT}), evapotranspiration (ET) and precipitation (P). Seepage is assumed to be zero. The inflow is mainly supplied by the s-47 tertiary irrigation canal. This canal can supply a maximum of 0.200 $m^3\ s^{-1}$ and, if replaced by an extension of the secondary canal, a maximum of 1.500 $m^3\ s^{-1}$ could be supplied (recommendation, RAC/SPA 1993). The outflow can be regulated at the embankment bordering the Kirdiniz lagoon (figure 3.1, discharge point) and should be equal to the difference between inflow and (ET-P). The monthly average evapotranspiration data for this region were calculated with meteorological data using the Penman-formula in Cropwat7 (FAO 1995) for a wet year (1997) and a dry year (1992). The monthly average precipitation data were obtained from the meteorological station in Menemen.

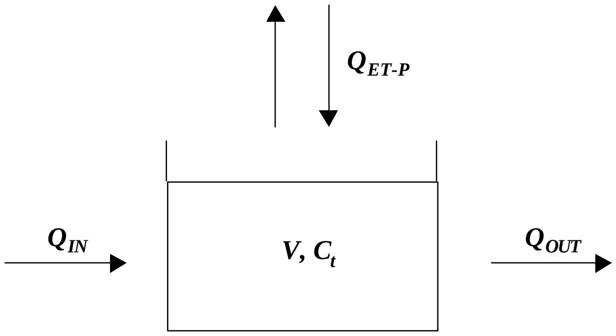
The ideal water depth is about 15 cm, which should be deep enough to provide fish and plankton for the birds. The area of the freshwater beds is about 1,100 ha. When the assumption is made that the freshwater area in the Kus Cenneti is completely flat and without obstacles and that the water spreads evenly over the whole area, the volume to be maintained is equal to the product of the area and the water depth (1.8 million m^3). This volume can be maintained, on a monthly basis, if the outflow is met by the inflow for each month.

The water requirement for maintaining a constant water level (Q_{ET-P}) follows directly from these values and the meteorological data, which are shown in table 3.2. Negative values mean that no inflow is required and water should be discharged to maintain the water level of 15 cm. The calculations show that with the assumptions mentioned, the intended increase in inflow from the s-47 irrigation canal to 0.700 m^3 s^{-1} will not be sufficient in the summer months, unless it is assumed that water can be stored in the Kus Cenneti to cover the demands for the summer period. In a wet year, an extra supply will not be needed until May to maintain a constant water level.

Table 3.2. Expected minimum requirement for the Kus Cenneti to maintain a constant water level.

Dry year					Wet year			
	ET mm d^{-1}	P mm d^{-1}	$ET - P$ mm d^{-1}	Q_{ET-P} m^3 s^{-1}	ET mm d^{-1}	P mm d^{-1}	$ET - P$ mm d^{-1}	Q_{ET-P} m^3 s^{-1}
January	2.2	0	2.2	0.280	1.4	2.0	-0.6	-0.076
February	2.3	0.3	2	0.255	2.0	1.0	1	0.127
March	2.9	1.5	1.4	0.178	2.8	2.0	0.8	0.102
April	4.1	1.3	2.8	0.357	2.9	2.3	0.6	0.076
May	5.9	0.5	5.4	0.688	5.2	0.3	4.9	0.625
June	6.9	0.1	6.8	0.867	5.9	0.0	5.9	0.752
July	7.4	0	7.4	0.943	6.5	0.0	6.5	0.829
August	7.4	0	7.4	0.943	6.4	0.0	6.4	0.816
September	6.2	0	6.2	0.790	4.5	0.0	4.5	0.574
October	3.8	0.7	3.1	0.395	1.2	1.8	-0.6	-0.076
November	2.4	2.8	-0.4	-0.051	1.5	2.2	-0.7	-0.089
December	1.7	3.7	-2	-0.255	1.3	6.3	-5	-0.637
Annual sum	1,625 mm	333 mm	1,292 mm	14.2 10^6 m^3	1,238 mm	547 mm	690 mm	7.6 10^6 m^3

Figure 3.2. The Kus Cenneti, represented as a well-mixed reservoir with constant volume V (m^3) and variable concentration C_t (kg m^{-3}). Q_{IN} represents the supply and Q_{OUT} the discharge. Q_{ET-P} represents the net evapotranspirative demand (ET-P). All flows are in m^3 s^{-1} and inflows are positive.



An extra amount of water is required to flush the salt accumulations. In practice, these salt accumulations are flushed locally/on the spot, but here a uniform dissolved salt concentration and uniform flushing will be assumed. A relation between the reservoir concentration and inflows and outflows can be found by solving the salt mass balance. The freshwater area will now be represented by a well-mixed reservoir (figure 3.2) and then the temporal variation of the salt mass is equal to the sum of inflowing and outflowing salt fluxes:

$$Q_{IN}C_{IN} \ ? \ Q_{ET?P}C_{ET?P} \ ? \ Q_{OUT}C_{OUT} \ ? \ \frac{dC_tV}{dt} \qquad (3.1)$$

where,

C_{IN}, C_{OUT} and $C_{ET\text{-}P}$ are the salt concentrations in kg m^{-3} corresponding to Q_{IN}, Q_{OUT} and $Q_{ET\text{-}P}$, respectively. This equation can be solved analytically, if the flow rates and inflowing salt concentration are assumed to be constant during a period t (s).

First, we assume that the water requirement is just met by the inflow: $Q_{IN} = -Q_{ET\text{-}P}$, $Q_{ET\text{-}P} < 0$, $C_{ET\text{-}P} = 0$ and $Q_{OUT} = 0$ and that the volume is kept constant. Equation (3.1) then simplifies to:

$$Q_{IN}C_{IN} \ ? \ V\frac{dC_t}{dt} \qquad (3.2)$$

Integrating equation (3.2) results in a linear expression for the reservoir salt concentration:

$$C_t \ ? \ C_0 \ ? \ \frac{Q_{IN}C_{IN}}{V}t \qquad (3.3)$$

where,

C_0 corresponds to the initial salt concentration (kg m^{-3}). Equation (3.3) shows that the salt concentration increases linearly and continuously with time (figure 3.3). This means that, without an additional water supply on top of the minimum requirement, the salt concentration in Kus Cenneti is expected to reach sea level or even salt pan salinities.

If precipitation dominates ($Q_{ET\text{-}P}$? 0), the inflow has to be put to zero ($Q_{IN} = 0$), $C_{OUT} = C_t$ and water has to be discharged to keep the volume constant ($Q_{OUT} = -Q_{ET\text{-}P}$,):

$$? \ Q_{ET?P}C \ ? \ V\frac{dC}{dt} \qquad (3.4)$$

Separating the variables, integrating both sides and calculating the integration constant with $C_t = C_0$ for $t = 0$ result in:

$$C_t \ ? \ C_0e^{? \frac{Q_{ET?P}}{V}t} \qquad (3.5)$$

Figure 3.3 shows the diluting effect of precipitation.

In case the inflow exceeds the water requirement and evapotranspiration is larger than precipitation ($Q_{IN} > -Q_{ET-P} > 0$) and if the volume is kept constant over time by discharging the difference between inflow and demand ($Q_{OUT} = -(Q_{IN} + Q_{ET-P})$), equation (3.1) can be expressed as:

$$Q_{IN}C_{IN} - (Q_{IN} + Q_{ET-P})C_{OUT} = V\frac{dC_t}{dt} \tag{3.6}$$

First, we replace the term Q_{IN} C_{IN} by p and the term (Q_{IN} + Q_{ET-P}) by q. Since the outflowing salt concentration is equal to the reservoir concentration we get:

$$p - qC_t = V\frac{dC_t}{dt} \tag{3.7}$$

Separating the variables results in:

$$\frac{dt}{V} = \frac{dC_t}{p - qC_t} = -d\left(\frac{1}{q}\ln(p - qC_t)\right) \tag{3.8}$$

Integrating equation (3.3) results in:

$$p - qC_t = e^{-\left(\frac{q}{V}t + K\right)} \tag{3.9}$$

where,

K is the integration constant that can be calculated with the initial condition $C_t = C_0$ for $t = 0$:

$$p - qC_0 = e^{-K} \tag{3.10}$$

From equations (3.9) and (3.10) it follows that:

$$C_t = \frac{p}{q} - \left(\frac{p}{q} - C_0\right)e^{-\frac{q}{V}t} = \frac{p}{q}\left(1 - e^{-\frac{q}{V}t}\right) + C_0 e^{-\frac{q}{V}t} \tag{3.11}$$

Resubstituting p and q finally results in:

$$C_t = \frac{Q_{IN}C_{IN}}{Q_{IN} + Q_{ET-P}}\left(1 - e^{-\frac{Q_{IN} + Q_{ET-P}}{V}t}\right) + C_0 e^{-\frac{Q_{IN} + Q_{ET-P}}{V}t} \tag{3.12}$$

or, after resubstituting Q_{OUT} (=-(Q_{IN} + Q_{ET-P})):

$$C_t = -\frac{Q_{IN}C_{IN}}{Q_{OUT}}\left(1 - e^{\frac{Q_{OUT}}{V}t}\right) + C_0 e^{\frac{Q_{OUT}}{V}t} \qquad (3.13)$$

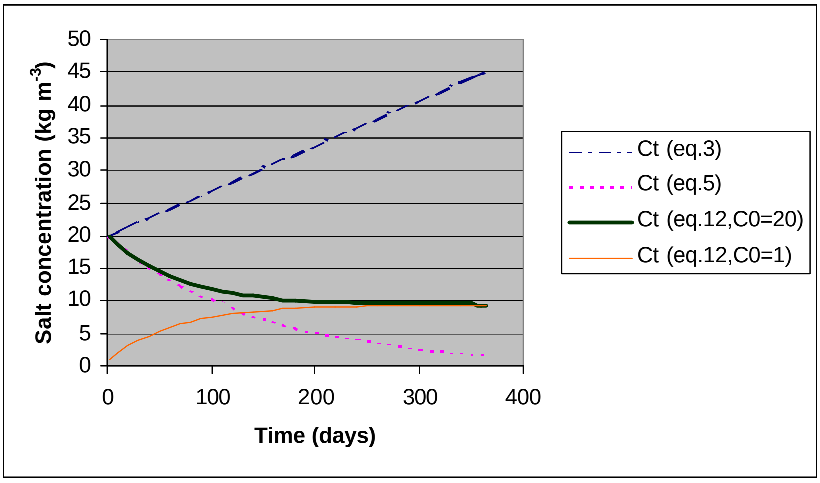
Equation (3.13) results in a stabilized salt concentration, which is almost independent of the initial concentration for periods exceeding 200 days (figure 3.3). This concentration (kg m^{-3}) is given by Q_{IN} C_{IN} Q_{OUT}^{-1}.

