MANAGEMENT OF RESERVOIR SEDIMENTATION
CASE STUDIES FROM TURKEY

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ABSTRACT

MANAGEMENT OF RESERVOIR SEDIMENTATION
CASE STUDIES FROM TURKEY

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Siltation is becoming a big problem as the dams get older all over the world. Conservation and sustainable management of existing reservoirs is gaining more importance than constructing new dams. In this study the program RESCON, which is outcome of a World Bank sponsored project, has been used to examine sediment removal strategies (flushing, hydrosuction sediment removal, dredging and trucking) for four dams of Turkey namely Çubuk I Dam, Bayındır Dam, İvriz Dam and Borçka Dam. Sediment measurements are made by governmental agencies in Turkey. In this study characteristics of these measurements will be presented for the future sediment related studies. Then sediment removal strategies which were used in RESCON will be introduced. Evaluation of RESCON results have been made and compared with previous studies for verification except Borçka Dam, since it is under construction.

Keywords: Siltation, reservoir sedimentation, sustainable management, sediment measurement.

ÖZ

REZERVUAR SEDİMANTASYONU YÖNETİMİ
TÜRKİYE’DEN VAKA ANALİZLERİ

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Dünya çapındaki barajların yaşı büyüdükçe siltasyon büyük bir problem olmaktadır. Mevcut barajların korunması ve sürdürülebilir yönetimi yeni barajlar inşa etmekten daha fazla önem kazanmaktadır. Bu çalışmada Dünya Bankası destekli bir projenin sonucu olan RESCON programı Türkiye’deki 4 baraj için (Çubuk I Barajı, Bayındır Barajı, İvriz Barajı ve Borçka Barajı) sediment kaldırma stratejilerini (yıkama, basınçlı emme rüsubat kaldırma, derin tarama ve kamyonla taşıma) incelemek için kullanıldı. Türkiye’de rüsubat ölçümleri devlet kurumları tarafından yapılmaktadır. Bu çalışmada yapılan ölçümlerin karakteristik özellikleri gelecekteki rüsubat ile ilgili çalışmalar için sunulmuştur. Bundan sonra RESCON programındaki rüsubat kaldırma stratejileri tanıtılacaktır. RESCON sonuçlarının değerlendirilmesi yapılmış ve doğrulama amacıyla daha önceki çalışmalarla karşılaştırılmıştır. Borçka Barajı inşaa halinde olduğu için daha önce yapılan bir çalışma yoktur.

Keywords: Siltasyon, rezervuar sedimantasyonu, sürdürülebilir yönetim, rüsubat ölçümü.

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LIST OF SYMBOLS

ASD	maximum percent of accumulated sediment removed per dredging event
AST	maximum percent of accumulated sediment removed per trucking event
C	unit cost of construction
CD	unit cost of dredging
CH	unit cost of hydrosuction
CLD	maximum percent of capacity loss that is allowable at any time in reservoir for dredging
CLF	maximum percent of capacity loss that is allowable at any time in reservoir for flushing
CLT	maximum percent of capacity loss that is allowable at any time in reservoir for trucking
C_S	sediment concentration (ppm) (mg/l)
Cw	concentration by weight of sediment to water removed
DU	expected life of hydrosuction sediment removal system
Gd	adjustment factor to approximate the gamma distribution
HI	cost of capital investment to install hydrosuction sediment removal system
MT	maximum amount of sediment removed per trucking event
Q_m	mixture flow rate in hydrosuction sediment removal operation
Q_R	sediment discharge (tons/day)
Q_s	sediment flow rate in hydrosuction sediment removal operation

S_0, C_0	original reservoir capacity
s1	the fraction of run-of-river benefits available in the year flushing occurs
s2	the fraction of storage benefits available in the year flushing occurs
sd	standard deviation of incoming flows
S_e	existing reservoir capacity
S_{min}	lower bound of remaining reservoir capacity
St	remaining reservoir capacity after year t
Vin	mean annual water inflow
W(0)	water yield from run-of-river project
$W(S_{t+1})$	water yield from storage capacity after flushing
Wt	reservoir yield at time t
X	amount of sediment dredged per cycle
X_t	sediment removed in year t
Y_t	amount of water required to remove sediment
Zpr	standard normal variate of percent probability (p%)

ABBREVIATIONS

CAT	Caterpillar
DDR	Drawdown Ratio
DSI	State Hydraulic Works
EIE	Directorate of Electrical Power Resources Survey and Development Agency
FW	Flushing Width
FWR	Flushing Width Ratio
HR	HR Wallingford Institute, United Kingdom
HSRS	Hydrosuction Sediment Removal System
LTC	Long Term Capacity
LTCR	Long Term Capacity Ratio
MAR	Mean Annual Runoff
N/A	Not Applicable
NPV	Net Present Value
O&M	Operation and Maintenance
ppm	parts per million
SBR	Sediment Balance Ratio
SBRd	Sediment Balance Ratio (independent of drawdown)
SSf	Flushing Channel Side Slope
TWR	Top Width Ratio

CHAPTER 1

INTRODUCTION

1.1 Problem Definition and Literature Survey

There are more than 45 000 large dams built all around the world for several purposes such as power generation, flood control, domestic or industrial water supply (WCD, 2000). *"The International Commission on Large Dams (ICOLD), established in 1928, defines a large dam as a dam with a height of 15 m or more from the foundation. If dams are between 5-15 m high and have a reservoir volume of more than 3 million* m^3*, they are also classified as large dams."* (WCD, 2000).Every year 0.5-1.0% of the world's reservoir capacity is lost due to sedimentation (White, 2000). Today, 19% of world energy is from hydropower. Nearly half the world's large dams were built exclusively or primarily for irrigation (WCD, 2000).

The demand for water is increasing with the population rise. In order to compensate this water demand existing storage capacity should be used efficiently or new sources should be found.

Quality is important as much as capacity since a large percent of dams have been built for irrigation and water supply. General tendency in determining reservoir capacity of a new dam is assuming an economical life for a dam such as 50-100 years. Another way of determining reservoir capacity is using previously made sediment measurements to supply water for specified economical lifetime.

Present and future water demand of each continent is given in Table 1.1. As can be seen from Table 1.1 demand for new storage increases. However, constructing new dams creates new problems as well as their benefits.

Table 1. 1 Water Demand According to Region (White, 2000)

	Demand For New Storage (km^3)		
Region	**2000-2010**	**2010-2020**	**2020-2030**
Europe	50	50	55
South&Central America	465	495	425
Africa	165	205	250
Asia	315	280	215
Total	**995**	**1 030**	**945**

In Turkey most of the dams can be considered as large dams and most of these large dams have been constructed for irrigation and domestic water supply. Therefore, we need to find out ways for sustainable management of existing reservoirs as well as new ones. Simonovic (1994), opposed a methodology for the reassessment of a reservoir. In this study obtaining storage requirement using current demand and finding the best management strategy for an existing reservoir was the objectives. If new policies are prepared in feasibility level for new dams, economical life of dams can be extended and capacity loss may be prevented. As a result of economical analysis and site investigations sediment deposited in existing reservoirs can be partially cleared. Thus, a capacity less or equal to its original capacity may be sustained.

Constructing new dams receives too much criticism due to resettlement problem, loss of aggricultural areas, environmental problems, and change in habitat, etc. Thus, small dams and maintenance of new dams gain importance. Sustainable management of a reservoir requires to examine the following topics:

- Economical analysis
- Environmental considerations
- Sediment removing operations
- Use of removed sediment
- Frequency of removal operations
- Removal equipment
- Sediment properties within the reservoir
- Detection of sediment distribution within the reservoir
- Applicability of removal operations
- Delta formation upstream of the reservoir
- Determination of sediment yield and trap efficiency of the reservoir etc.

All these activities need finance. Either we will deal with the problem or leave it to next generation. Palmieri et al. (2001), presented a new methodology in order to evaluate economics of reservoir sedimentation and sustainable management of dams. In their works, various sediment removal techniques are compared economically and compared from sustainability point of view. If we do not pay enough attention for sedimentation problems, next generations will have to pay for it but it may be too late for them to solve the problem.

Worldwide storage, power and sedimentation is shown in Table 1. 2

Table 1.2 Worldwide Storage, Power and Sedimentation (RESCON Manual Volume I, 2003)

Region	**Number of large dams**	**Storage (km^3)**	**Total Power (GW)**	**Hydropower production in 1995 (TWh/yr)**	**Annual loss due to sedimentation (% of residual storage)**
Worldwide	45 571	6 325	675	2 643	0.5-1
Europe	5 497	1 083	170	552	0.17-0.2
North America	7 205	1 845	140	658	0.2
South and Central America	1 498	1 039	120	575	0.1
North Africa	280	188	4.5	14	0.08-1.5
Sub Saharan Africa	966	575	16	48	0.23
Middle East	895	224	14.5	57	1.5
Asia (excluding China)	7 230	861	145	534	0.3-1.0
China	22 000	510	65	205	2.3
Source: Adapted from White, 2001.					

When a river flows into a reservoir, velocity of water decreases and coarser particles deposit mostly at entrance of the reservoir forming a delta as shown in Figure 1.1. On the other hand, finer sediment is carried by quasi-homogeneous flow to nearer parts of the body of a dam (Yu et al., 2000). Moreover, turbidity currents are also sources of sediment at downstream parts of a reservoir as in Figure 1.1. Characteristic unit weight values of sediments in a reservoir are between 8.83-13.24 kN/m^3 (RESCON Manual, 2003).

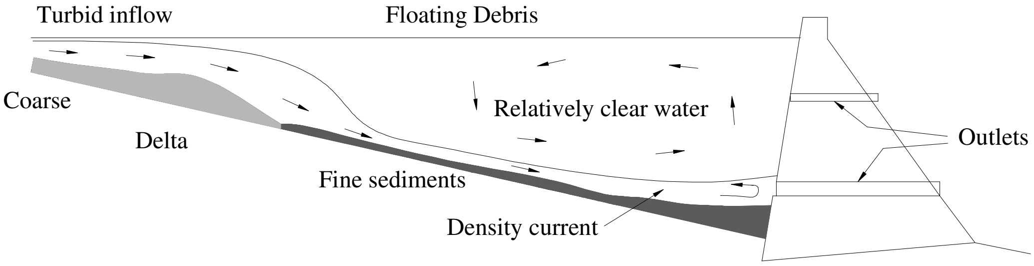


Figure 1.1 Sedimentation Process (RESCON Manual Volume I, 2003)

Sedimentation is a big problem for reservoirs. Especially, for the reservoirs with no watershed management or the reservoirs on high-sediment-carrying rivers this problem may be more severe. Four arch dams constructed in New South Wales have been examined by Chanson and James (1998). Common feature of these dams is sedimentation resulted in closure of the dams from service in a small period of time although they had been designed structurally very well. These dams are More Creek Dam, Gap Weir, Korrumbyn Creek Dam and Quipolly Dam. Information of use and siltation for these dams is shown in Table 1. 3.

Table 1. 3 Characteristics of Creek Dam, Gap Weir, Korrumbyn Creek Dam and Quipolly Dam

Reservoir (1)	**Location (2)**	**Stream (3)**	**Volume* of reservoir (m^3) (4)**	**Catchment area (km^2) (5)**	**Use (6)**	**Remarks (7)**
Moore Creek Dam, 1898	20 km north of Tamworth, NSW	Moore Creek	220E+03	51	Water supply for the town of Tamworth	Complete reservoir siltation by 1924(and probably earlier);bed load siltation primarily
Gap weir, 1902	5 km west of Werris Creek, NSW	Werris Creek	-	160	Water supply for railway purposes	Sediment by suspension load; fully silted in 1924
Korrumbyn Creek dam, 1917-1918	Mount Warning National Park, 20km west of Murwillumbah	South Korrumbyn Creek	27.28E+03	3	Water supply for the town of Murwillumbah	Rapid bed-load sedimentation associated with jammed scour valve
Quipolly dam, 1932	20 km southeast of Werris Creek, NSW	Quipolly Creek	860E+03	70	Water supply of the town of Werris Creek	Sedimentation volume larger than half of the initial storage by 1952; disused since 1955
*Original capacity						

In Turkey, there are limited number of studies related to reservoir sedimentation. Yalçınkaya (1991) studied deposition mechanism of sediment within a reservoir area. Area Increment Method and Empirical Area Reduction Method are applied in order to find out real distribution of sediment within a reservoir using previously made sediment measurements. The two methods are used for 16 reservoirs of Turkey and results were compared with the actual measurements.

Altınbilek (2002), presented need for sustainable management of finite water resources, need for constructing dams, debate between construction of large dams, benefits of dams and diverse effects of dam construction, such as resettlement and change in environmental properties. Also, the contribution of dams to the Turkish economy has been stated.

Sönmez and Dinçsoy (2002) prepared a report for the determination of annual sediment yield and possible precautions for Ivriz reservoir using universal soil loss equation namely USLE. Geographic Information System (GIS) applications were also used in this study.

Yılmaz (2003), introduced a new and simple graphical method for estimating half life of an existing dam using previously made sediment measurements.

1.2 Scope of the Study

In this study it is aimed to present possibility of use of RESCON for Turkish reservoirs and giving information about sustainable reservoir management. For this purpose sediment removal techniques, sediment measurement methods used in Turkey, sediment measurements and sediment measuring institutions have been introduced herein.

The sedimentation mechanism needs extensive studies from several aspects. Geography, climate, hydrology, geometrical structures of the dam and river morphology are the main components. However, in this thesis it is not aimed to study the mechanism of sedimentation within reservoir area. Instead, the management of sedimentation of reservoirs will be discussed. Turkey is one of the countries with high erosion problem. Annual sediment transport rate in Turkey is approximately $5x10^9$ kN (Yanmaz, 1997). To prevent sediment from coming into the reservoir watershed management is needed. Within the scope of this thesis sediment removal techniques will be discussed with the help of package program RESCON promoted by World Bank.

Second chapter of this study is allocated for presenting sedimentation, general situation in the world and definitions of sediment removal operations. In third chapter, life cycle management approach is introduced. Importance of sustainability for reservoirs is presented. RESCON program and its running logic is given. Fourth chapter is devoted to sedimentation in Turkey. The institutions taking sediment measurements and the current situation of sedimentation in Turkey are given. Case studies from Turkey are presented with comments on program results. Appendices include great amount of data related to dams in Turkey, previously taken sediment measurements and basins of Turkey. Table A.1 lists the dams in Turkey which are under operation. Table A.2 classifies these dams according to single purpose of use and Table A.3 classifies them according to multipurpose use. Table D.1 includes all previously taken sediment measurement data (taken by DSI). Appendix H is for maps of basins in Turkey. In these maps all the observation stations (closed and open) operated by EIE are shown. This enables a person for selecting the proper sediment measurement stations for sediment studies.

CHAPTER 2

SEDIMENT REMOVAL TECHNIQUES

2.1 General

In this chapter sediment removal techniques have been presented with their applications in the world. These techniques are flushing, hydrosuction sediment removal system (HSRS), trucking and dredging, decommissioning (removal of a dam completely).

2.2 Flushing

2.2.1 Definition of Flushing and Flushing Parameters

Flushing is a way of increasing reservoir capacity using bottom outlet or similar structures by mobilizing the sediment within the reservoir and evacuating it with water under favourable conditions. Flushing is not applicable for all types of reservoirs therefore investigation works should be carried out before flushing operation related to scale of the sedimentation problem. All of these works are very detailed and large amount of money is required to carry out researches. Therefore supporting evidence should be obtained as a result of investigations. There is another method called sediment sluicing. However, sediment flushing and sediment sluicing are a bit different. Sediment flushing evacuates previously deposited sediment and sediment sluicing evacuates the sediment coming with high discharges resulted from melted snow or heavy rain. Another difference is the size of sediments evacuated. In sediment flushing finer sediments are evacuated as well as sands and gravels. However, in sediment sluicing mostly finer sediments are evacuated.

There are some parameters calculated during flushing calculations. These parameters will be given in this section in order flushing calculations to be understood more easily.

Long Term Capacity Ratio (LTCR): This is the ratio of long term sustainable capacity of the reservoir to its original capacity. Considering reported cases to the RESCON team for flushing operations LTCR estimations made by the program seems to be lower than reported values. Various reasons can lead to this result such as geometry of the reservoir or gradation of sediment within the reservoir (RESCON Manual, 2003). There may be other reasons to be evaluated. Sometimes RESCON gives very low values of LTCR although flushing is an economic and feasible sediment management operation (Rescon Manual, 2003). This implies that the scoured valley as a result of flushing operation does not cover the width of the reservoir and other outlets other than existing bottom outlet or derivation channels are required in order to make a successful flushing operation. Besides economic parameters do not affect LTCR for flushing since flushing is related to engineering parameters rather than economic parameters (RESCON Manual, 2003). If LTCR<0.35, caution should be exercised.

Sediment Balance Ratio (SBR): This is the ratio of sediment flushed annually to the sediment deposited annually. For a feasible solution, SBR>1.0 condition should be satisfied (RESCON Manual, 2003).

Sediment Balance Ratio (SBRd): This ratio has a calculation similar to SBR. However, in calculation of SBRd El_f (reservoir elevation during flushing) is equal to El_{min} (Minimum Reservoir Elevation). SBRd > 1.0 is preferable (RESCON Manual, 2003).

Drawdown Ratio (DDR): The extent of reservoir drawdown is unity minus a ratio of flow depth for the flushing water level to flow depth for the normal impounding level. In order drawdown to be sufficient, DDR should be approximately 0.7 (RESCON Manual, 2003).

Flushing Width Ratio (FWR): This is the ratio of the width formed as a result of flushing operation to the representative bottom width provided by user. FWR>1 is preferable (RESCON Manual, 2003).

Flushing Width (FW): Estimated actual flushing width using a best-fit equation resulting from empirical data (Atkinson, 1996).

Top Width Ratio (TWR): This is the ratio of width of the scoured valley at top water level with the complete drawdown assumption to width of the reservoir at top water level of the reservoir calculated on the basis of simplified geometry. If TWR is a constraint TWR>2 is preferable. If TWR is not a constraint TWR approaching 1 is sufficient (RESCON Manual, 2003).

Long Term Capacity Ratio (LTCR), Sediment Balance Ratio (SBR, SBRd), Flushing Width Ratio (FWR) and Top Width Ratio (TWR) are the criteria for flushing stated by Atkinson (1996). In RESCON, the criterion used for feasibility of flushing is Sediment Balance Ratio.

Brune Ratio: This is ratio of the original reservoir capacity to the mean annual reservoir inflow. Using this value and the sediment type provided by user program calculates trap efficiency. Calculating the Brune ratio excel uses a piecewise equation which gives a curve close enough to Brune's Curve for three types of sediment gradation.

Trap Efficiency: Trap efficiency is the percent of entrapped sediment to the inflowing sediment to the reservoir.

Flushing Channel Side Slope (SSf): Representative side slope for deposits exposed during flushing. This adjusted Migniot's equation often over-estimates side slopes by 10 times, so the equation was divided by 10 to obtain a more reasonable result (RESCON Manual, 2003).

Actual Flushing Width: The actual flushing width is estimated using a best-fit equation resulting from empirical data (Atkinson, 1996).

2.2.2 Factors Affecting Applicability and Efficiency of Flushing

Some hydraulic conditions should be provided for a successful flushing operation. These are:

- Hydraulic capacity of the outlet must be sufficient enough to keep reservoir level as constant as possible until flushing ends (Howard, 2000).

- Flushing discharges of at least twice the mean annual flow are required (Howard, 2000).
- Amount of water used in flushing operation should be at least 10% of the mean annual runoff (Howard, 2000).

Reservoirs having annual runoff larger than volume of the reservoir are more suitable for sediment flushing (Howard, 2000), since these reservoirs have enough water for flushing. Another important parameter is selecting flushing time. It needs careful evaluation of seasonal properties of the site since considerable water can enter the reservoir as a result of snowmelt or heavy rain. The amount of water required is not only critical for flushing operation but also water required for irrigation, domestic and industrial water supply and hydropower generation. Coarser sediment mostly deposits at the entrance of the reservoir. Therefore, this deposit can be removed by trucking instead of flushing since these sediments cannot be mobilized by flushing. As a result of operation an incised channel forms in the reservoir. The reservoirs having similar shape to this incised channel are suitable for flushing. This means, long, relatively narrow reservoirs are more suitable for flushing than short, wide and shallow reservoirs.

Atkinson (1996) discusses the feasibility of flushing and states that previously presented flushing criteria are not reliable enough according to literature survey of Sloff (1991). Therefore he uses some new criteria for feasibility of flushing such as Sediment Balance Ratio (SBR) and Long Term Capacity Ratio (LTCR). Four more criteria are used by Atkinson(1996) for a successful flushing. These criteria are Drawdown Ratio (DDR), Flushing Width Ratio (FWR), Top Width Ratio (TWR) and SBRd (same as SBR but SBRd is independent of drawdown).

2.2.3 Worldwide Experience of Flushing

HR Wallingford Institute study results over 50 reservoirs worldwide has given the following findings (Howard, 2000):

- The hydrology and sedimentalogy of the catchement should be fully understood.
- Hydrologically small reservoirs with storage capacity to annual runoff ratio of 0.3 have greater chance for successful flushing.
- Hydrologically large dams may need lateral and longitudinal diversion channels for flushing.
- Downstream impacts (following reservoirs, fisheries, etc.) may be a constraint.

In order flushing facilities to be cost effective the reservoirs which have lost 40%-60% of their original capacity are more suitable. In this case cost of construction of flushing facilities becomes 10%-30% of the cost of a new dam with similar capacity (Howard, 2000).

There are numerous models for predicting the reservoir sedimentation, riverbed evolution, and sediment concentration during flushing such as HEC-6 of the U.S. Army Corps of Engineers (1991) and the FLUVIAL-12 model developed by Chang (1998) (Liu et al., 2004). In the model of Liu et al. (2004), a one dimensional numerical model is proposed for predicting the sediment concentration variations, bed evolutions, and amount of sediment flushed. Two reservoirs in Japan, Daishidaira and Unazuki reservoirs, were selected to varify the model. The predicted results are in good aggreement with the measurements as can be seen in Figure 2.1 and Figure 2.2. However, it should be kept in mind that the model is based on riverine conditions of the rivers in Japan and economical considerations are not included in the model.

Fourteen previously flushed reservoirs worldwide have been examined by Atkinson (1996). Six of these reservoirs have been flushed successfully and rest of the reservoirs are not successfully flushed. SBR and LTCR criteria are met for six successfully flushed reservoirs and LTCR criterion is not met for eight unsuccessfully flushed reservoirs. Other four criteria are also met for six successfully flushed reservoirs and at least one is not met for eight unsuccessfully flushed reservoirs.

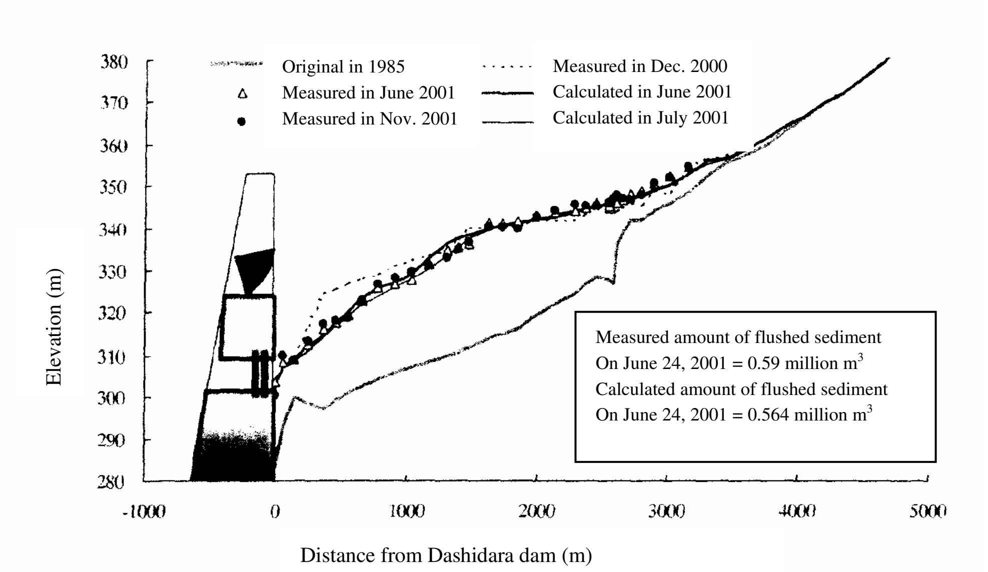


Figure 2. 1 Measured and Calculated Thalweg Profiles in Dashidaira Reservoir (Liu et al., 2004)

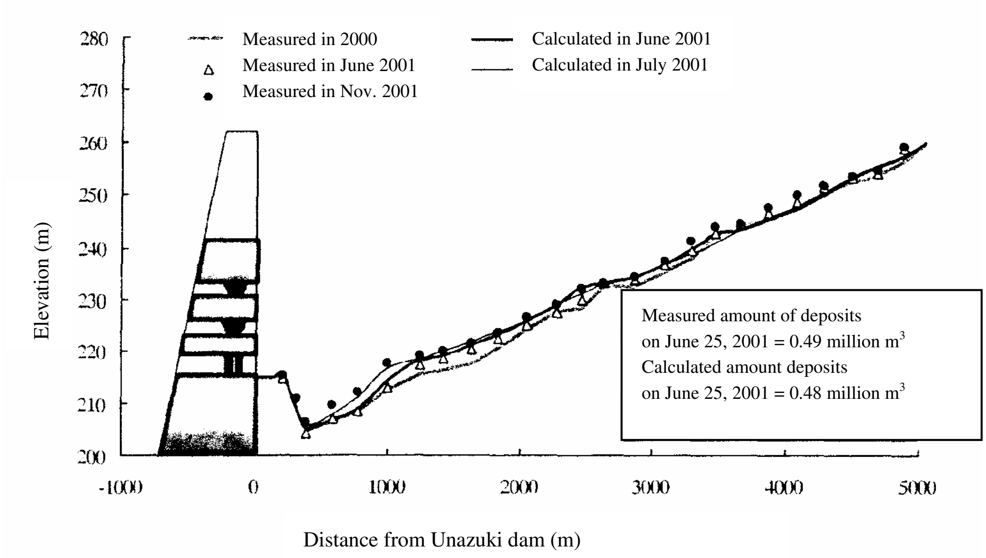


Figure 2.2 Measured and Calculated Thalweg Profiles in Unazuki Reservoir (Liu et al., 2004)

2.2.4 Importance of Full Drawdown

According to report of Atkinson (1996) incomplete drawdown makes a flushing operation less effective. Purpose of drawdown is decreasing water level to original flowing river elevation and increasing velocity. Thus incipient motion of deposited sediment is provided. Sediment concentration in flow leaving reservoir vs. time from start of drawdown plot for Baira Resevoir in India is shown in Figure 2.3. When drawdown is completed concentration increases tremendously. Therefore, if possible full drawdown should be practiced for a successful flushing operation.

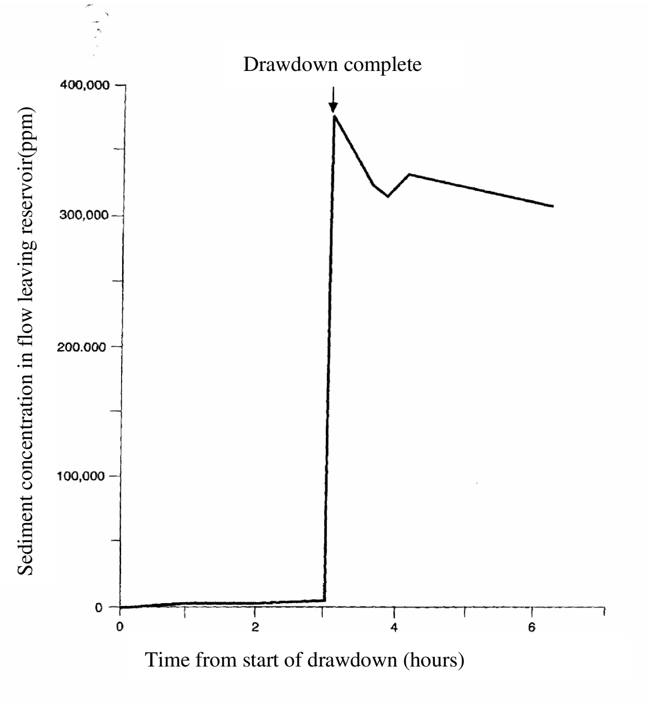


Figure 2.3 Sediment Concentration During Drawdown of Baira Reservoir (Atkinson, 1996)

Flushing operation may result in gain of most of the lost capacity for hydraulicaly small reservoirs. However, for large dams situation is different. As a result of flushing operation an incised channel is formed. Thalweg elevation of the reservoir can be maintained as a result of successful flushing operations but deposited sediment far from bottom outlet cannot be mobilized. Due to this reason, sediment is deposited at these parts. This situation can be seen in Figure 2.4 presenting storage plot and a cross-section before and after flushing. As can be seen flushing is only effective in neigbourhood of bottom outlet.

In the model of Atkinson real reservoir model is idealized and a simple model for evaluation of criteria is formed. In Figure 2.5 the simplified model, cross section properties used in calculation of LTCR and meaning of LTCR can be seen.

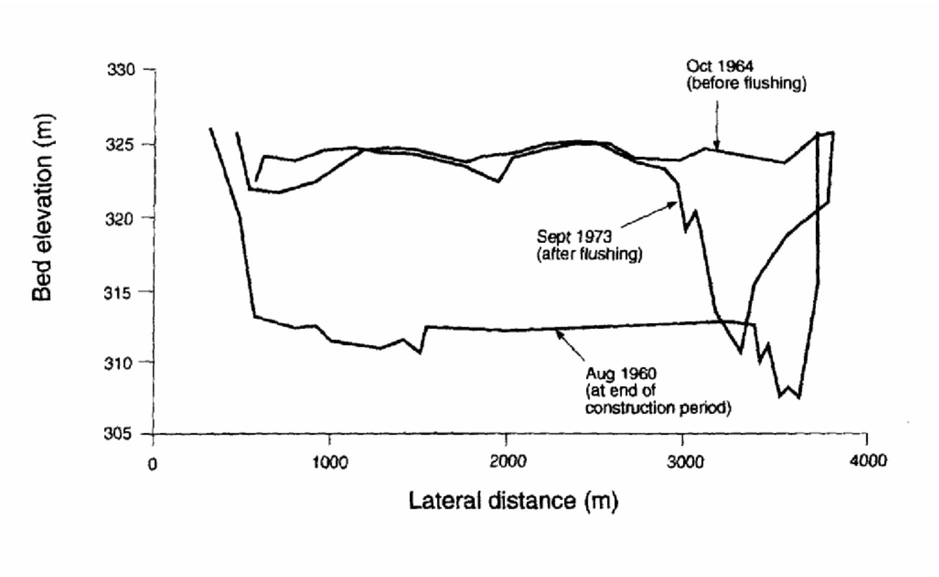
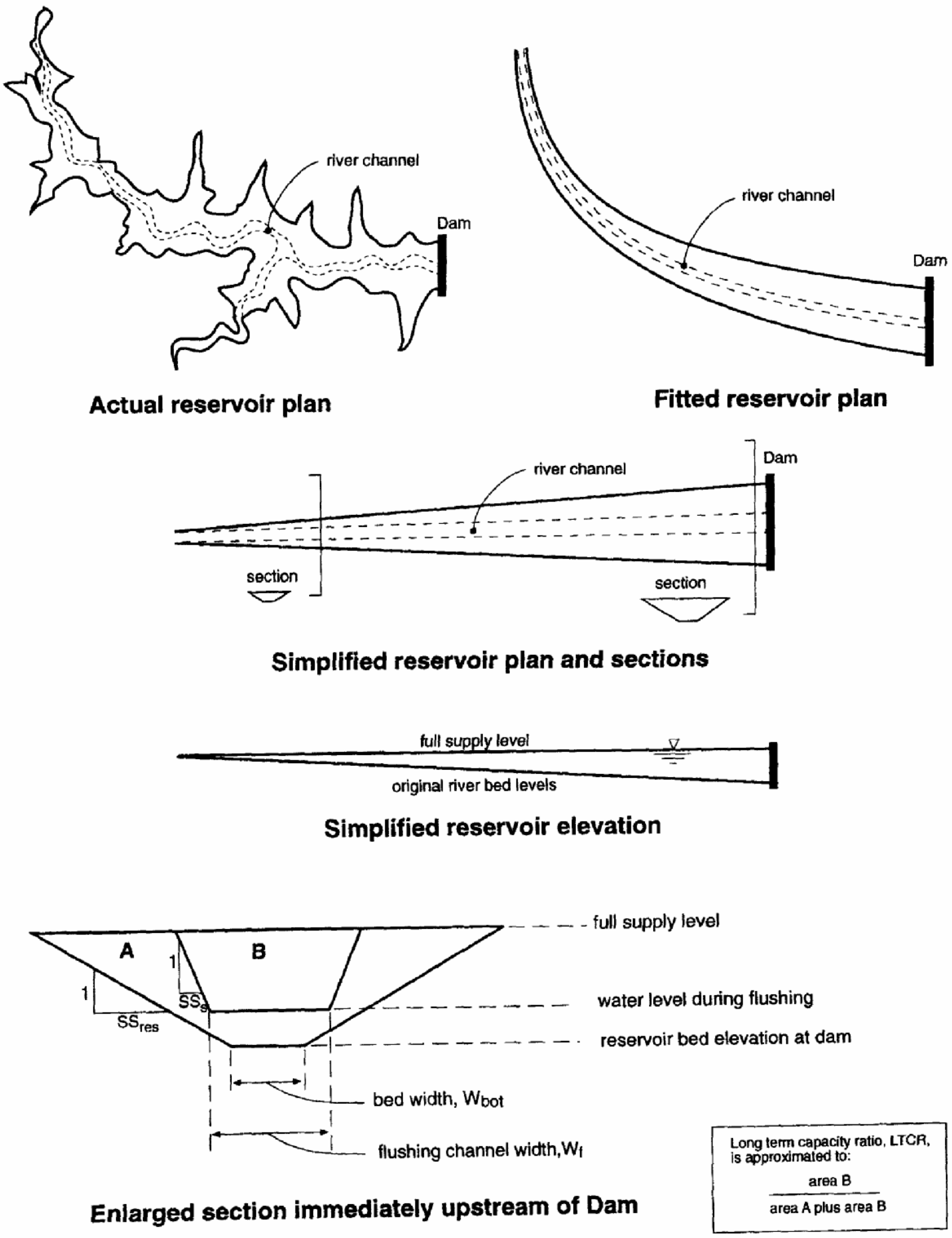