To relate concentration and water inputs the following flow ratio (*f*) was defined:

$$f = -\frac{Q_{IN}}{Q_{ET-P}} \qquad (3.14)$$

As is shown in equation (3.3), *f* must be higher than 1.0 to prevent constant salt accumulation.

Figure 3.3. The relation between the inflowing and reservoir salt concentration for different flow ratios (f) and a constant annual water demand (Q_{et-p} = -2.2 mm d^{-1}) (for comparison, the salt concentration of the Aegean Sea is 36 kg m^{-3}).



When the temporal variation of the water demand is taken into account the concentration in the reservoir will have an annual fluctuation (figures 3.4 and 3.5). In the winter, the rainwater dilutes the salt but after winter, the salt concentration rises and reaches a plateau, depending on weather conditions. High water inputs are required to decrease the salt concentration, although it is clear that it will never reach an acceptable level with the assumed concentration of inflowing water (1 kg m^{-3}). As no information was found about ideal salt levels or salt tolerance of reed and birds—probably the lower the better—a different approach has to be considered.

Figure 3.4. The expected annual fluctuation of the reservoir salt concentration at the end of each month in a representative dry year for different ratios of inflow and demand (f). The inflow concentration is 1.0 kg m^{-3}.

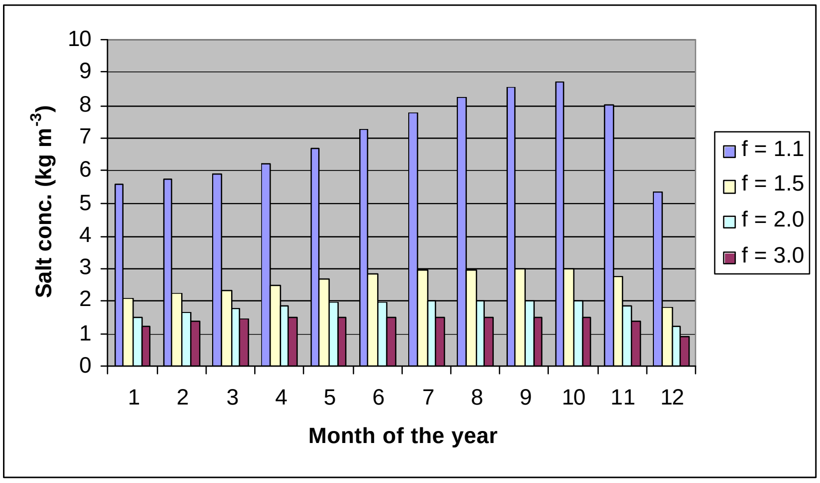
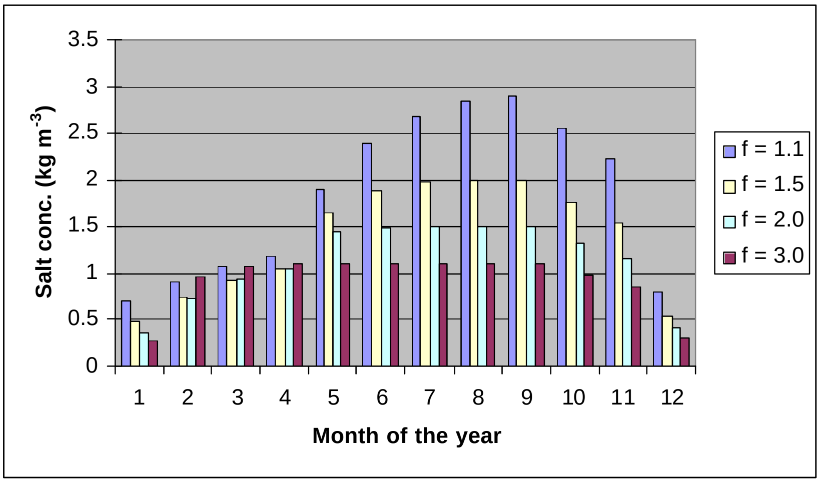
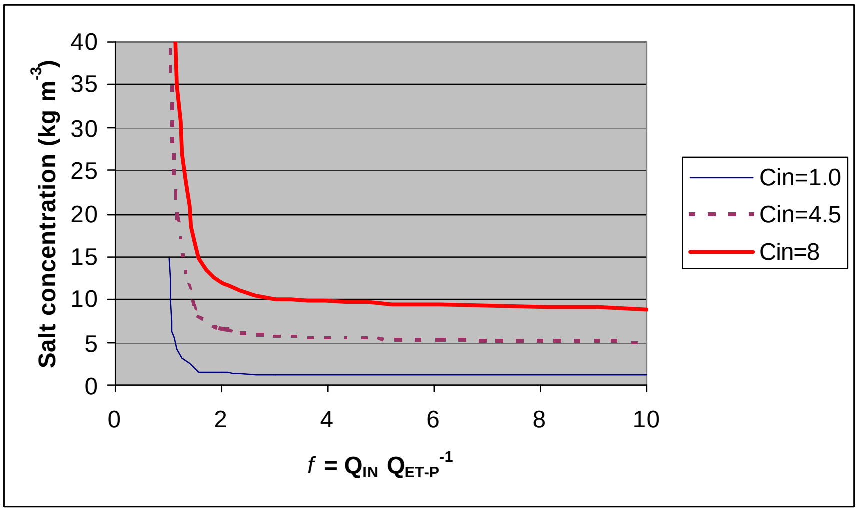


Figure 3.5. The expected annual fluctuation of the reservoir salt concentration at the end of each month in a representative wet year for different ratios of inflow and demand (f). The inflow concentration is 1.0 kg m^{-3}.



It appears from figure 3.6 that flow ratios higher than about 2 will hardly reduce reservoir salt concentration. After this point, the diluting effect of inflow exceeds the increase of concentration due to evaporation and, therefore, a flow ratio of 2 could be chosen as a minimum water requirement. The inflow concentration of 1.0 kg m^{-3} was the minimum concentration found in the available data (Rama pump), 8.0 kg m^{-3} was the maximum concentration in the drainage canal water and 4.5 kg m^{-3} was the summer average value. Although an increase in water input at high-flow ratios contributes relatively little to a decrease in salt concentration, it can still be useful in terms of overall wetland quality. A comparative study in the Camargue wetland, France, showed that a limited decrease of the salt concentration might result in an increase in wetland quality in terms of number of bird species (Britton and Johnson 1987). Until more information is available about this relation, the effect of flow ratios higher than 2 should be evaluated as well.

Figure 3.6. The influence of an increased inflow on the reservoir salt concentration.



Lower salt concentrations can only be obtained if the inflow concentration is reduced (figure 3.6). The minimum recommended flow ratio, however, would still be about 2. It was noted earlier that the stabilized reservoir concentration was equal to $Q_{IN}\,C_{IN}\,Q_{OUT}^{-1}$. If this term is combined with equation (3.14), we get a stabilized concentration equal to $f\,(f\text{-}1)^{-1}\,C_{IN}$. From this equation the stabilized (summer) reservoir salt concentration can also be calculated if inflow concentrations are lower than 1 kg m^{-3} (e.g., for f=10 the reservoir salt concentration is always about 10% higher than the inflow concentration). Fluctuations in the summer concentration, due to variation in evapotranspirative demand during the year, are less than 10 percent for flow ratios greater than 1.1 and less than 0.5 percent for flow ratios greater than 2.

Based on these conditions, a range of water requirements can be selected. The requirements vary with inflow concentration and weather conditions. If the most extreme weather conditions are chosen and flow ratios are varied between 2 and 10, the most possible reservoir concentrations should fall within the range of these chosen water requirements. Flow ratios less than 2 result in a high increase in salt concentration while a flow ratio of 10 approximately corresponds to the maximum Gediz base flow and thus the maximum deliverable supply.

3.4 Alternative Supply Options

It might not be possible to provide a continuous supply on a daily basis for reasons of management discussed in chapter 5. Supply on a weekly basis will result in a change of storage and an increase of salt concentration in the intervals in which no water is supplied. In these intervals, the water level will decrease as water is leaving the reservoir by evaporation and discharge. Salt concentration can then be calculated analogous to section 3.3, but now with a volume that decreases or increases in time.

The derivation of the time-dependent reservoir volume and salt concentration is described in appendix A. Table 3.3 indicates the resemblances and differences between a continuous supply and a weekly supply. In both cases, the Kus Cenneti gets an equal amount of water per week.

Table 3.3. Comparison of salt concentrations in the summer of a dry year between a weekly and continuous supply. The supply options are compared for minimum and maximum salt concentrations (min. conc. and max. conc.), inflowing salt concentrations and maximum water depth. The minimum water level is always 0.15 m.

C_{IN}			Weekly supply			Continuous supply		
(kg m-3)			*f* = 2	*f* = 3	*f* = 10	*f* = 2	*f* = 3	*f* = 10
1.0	Min. conc.	(kg m^{-3})	1.8	1.4	1.1	2.0	1.5	1.1
	Max. conc.	(kg m^{-3})	2.2	1.74	1.1	2.0	1.5	1.1
4.5	Min. conc.	(kg m^{-3})	8.1	6.2	4.7	9.0	6.8	5.0
	Max. conc.	(kg m^{-3})	10.1	7.5	4.8	9.0	6.8	5.0
8.0	Min. conc.	(kg m^{-3})	14.4	10.9	8.4	16.0	12.0	8.9
	Max. conc.	(kg m^{-3})	14.9	11.2	8.6	16.0	12.0	8.9
	Max. Depth	(m)	0.23	0.27	0.56	0.15	0.15	0.15

The most obvious difference is the change in water depth. For a weekly supply, water depth varies between 0.15 m and the maximum depth, which is proportional to the supply. The salt concentration tends to be lower for a weekly supply than for a continuous supply at high-inflowing salt concentrations, but for low-inflowing salt concentrations the differences are insignificant. Maximum concentrations never exceed the concentrations at a continuous supply by more than 12 percent.