Figure 2.4 Bed Elevations at a Cross Section of Sanmenxia Reservoir (Atkinson, 1996)

2.2.4 Problems Related to Initiation of Flushing

For a reservoir whose most of the capacity has been lost due to sedimentation, initiation of flushing operation is a real problem. Because, for such a reservoir opening of bottom outlets may be very diffucult. In order to overcome this problem tactical dredging may be done around bottom outlets. By tactical dredging only a small part of the deposited sediment is removed but its importance is very high. If possible, use of original diversion tunnel may result in a successful flushing (Annandale, 2005) . Sometimes capacity of bottom outlets may not be enough, therefore, use of original diversion facilities or construction of new tunnels may lead to a successful flushing operation. However, construction of new tunnels greatly increase cost of sediment removal.


Actual reservoir plan

Fitted reservoir plan

Simplified reservoir plan and sections

Simplified reservoir elevation

Enlarged section immediately upstream of Dam

Figure 2.5 The Simplified Geometry for Calculation of Criteria (Atkinson, 1996)

2.3 Hydrosuction Sediment Removal System (HSRS)

There are two types of hydrosuction sediment removal:

1. Hydrosuction Dredging
2. Hydrosuction Bypassing

In hydrosuction dredging accumulated sediment is removed and transported to a downstream location through a pipe using head difference between the upstream and the downstream. There is no need for power supply (Figure 2.6). In hydraulic bypassing, the same principle is valid but a pipeline is constructed between entrance of the reservoir and downstream of the dam. Sediment is conveyed through the pipe before it deposits in the reservoir bottom area (Figure 2.7). Unfortunately, releasing sediment has harmful effects on downstream part of the dam since it increases turbidity. On the other hand, sediment carrying capacity of downstream river does not increase. Using HSRS these effects can be minimized by selecting a proper destination point for sediment deposition. If HSRS-bypass is installed at the beginning of construction of the dam sedimentation problem may be less severe (Hotchkiss and Huang, 1995).

Principle components of HSRS are intake, pipeline, valve, outlet works and auxillary facilities. For HSRS-bypass a sediment excluding system is required to separate sediment from water. In hydrosuction dredging ancillary facilities such as a raft or barge to move the pipeline inlet in the reservoir, an exernally powered water jet or cutter head at the inlet to break up consolidated sediments (if required) and instrumentation to monitor the operation are required (Hotchkiss and Huang, 1995).

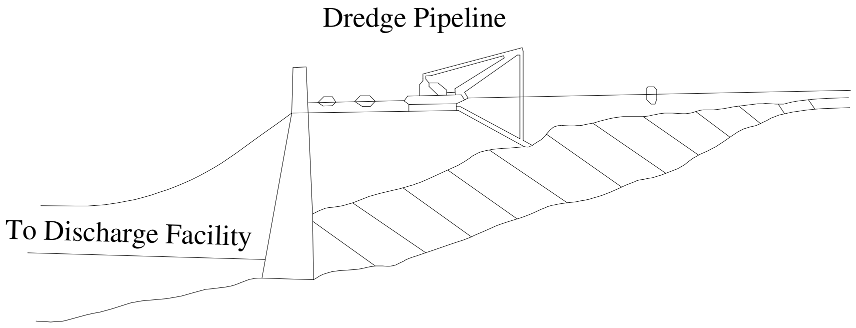


Figure 2.6 Hydrosuction Dredging (Hotchkiss and Huang, 1995)

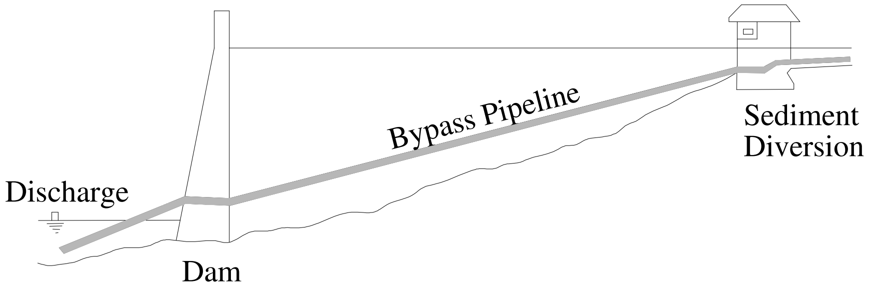


Figure 2.7 Hydrosuction Bypassing (Hotchkiss and Huang, 1995)

HSRS dredging was first performed in Djidiouia Reservoir in Algeria from 1892 to 1894 (Hotchkiss and Huang, 1995, ref. Fan, 1985). In this two-year period 1 400 000 m^3 of silt and clay was dredged by a 61cm-diameter and 1.6 km-long pipe. Half of the incoming sediment is removed each year by HSRS dredging from Xiao Xua-shan reservoir in China. Benefit, cost ratio was 3.6 for this project. A 10-step design procedure is applied for the design of HSRS pipeline by Hotchkiss and Huang (1995). Before selecting HSRS to remove sediment from the reservoir its downstream should be evaluated in terms of environmental considerations as well.

2.4 Dredging and Trucking

Dredging is removing deposited sediment in the reservoir area mechanically within the reservoir without emptying the reservoir. That means service of the reservoir is continued during the period of dredging operation. For dredging operations, mechanical dredging system is installed on a boat. Removed sediment is transported through pipes by pumping. Pumping water-sediment mixture is difficult and expensive. In Figure 2.8 pumping of dredged material is seen.

According to Mahmood (1987), cost of dredging varies between \$2.0 - \$3.0 per cubic meter of sediment. Prior to dredging sediment properties of the site should be inspected in order to select proper equipment for dredging and determine potential uses of dredged material.

An important problem related to dredging is handling of dredged material. Transporting dredged material far away from reservoir increases the cost. Therefore, removed material should be deposited in a close site or should be used for some other purposes. Dredged material can be used for landscaping and island formation (Marlin, 2002). Dredging operation done in Upper Peoria Lake in USA is shown in Figure 2.9. In this figure conventional clamshell bucket is used. After the sediment in the reservoir has been dredged it is trucked to a proper location for drying. For large dams with large depths cost of dredging may be very high or dredging may be infeasible to be practiced (Annandale, 2005).

Figure 2.8 Pumping of Sediment – Water Mixture By A Positive Displacement Pump (Marlin, 2002)

The difference of trucking from dredging is to empty reservoir before operation. In trucking all the water in a reservoir is released and deposited sediment within the reservoir is transported by using heavy equipment. Sediment is removed by using excavators and is loaded on trucks and is transported to a proper location. Cost of trucking changes according to transportation distance. In Turkey, this cost varies between \$0.83 for 1 km of distance and \$2.62 for 10 km of distance

(Koyuncu, 2005). After 10 km of distance trucking is not economically feasible for sediment removal.

Figure 2.9 Dredging Operation in Upper Peoria Lake (Marlin, 2002)

2.5 Decommissioning (Removal of a Dam)

Decommissioning is the complete removal of a dam and make deposited sediment to flow freely. The main factor for decommissioning is the difference between cost of repairing and cost of decommissioning. Sometimes cost of repairing may be very high especially for large dams. There is no reported case of decommissioning of a large dam higher than 40 m (RESCON Manual, 2003). There is an important point to be kept in mind that decommissioning should be avoided as much as possible. The purpose of this operation is providing original riverine and environmental conditions for that habitat required for continuity of life in that neighbourhood. Most of the time dams have no fish passage and construction of a new dam disrupts routes of fish and fish habitat takes damage.

Continuous sedimentation depletes reservoir capacity as well as decreases oxygen capacity. Benefit which can be obtained from the reservoir decreases due to low water quality. As for hydropower plants, benefits of power generation and run-off river benefits may be enough not to employ decommissioning. Before employing decommissioning careful evaluation of benefits to be lost and benefits to be gained are very important.

Decommissioning has been applied in USA several times. In Figure 2.10 number of dams which are removed are classified according to their heights and in Figure 2.11 number of dams removed by the years can be seen. It can be understood from these graphs that decommissioned dams are mostly small dams with a height of less than 10 m. The main discussion on decommissioning is removal of large hydropower dams (Doyle et al., 2000). In USA large hydropower dams represents less than 3% of 75 000 dams (greater than 1.8 m in height with at least 0.2 km^2 impoundment). This rate is approximately 15% in Turkey (Table A.2).

After removal of a dam large amount of sediment flows freely and a disastrous situation may occur. There are different cases of dam removal in the literature. Forming of original riverine conditions may take several months to 2 years or more. Change in cross-section after removal of Oakdele Dam can be seen in Figure 2.12. It is certain that gain of original habitat conditions may take more time. The sediment coming from deposited position moves toward the reservoir of next dam. Therefore, in 1 – 2 years of time approximately this amount of sediment will be deposited in the reservoir of next dam. This point should be underlined. In this period of time probably there will be no fish habitat or similar things in that part of the river.

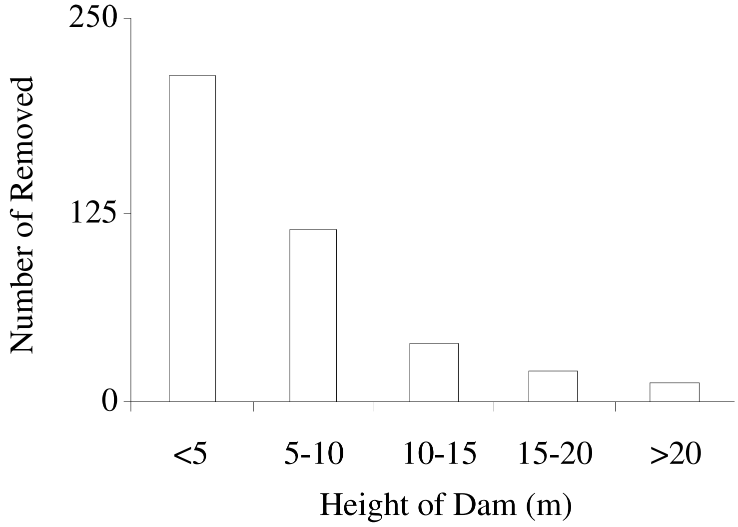


Figure 2.10 Number of Dams Removed in USA According to Their Heights (Doyle et al., 2000)

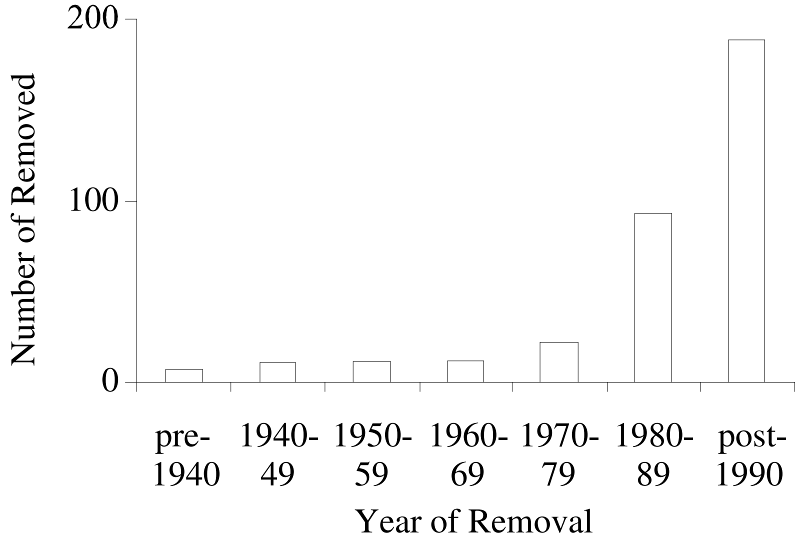


Figure 2.11 Number of Dams Removed in USA by the Years (Doyle et al., 2000)

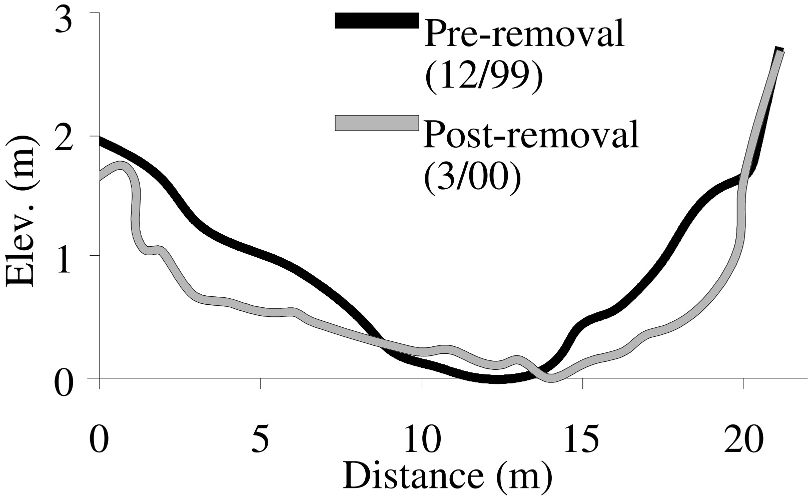


Figure 2.12 Changes in Channel Cross Section Caused by Removal of Oakdale Dam in 1/00 (Doyle et al., 2000)

CHAPTER 3

LIFE CYCLE MANAGEMENT METHOD

3.1 Introduction

The design life approach is widely applied in the design of dams. In this approach cost-benefit calculation is carried out over a certain time period, which is called the economic life of the dam. This time period is taken as 50 years in Turkey, whereas it can change for other countries such as 75 or 100 years. It is the economically feasible operation and maintenance of the project. In this approach environmental and social issues are only included at the initial stage of the project and any change over the operation and maintenance period is not included (RESCON Manual, 2003). In Figure 3.1, the description of design life approach of RESCON is given. In this figure environmental and social concerns are related with the project by dashed lines, indicating weak relations. Sedimentation problem is not considered as long as sedimentation threatens water intake structures or other facilities of a dam. In case of such a problem local sediment removal operations can be made but extending economical life of a dam is not included in pre-feasibility level. Economy of sediment removal operations and decommissioning are not included in dam budget. These operations are economically expensive operations and maintenance of a dam should be made for future generations.

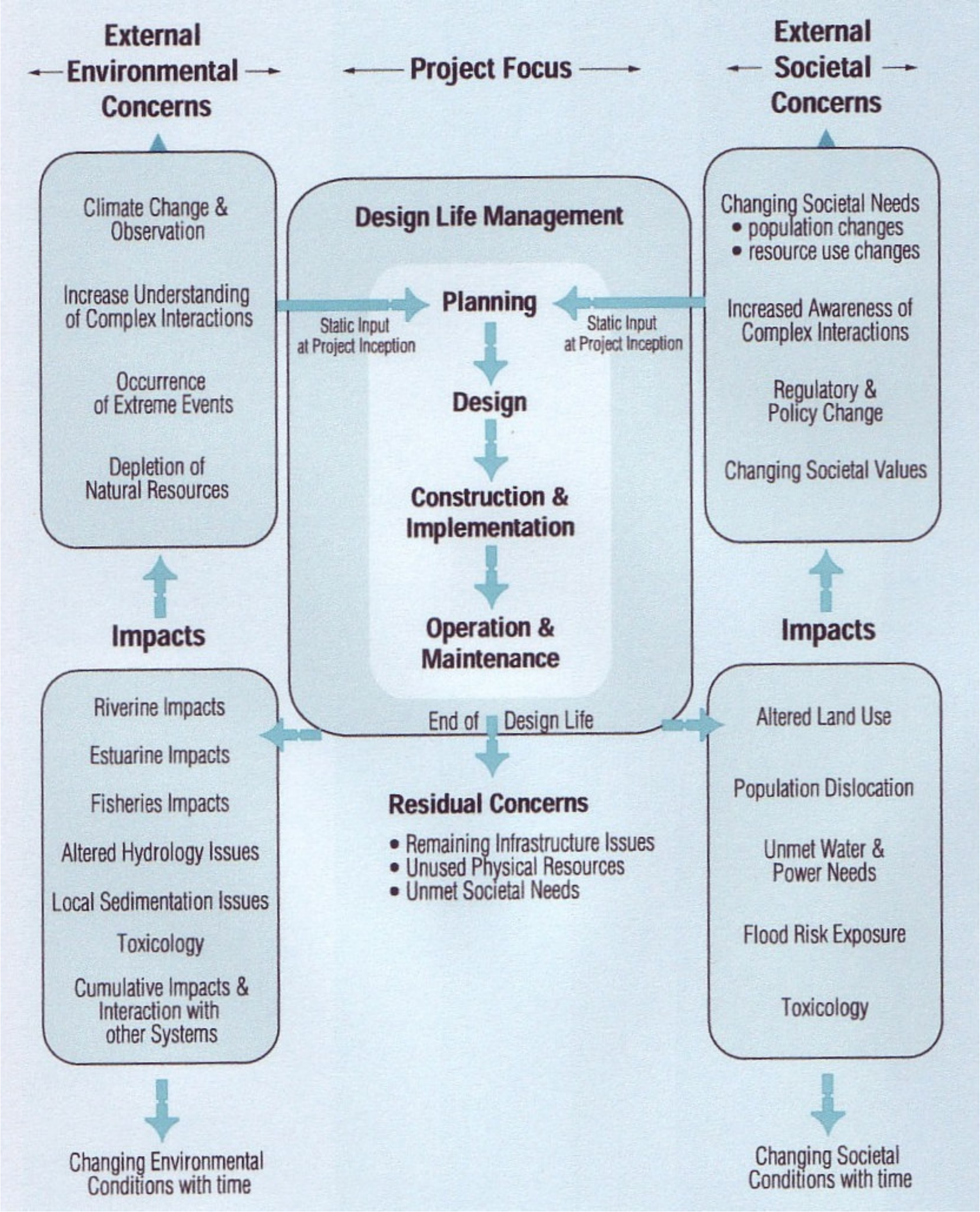


Figure 3.1 Design Life Approach (RESCON Manual Volume I, 2003)

3.2 Life Cycle Management Approach

Life cycle management approach is different from conceptual design life approach. In this approach sedimentation, decommissioning of the dam, different reservoir sedimentation management alternatives, social and environmental safeguards, economical optimizations for all of the management techniques can be included in pre-feasibility level. Moreover, intergenerational equity is considered in the approach. Figure 3.2 shows life cycle management approach schematically. Considering these two figures difference between the two approaches can be understood.

Since sedimentation is not considered in conceptual design life approach, some bad consequences may occur. For example, in case of a sudden sedimentation due to rapid melt of snow or a high rainfall, capacity of the dam may be lost tremendously. Removal of deposited sediment, renewal of facilities such as water intakes or clearance of entrance of sluice gates may cost too much. Furthermore, the benefits that can be gained as a result of operations such as power generation or irrigation may be lost.

In life cycle management approach continuity of reservoir management is under control and carried out in determined times. Therefore, any effect which may cause problem can be overcome due to continuous monitoring.

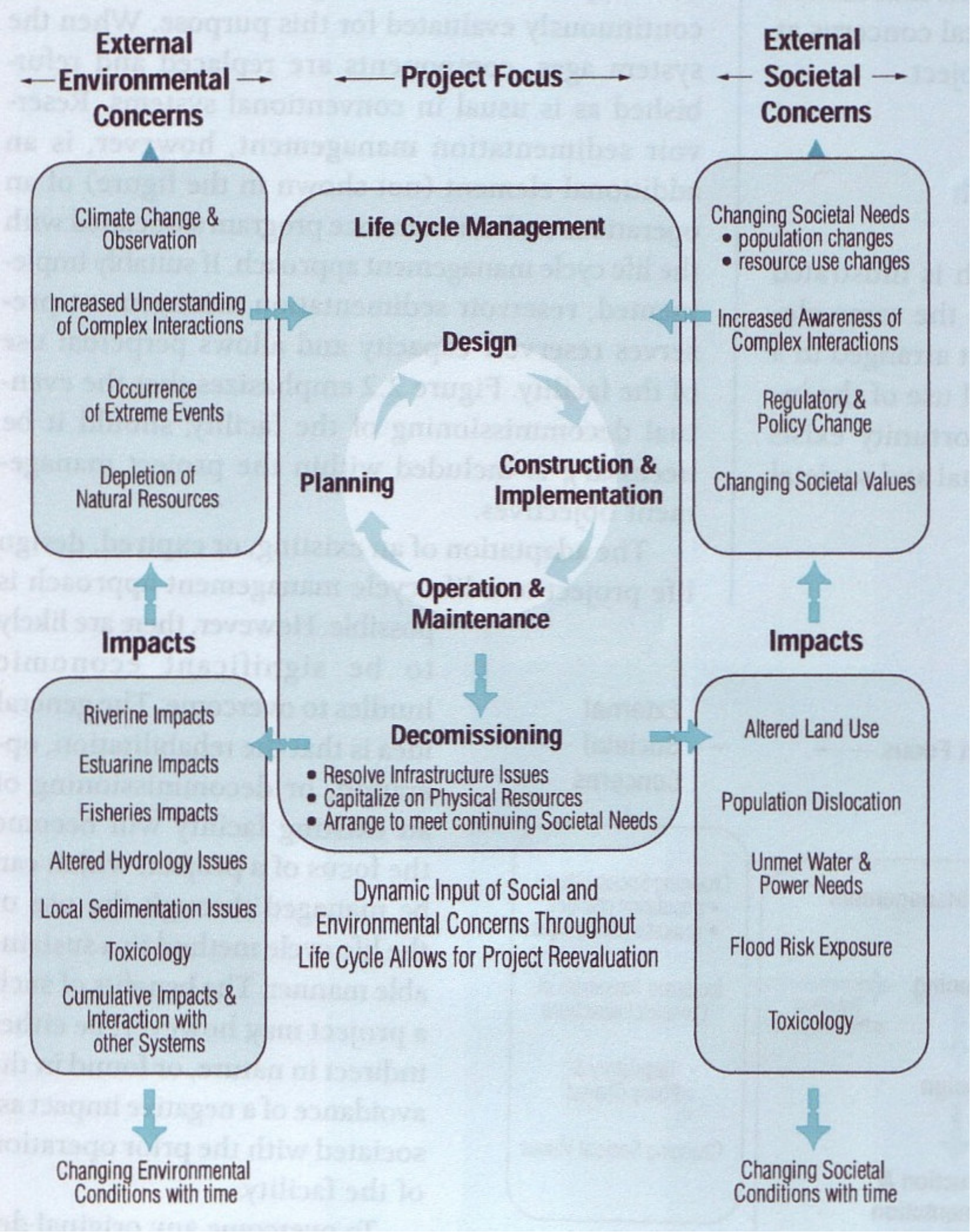


Figure 3.2 Life Cycle Management Approach (RESCON Manual Volume I, 2003)

3.3 RESCON Program

RESCON is a program based on excel and written in Visual Basic programming language. It has two pages for data input. First page is concerned with data related to geometry of reservoir, sediment and water inflows, parameters for sediment management alternatives and economy. Second page is related to environmental parameters. This page is optional and may be used if user is concerned about environmental results. Output of the program gives information about the followings:

- HSRS technical calculations and results
- Flushing technical calculations and results
- Economic calculations and results
- Safeguard results

There are 4 sediment removing methods used in RESCON. These are:

- Hydrosuction Sediment Removal System
- Flushing
- Dredging
- Trucking

Dredging and Trucking are always feasible sediment management alternatives in RESCON. However, the user should be aware of the physical removal capacity of these methods. Since the sediment inflow may be much higher than removal capacity of this method. HSRS is a method which can be used especially in small reservoirs because the sediment removing capacity of HSRS is also not high. Another constraint is the sensitivity of the program to the values of variables. Sensitivity analysis made in RESCON Manual is given in Appendix C.

The difference of RESCON from other sediment management programs is the general usage of the program. RESCON can be used for any reservoir (new reservoir or existing reservoir), but conclusions should be used with caution. As RESCON calculates the economic life of a dam, it assumes that all capacity of the reservoir is depleted. Another important point is the calculation of long term capacity of reservoir. RESCON makes calculation in two parts which are phase I and phase II. Phase I is the period prior to reaching the long-term capacity and phase II is the period after the long-term capacity has been reached. The program calculates the application frequencies for sediment removing techniques for both of the phases. This frequency can be different from the frequency given by the user since the frequency calculated by the program is an optimal value. However, calculated values for sediment management alternatives are based on user input. There are also other sediment management techniques but they are not considered in RESCON since including all the management techniques in one program is very difficult. Another reason is all the techniques have not been clearly understood yet, for example, watershed management. Effectiveness of this technique is not clear enough. Although watershed management is not an alternative in RESCON, it can be included by lowering the amount of sediment inflowing to the reservoir by an amount considering the catchment's properties, area of reservoir, etc. Also, increasing frequency of flushing events is another way if removing capacity is not enough to remove annual deposited sediment. There are some parameters calculated in

RESCON. In order these parameters to be clearly understood some explanation is given in the following parts.

3.3.1 Yield Estimation in RESCON

In RESCON water yield estimation is made using Gould's Gamma Distribution. This yield is required in economical calculations to calculate economical value of the water which is to be used in sediment removal operations. The Gould equation used in RESCON is:

$$W_t = \frac{4 \cdot S_t \cdot V_{in} - Zpr^2 \cdot sd^2 \cdot +4 \cdot Gd \cdot sd^2}{4 \cdot \left(S_t + \frac{Gd}{V_{in}} \cdot sd^2 \right)} = W(S_t) \qquad (3.1)$$

where

W_t = reservoir yield at time t (volume)

S_t = remaining reservoir capacity after year t (volume)

V_{in} = mean annual water inflow (volume)

Zpr = standard normal variate of percent probability (p%)

Gd = adjustment factor to approximate the Gamma distribution (offset from Normal distribution)

sd = standard deviation of incoming flows calculated from the user specified coefficient of variation and V_{in}

3.3.2 Water Required for Sediment Removal in Economic Models

3.3.2.1 Water Required for Sediment Flushing

If flushing operation is carried out in year t, it is assumed by RESCON that the reservoir is to be completely emptied. Water yield is estimated as follows:

$$W_t = s1 \cdot W(0) + s2\left(W\left(S_{t+1}\right) - W(0)\right) \tag{3.2}$$

where

s1 = the fraction of Run-of-River benefits available in the year flushing occurs

s2 = the fraction of storage benefits available in the year flushing occurs

W(0) = water yield from Run-of River project,

$W(S_{t+1})$ = water yield from storage capacity after flushing

3.3.2.2 Water Required for HSRS

Hotchkiss and Huang's (1995) hydrosuction method is used for HSRS operations in RESCON. Water required to remove sediment (Y_t) is (RESCON Manual, 2003):

$$Y_t = \left(\frac{Q_m}{Q_s}\right) \cdot X_t \tag{3.3}$$

where

Q_m = mixture flow rate (volume per time),

Q_s = sediment flow rate (volume per time),

X_t = sediment removed in year t (volume).

3.3.2.3 Water Required for Traditional Dredging

Concentration by weight of sediment to water removed (Cw) is specified by user and volume of water required to remove given sediment volume (Y_t) is calculated as (RESCON Manual, 2003):

$$Y_t = \left(\frac{100 \cdot 2.65}{Cw} \right) \cdot X_t \tag{3.4}$$

3.3.2.4 Water Required for Trucking

For trucking operations significant amount of water is not used. Therefore, water yield for trucking operations is assumed to be zero for simplicity.

3.3.3 Optimization Framework in RESCON

Selection of feasible sediment removal technique, the highest aggregate net benefit, frequency and phase lengths of removal operations, retirement fund calculations are the result of optimizations made by RESCON. Brief information is given in the following paragraphs to clarify where RESCON makes optimization.

3.3.3.1 No Sediment Removal Option

3.3.3.1.1 Decommissioning of the Dam

In case of decommissioning, an optimal time is determined. Annual net benefit and salvage value are important in calculation of this time. An annual retirement fund is calculated.

3.3.3.1.2 Run-of-River Option

For run-of-river option it is assumed by the program that the entire capacity of the reservoir has been depleted and reservoir has filled with sediment. An annual retirement fund is not calculated since the dam is not removed in this case. Run-of-river benefits are possible only if there is a power generation unit in the dam.

3.3.3.2 Flushing Option

Flushing model used in RESCON is based on the report written by Atkinson (1996) as a part of TDR (Technology Development and Research) Project. There are two main criteria set by Atkinson are Sediment Balance Ratio (SBR) and Long Term Capacity Ratio (LTCR). RESCON calculations of feasibility of flushing are based on SBR alone. Failure of LTCR criteria does not eliminate feasibility of flushing (RESCON Manual). LTCR is a ratio of the sustainable capacity that can be achieved over the long-term to the original capacity. Atkinson (1996) states four more criteria, DDR – Drawdown Ratio, SBRd-Sediment Balance Ratio based on minimum reservoir elevation, FWR – Flushing

Width Ratio, TWR – Top Width Ratio but RESCON presents these criteria as a guideline to make user exercise caution.

Optimization is made to maximize aggregate net benefit. There are two phases in this optimization. These are:

- Phase I
- Phase II

In phase I regular flushing operations are made until reservoir capacity reaches long term capacity. In phase II, new flushing frequency is calculated in a way such that reservoir capacity can be maintained at LTC. Phase I and phase II are independent of each other. A higher LTC can be achieved by increasing the frequency of flushing but RESCON does not consider this. Since RESCON makes optimizations on the basis of economy not capacity. Length of phase I is determined in a way which maximizes the sum of NPV of phase I and phase II (RESCON Manual). As a result of optimization possible time path for flushing in a form like shown in Figure 3.3 is obtained.