3.5 Conclusions

In addition to the base volume required to meet evapotranspiration, an extra supply of water is required to keep the salt concentration to a minimum. If this additional supply is not provided (*f* ? 1) the reed beds will turn into salt pans in the long term. With high salt concentration the reed beds will not be able to develop and the birds will not have a suitable breeding environment.

Calculations showed that the maintenance of a constant acceptable salt concentration is far more demanding than the maintenance of a constant water level. Water supplies that exceed the evapotranspirative requirement (Q_{ET-P}) will stabilize the Kus Cenneti salt concentration, but not at a level below the assumed inflow concentration of 1 kg m^{-3}. This is only possible when the Kus Cenneti is supplied with less saline water. Precipitation is clearly not sufficient to keep the water at a constant level.

It is difficult to determine the exact water requirement for the Kus Cenneti due to a lack of information about inflowing salt concentrations and relations between salt level and wetland quality (number of bird species, reed-covered area). The determination of the final Kus Cenneti water requirements is based on three statements:

1. A salt concentration of 1 kg m^{-3} is lethal for the reed beds in the long term for a static reservoir (RAC/SPA 1993), due to salt accumulation. In a flushed reservoir where accumulation is avoided, the salt concentration will stabilize and fluctuations will decrease with increasing flow ratios.

2. A comparative study in the Camargue, France, shows that even a small drop in salt concentration might result in an improvement of wetland quality.

3. Equation (3.12) can be used to derive (stable) summer reservoir salt concentrations for inflow concentrations lower than 1 kg m^{-3}. This means that if the salt concentration of the inflow is halved, the reservoir salt concentration too halves (for high-flow ratios).

These statements indicate that, for the basin modeling with SLURP, several flow ratios between 2 and 10 should be chosen to cover a large range of possible salt levels. The resulting total water requirements (Q_{mean}) for the flow ratios 2, 3 and 10 for average weather conditions are shown in table 3.4.

The way in which the water is supplied (weekly or continuously) does not affect the salt concentrations in the Kus Cenneti to a large extent. The choice for one of these options has to be made based on bird preferences (constant or fluctuating water depth). More research on this topic is required.

Table 3.4. Evapotranspirative requirement (Q_{ET-P}) for a dry year and a wet year and the total average water requirement (Q_{mean}) for the Kus Cenneti for three flow ratios.

	Dry year	Wet year	*f* = 2	3	10
	Q_{ET-P} $m^3\ s^{-1}$	Q_{ET-P} $m^3\ s^{-1}$	Q_{mean} $m^3\ s^{-1}$	Q_{mean} $M^3\ s^{-1}$	Q_{mean} $m^3\ s^{-1}$
January	0.280	-0.076	0.204	0.306	1.020
February	0.255	0.127	0.382	0.574	1.912
March	0.178	0.102	0.280	0.421	1.402
April	0.357	0.076	0.433	0.650	2.167
May	0.688	0.625	1.313	1.970	6.565
June	0.867	0.752	1.619	2.429	8.095
July	0.943	0.829	1.772	2.658	8.860
August	0.943	0.816	1.759	2.639	8.796
September	0.790	0.574	1.364	2.046	6.820
October	0.395	-0.076	0.319	0.478	1.594
November	-0.051	-0.089	-0.070	-0.070	-0.070
December	-0.255	-0.637	-0.446	-0.446	-0.446
Sum (10^6 m^3)	14.2	7.9	23.5	35.9	122.8

CHAPTER 4

Computing the Water Availability

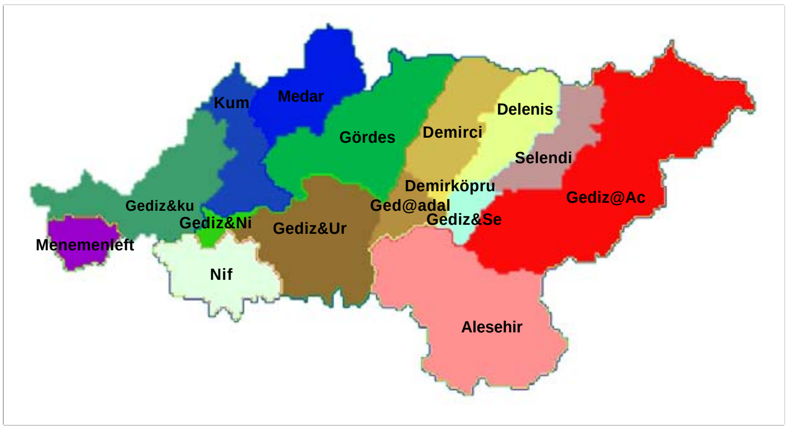
4.1 Why Do We Need to Model the Entire Basin?

The Kus Cenneti water requirement has to be provided at the expense of other water users in the Gediz basin. In this study, the SLURP model was used to evaluate the effect of this requirement on the water user that is most likely to be affected, i.e., irrigated agriculture. This chapter shows how SLURP computes the effect of irrigation management on water usage and the availability for the entire basin.

4.2 Description of the Model

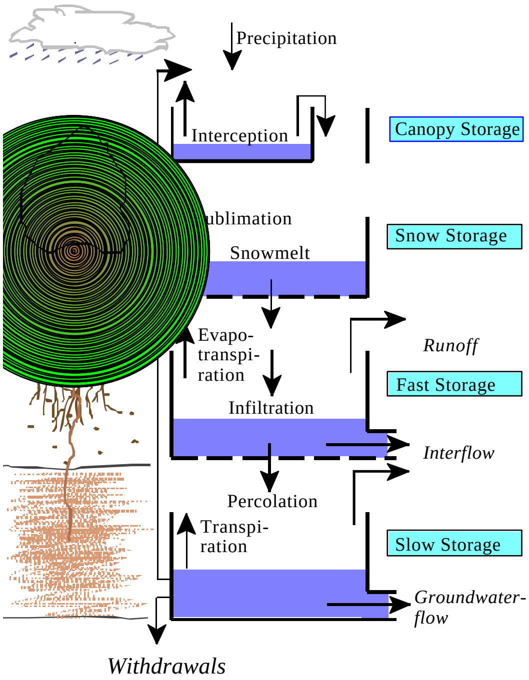
SLURP (**S**emi-Distributed **L**and **U**se-Based **R**unoff **P**rocesses) is a hydrological basin model, which simulates the hydrological cycle from precipitation to runoff including the effects of stores, dams, regulators, water extractions and irrigation. It divides the basin into subbasins on the basis of topography. These subbasins known as Aggregated Simulation Areas, (ASAs, figure 4.1) are, in turn, subdivided into areas of different land use. For the Gediz basin, the topography was determined with public-domain satellite data. For each land cover, satellite data were used to derive the Normalized Difference Vegetation Index (NDVI), which shows the relative activity of green vegetation. From the NDVI the Leaf Area Index (LAI) is calculated to determine evaporation and transpiration. Stream flows are routed by calculating the distance traveled by water to the nearest stream, and then downstream to the ASA outlet.

Figure 4.1 ASAs in the Gediz basin.



The hydrological model simulates the vertical water balance for each land cover within each ASA and accumulates the water down to the basin including the effects of regulations and interventions. This vertical water balance operates on a daily timestep. Each element of the (ASA * land cover) matrix is simulated by four nonlinear stores or reservoirs representing canopy interception, snowpack, fast storage and slow storage (figure 4.2).

Figure 4.2. Vertical water balance as calculated in the SLURP model (Kite1999).



4.3 Processes

The first operation within the vertical water balance for a particular land cover and ASA is to calculate the evapotranspirative demand. For the Gediz basin, this was calculated with the FAO version of Penman-Monteith (Verhoef and Feddes 1991):

$$? \ ?ET \ ? \ \frac{s(Q^{*} \ ? \ G)}{s \ ? \ ?(1 ? \frac{r_s}{r_a})} \ ? \ \frac{?_a c_p \frac{e_s ? e_a}{r_a}}{s \ ? \ ?(1 ? \frac{r_s}{r_a})} \qquad (4.1)$$

where,

? is the latent heat of vaporization (Jg^{-1}), ET is the potential transpiration rate ($gs^{-1}m^{-2}$), s is the slope of the vapor pressure curve (Pa K^{-1}), Q^* is the net radiation (Wm^{-1}), G is the soil heat flux (Wm^{-1}), ? is the psychrometric constant (PaK^{-1}), r_a is the aerodynamic resistance (sm^{-1}), r_c is the crop resistance (sm^{-1}), e_s is the saturated vapor pressure (Pa), e_a is the actual vapor pressure (Pa), $?_a$ is the air density (g m^{-3}), and c_p is the heat capacity of moist air ($Jg^{-1}K^{-1}$).

Precipitation data were derived from five meteorological stations.The distribution of precipitation over the basin was calculated using Thiessen polygons. The vertical water balance can be determined by calculating storage in and movement out of all four stores.

The canopy interception needs data about LAI and canopy capacity to calculate the maximum canopy interception for each month. The output from this store is either evaporation or runoff to the second or third store. When the daily temperature is below a critical point the precipitation will fall as snow and will be accumulated in the second store. From this store SLURP generates snowmelt output depending on the daily temperatures and radiation. The fast storage represents a combined surface storage and top soil layer storage, while the slow store represents groundwater. Precipitation and snowmelt will infiltrate into the fast storage using equation (4.2) which calculates the current infiltration rate:

$$Inf \; ? \; ?1 ? \frac{S_1}{S_{1,\max}} ? ?Inf_{\max} \qquad (4.2)$$

where,

S_1 is the current contents of the fast store (mm), $S_{1,max}$ is the maximum possible contents of the fast store (mm), Inf is the current infiltration rate (mm day^{-1}) and Inf_{max} is the maximum possible infiltration rate (mm day^{-1}).

If the current infiltration rate is not sufficient enough to store all the precipitation, then the surplus of water will be spilt as surface runoff. The fast store generates outflow $Q_{1,out}$ making use of equation (4.3):

$$Q_{1,out} \; ? \; \frac{1}{k_1} ?S_1 \qquad (4.3)$$

where,

$Q_{1,out}$ = outflow from the fast store (mm day^{-1}) and k_1 is the retention constant for the fast store. The outflow $Q_{1,out}$ will then be separated into deep percolation RP flowing to the slow store and interflow RI using equations (4.4) and (4.5):

$$RP \; ? \; \frac{Q_{1,out}}{1 ? \frac{S_2}{S_{\max}}} \qquad (4.4)$$

$$Q_{1,out} \; ? \; RP \; ? \; RI \qquad (4.5)$$

where,

S_2 is the current contents of the slow store (mm) and S_{max} is the maximum possible contents of the slow store (mm).

Finally, the slow store generates outflow $Q_{2,out}$ using equation (4.6), or if the slow store flows over, the surplus of water will be added to the interflow:

$$RG \; ? \; \frac{1}{k_2} * S_2 \tag{4.6}$$

where,

k_2 is the retention constant for the slow store.

The model routes precipitation through the vertical water balance and generates outputs (evaporation, transpiration and runoff) and changes in the different storages (canopy interception, snowpack and the slow- and fast-storage contents). From each land cover in an ASA the runoffs are accumulated using a time/contributing area relationship for each land cover and then the combined runoff is converted to the streamflow and routed between each ASA. For first order ASAs (those that directly discharge to the river) the streamflow is routed by simply accumulating the flows down the basin with no delay or attenuation. For second order ASAs Muskingum routing is used, which describes the relation between inflow, outflow and storage from an ASA.

4.4 The Use of SLURP for the Gediz Basin

In a longer-term study being conducted jointly by GDRS (General Directorate of Rural Service) and IWMI (Internation Water Management Institute), the Gediz basin has been thoroughly surveyed and modeled with SLURP, which was calibrated and found valid to describe the basin’s hydrology. Interventions like irrigation or water extractions for urban use as well as the operating rules for the reservoirs were included in the model. Each ASA is divided in groups of crop cover to simplify the simulation of irrigation applications. The groups of crop cover are irrigated in a sequential order, described in an intervention input file.

The input files that contain the records with these data were modified for the simulations described in chapter 5 and compared against the scenario that describes the present situation. Table 4.1 gives an example of a diversion file where dates are defined on which water is diverted, the amounts of water ($m^3 s^{-1}$), in this example, for Menemen left and right bank irrigation systems and the minimum base flow to be maintained at the regulator in ASA “gediz&ku.”

Table 4.1. Example of a diversion file.

```
Gediz&ku menemenl.sir
Gediz&ku menemenr.sir
Gediz&ku 1992 4 25 1992 5 10 12.0 6.0 1.565
Gediz&ku 1992 5 11 1992 7 19 0.0 0.0 1.565
Gediz&ku 1992 7 20 1992 8 8 12.0 6.0 1.565
Gediz&ku 1992 8 9 1992 9 30 0.0 0.0 1.565
```

The Gediz basin was simulated for the period 1988–1998 from which 2 years were selected to represent extreme weather conditions. From the drought period 1989–1994, the year 1992 was chosen to represent a very dry year and 1997 was selected as the wettest year. This means that hydrological conditions such as soil moisture and precipitation patterns for these years were used in simulations to show what would happen under current conditions and under modified management strategies. As there is almost no rainfall in summer in both dry and wet years, the reservoir release period can be defined in March as the reservoir volume divided by the volume carried by its canal when full (75.0 m^3s^{-1}).

The output data give for every day each component of the water balance, from which transpiration and streamflow data were used to analyze the result of the scenarios. SLURP divides the water following an order based on the relative position of the ASA/irrigation systems to the reservoir, which implies that, in periods in which water shortages occur, irrigation systems get whatever is left after upstream ASA/irrigation systems have been supplied to their full demand. The same restriction counts for the irrigation applications to the crop covers. Available water is applied first to the first (=arbitrary) crop cover in the intervention input file. This means that results as discussed in chapter 5 are not crop-specific.

CHAPTER 5

The Conflict between the Kus Cenneti and Irrigated Agriculture

5.1 Why Is There a Conflict?

Chapter 2 described the threats the Kus Cenneti is confronted with; chapter 3 determined the water requirements; chapter 4 determined how much water can be supplied with the mentioned assumptions and, therefore, we know now, given certain assumptions, what the effects of the Gediz basin on the Kus Cenneti are. Using the simulations described in the following sections, the following questions will be answered: (i) How far can the Kus Cenneti water demand be fulfilled? (ii) What are the effects of the Kus Cenneti water demand on the other interests in the basin? (iii) Which management options can be found to satisfy the Kus Cenneti and to minimize the effects on agricultural productivity?

Water can be supplied to the Kus Cenneti if a minimum base flow is maintained at one or more of the three regulator(s) and by diverting less water to the irrigation systems if necessary. Figure 5.1 shows the regulatory structure for the Gediz basin. At the moment, there is no direct connection between the Gediz river and the Kus Cenneti and the surplus river water and return flows from the irrigation systems flow directly to the sea. The only way the Gediz river water reaches the Kus Cenneti is through the irrigation system on the left bank after the Emiralem regulator and then through the s-47 tertiary irrigation canal.

For the determination of the water requirements and for the following simulations we make the assumption that the Kus Cenneti gets priority treatment. The other alternatives are that this priority treatment is given to agriculture or that both water users get a proportional share. Section 5.2 discusses the relation between these three priority options.

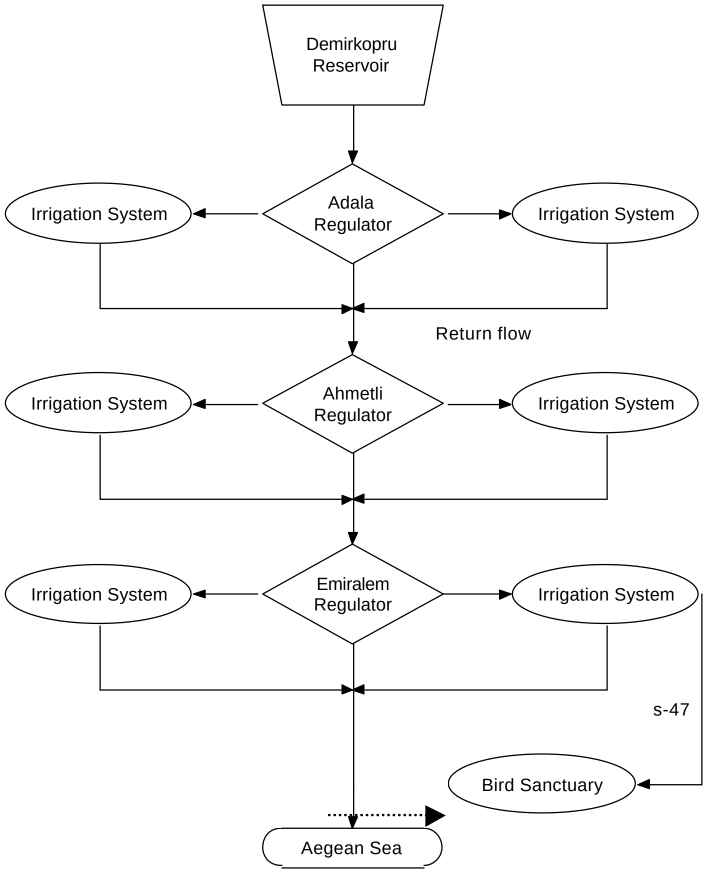
In section 5.3 the minimum base flow will be maintained at the most downstream regulator only and in section 5.4 the effects of distributing the Kus Cenneti water demand over all irrigation systems in the Gediz basin will be evaluated.

The effects of water diversion for the Kus Cenneti are expressed as reductions of transpiration but can also be thought of as reductions in yield since yield can be calculated with:

$$\frac{Actual\,Yield}{Maximum\,Yield} \; ? \; \frac{Actual\,Transpiration}{Potential\,Transpiration} \qquad (5.1)$$

where, yields can be expressed in kg ha^{-1} and transpirations in m^{3} s^{-1}.

Figure 5.1. Organization of a regulatory structure (see also figure 1.3).



5.2 Predictions of Yield Loss and Water Availability

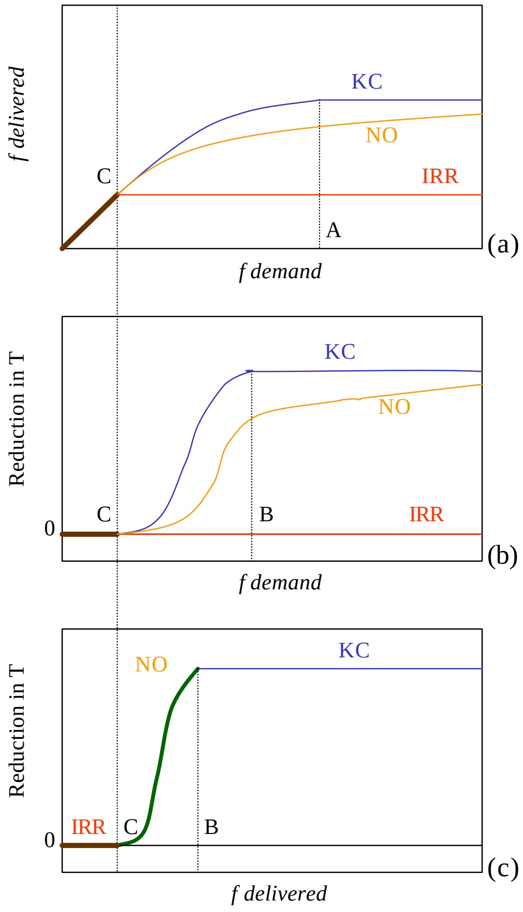
In this section we will predict theoretically the effects of a minimum base flow in terms of crop transpiration and Gediz river outflow for the three ways in which the water supply to the Kus Cenneti can be realized. This will show what the relation is between the three ways in which the Kus Cenneti can be supplied and that it is only necessary to simulate a priority treatment for the Kus Cenneti. Further it will show how far SLURP simulation corresponds with theory.

Although we assume, for the SLURP simulations, that water from the Gediz basin will be distributed primarily to the Kus Cenneti with the irrigated areas receiving whatever remains, the Gediz basin can provide freshwater to the Kus Cenneti in two other ways:

? The irrigated fields get priority.
? No water user gets priority; both water users get a proportional share.

The theoretical expectations of these three alternatives and the relation between one another are shown in figure 5.2.