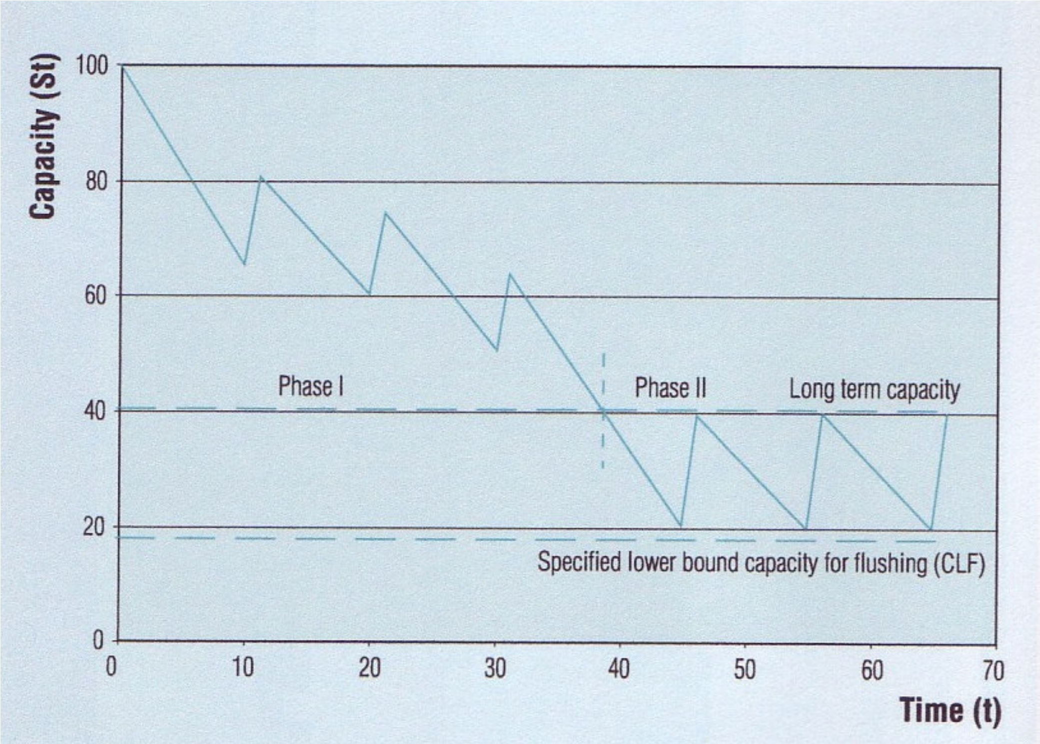


Figure 3.3 Possible Time Path of Remaining Capacity for Flushing (RESCON Manual Volum II, 2003)

3.3.3.3 Hydrosuction Sediment Removal System Option

The Hydrosuction technical model used in RESCON is based on Hotchkiss and Huang (1995). Energy requirement for HSRS operation is provided from the head difference between the upstream and the downstream water levels of the dam. Using an iterative scheme, a mixture velocity is calculated and annual sediment amount which can be removed by HSRS is calculated. This result is compared with annual sediment inflow to the reservoir. Hydrosuction is assumed to occur annually and the timing of HSRS installation is determined through economic optimization (RESCON Manual, 2003). If HSRS cannot remove annual incoming sediment, non-sustainable solution is obtained. In this case HSRS can only increase economic life of the dam and cannot prevent all capacity from being depleted in finite time. As a result of optimization possible time path for HSRS in a form like shown in Figure 3.4 is obtained.

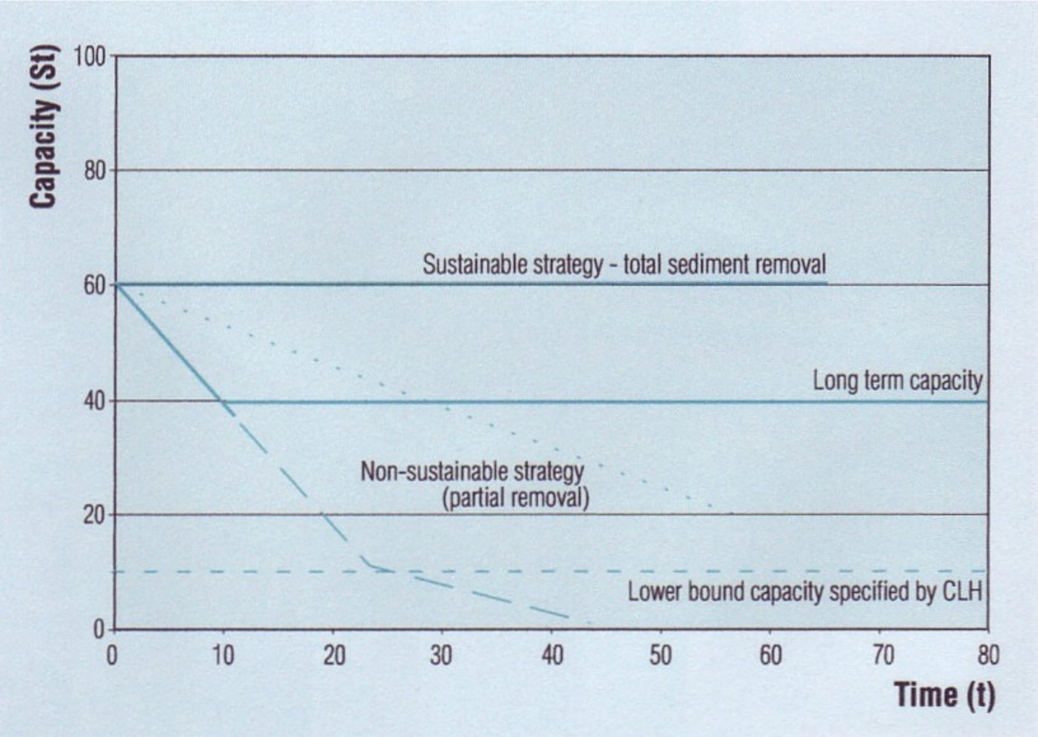


Figure 3.4 Possible Time Path of Remaining Capacity for Hydrosuction

(RESCON Manual Volume II, 2003)

3.3.3.4 Traditional Dredging and Trucking Option

There are two phases for dredging and trucking. Length of phase I is dependent on S_{min} (lower bound of remaining reservoir capacity) which is calculated as a result of optimization. LTC is determined on the basis of optimal cycle length of phase II. Whether existing capacity of the reservoir S_e is bigger or smaller than S_{min} affects length of phases. There are two different time paths for these cases.

If $S_e > S_{min}$ (where Smin is the lower bound capacity specified) no dredging or trucking operation is done until S_{min} has been reached. Cycle length of phase II is calculated using the difference between S_{min} and LTC. On the other hand, if $S_e < S_{min}$ immediate dredging or trucking is required until LTC has been reached and cycle length of phase II is calculated using the difference between LTC and S_{min}. As a result of optimization possible time path for dredging and trucking in a form like shown in Figure 3.5 and Figure 3.6 is obtained.

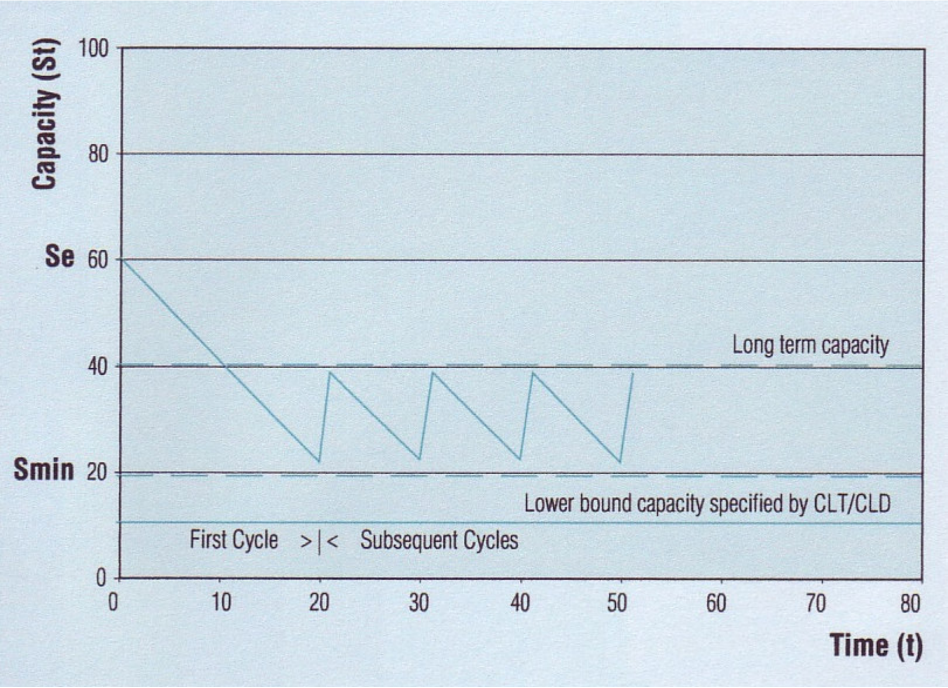


Figure 3.5 Possible Time Path of Remaining Capacity For Dredging and Trucking ($S_e > S_{min}$) (RESCON Manual Volume II, 2003)

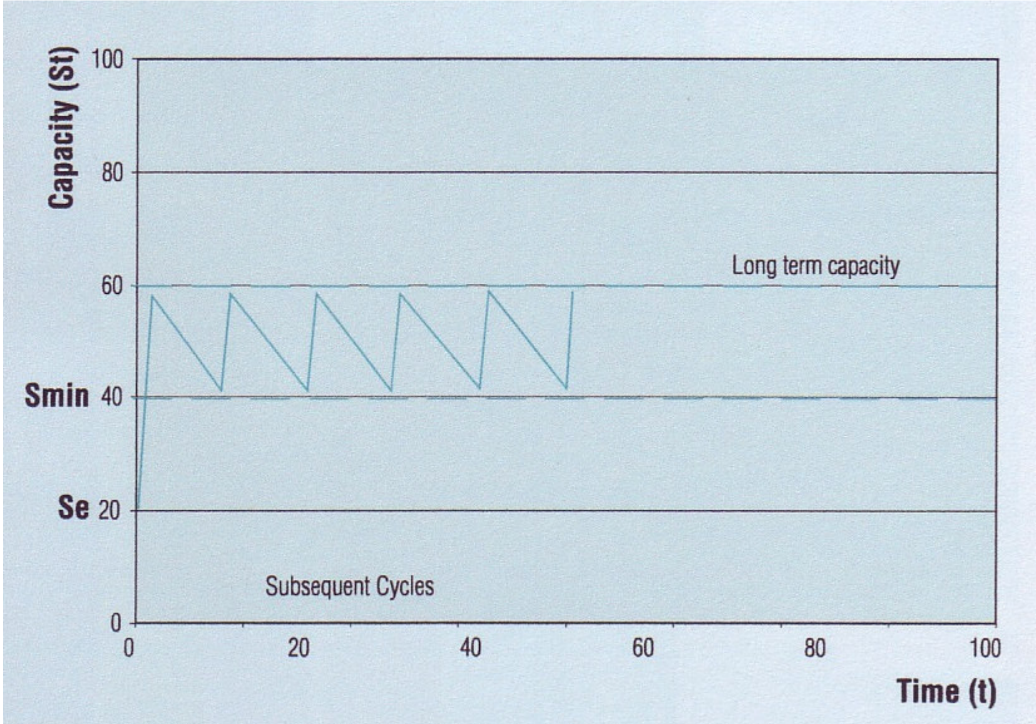


Figure 3.6 Possible Time Path of Remaining Capacity For Dredging and Trucking (S_e<S_{min}) (RESCON Manual Volume II, 2003)

3.3.4 Sensitivity Analysis for RESCON

A detailed sensitivity analysis has been carried out for Tarbela Dam by RESCON team to find out how results of RESCON can vary by changing input parameters. During the analysis some parameters have been kept constant and some parameters have been changed. As a result of this analysis sensitivities to input parameters can be summarized as follows:

1. Increasing width of reservoir for a constant value of flushing flow results in lower long term capacity ratios.

2. According to Basson's and Rooseboom's empirical flushing results and RESCON results, flushing could be preferred as a sediment management technique when reservoirs are hydraulically small and sediment loads are relatively high (RESCON Manual, 2003).
3. If Wt/MAR is less than 0.4, RESCON results may be unreliable (For the Wt/MAR checks of tested reservoirs in this study, see Appendix B.
4. If unit value of reservoir yield (P1) is doubled from \$0.1/m^3 to \$0.2/m^3, the NPV for all strategies increase by nearly \$140 billion. Also, the long term capacity ratio increases by 31% and 6%, respectively, for dredging and trucking.
5. If discount rate(r) is lowered from 5% to %3, NPV for each strategy increases by %50. Furthermore LTCR increases by 33% and 4%, respectively, for dredging and trucking.
6. Program is highly sensitive to market rate of interest. Even 1% of change can affect economical results seriously.
7. Program is not sensitive to operations and maintenance cost (omc). This parameter has a small effect on NPV.
8. If the parameters describing the cost of sediment removal are considered, when cost of sediment removal is reduced, NPV increases for all of the strategies tremendously.
9. The details of this sensitivity analysis can be seen in Appendix C. From applicability point of view this sensitivity analysis should be carried out on reservoir base.

3.3.5 Cost Calculations in Economic Models

For cost calculations RESCON has internal routines to estimate the unit cost of operations if the user does not know site specific values. However unit cost of operations pretty much affect the cost of operations, net present value calculations, the method giving the highest aggregate net benefit and other economical optimizations. Therefore, site specific values have great importance.

3.3.5.1 Unit Cost of Hydrosuction

Unit cost of hydrosuction is calculated using the following formula (RESCON Manual, 2003). Technical maximum sediment transport rate is calculated by the program

$$CH = \frac{HI}{DU \cdot Q_s} \tag{3.5}$$

where

CH = unit cost of hydrosuction

HI = cost of capital investment to install HSRS

DU = expected life of HSRS

Q_s = technical maximum sediment transport rate (annual)

3.3.5.2 Unit Cost of Dredging

Unit cost of dredging calculated using the following criteria. The criteria is based on experience (RESCON Manual, 2003).

IF $X<150\,000\text{m}^3$ $\quad$ $CD(X) = 15.0$ $\quad$ (3.7)

IF $X>16\,000\,000\text{m}^3$ $\quad$ $CD(X) = 2.0$ $\quad$ (3.8)

$$\text{Else } CD(X) = 6.62\left(\frac{X}{10^6}\right)^{-0.43} \quad (3.9)$$

where

X= amount of sediment dredged per cycle (m^3)

CD = unit cost of dredging (US\$/m^3)

3.3.5.3 Unit Cost of Construction

Unit cost of construction is calculted using the following criteria (RESCON Manual, 2003). This calculation is also based on experience as dredging.

IF $S_0>500\,000\,000\text{m}^3$ $\quad$ c=US\$0.16/m^3

$$\text{Else } c = 3.5 - 0.53LN\left(\frac{S_0}{1000000}\right) \quad (3.10)$$

where

c = unit cost of construction (US\$/m^3)

S_0 = original capacity of the reservoir (m^3)

3.3.6 Hydrosuction Removal System (HSRS) Calculations in RESCON

A 9-step routine is applied for HSRS calculations in RESCON. This routine is the calculation method proposed by Hotchkiss and Huang (1995). The program calculates sediment transportation rate, mixture velocity, mixture flow rate and concentration in pipe (ppm).