Figure 5.2a, b, c. Expected relations between f demanded, f delivered and irrigation system reductions in transpiration (%) for different priority treatments (KC=Kus Cenneti, NO=no priority, IRR=irrigation systems).



A. Point at which the supply is limited by the maximum river supply.
B. Point at which the maximum reduction in transpiration is reached.
C. Point up to which sufficient water is available for both the Kus Cenneti and the irrigation systems.

In chapter 4 the flow ratio *f* was defined as the ratio of net evapotranspirative demand ($m^3\ s^{-1}$) to inflow ($m^3\ s^{-1}$). Here the flow ratio *f delivered*, which is a measure of the amount of water that can be supplied to the Kus Cenneti, is defined as:

$$f\ \ delivered = f\ \ demanded \left(\frac{water\ delivered}{water\ demanded} \right) \tag{5.1}$$

where, the amounts of water delivered and demanded are annual averages (m^3).

Figure 5.2a shows that the amount of water that can be delivered is equal to the amount demanded up to the limit at which sufficient water is available for both the Kus Cenneti and the irrigation systems (point C). After that the delivered amount cannot keep up with the demand due to periodical water deficits. Finally, the point is reached where the deliverable amount of water is limited by maximum river supply (point A).

Figure 5.2b shows that reduction in transpiration should be zero till point C. After this point, crop transpiration will reduce according to the crop-response function: a sigmoid curve as is displayed. Finally, the reduction in crop transpiration will reach a maximum value (point B).

Figures 5.2a and b also indicate that the different priority treatments are related and do not have to be simulated separately. This can be seen as follows: when water is shared proportionally (no priority), *f delivered* is always half the *f demanded*. A certain *f demanded* then corresponds to a higher *f demanded* when water is provided with priority for the Kus Cenneti. The straight line corresponding to a priority treatment for irrigation shows that the Kus Cenneti only gets water if the supply for irrigation is higher than its demand. The deliverable supply is therefore the same for each treatment, as shown by the overlapping curves in figure 5.2c. Only the maximum *f delivered* varies for the different priority treatments.

5.3 Diversion at One Regulator

Diverting water at Emiralem regulator, which is the closest regulator to the Kus Cenneti, is expected to affect the total Gediz river outflow and the Menemen Left and Right Bank irrigation systems (MLB and MRB).

Figure 5.3a shows that the Gediz river has no trouble at all fulfilling the Kus Cenneti requirement for flow ratios lower than 2 in a dry year and for ratios lower than almost 6 in a wet year. These ratios correspond to the average summer demands of 1.8 $m^3 s^{-1}$ in a dry year and 4.8 $m^3 s^{-1}$ in a wet year (derived from table 3.2). These are the points in figure 5.3a at which the curves diverge from a straight line, i.e., the delivery can no longer keep up with the demand. For high-flow ratios the nonlinearity between *f delivered* and *f demanded* is caused by the limited river supply.

Because *f demanded* was defined in equation 5.1 as an annual average, salt concentration might rise in periods of low supply even though average annual demand is met. This means that for flow ratios where shortages arise, the condition of a constant salt level cannot be fulfilled. Either supplies have to be increased further during these periods or the Kus Cenneti has to cope with fluctuating salt concentrations. Again it is uncertain how the animals and vegetation will react to such fluctuations.

Figures 5.3b and c show that for each flow ratio, reductions in transpiration in MLB and MRB are low and vary almost linearly with this ratio. An increase in water demand results in a proportionally higher shortage for irrigation and, therefore, a decrease in transpiration.

Reductions in transpiration will occur even for flow ratios less then 2 because streamflows periodically reduce to zero during irrigation periods.

The SLURP model outputs as presented in figure 5.3 correspond to the theoretical graphs in figure 5.2 insofar as the curves in figure 5.3a tend towards a lower slope, but the maximum demand has not been reached. The maximum reduction in transpiration was not reached either, even at a flow ratio of 10. As SLURP does not take into account the importance of the phenological stages, the sigmoid crop response cannot be found back in figure 5.3c.

The hydrographs of the Gediz river outlet of a dry year and a wet year in figures 5.4a and b show the times when the demand (see table 3.4) is higher than the river supply. These years are equivalent to the climatic conditions in 1992 and 1997. In both the dry year and the wet year, the river supply is sufficient until the pre-irrigation period. Shortages for the Kus Cenneti start during this period, halt for low-flow ratios during the main irrigation period from the 20 July till 8 August, and cease in October.

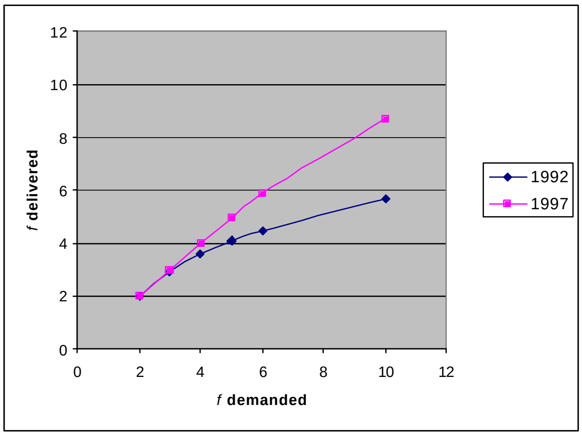
The cumulative deficits for the Kus Cenneti are displayed in figures 5.4c and d. It is evident that shortages increase with increasing flow ratio. It is also clear that deficits arise in summer when the water is most needed.

Figures 5.4e and f display the cumulative deficits for the irrigation systems, that is, the reduction in water for irrigation as a result of the Kus Cenneti demand. Deficits occur during the irrigation periods only, and again the increased deficit with increasing flow ratio is evident.

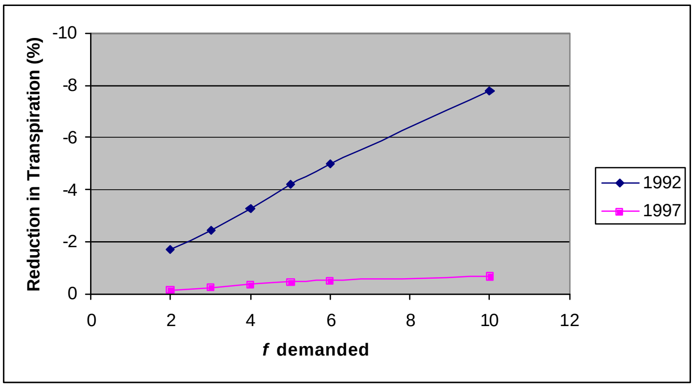
At a flow ratio of 10, the annual deficits for a dry year and a wet year are 9.3 and 13.4 million m^3, respectively. As the diversion to MLB and MRB at Emiralem is 18.0 m^3 s^{-1}, which corresponds to an annual supply of 54 million m^3 for a dry year and 120 million m^3 for a wet year, the relative deficits are 17 percent and 11 percent for a dry year and a wet year, respectively. It is surprising that the corresponding reductions in transpiration are only 8 percent for a dry year and less then 1 percent for a wet year. This could be explained partially by inefficient use and high return flows, but these were negligible in 1992.

An evaluation of the monthly output transpiration values of the model shows that the shortages in MLB and MRB arise in the main irrigation period only, because there is no crop on the field in the pre-irrigation period and thus no reduction in transpiration. This pre-irrigation period is important for the germinating period and a water shortage in this period may have serious consequences, but SLURP does not take into account the importance of the several phenological stages. The effect that a depletion of soil moisture in this period would have on reductions in transpiration in later months in terms of soil moisture availability, would be visible in the SLURP output files but no such effect is visible. The soil-moisture depletion, just before the main irrigation period starts, is independent of the much-earlier soil-moisture conditions in the pre-irrigation period. This statement was verified by comparing the fast store values of May and July 1992 for the present situation (scenario 0) and the scenario with f =10. In SLURP, the fast store represents both surface water storage and top-layer soil moisture, but here the former is negligible.

Figure 5.3a, b, and c. The relation between (simulated) reductions in transpiration, f demanded and (simulated) f delivered for MLB and MRB for a dry year and a wet year with priority for the Kus Cenneti.



(a)



(b)

(c)

In the wet (1997) hydrograph, a slight decrease in cumulative shortage can be noticed. As it is not possible for water to flow back to the irrigation systems, this decrease must mean that, compared to the present situation less groundwater or soil-moisture surpluses are discharging as return flow to the sea. During the irrigation periods, the crops used more groundwater and soil moisture through capillary rise in the scenario where a minimum base flow was maintained. There was no capillary rise at all and no return flow in 1992 because the soil had already dried out.

5.4 Diversion at Three Regulators

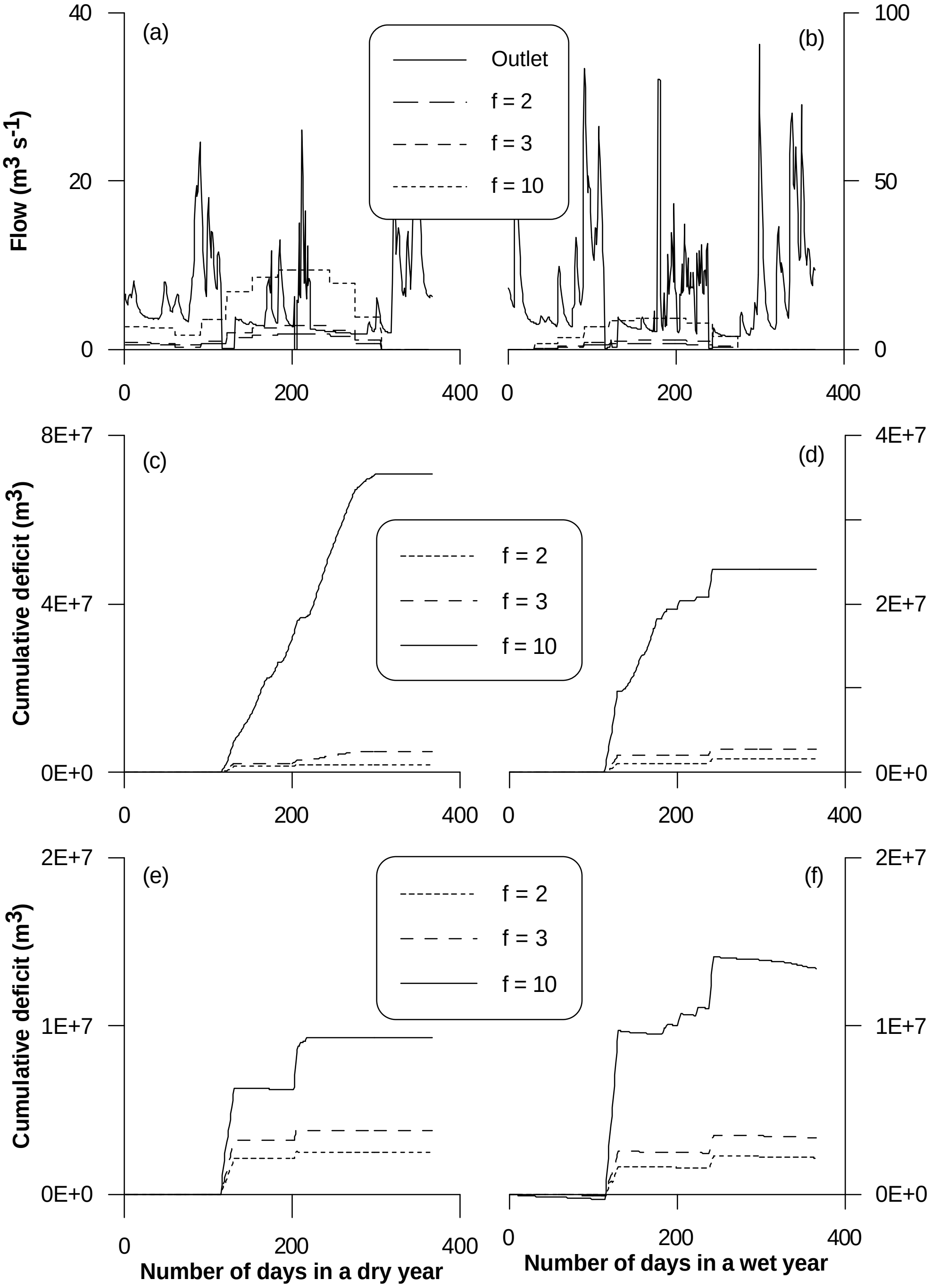
Section 5.3 examined the effects of modifying the operating rules for the Emiralem regulator only. It is also of interest to consider whether the reductions in transpiration could be more evenly distributed by changing the operating rules for all three regulators in the Gediz basin. Figure 5.1 displayed the relations between reservoir, regulators, irrigation systems and Kus Cenneti. Again this diagram shows the relation between the Gediz river and Kus Cenneti for simulation purpose only. In reality, there is no direct connection.

If extra water is to be provided for the Kus Cenneti then it seems only just that the upstream farmers should suffer equally from this higher priority for the environment. Each regulator should maintain the minimum base flow plus the amount that is required for irrigation purposes downstream. Changing the operating rules in this way would be easy if they were synchronized for each regulator, but this is not the case without synchronization. Upstream regulators would provide water for downstream regulators when it is not needed and vice versa. In addition, weather conditions cause outflows to be irregular and it is, therefore, difficult to determine the minimum base flow that should be defined at all three regulators. In such a case, only the Kus Cenneti would benefit from the higher diversion at the cost of the upstream ASAs/irrigation systems. There would be more water available during the main irrigation season but, in some cases, this might even exceed the demand (figure 5.4a and b) and all the surplus water would be spilled.

An attempt was made to adjust the operating rules in such a way that, at least during the irrigation season, the Kus Cenneti requirement is satisfied. The first two management alternatives are based on a continuous supply, the third on a weekly supply. The management alternatives will be compared with the reductions in transpiration averaged per irrigation system.

There are twelve irrigation systems that are provided with surface irrigation water. Table 5.1 shows how much water is diverted at each ASA/irrigation system during the reservoir release period.

Figure 5.4. The hydrographs of the Gediz basin for a dry year and a wet year with the Kus Cenneti requirements for three flow ratios (a and b), the resulting cumulative deficits in the Kus Cenneti (c and d), and cumulative deficits for MLB and MLB together (e and f).



In management option 1, the Kus Cenneti demand is divided over all irrigation systems by reducing each diversion by an amount of water proportional to its relative current supply, that is:

$$new\ diversion\ ?\ \frac{current\ diversion}{reservoir\ release}\ ?Kus\ Cenetti\ demand \tag{5.2}$$

where,

all terms are daily flows (m^3 s^{-1}). The supply to the Kus Cenneti is continuous. Simulations were carried out for flow ratios of 2, 3 and 10.

In management option 2, one or more canals are closed or their supply is severely reduced each day in an alternating sequence and this sequence is repeated during the irrigation season. The sequence period is determined by dividing the total diversion to irrigation systems with the number of irrigation systems, which turned out to be 8 days in this simulation. As this management alternative involves intricate changes in the irrigation scheme, which depend on the Kus Cenneti demand, only one simulation for a flow ratio of 10 was carried out.

In management option 3, the Kus Cenneti demand is supplied one day a week and during this day only a few canals can be (partly) supplied. Again, only one simulation for a flow ratio of 10 was carried out.

The details of the irrigation schemes under all three management options are elaborated further in appendix B.

In all three management options, the importance of irrigation timing was not taken into account, although it is well known that water is less important at the end of the irrigation season. Again, SLURP does not take the importance of phenological stages into account.

In periods of drought as that occurred in 1992, diversions cannot be defined based on Kus Cenneti plus downstream requirements.

As an equal treatment of all irrigation systems was assumed, the resulting deficits have to be shared as well, proportional to their current relative diversion (diversion divided by total water diverted for irrigation). For example, the diversions for 1992 in table 5.1 add up to 70.8 m^3 s^{-1} while the amount released was only 67.0 m^{3}s^{-1}. This means that for simulations, the diversion to Menemen Left Bank, for example, has to be reduced by an additional 12.0/70.8*(70.8-67.0)=0.64 m^{3}s^{-1}.

Table 5.1. The diversion at each ASA/irrigation system in 1992 and 1997.

Regulator	ASA_ID	Name ASA/Irrigation System	Diversion (m^3s^{-1})	
			1992	1997
Adala				
	14	Salihli Left Bank*	10.4	8.8
	15	Salihli Right Bank*	2.4	7.4
Ahmetli				
	17	Ahmetli	3.5	3.5
	18	Turgutlu	7.5	7.5
	19	Sarikiz	13.5	13.5
	22	Mesir	9.0	9.0
	23	Gediz	6.0	6.0
Emiralem				
	25	Menemen Left Bank	12.0	12.0
	26	Menemen Right Bank	6.0	6.0
	Annual diversion		70.8	74.2

* The Salihli irrigation systems are not supplied with water continuously but only during a certain number of days within the reservoir release period. Diversions here are average values over the whole irrigation season.

The results of simulating these management alternatives are shown in tables 5.2 and 5.3. Differences between the three management options are not significant both in terms of average reduction and distribution of the damage (standard deviation). This is not surprising as the same amount of water over the whole irrigation season was withdrawn in each management option.

In a dry year, it seems favorable to close the canals to the irrigations systems alternatively and in a wet year a proportional reduction in supply to all canals is preferred. The most outstanding results are the reduction values for MLB and MRB (25 and 26), which are higher than the values found in section 5.3, where the Kus Cenneti demand was drawn from MLB and MRB only. In that simulation, the diversions were not decreased and MLB and MRB could profit from the periods when the Gediz river supply exceeded the Kus Cenneti demand. For the same reason, reductions in transpiration in these irrigation systems do not decrease significantly when distributing the Kus Cenneti demand over all irrigation systems, especially for high-flow ratios.

Next, the Salihli irrigation systems (14 and 15) obviously suffer more from a distributed reduction in diversion than other systems. This is because they have a priority in periods of drought in comparison to other irrigation systems in the present situation, being an upstream irrigation systems (see also section 4.3). In the simulation they suffer equally from water deficits and reductions in diversions and, therefore, they have a bigger relative impact on transpiration.

Table 5.2. Simulated reductions in transpiration (%) in a dry year for diversion from one regulator (Emiralem) and for three management options (MO).

ASA_ID	Diversion from 1 regulator			MO 1			MO 2	MO 3
	f = 2	*f* = 3	*f* = 10	*f* = 2	*f* = 3	*f* = 10	*f* = 10	*f* = 10
14	0	0	0	3.3	3.1	4.4	3.1	2.8
15	0	0	0	5.3	5.1	6.4	8.5	2.5
17	0	0	0	0.4	0.7	3.4	2.5	2.9
18	0	0	0	0.0	0.0	0.0	0.0	2.2
19	0	0	0	0.1	1.0	4.6	0.6	2.7
22	0	0	0	0.3	0.9	3.8	2.6	4.7
23	0	0	0	0.3	0.4	1.7	2.3	3.0
25	1.1	1.7	5.6	0.2	1.1	3.9	2.5	3.8
26	1.7	2.5	7.8	0.1	1.2	7.0	2.1	4.8
Avg.	1.4	2.1	6.7	0.8	1.2	3.6	2.4	3.2
St. Dev.	0.3	0.4	1.1	1.9	1.6	2.1	2.4	0.9

(Avg. = Average; St. Dev. = Standard deviation.

Table 5.3. Simulated reductions in transpiration (%) in a wet year for diversion from one regulator (Emiralem) and for three management options (MO).

ASA_ID	Diversion from 1 regulator			MO 1			MO 2	MO 3
	f = 2	*f* = 3	*f* = 10	*f* = 2	*f* = 3	*f* = 10	*f* = 10	*f* = 10
14	0	0	0	1.2	1.2	1.6	3.7	9.9
15	0	0	0	1.7	1.6	2.3	4.6	7.6
17	0	0	0	0.8	0.8	2.3	0.3	3.2
18	0	0	0	0.4	0.4	0.4	0.4	1.3
19	0	0	0	0.2	0.3	1.7	2.4	2.5
22	0	0	0	0.8	1.2	2.7	3.1	2.6
23	0	0	0	0.7	1.1	3.2	4.6	4.1
25	0.2	0.3	0.7	-0.1	0.0	0.7	2.3	2.1
26	0.0	0.0	0.1	0.0	0.2	1.1	0.9	0.0
Avg.	0.1	0.2	0.4	0.6	0.7	1.8	2.4	3.3
St. Dev.	0.1	0.2	0.3	0.6	0.5	0.9	1.7	3.1

Avg. = Average; St. Dev .= Standard Deviation.