3.3.7 Definitions of RESCON Input Parameters

RESCON is an excel-based program which is written in Visual Basic programming language. It works with macros. Two working sheets are available in order to input the required data. There are 8 types of data user should input for the program RESCON in these two pages. These are given in Table 3.1~Table3.11

Table 3.1 Reservoir Characteristics

Parameter	Units	Description
S_o	(m^3)	Original (pre-impoundment) capacity of the reservoir
S_e	(m^3)	Existing storage capacity of the reservoir
W_{bot}	(m)	Representative bottom width for the reservoir--use the widest section of the reservoir bottom near the dam to produce worst case for criteria
SS_{res}		Representative side slope for the reservoir. 1 Vertical to SS_{res} Horizontal.
EL_{max}	(m)	Elevation of top water level in reservoir--use normal pool elevation.
EL_{min}	(m)	Minimum bed elevation--this should be the riverbed elevation at the dam.
EL_f	(m)	Water elevation at dam during flushing - this is a function of gate capacity and reservoir inflow sequence. Lower elevation will result in a more successful flushing operation.
L	(m)	Reservoir length at the normal pool elevation.
h	(m)	Available head--reservoir normal elevation minus river bed downstream of dam

Table 3.2 Water Characteristics

Parameter	Units	Description
V_{in}	(m^3)	Mean annual reservoir inflow (mean annual runoff)
Cv	(m^3)	Coefficient of Variation of Annual Run-off volume. Determine this from statistrical analysis of the annual runoff volumes
T	(°C)	Representative reservoir water temperature

Table 3.3 Sediment Characteristics

Parameter	Units	Description
P_d	(tonnes/m^3)	Density of in-situ reservoir sediment. Typical values range between 0.9 - 1.35.
M_{in}	(metric tonnes)	Mean annual sediment inflow mass.
¥	1600, 650, 300, 180	Select from: 1600 for fine loess sediments; 650 sediments with median size finer than 0.1mm; 300 for sediments with median size larger than 0.1mm; 180 for flushing with $Qf < 50\ m^3/s$ with any grain size.

Table 3.3 Sediment Characteristics (continued)

Parameter	Units	Description
Brune Curve No	1 2 3	Is the sediment in the reservoir: (1) Highly flocculated and coarse sediment (2) Average size and consistency (3) colloidal, dispersed, fine-grained sediment
Ans	3 or 1	This parameter gives the model a guideline of how difficult it will be to remove sediments. Enter "3" if reservoir sediments are significantly larger than median grain size (d_{50}) = 0.1mm or if the reservoir has been impounded for more than 10 years without sediment removal. Enter "1" if otherwise.
Type	1 or 2	Enter the number corresponding to the sediment type category to be removed by hydrosuction dredging: 1 for medium sand and smaller; 2 for gravel.

Table 3.4 Removal Parameters

Parameter	Units	Description
HP	1 or 2	Is this a hydroelectric power reservoir? Enter 1 for yes; 2 for no.
Q_f	(m^3/s)	Representative flushing discharge. This should be calculated with reference to the actual inflows and the flushing gate capacities.
T_f	(days)	Duration of flushing after complete drawdown.
N	(years)	Frequency of flushing events (whole number of years between flushing events)
D	(feet)	Assume a trial pipe diameter for hydrosuction. Should be between 1 - 4 feet.
NP	1, 2, or 3	Enter the number of pipes you want to try for hydrosuction sediment removal. Try 1 first; if hydrosuction cannot remove enough sediment, try 2 or 3.
YA	Between 0 and 1	Maximum fraction of total yield that is allowed to be used in HSRS operations. This fraction of yield will be released downstream of the dam in the river channel. It is often possible to replace required maintenance flows with this water release. Enter a decimal fraction from 0 - 1.

Table 3.4 Removal Parameters (continued)

Parameter	Units	Description
CLF	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Flushing. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled completely.
CLH	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Hydrosuction. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled completely.
CLD	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Dredging. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled completely.

Table 3.4 Removal Parameters (continued)

Parameter	Units	Description
CLT	(%)	Maximum percent of capacity loss that is allowable at any time in reservoir for Trucking. For an existing reservoir, this number must be greater than the percentage of capacity lost already. Sustainable solutions will attempt to remove sediment before this percent of the reservoir is filled completely.
ASD	(%)	Maximum percent of accumulated sediment removed per dredging event. Sustainable removal dredging will be subject to this technical constraint.
AST	(%)	Maximum percent of accumulated sediment removed per trucking event. Sustainable removal trucking will be subject to this technical constraint.
MD	(m3)	Maximum amount of sediment removed per dredging event. The user is warned if this constraint is not met, but the program still calculates the NPV. Use default value unless better information is available.

Table 3.4 Removal Parameters (continued)

Parameter	Units	Description
MT	(m3)	Maximum amount of sediment removed per trucking event. The user is warned if this constraint is not met, but the program still calculates the NPV. Use default value unless better information is available
Cw	(%)	Concentration by weight of sediment removed to water removed by traditional dredging. Maximum of 30%. Do not exceed this default unless you have studies for your reservoir showing different dredging expectations.

Table 3.5 Economic Parameters

Parameter	Units	Description
E	0 or 1	If dam being considered is an existing dam enter 0. If the dam is a new construction project enter 1.
c	($/m^3)	Unit Cost of Construction. The default value given here is a crude estimate based on original reservoir storage capacity. The user is encouraged to replace this value with a project specific estimate.

Table 3.5 Economic Parameters (continued)

Parameter	Units	Description
C2	($)	Total Cost of Dam Construction. This cost is calculated as unit cost of construction times initial reservoir storage volume ($C2 = S_o*c*E$). If you entered E = 0 above, your total construction cost will be taken as 0; if you entered E = 1, this cost will be calculated in the above manner.
r	decimal	Discount rate
Mr	decimal	Market interest rate that is used to calculate annual retirement fund. This could be different from discount rate "r".
P1	($/$m^3$)	Unit Benefit of Reservoir Yield. Where possible use specific data for the project. If no data is available refer to RESCON Manual Volume I report for guidance.
V	($)	Salvage Value. This value is the cost of decommissioning minus any benefits due to dam removal. If the benefits of dam removal exceed the cost of decommissioning, enter a negative number.

Table 3.5 Economic Parameters (continued)

Parameter	**Units**	**Description**
omc		Operation and Maintenance Coefficient. This coefficient is defined as the ratio of annual O&M cost to initial construction cost. Total annual O&M cost is calculated by the program as C1= omc*c* So.
PH	($/m^3)	Unit value of water released downstream of dam in river by hydrosuction operations. This could be zero, but may have value if downstream released water is used for providing some of required yield.
PD	($/m^3)	Unit value of water used in dredging operations. This could be zero, but may have value if settled dredging slurry water is used for providing some of required yield.
CD	($/m^3)	Unit Cost of Dredging--The user is encouraged to input her/his own estimate. Should this be difficult at the pre-feasibility level, enter "N/A" to instruct the program to calculate a default value of the unit cost of dredging. The calculated value is reported in Econ. Results& Conclusion Page.

Table 3.5 Economic Parameters (continued)

Parameter	Units	Description
CT	($\$/m^3$)	Unit Cost of Trucking--The user is encouraged to input her/his own estimate. Should this be difficult at the pre-feasibility level, the default value is recommended.

Table 3.6 Flushing Benefits Parameters

Parameter	Units	Description
s1	decimal	The fraction of Run-of-River benefits available in the year flushing occurs (s1 ranges from 0 to 1).
s2	decimal	The fraction of storage benefits available in the year flushing occurs (s2 ranges from 0 to1).

Table 3.7 Capital Investment Parameters

Parameter	Units	Description
FI	$	Cost of capital investment required for implementing flushing measures. The cost entered will be incurred when flushing is first practiced.
HI	$	Cost of capital investment to install Hydrosuction Sediment-Removal Systems (HSRS).
DU	Years	The expected life of HSRS.

Table 3.8 Environmental Parameters (Optional)

Safeguard Ratings for Each Sediment Management Strategy	Safeguard Ratings
No impact and potential benefits	1
Minor impact	2
Moderate impact	3
Significant impact	4

Table 3.9 Classification of Safeguard Policy Criteria

Safeguard Policy Criteria	Interpretation	Policy Level
6	No impact and potential benefits	A
7 to 11, with no 3's	Minor impact	B
12 to 15 or at least one 3	Moderate impact	C
16 or higher, or at least 4.	Significant impact	D

Table 3.10 Safeguard Policy Criteria

	Policy Level
Maximum allowable environmental and social damage (A to D)	**D**

Estimate of environmental and social impact levels can be seen in Table 3.11. “N/A” is written for some of the strategies in this table. This means there is no technique used in this option.

Table 3.11 Estimate of Environmental and Social Impact Levels

Possible Strategies	**Technique**	**Estimated Environmental & Social Impact Levels (Enter 1 to 4)**						**TOTAL**
		Natural Habitats	**Human Uses**	**Resettlement**	**Cultural Assets**	**Indigenous Peoples**	**Transboundary Impacts**	
Non-sustainable (Decommission) with No Removal	N/A	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Non-sustainable (Decommission) with Partial Removal	HSRS	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Non-sustainable (Run-of-River) with No Removal	N/A	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Non-sustainable (Run-of-River) with Partial Removal	HSRS	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Sustainable	Flushing	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Sustainable	HSRS	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Sustainable	Dredging	**1**	**1**	**1**	**1**	**1**	**1**	**6**
Sustainable	Trucking	**1**	**1**	**1**	**1**	**1**	**1**	**6**

3.3.8 Precautions Using RESCON Program

RESCON does not make an analysis about the feasibility of dredging and trucking. It gives some cautions but gives the responsibility of evaluating outcomes of these two methods to the user since RESCON assumes that these two methods are always feasible. However, the physical applicability of these methods and placement of the removed sediment is a big problem.

RESCON should be used as a preliminary tool. Its results should be evaluated carefully with caution. It is advised by RESCON team that the program should be used for a number of isolated reservoirs rather than a single reservoir. This excel based program determines the engineering feasibility and economical values of sediment management techniques and rank them. The program can be used for existing dams as well as new dams.

The final aim of the program is to select the sediment management technique which is technically feasible and having the maximum net benefit. Site specific data are crucial. The program makes economical optimization for each of the sediment removal technique and comparison with each other becomes possible in this way. Aggregate Net Benefit is the benefits taken from dam minus any kind of expenses including installation of HSRS equipment of construction of new channels for flushing operations over entire life of the dam. NPV (Net Present Value) is the discounted value of Aggregate Net Benefit to present.

Solution of the program comes to user in two forms (RESCON Manual, 2003):

1) SUSTAINABLE, where reservoir capacity can be maintained at original or a lower capacity,

2) NON-SUSTAINABLE, where reservoir fills with sediment in finite time. This solution divides into two:

> a) The dam is decommissioned at an optimally determined time allowing salvage value (= cost of decommissioning minus any benefits due to decommissioning) to be collected at this time; or
> b) The dam is maintained as a "run-of-river" project even after the reservoir is silted.

If decommissioning is the best solution an annual retirement fund is calculated by the program. For sustainable solutions NPV is calculated as well as for run-of-river option. This creates a chance to compare outcomes of each technique.

Environmental results are also important even if a sediment removal technique leads to a sustainable solution. Since removed sediment is also a big problem for neighborhood of the dam or for the next dam.

RESCON is a program to be used for a single isolated reservoir and using RESCON for systems of reservoirs (reservoirs following each other) may not give good results. Since application of flushing or HSRS changes the amount of sediment inflowing to next reservoir. This lowers economic life of the dam whose inflowing sediment is higher than before. Therefore, in order RESCON to be used for systems of reservoirs modifications should be made to the program code (RESCON Manual Volume I, 2003).

3.3.9 Important Points for Evaluating RESCON Results

After calculations RESCON gives the method having the highest aggregate net benefit, about frequencies of the method, partial removal options, long term capacity, etc. However, caution should be exercised when using these results since from practical or economical point of view these results may be impossible. In the following subsections hints about each technique are presented.

3.3.9.1 Flushing Results

Although flushing is feasible and evacuating incoming sediment successfully in RESCON results, width of the reservoir may not be sufficient to get a successful flushing operation. This results in evacuating less amount of sediment than planned.

3.3.9.2 Hydrosuction Sediment Removal System Results

The number of pipes and diameter of pipes used in RESCON solution for HSRS are limited to 3 and 4 feet, respectively. The capacities of pipes are not too high especially for large dams. Therefore, considering Hydrosuction Sediment Removal System as an option, amount of incoming sediment should be evaluated carefully. As a result of this HSRS is a suitable method for small reservoirs or partial removal around water intakes or in similar places. Another constraint about HSRS is the length of reservoir. In a long reservoir application of HSRS may not be feasible.

3.3.9.3 Dredging and Trucking Results

The highest amount of sediment removed by dredging operation in the world is 11 000 000 tons (RESCON Manual Volume I, 2003). Therefore, the results exceeding this value are not physically possible. In RESCON it is assumed for dredging that reservoir depth is less than 30 m. If a dam has a height more than 30 m cost of dredging should be revised manually.

As for trucking, information of trucks given in Caterpillar Performance Handbook (28th Edition, CAT Publication by Caterpillar Inc., Peoria, Illinois, USA, October 1997) is used. Number of loads , which is required to carry annual incoming sediment, is calculated for each type of truck. However, there is a physical capacity of trucks and this number of loads may not be physically possible.

3.3.9.4 Gould’s Gamma Function

This function is used to calculate reservoir yield (water available for use). Yield is important because in economic calculations, water price and yield may affect the method which has the highest aggregate net benefit. However, this function gives acceptable values if Wt/MAR ratio is higher than 0.4 where Wt is the water yield and MAR is the mean annual runoff. If $0.2<Wt/MAR<0.4$, the user should be careful. Wt/MAR values less than 0.2 are not acceptable (RESCON Manual Volume I, 2003).

CHAPTER 4

REVIEW OF RESERVOIR SEDIMENTATION IN TURKEY

4.1 General

In Turkey, sediment studies related to sustainability are quite a few. There is no sediment removal operation done in a large scale in any reservoir. Practiced sediment removal operations are only for clearing around water intake structures or similar local operations. There are some studies done by State Hydraulic Works but they are generally related to sediment problem in local places and written to advise sediment prevention ways for that region. Turkey is a country having vary wide areas subject to erosion. Green cover in Turkey is not enough to prevent sediment coming into reservoirs. Large seasonal flows also threat watershed and may increase sedimentation.

4.2 Data Collection

4.2.1 Sediment Information in State Hydraulic Works (DSI)

In order to use RESCON we need site-specific data, such as geometrical data of dam and reservoir, sediment data, annual water inflow. Obtaining data were a tough work since there is not any archive having all measurements taken for discharge and sediment. Therefore, all the departments in General Directorate of State Hydraulic Works related to sediment were visited and sediment information was requested. At the end of these visits it is understood that sediment measurements had been taken for some of the dams in Turkey (totally 58 dams). Some of the measurements are not reliable and some of them are reliable. Because for some of the reservoirs capacity value is larger than previous capacity value which is impossible without a sediment removal operation. This situation can be seen in Table D.1. Incorrect measurements are highlighted for easy inspection. Investigation and Planning Department is the department responsible for gathering sediment information. Operation and Maintenance Department is the department which is in charge of evaluating sediment data. Field related maps are prepared by Mapping Section and given to Operation and Maintenance Department. These maps are evaluated by this department and how much sediment had been accumulated between two measurements is calculated. Some brief information shall be given here to introduce these departments and their duties.

4.2.1.1 DSI Investigation and Planning Department

General Directorate of State Hydraulic Works Investigation and Planning Department carries out its duties and responsibilities under specified plans. In order to carry observation projects properly, reliable data should be obtained. DSI works in cooperation with State Meteorological Works Agency and Electrical Survey Agency (EIE). DSI provides oportunity for discharge, sediment, quality of water and pollution observations by installing observation stations on rivers. Besides these, in lake observation stations level measurements are taken, in meteorological stations rainfall, temperature, evaporation, humidity and similar meteorological observations are made.

According to records by the end of 2002, 1139 stream gaging stations, 115 reservoir observation stations, 392 meteorological observation stations and 115 snow observation stations are under operation.

Precautionary measures are taken by DSI in order to prevent erosion and save aggricultural areas from sediment which is carried by water or wind. Using results of investigations pre-examination and planning reports are prepared by Erosion and Control Section of Investigation and Planning Department. Success of these works is related to economy. Due to conditions of the country, financing is a big obstacle for these services.

4.2.1.2 DSI Mapping Section

Mapping Section of Investigation and Planning Department of DSI makes the following duties:

- Preparing of all kind and various topographical maps
- Cross section, profile works and project application
- Control of maps
- Technical mapping archive

1/5000 or larger scaled photogrammetric maps are prepared in coordination with General Command of Mapping, General Directorate of Land Registry and

Cadastre in compliance with the laws. The maps regarding to dam reservoirs are given to Operation and Maintenance Department in order to be evaluated.