5.5 Extension of the Release Period

So far we have looked at reallocating the river using the outflows of the existing reservoirs. It is reasonable to ask if we could improve the situation by increasing the Demirköprü reservoir outflows during the irrigation season or even during the whole year. The question that arises then is whether Demirköprü has the capacity to maintain such additional releases during the following decades. As no reliable information was available about the Demirköprü dimensions and time-dependant reservoir level, the effects of increasing the releases or extending the release period could not be simulated.

5.6 Conclusions

The objective described in this chapter was to find the best way to satisfy the Kus Cenneti water demand in a way that would cause the least damage in terms of reductions in crop transpiration and therefore reductions in yield and to evaluate the effects that fulfilling this demand would cause. The results of maintaining a minimum base flow were according to theoretical predictions (section 5.2), but SLURP is not a crop-growth model and, therefore, the actual effect of water deficits on agricultural productivity cannot be determined adequately. This also results in a zero reduction in transpiration in the pre-irrigation period for MLB and MRB irrigation systems. From the Gediz river outlet hydrographs, the following conclusions can be drawn. If the condition of a constant salt level is kept up through the entire year, the supply is limited by the lowest daily supply from the Gediz river. If this conditions is dropped and salt fluctuations within the year are allowed, the deliverable flow ratio can be defined as in equation (5.1). Results then show that the Gediz river is able to deliver the full demand to a flow ratio of 2 in dry years and flow ratios up to 6 for wet years. For higher-flow ratios, a minimum base flow should be maintained from the other regulators as well. This again provides only a solution from a hydrological point of view and may be satisfactory from a water management point of view.

The three management alternatives to satisfy the Kus Cenneti requirement, mentioned in section 5.4, fail to distribute the reductions in transpiration and, therefore, yield losses. A distribution of the water demand over the three regulators will increase the overall reductions in transpiration because regulator-operating rules are not synchronized and water will be spilled in periods when it is not needed. In addition, it is difficult in terms of management to determine when water excesses occur and how to divide them equally over all irrigation seasons. There is no significant difference in overall yield loss simply because the total annual demand was the same for each management alternative. Execution of management option 3 is unlikely because of the large structural measures involved with a weekly supply (e.g., 18 m^3s^{-1} for a flow ratio of 3).

All management options show that even flow ratios of 10 can be supplied with only a few percent of yield loss. The least damage is to be expected when the entire demand is drawn from the last regulator (Emiralem) only, although the farmers involved might protest vehemently against this solution. Compensation might be found for this problem. Modifications in operating rules from regulators and reservoirs might involve large social, institutional, financial and structural management problems.

CHAPTER 6

Conclusions, Discussion and Recommendations

6.1 Conclusions

The first objective of this study was to define criteria for wetland quality. With the available information it was not possible to establish a relationship between water supply and its effect on the Gediz basin and wetland quality. Instead of choosing the number of bird species or reed-bed area, we chose to model the average salt concentration, which is expected to be closely related to the wetland quality. This objective then became to find a relationship between the quality of the Kus Cenneti wetland and yield losses in irrigated agriculture as a result of conflicting water demands between these water users. The second objective was to evaluate management alternatives that minimize yield losses in the Gediz basin.

The second objective was to assess how much water must be supplied to the Kus Cenneti. The demand can be defined as the sum of evapotranspirative demand and an additional supply to keep the salt level constant. This additional supply has to exceed the evapotranspirative demand by a factor of at least 2 to maintain a constant salt level. The assumption was made that if the Kus Cenneti is continuously flushed with low-salinity water, damage to the reed beds will be prevented. If not, salinities will reach sea-level values. If the water requirement is met once a week, fluctuations in the salt concentrations are not expected to be above 12 percent.

As a result of the definition in equation 5.1, salt accumulation might occur in short-term periods even though the average annual demand or even the average monthly demand is met. This means that the maximum deliverable supply will not meet the condition of constant salt level for each month. If the condition is strictly maintained then the deliverable supply to the Kus Cenneti is equal to the lowest Gediz river flow outside the irrigation season. If this condition is dropped then the maximum deliverable supply defined in equation 5.1 is equal to the average daily Gediz river outflow divided by the Kus Cenneti evapotranspirative demand.

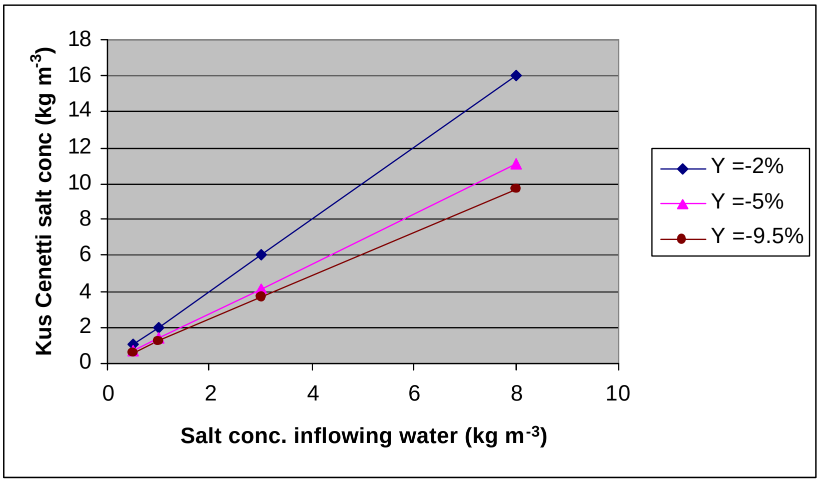
The third objective was to determine how water allocations in the Gediz basin can be modified to satisfy the hydrological demand of the Kus Cenneti. Simulation with the SLURP model showed that the deliverable supply depends on weather conditions outside the irrigation seasons. In dry years, the deliverable supply exceeds the evapotranspirative demand of the Kus Cenneti by a factor of 2 and in wet years by a factor of 6.

The fourth and last objective was to evaluate the damage that would be caused to agriculture as a result of a priority treatment of the Kus Cenneti. Results showed that transpiration losses are in the order of a few percent for a dry year if the entire demand is drawn from the last regulator (Emiralem) only. For a wet year, expected transpiration losses are negligible. As regulator operating rules are not synchronized and water excesses and deficits cannot be distributed equally, overall transpiration losses will increase when the Kus Cenneti demand is distributed over all three regulators. Modifications in operating rules from regulators and reservoirs might involve large social, institutional, financial and structural management problems.

As alternative management options do not significantly differ in distributing yield losses over all irrigation systems in the Gediz basin, management decisions should be based on feasibility and financial implications rather than on minimizing yield loss.

Figure 6.1 shows the relation between the Kus Cenneti salt concentration and Gediz river salt concentrations for several accepted levels of yield losses. Here the relation is displayed for MLB cotton in 1992 but other crops, irrigation systems and years indicate the same. It clearly shows that a reduction in the river salinity has a larger impact on the salt concentration than taking into account a 10-percent loss in yield.

Figure 6.1. The relationships between required Kus Cenneti salt concentrations and Gediz river salt concentrations for a dry year for several MLB cotton yield losses (Y).



As the evaluated management options do not distribute yield losses over all irrigation systems there is no best management option in terms of minimizing this yield loss. Reducing the diversions to the irrigation systems (management option 1) is the simplest one to carry out and offers clarity to farmers, as every application is the same. Management option 2 should minimize yield losses in dry years, but is difficult to carry out. Management option 3 is in between the former options in terms of simplicity. During the irrigation season, each farmer loses access to water only once per week. However, it is unlikely that a weekly supply can be transported into the reed beds of the Kus Cenneti. Financial issues are always important in management decisions and the costs can be determined as follows. If water has a productive value of US$ 0.05 per m^3, and all water is in demand, diverting 1 m^3s^{-1} to the Kus Cenneti “costs” US$43,200 per day.

6.2 Discussion

It is obvious that a solution cannot be provided from a hydrological point of view alone. It is also obvious that the Kus Cenneti needs more water than it receives at the moment and that the supply should be constant over time. The main question, however, remains unanswered: how much water is required exactly? Too many other aspects disallow a direct solution. Not only are there conflicts between water users (with agriculture) and land use (with commercial expansions such as shipyards), but there are definitely differences in the way the Kus Cenneti water requirement should be determined. In addition, structural and organizational measures will have to be taken to deliver the Gediz river water at the Kus Cenneti borders as present structures will not be sufficient.

First, there might be questions about the maintenance of a constant water level for wetlands whereas wetlands in other part of the world are subject to, and even require, alternating supplies (Sutcliff and Parks 1993; Jones, Desmond, and Lemeshewsky 1998). A variation in supply would decrease the annual requirement to a large extent. On the other hand, a comparison between wetlands is difficult due to differences in ideal water salinity, flora and fauna and the impact of human presence.

Next, there might be disagreement about the representation of wetland quality in terms of salt concentration alone as the Gediz river water contains many other pollutants. Knowledge about bird and vegetation tolerance to these pollutants was not available.

Finally, as information was lacking, seepage could not be implemented in the Kus Cenneti water balance. For a better understanding of detailed processes in the water balance, infiltration measurements should be made and these should be implemented together with water-quality measurements in a small-scale water-quality model.

Alternative solutions might be found in the use of clean groundwater, saving water or addressing the other major water users in the Gediz basin: the domestic and industial sectors. Management of wetlands is a complex subject which requires a substantial amount of field data on the site, much of which is missing at the Kus Cenneti. There are no easily available data on plant distribution, soil salinities or water-level fluctuations, and while the information on birds is better, more surveys are needed before the natural wealth of the area is fully understood. Management decisions should be taken on the basis of this monitoring data. Until that day, the Kus Cenneti is likely to be increasingly endangered by economically more “rewarding” interests.

6.3 Recommendations

Based on the results and conclusions of this study, the following recommendation can be made to improve the condition of the Kus Cenneti and minimize yield losses in the Gediz basin simultaneously.

- In dry years, implement a program of reduction of water deliveries in each irrigation canal by only a few percent and divert this to the Kus Cenneti. Also seek methods to encourage farmers to apply water-saving technologies.

- In wet years, keep all canals full and deliver a small additional flow of 3 m^3s^{-1} from Demirköprü to Kus Cenneti.