4.2.1.3 DSI Operation and Maintenance Department

The mission of Operation and Maintenance Department is to operate and maintain the facilities related to irrigation, flood protection and flood control developed by DSI. Monitoring the performance of the facilities and collecting assesment of all statistical data related to reservoir are the responsibilities of this department.

4.2.1.4 Sediment Measurement Studies of DSI

When a dam is to be constructed, DSI requests for sediment data from EIE, if EIE has gauging station in that region or at neighbourhood. If there is no gauging station sediment measurements are taken by DSI in that region in a frequency satisfying precision of sediment yield for a period (it may be daily, weekly or monthly). Because precision of sediment yield is may be important for small structures like weirs, run-off river power plants, etc. If previously taken sediment measurement data are not available, sediment data of the dams or water structures previously constructed in that region are used with some approximation. Finally, if approximation is also not possible, approximate value for sediment yield is assumed using erosion or sediment yield maps. Dead volume of a reservoir is calculated assuming a 50 year economic life for a dam. Annual sediment yield obtained for that dam is multiplied by 50 in order to obtain volume of sediment which would deposit in 50 years. This calculated volume is allocated as dead volume for that dam.

There are 3 sampling methods practiced by DSI. These are

1. Point Sampling Method
2. Point Integration Method
3. Depth Integration Method

Most of the time the third one, depth integration method is used by DSI. It obtains vertical variation of suspended sediment concentration at a river section (DSI report, 2005).

For suspended sediment sampling US.P-46 and US.P-46R type of samplers are used for point integration method and US.DH-48, US.D-49 and US.D-43 type of samplers are used for depth integration method.

Yalçınkaya (1991), studied real sediment distribution in a reservoir based on hydrographic surveys using Area Increment Method and Empirical Area Reduction Method. In this work real sediment distribution has been made for 16 dams of Turkey. Applicability of these methods for Turkish reservoirs are tested and draingage area versus mean annual sediment inflow curve is plotted. It is proposed that this curve can be used for other reservoirs in Turkey with an adequate accuracy. As a result of her study, it was obtained that previously stated sediment yields are underestimated. Another conclusion is distribution of sediment within the reservoir. In dead volume calculation it is assumed by DSI that sediment deposits only in dead volume but this study shows that sediment deposits not only in dead volume but also in active volume. This means dead volume calculations done by DSI are not correct. This situation leads DSI to miscalculate economical life of a dam. Another important point in this study is related to unit weight of sediment. Unit weight of sediment becomes bigger as time goes by and volume occupied by sediment becomes smaller resulting in a longer economical life.

In the study of Yalçınkaya (1991) sediment measurements of DSI, calculation of dead volume of a dam, sediment yield calculations, devices used for sediment measurements, comparison between resurvey data and actual measurements are explained in detail. By using the result of such a work a water management policy can be prepared before dam construction in order to extend life of dam and decreasing the harmful environmental effects created by dam construction. If this method is used for an existing reservoir it enables the engineers in charge to select a proper sediment removal technique minimizing harmful removal effects and maximizing net benefits.

In the study of Yılmaz (2003), a method for estimating life of a dam is presented. In this study level-capacity values , taken at different dates, of dam are used to foretell the date at which the use of that dam is not possible. In order to use the method sediment measurement data at different times for different elevations are crucial. Method is based on plotting simple graphs of capacity versus time for different elevations and finding the time when half of the capacity of that dam is depleted. Logic in this method is the assumption that capacity of minimum elevation cannot be depleted before that of maximum elevation. The first capacity measurement which is original capacity of a dam is accepted as the most correct one.

The step by step procedure in this method is as follows:

1. The difference of capacity between last and first measurement is calculated and divided by difference in years to find out sediment deposited
2. Trap efficiency is calculated using the capacity value at the middle of the period between first and last measurement with the assumption that trap efficiency has a characteristic value approximately at the middle of the period
3. Observed sediment yield is divided by the trap efficiency to find out sediment yield of that catchment
4. Capacity and Trap efficiency values are updated for each period
5. Capacity vs. Time graphs are plotted for different elevations of the reservoir
6. Half life of the reservoir is read from graph

A sample graph for Çubuk I Dam is shown in Figure 4.1. It can be seen from this graph that half life of Çubuk I Dam is 68 years.

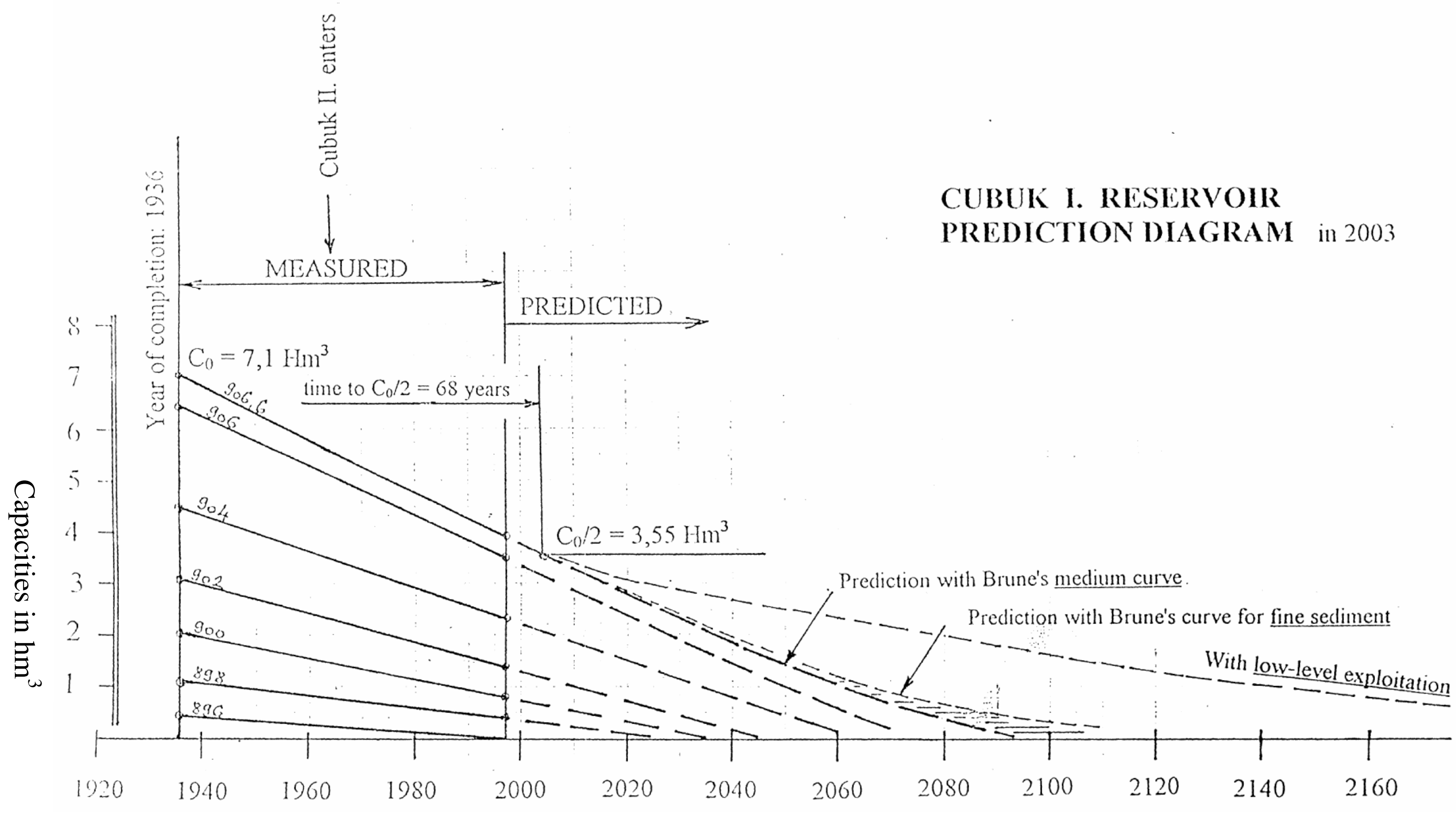


Figure 4.1 Half Life Calculation of Cubuk I Dam (Yılmaz, 2003)

4.2.2 Sediment Studies of Electrical Survey Agency (EIE)

4.2.2.1 General

EIE (Electrical Survey Agency) is the second biggest institution in Turkey studying on sediment. Some important duties of EIE are as follows.

- Hydrological studies
- Geotechnical researches
- Engineering services for dams and HEPPs
- Design studies are executed for dams and HEPPs

Discharge and sediment measurements are taken by this agency. These measurements were published as yearbook titled as "Suspended Sediment Data and Sediment Transport Amount for Surface Waters in Turkey" in 1982, 1987, 1993 and 2000. Yearbooks on water quality were published in 1989 and 1996. However, after examining this yearbook it was concluded that taken measurements may not be enough to predict annual sediment inflow for every reservoir in Turkey. This has mainly two reasons: First reason is that sediment samples are not taken at every tributary joining to a reservoir. Second reason is change in calculated amount of sediment even if at different parts of a river section. For example Table 4.1 shows calculated amount of sediment at different stations operated by EIE. Looking at this table it can be concluded that in order to predict sediment inflow to a reservoir sediment measurements should be done at the dam site before construction. By this way sediment inflow can be predicted as much as possible. Sediment discharge value is a bit unreliable because this value is dependent on location as well as time. Since sediment sampling has been made at one section once a month this value is not enough for precise annual sediment inflow prediction. Besides sediment coming from sides of reservoir throughout its life is not taken into consideration in these measurements because stations are located before reservoir entrance. However, if missing data of these yearbooks are excluded these yearbooks are the sources that are containing the largest amount of information about sediment measurements in Turkey. The data given by EIE and brief explanation about this data shall be given in the following section.

Table 4.1 Calculated Sediment Yields of Different Stations of EIE

Station No	River/Creek Name	Catchment Area (km^2)	Sediment Yield (tons/year/km^2)	Sediment (tons/year)	Observation Years
2315	Çoruh R.	17 835	396	10 594 000	1967-1990
2316	Çoruh R.	5 514	107	885 000	1970-1990
2320	Çoruh R.	4 767	63	450 000	1971-1990
2322	Çoruh R.	16 507	349	8 640 000	1984-1990
2325	Oltu Suyu	1 800	256	4 608 000	1977-1990

4.2.2.2 Sediment Sampling of EIE

Sample is taken by three different types of tools. If the sample is taken by entering into the river US.DH-48 type of bottle is used. If teleferic or cren is used US.D-49 type of bottle is used.

As a result of analysis and calculations following sediment information is given in the yearbook of EIE for every sediment measurement station:

- Gross rain area(km^2)
- Net rain area(km^2)
- Average sediment amount(Long-time average, tons/year)
- Sediment yield of catchment(tons/year/km^2)
- Average sand percentage(%)
- Net sample weight(gr)
- Net sediment weight(gr)
- Sand weight(gr)
- Clay+Silt weight(gr)
- Amount of sediment(tons/day)

Amount of sediment is calculated in the yearbook of EIE using the following equation:

$$Q_R = 0.0864 Q_S C_S \tag{4.1}$$

where

Q_R = Sediment Discharge (tons/day)
Q_S = Water Discharge (m^3/s)
C_S = Sediment Concentration (ppm) (mg/l)

Sediment concentration (C) in equation 4.1 is calculated using equation 4.2.

$$C = \frac{Sediment\ Weight\ (Total\ Weight\ of\ Sand + Clay + Silt)}{Sample\ Weight\ (Weight\ of\ Water + Sediment)} x10^6 \qquad (4.2)$$

Calculated sediment amount using equation 4.1 and equation 4.2 is the amount of suspended sediment. In order to calculate total sediment load for a sediment measurement station 10-50% of suspended sediment is added according to flow properties of the river on which station is founded.

There are two sections of EIE working on sediment. These are:

- Soil and Erosion Section
- Sediment Investigation and Laboratory Section

4.2.2.3 Duties of Soil and Erosion Section

- Makes erosion investigation and researches related to sediment movement, sediment accumulation and river bed movements required for plannings and projects
- Makes erosion classification in order to determine amount of erosion about reservoir catchments

4.2.2.4 Duties of Sediment Investigation and Laboratory Section

- Makes required laboratory analysis of sediment samples taken from sediment observation stations

- Makes water quality analysis taken from discharge observation stations and publishes results
- Evaluates sediment movement observations and publishes results

4.2.3 Economical Parameters for Turkey

Economical parameters for Turkey are obtained by consulting Koyuncu (2005). As a result of personal communication values given in Table 4.2 are obtained.

Table 4.2 Cost Calculation Data for Turkey

Parameter	**Type**	**Value**
Discount Rate	Hydroelectric Power Dam	9.5%
	Irrigation Dam	5.0%
	Domestic Water Supply	8.0%
Market Interest Rate		3.0%
Unit Benefit of Reservoir Yield	Hydroelectric Power Dam	0.06%/kW
	Irrigation Dam	\$0.20-\$0.30
	Domestic Water Supply	\$0.25-\$0.40
Salvage Value		Varies (Negative or Positive)

Table 4.2 Economical Parameters for Turkey (continued)

Parameter	**Type**	**Value**
Unit Value of Water Used in Dredging Operations		0.02-0.05 $/m3
Dredging		3.0 $/m^3 of sediment
Trucking	1km of distance	0.83 $/m^3 of sediment
	5km of distance	1.85 $/m^3 of sediment
	10km of distance	2.62 $/m^3 of sediment
	more than 10km	not rantable
If a new channel is required for flushing 3m-diameter tunnel		3 000 $/m (with concrete lining)
		2 000 $/m (without lining)
If bottom outlet is to be used for flushing		$1 000 (workmanship included)
Pipe for HSRS with 4ft of diameter		150 $/m
The Expected Life of HSRS		Up to 10 years

4.3 Case Studies from Turkey

Four dams have been selected for this study. These dams are Cubuk I Dam, Bayındır Dam, Borcka Dam and Ivriz Dam. Selection criteria for case studies are:

- There are some preliminary studies
- They have relatively small volumes (such as Cubuk I Dam which has a volume of 7 100 000 m^3)
- Annual sediment and water inflow are known from previous studies
- They are quite isolated reservoirs

4.3.1 Cubuk I Dam

Çubuk I Dam is located on 12 km north of Ankara, on Cubuk creek (Figure 4.2). It is a concrete gravity dam with a height of 25 m from river bed. Combined discharge capacity of spillway and bottom outlet is 227 m^3/s and capacity of bottom outlet is 40 m^3/s. Its construction was started in 1930 and completed in 1936. There is no power unit installed in the dam. Purpose of the dam is domestic and industrial water supply to the city of Ankara and flood control. It has a reservoir capacity of 7.1 hm^3 at normal reservoir level. Due to siltation Çubuk I Dam is used only for recreational purposes at present. Initial capacity of the reservoir is smaller than annual discharge of watershed Yılmaz (2003). According to size, deposited sediment in the reservoir is clayey silt and silt, according composition calcerous sandy silt and calcerous clay (Kılıç, 1986).

Catchment area has low green cover. Sediment deposition between 1936 and 1983 is 5.72 hm^3 according to Kılıç (1984) and 3.55 hm^3 according to General Directory of State Hydraulic Works, Operation and Maintenance Department. In this study calculation of Yılmaz (2003) has been taken as a basis and capacity loss has been taken as 50%. User input for Cubuk I dam is shown in Table 4.3.

Figure 4.2 Location of Cubuk I and Bayındır Dams

4.3.1.1 Cubuk I Dam RESCON User Input

Table 4.3 Cubuk I Input Data

Parameter	Unit	Value	Source
Reservoir Geometry			
S_0	m^3	7 100 000	Yılmaz (2003)
S_e	m^3	3 550 000	Yılmaz (2003)
W_{bot}	m	57.0	Measured from drawings (Dams in Turkey, 1991)
SS_{res}		1.0	Measured from drawings (Dams in Turkey, 1991)
El_{max}	m	907.6	Dams in Turkey (1991)
El_{min}	m	882.6	Dams in Turkey (1991)
El_f	m	895	Assumed due to not knowing bottom outlet sill elevation
L	m	6 500	Measured from map
Water Characteristics			
V_{in}	m^3	65 500 000	Yılmaz (2003)
Sediment Characteristics			
M_{in}	metric tonnes	81 000	Yılmaz (2003)
Removal Parameters			
Q_f	m^3/s	27	Bottom outlet rating curve for El_f=895m (Dams in Turkey, 1991)
Economic Parameters			
r	decimal	0.08	Koyuncu (2005)
Mr	decimal	0.03	Koyuncu (2005)
P1	$\$/m^3$	0.35	Koyuncu (2005)
omc	$\$/m^3$	0.085	Koyuncu (2005)
CD	$\$/m^3$	3.00	Koyuncu (2005)
CT	$\$/m^3$	2.62	Koyuncu (2005)

For definitions of parameters see section 3.3.8.