- Investigate the possibility of direct pumping from the Gediz river into the reed beds.

- Initiate a study on the tolerance of the reed beds in the Kus Cenneti to different salt concentrations. This will provide a better understanding of the water requirements.

- Extend the secondary irrigation canal in the Menemen Left Bank to the borders of the Kus Cenneti as was already recommended by RAC/SPA (1993).

Appendix A

Fluctuations in Salt Concentrations by Varying the Kus Cenneti Volume

If the Kus Cenneti demand is given in pulses, for example, once a week, and the discharge is kept the same as under a continuous supply, then during the pulse the water level will rise and salt concentrations will decrease. In the intervals between the supplies, the water level will decrease and salt concentrations will increase.

If the pulse is applied with a period T and is equal to $Q_T = T\ Q_{IN}$, with the corresponding concentration equal to C_T *then* the salt balance can be given by:

$$Q_T C_T \ ? \ Q_{ET?P} C_{ET?P} ? Q_{OUT} C_{OUT} \ ? \ \frac{dC_t V_t}{dt} \qquad \text{(B.1)}$$

During the pulse of one day, the volume increases according to:

$$V_t \ ? \ V_0 \ ? \ ?Q_T \ ? \ Q_{ET?P} \ ? \ Q_{OUT} ??t \qquad \text{(B.2)}$$

Again, the flows are interrelated:

$$Q_{ET?P} \ ? \ ? \frac{1}{T?f} Q_T \qquad \text{(B.3)}$$

and

$$Q_{OUT} \ ? \ ? \overset{?}{\underset{?}{?}} \frac{1}{T} Q_T \ ? \ Q_{ET?P} \overset{?}{\underset{?}{?}} ? \frac{1?f}{T?f} Q_T \qquad \text{(B.4)}$$

where,

f is the flow ratio as defined in equation (4.13). Combining equation (B.2), (B.3) and (B.4) gives:

$$V_t \ ? \ V_0 \ ? \ \overset{?}{\underset{?}{?}} \frac{T \ ? \ 1}{T} \overset{?}{\underset{?}{?}} Q_T \ ?t \qquad \text{(B.5)}$$

Using the chain rule on equation (B.1), substituting equations (B.3) till (B.5) and calculating *dV/dt* result in:

$$Q_T C_T \ ? \ \overset{?}{\underset{?}{?}} \frac{Tf \ ? \ 1}{Tf} \overset{?}{\underset{?}{?}} Q_T C_t \ ? \ \overset{?}{\underset{?}{?}} V_0 \ ? \ \overset{?}{\underset{?}{?}} \frac{T \ ? \ 1}{T} \overset{?}{\underset{?}{?}} Q_T \ ?t \overset{?}{\underset{?}{?}} \frac{dC_t}{dt} \qquad \text{(B.6)}$$

If the constant terms containing Q_T are replaced by p, q and r, we get:

$$p - qC_t = (V_0 + rt)\frac{dC_t}{dt} \tag{B.7}$$

Separating the variables and integrating gives:

$$-\frac{1}{q}\ln(p - qC_t) = \frac{1}{r}\ln(V_0 + rt) + K \tag{B.8}$$

where,

K is an integration constant. Multiplying both sides by q and raising e to all terms result in:

$$p - qC_t = e^{-qK} e^{-\frac{q}{r}\ln(V_0 + rt)} \tag{B.9}$$

Substituting the initial condition that $C = C_0$ for $t = 0$ gives the value for the integration constant:

$$e^{-qK} = (p - qC_0)e^{\frac{q}{r}\ln V_0} \tag{B.10}$$

Combining equation (B.9) and (B.10) results in

$$C_t = \frac{p}{q} - \left(\frac{p}{q} - C_0\right)e^{-\frac{q}{r}\ln\left(1+\frac{r}{V_0}t\right)} = \frac{p}{q}\left(1 - e^{-\frac{q}{r}\ln\left(1+\frac{r}{V_0}t\right)}\right) + C_0 e^{-\frac{q}{r}\ln\left(1+\frac{r}{V_0}t\right)} \tag{B.11}$$

where,

$$\frac{p}{q} = \frac{Tf}{Tf - 1}C_T \tag{B.12}$$

$$\frac{q}{r} = \frac{Tf - 1}{T(f - 1)} \tag{B.13}$$

$$r = \frac{T - 1}{T}Q_T \tag{B.14}$$

In between the pulses, the decrease in volume can be described as:

$$V_t ? V_0 ? ?Q_{ET?P} ? Q_{OUT}??t ? V_0 ? \frac{1}{T} Q_T ?t \tag{B.15}$$

where,
Q_T is the inflow during the pulse.

In between the pulses, there is no inflow and the outflowing concentration is again equal to the reservoir concentration and equation (B.1) thus becomes:

$$Q_{OUT} C_t ? ? \frac{1}{T} Q_T C_t ? \overset{?}{\underset{?}{?}} V_0 ? \frac{1}{T} Q_T ?t \overset{?}{\underset{?}{?}} \frac{dC_t}{dt} \tag{B.13}$$

Substituting equation (B.4) in (B.13) and separating variables give:

$$\frac{Tf}{Q_T} \frac{dC_t}{C_t} ? \frac{dt}{V_0 ? \frac{Q_T}{T} t} \tag{B.14}$$

Integrating equation (B.14) gives:

$$\frac{Tf}{Q_T} \ln C_t ? ? \frac{T}{Q_T} \ln \overset{?}{\underset{?}{?}} V_0 ? \frac{Q_T}{T} t \overset{?}{\underset{?}{?}} ? K \tag{B.15}$$

Dividing all terms by Tf Q_T^{-1} and raising *e* to each term result in:

$$C_t ? e^{\frac{KQ_T}{Tf}} e^{? \frac{1}{f} \ln \overset{?}{\underset{?}{?}} V_0 ? \frac{Q_T}{T} t \overset{?}{\underset{?}{?}}} \tag{B.16}$$

With the initial condition $C_t = C_0$ for $t = 0$ equation (B.16) becomes

$$C_t ? C_0 e^{? \frac{1}{f} \ln \overset{?}{\underset{?}{?}} 1 ? \frac{Q_T}{V_0 T} t \overset{?}{\underset{?}{?}}} \tag{B.17}$$

Appendix B

Irrigation Schedules

All schedules are examples of the execution of the management options as discussed in chapter 5. The schedules are displayed for a flow ratio of 10. This means that the Kus Cenneti demand is equal to 8.8 m^3s^{-1}.

Table B1. Reservoir release characteristics.

	1992	1997
Reservoir release period	20 July–8 August	27 June–26 August
Release ($m^3\ s^{-1}$)	67.0	75.0

Management Option 1

Reduce all irrigation system diversions proportional to the Kus Cenneti water requirement on a *continuous* basis.

Table B2. Irrigation schedule of management option 1.

		1992			1997		
ASA_ID	Name	Present diversion $m^3\ s^{-1}$	Reduction $m^3\ s^{-1}$	Simulated diversion $m^3\ s^{-1}$	Present diversion $m^3\ s^{-1}$	Reduction $m^3\ s^{-1}$	Simulated diversion $m^3\ s^{-1}$
14	Salihlil	10.4	1.9	8.5	8.8	1.0	7.8
15	Salihlir	2.4	0.4	2.0	7.4	0.9	6.5
17	Ahmetli	3.5	0.6	2.9	3.5	0.4	3.1
18	Turgutlu	7.5	1.4	6.1	7.5	0.9	6.6
19	Sarikiz	13.5	2.5	11.0	13.5	1.6	11.9
22	Mesir	9.0	1.7	7.3	9.0	1.1	7.9
23	Gediz	6.5	1.2	5.3	6.5	0.8	5.7
25	Menemenl	12.0	2.2	9.8	12.0	1.4	10.6
26	Menemenr	6.0	1.1	4.9	6.0	0.7	5.3
Total		70.8	13.1	57.7	74.2	8.7	65.5

Table B3. Minimum base flow at each regulator.

	Minimum base flow to be maintained (m^3s^{-1})	
Regulator	1992	1997
Adala	56.1	60.0
Ahmetli	23.5	24.7
Emiralem	8.8	8.8

Management Option 2

Reduce supplies or close each day one or more canals with the demand of the Kus Cenneti and circulate turns on a *periodical* basis. The period here was 8 days.

Table B4. Irrigation schedule for management option 2. The underlined numbers refer to the irrigation systems. The values after the irrigation system numbers are the factors by which diversions are divided. The column "not diverted" is the supply available for the Kus Cenneti.

1992			1997		
Date	ASA(s) closed	Not diverted (m^3s^{-1})	Date	ASA(s) closed	Not diverted (m^3s^{-1})
20-7	(14+15+19)/3	8.8	27-6	(14+15+19)/3	8.8
21-7	(14+15+19)/3	8.8	28-6	(14+15+19)/3	8.8
22-7	(14+15+19)/3	8.8	29-6	(14+15+19)/3	8.8
23-7	(17+18+23)/2	8.8	30-6	(17+18+23)/2	8.8
24-7	(17+18+23)/2	8.8	1-7	(17+18+23)/2	8.8
25-7	22	9.0	2-7	22	9.0
26-7	(25+26)/2	9.0	3-7	(25+26)/2	9.0
27-7	(25+26)/2	9.0	4-7	(25+26)/2	9.0
~	Sequence repeated 1 time		~	Sequence repeated 6 times	
5-8	(14+15+19)/3	8.8	20-8	(14+15+19)/3	8.8
6-8	(14+15+19)/6 +22/2	8.5	21-8	(14+15+19)/3	8.8
7-8	(17+18+23)/2	8.8	22-8	(14+15+19)/3	8.8
8-8	(25+26)/2	9.0	23-8	(17+18+23)/2	8.8
			24-8	(17+18+23)/2	8.8
			25-8	22	9.0
			26-8	(25+26)/2	9.0

Management Option 3

Calculate weekly requirement and reduce diversions to zero one day a week. With a flow ratio of 10, the weekly demand is 61.6 m^3 s^{-1} and the remaining 5.4 m^3 s^{-1} for 1992 and 13.4 m^3 s^{-1} for 1997 are divided over the irrigation systems in an alternating way during the irrigation season.

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Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Tel.
94-1-867404, 869080

Fax
94-1-866854

E-mail
iwmi@cgiar.org

Website
www.iwmi.org

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