4.3.1.2 Evaluation of Cubuk I Dam RESCON Results

As a result of economical optimizations RESCON gives information about sustainable and nonsustainable solutions, their aggregate net present values and the strategy yielding the highest aggregate net benefit as can be seen in Table 4.4. Analysis show that sustainable solution can be obtained for all of the strategies. In Table 4.4 detailed results for sustainable and nonsustainable solutions can be seen.

Table 4.4 Economic Results for Cubuk I Dam

Possible Strategies	Technique	Aggregate Net Present Value
Do nothing	N/A	198 837 392
Nonsustainable (Decommissioning) with Partial Removal	HSRS	Partial Removal with HSRS is technically infeasible. See Partial Removal with HSRS
Nonsustainable (Run-of-River) with No Removal	N/A	198 762 340
Nonsustainable (Run-of-River) with Partial Removal	HSRS	Partial Removal with HSRS is technically infeasible. See Partial Removal with HSRS
Sustainable	Flushing	196 870 145
Sustainable	HSRS	209 857 262
Sustainable	Dredging	214 531 501
Sustainable	Trucking	206 129 328

In Table 4.4 "N/A" means that there is no technique used in that option such as HSRS. Nonsustainable solution with partial removal using HSRS is technically infeasible. Aggregate Net Present Value is the discounted value of the money which can be gained from this reservoir over entire life of the dam.

Information on economic conclusion is given Table 4.5. In Table 4.5 information about the strategy yielding highest aggregate net benefit is given. This information includes whether the strategy is sustainable or nonsustainable, name of the strategy and its aggregate net benefit.

Table 4.5 Economic Conclusion for Cubuk I Dam

Strategy yielding the highest aggregate net benefit:		Sustainable
Technique yielding the highest aggregate net benefit:		Dredging
The highest aggregate net benefit is:	$	2.145E+08

Detailed results of sustainable and nonsustainable solutions are given in Table 4.6, Table 4.7, Table 4.8, Table 4.9, Table 4.10 and Table 4.11.

In Table 4.6, number of years until partial removal option with HSRS is practiced is given. For Cubuk I Dam nonsustainable solution with partial removal using HSRS is not technically feasible. Therefore "Not applicable" is written for this part. If this would be feasible it would indicate the number of years between the solution time and first HSRS operation time. Second information is number of years until retirement for decommission with no removal option which is 68 years. This means using current information of the dam solution has been obtained and if no sediment removal operation is carried out 68 years later 100% capacity of the dam will be depleted. Third information is number of years until retirement for decommission with partial removal using HSRS. “Not applicable” is written for this part since partial removal with HSRS is technically infeasible. The next information is the reservoir capacity at retirement time for decommission with no removal option and with partial removal using HSRS.

Table 4.6 Nonsustainable (Decommission) for Cubuk I Dam

# of years until Partial Removal Option with HSRS is practiced:	Not applicable	years
# of years until retirement for Decommission-with no Removal Option:	68	years
# of years until retirement for Decommission: Partial Removal Option with HSRS:	Not applicable	years
Remaining reservoir capacity at retirement for Decommission-with No Removal Option:	37 663	m^3
Remaining reservoir capacity at retirement for Decommission: Partial Removal Option with HSRS:	Not applicable	m^3

A retirement fund is calculated by the program for nonsustainable solutions. This annual fund is allocated for future generations. Amount of this fund is given in Table 4.7.

Table 4.7 Annual Fund Results for Cubuk I Dam

Annual Retirement Fund Payment for nonsustainable options: Decommission	20 887	$
Annual Retirement Fund Payment for nonsustainable options: Partial Removal with HSRS	Not applicable	$

For nonsustainable solution with run-of-river, information is given Table 4.8. First information in Table 4.8 is number of years until partial removal option with HSRS is practiced. Since HSRS is technically infeasible "Not applicable" is written. Second information is number of years until dam is silted for run-of-river with no removal option which is 69 years. This number is different from that of decommission, which is 68 years. This is because two different routines are used for the solutions. Third information is approximate number of years until dam is silted for run-of-river with partial removal option. Since HSRS is technically infeasible "Not applicable" is written.

Table 4.8 Nonsustainable (Run-of-River) for Cubuk I Dam

# of years until Partial Removal Option with HSRS is practiced:	Not applicable	years
Approximate # of years until dam is silted for Run-of-River-with No Removal Option:	69	years
Approximate # of years until dam is silted for Run-of-River-with Partial Removal Option:	Not applicable	years

Long term capacity ratios of each technique is given in Table 4.9. Long term capacity is the sustainable capacity for a reservoir.

Table 4.9 Long Term Capacity Values for Cubuk I Dam

Long term reservoir capacity for Flushing	3 115 443	m^3
Long term reservoir capacity for HSRS	3 550 000	m^3
Long term reservoir capacity for Dredging	5 894 272	m^3
Long term reservoir capacity for Trucking	6 628 194	m^3

In Table 4.10 number of years until the dam is sustained at long term capacity is given for each technique. This number actually indicates the length of phase I for a sediment removal option. For dredging "right now" is written which means there is no phase I and dredging operation should be made immediately.

Table 4. 10 Phase I Lengths for Cubuk I Dam

Approximate # of years until dam is sustained at long term capacity for Flushing	10	years
Approximate # of years until dam is sustained at long term capacity for HSRS	1	years
Approximate # of years until dam is sustained at long term capacity for Dredging	Right now	years
Approximate # of years until dam is sustained at long term capacity for Trucking	6	years

Number of flushing events in phase I is given in Table 4.11. This number is different from that in phase II.

Table 4.11 # of Flushing Events in Phase I, Cubuk I Dam

Approximate # of Flushing events until dam is sustained at long term capacity	0	times

Technical conclusions based on economics are given in Table 4.12. It includes frequency of removal event if the given sustainable outcome had the highest aggregate net benefit. The cycle is the number of years between removal events; often the first cycle is different from remaining cycles, depending on whether the reservoir is new or existing or what percent of reservoir is allowed to fill before event occurs. Note that if flushing frequency is reported it is not necessarily the same as the frequency input by the user as variable “N”: rather it is the economically optimal flushing frequency.

Table 4.12 Frequency of Removal for Cubuk I Dam

Strategy	Technique	Cycle/Phase	Frequency of Removal (years)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	Not applicable
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	Not applicable
Sustainable	Flushing	Phase I	No Flushing occurs
Sustainable	Flushing	Phase II	1
Sustainable	HSRS	Annual cycle	1
Sustainable	Dredging	Phase I	Right now (No Cycle)
Sustainable	Dredging	Phase II	1
Sustainable	Trucking	Phase I	6
Sustainable	Trucking	Phase II	66

Table 4.13 indicates quantity of sediment removal per event if the given sustainable outcome had the highest aggregate net benefit. Note that when removal occurs, the same quantity is removed after each cycle.

Table 4.13 Sediment Removed per Event for Cubuk I Dam

Strategy	Technique	Cycle/Phase	Sediment Removed (m^3)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	Not applicable
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	Not applicable
Sustainable	Flushing	Phase I	0
Sustainable	Flushing	Phase II	52 423
Sustainable	HSRS	Annual cycle	52 423
Sustainable	Dredging	Phase I	2 411 455
Sustainable	Dredging	Phase II	52 423
Sustainable	Trucking	Phase I	N/A
Sustainable	Trucking	Phase II	3 459 914

Values for fraction of accumulated sediment removed (ASD or AST) and fraction of reservoir capacity lost (CLF, CLD and CLT) at the time removal event occurs are indicated in Table 4.14. Note that these values are likely to be only approximate of discrete step sizes and possible rounding errors (RESCON Manual, 2003). These values are optimal values economically, not physically.

Table 4.14 Optimal Values of ASD/AST and CLF/CLD/CLT, Cubuk I Dam

Technique	**ASD/AST(%)**	**CLF/CLD/CLT**
Flushing(Phase I)	N/A	57
Flushing(Phase II)	1	
HSRS	1	50
Dredging(Phase I)	68	50
Dredging(Phase II)	4	
Trucking(Phase I)	N/A	55
Trucking(Phase II)	89	

Information about concentration of sediment to water leaving reservoir is given in Table 4.15 for each technique.

Table 4.15 Technical Comments for Cubuk I Dam

Average expected concentration of sediment to water flushed per flushing event:	19 417	ppm
Average expected concentration of sediment to water released downstream of dam per hydrosuction event:	359	ppm
Average expected concentration of sediment to water removed from reservoir per dredging event:	300 000	ppm
Note: Because reservoir is dewatered prior to a trucking event and river is diverted during a trucking event, material removed is moist sediment (negligible water)		

Table 4.16 indicates the number of truck loads required to complete sustainable sediment trucking removal option. Table 4.16 should be examined carefully since indicated number of truck loads may not be accomodated at dam site in the time allowed (the maximum is one year).

Table 4.16 Number of Truck Loads* Required to Complete Sustainable Sediment Trucking Removal Option, Cubuk I Dam

Truck Model Number	m^3/Truck Load	Number of Loads (Phase I)	Number of Loads (Phase II)
769D	16.2	N/A	213 575
771D	18.0	N/A	192 217
773D	26.0	N/A	133 074
775D	31.0	N/A	111 610
777D	42.1	N/A	82 183
785B	57.0	N/A	60 700
789B	73.0	N/A	47 396
793C	96.0	N/A	36 041

*1997. Caterpillar Performance Handbook, Ed. 28. CAT Publication by Caterpillar Inc., Peoria, Illinois, USA. October 1997.

Number of dredges required to remove the optimally determined removed sediment is shown in Table 4.17. The highest sediment volume removal by dredging that can be expected from typical system over a year is approximately 11 Mm^3. To remove more sediment, additional dredges could possibly be installed on a reservoir, but this would increase the overall cost of the project. Based on this gross estimate of sediment removal capability, the number of dredges to remove enough sediment annually to keep the reservoir sustainable is shown in Table 4.17.

Note that the approximated removal per dredge is very crude; site specific analysis must be done to confirm volume of sediment removal per dredge per year (RESCON Manual, 2003). It should be kept in mind that dredging calculation is made assuming dredging mixture velocity through pipe is 5 m/s, diameter of dredge pipe is 0.8 m, reservoir length less than 4 km, dam height is less than 30 m, and dredge runs 70% of the time.

Table 4.17 Number of Dredges Required to Complete Sustainable Sediment Dredging Removal Option, Cubuk I Dam

Volume Removed per Dredge (m^3/Dredge)	No. of Dredges (Phase I)	No. of Dredges (Phase II)
11 000 000	1	1

Unit Cost of Sediment Removal for dredging and HSRS is given in Table 4.18.

Table 4.18 Unit Cost of Sediment Removal for Cubuk I Dam

	Phase I	Phase II
Unit Cost of Dredging(\$/m^3)	3.00	3.00
Unit Cost of HSRS(\$/m^3)	1.77	

After presenting the detailed RESCON results for Cubuk I Dam comments for these results can be given.

All the strategies have yielded sustainable solution for Cubuk I dam. Dredging is the method having the highest aggregate net benefit. Long term capacity for dredging is 5 894 272 m^3 (83% of the original capacity) and this capacity is quite a high capacity. There is no phase I for dredging which means an immediate dredging operation is required. Partial removal with HSRS is not applicable due to infeasibility. Therefore total removal with HSRS or removal of sediment with other methods should be considered. For flushing present condition of bottom outlets should be investigated for applicability of flushing. It can be seen understood from bottom outlet drawings of Cubuk I dam (Dams in Turkey, 1991) that this bottom outlet can not be used for sediment evacuation. Because, it was designed for taking water from reservoir not sediment. Since original capacity is approximately 9% of the annual runoff, which is less than 30%, water required for flushing is available. Depth of the dam is less than 30 m which is a limit for dredging calculations of RESCON. Length of the reservoir is also not quite long for the application of HSRS. Çubuk I Dam is now out of service because of siltation. Since it is a dam for domestic&industrial water supply its water can not be used now due to health reasons. However, if required studies for removing sediment from the reservoir would be done.

Under the light of these comments if a study for the properties and locations of sediment within the reservoir is done Cubuk I dam is still beneficial.

4.3.2 Bayındır Dam

Bayındır Dam is located on 12 km southeast of Ankara, on the Bayındır stream (Figure 4.2). It is an earthfill dam with the purpose of domestic and industrial water supply. Its initial storage capacity is 7.0 hm^3 and annual discharge of watershed is 3.9 hm^3. The construction of the dam was started in 1962 and completed in 1965. Water for domestic use has not being taken from Bayındır Dam since 2003. Besides this, the area surrounding the reservoir is used for recreational purposes. It has an elevation of 30 m from river bed. A power plant is not installed in the dam. Green cover around the reservoir is not enough for preventing large amount of sediment from inflowing to the reservoir. For user input and RESCON results of Bayındır Dam is given in Appendix E.

4.3.2.1 Evaluation of Bayındır Dam RESCON Results

For Bayındır Dam all the strategies have yielded sustainable results. However, all the sustainable solutions have negative aggregate net present value. This means that Bayındır Dam is not an economically feasible dam. Therefore, removing sediment from this reservoir will not result in beneficial results. As a result of this, the strategy having the highest aggregate net benefit is doing nothing. The dam has a long life even if the sediment within the reservoir is not removed (76 years of half life). Half life of the dam has been calculated by Yılmaz (2003) as 73 years. Therefore result of this study and that of Yılmaz (2003) are in good aggreement. Bayındır Dam has a long life because annually deposited sediment is low (63 500 tonnes/year).

Long term capacities for HSRS, dredging and trucking are 5 124 196 m^3 (73.2%), 5 122 034 m^3 (73.17%) and 5 717 487 m^3 (81.68%), respectively. All of them are quite high capacities. Frequency of removal for trucking in phase I is 2 years and for phase II that is 14 years. This frequencies are quite good from physical application point of view. Dredging also provides a high capacity without disturbing the service. It has a removal frequency of 2 years for phase I and 1 year for phase II. Sediment removed per cycle in phase I is “N/A” in Table E.11. This is normal because existing capacity of the reservoir (5 170 000 m^3) is very close to the long term capacity (5 122 034 m^3). 2 years of frequency for phase I means 2 years later phase I will be completed and phase II will begin. Trucking has similar situation with dredging. It has a removal frequency of 2 years for phase I. In Table E.10. “N/A” is written for sediment removed per trucking event. This also means 2 years later phase I for trucking will be completed and phase II will begin.

As for flushing, it has a low long term capacity. For physical application it may be required to allocate quite an amount of money. Since, a new tunnel should be drilled or existing derivation tunnel should be opened. All the investment is useless because flushing operation for Bayındır dam requires that 82% of capacity loss for economical reasons. All these means that flushing should not be thought as a sediment removal alternative.

4.3.3 Borcka Dam

Borcka Dam is the dam with highest reservoir capacity in this study. Borcka Dam is being constructed at the time of this study. It is in Borcka district, Artvin (Figure 4.3). It is a part of series of dams to be constructed on the Coruh River. This project is called the Coruh Project and includes construction of 14 dams. Construction of Borcka dam was started in 1998. It is an eartfill dam with a reservoir capacity of 419 hm^3. Height of the dam from river bed is 86 m. There is green cover around the reservoir but sediment inflow to the reservoir is high according to preparation report of Borcka Dam which was prepared by contractor company. Purpose of the dam is energy production and installed power capacity is 300 MW.

Figure 4.3 Location of Borcka Dam

4.3.3.1 Evaluation of Borcka Dam RESCON Results

All the strategies except HSRS have yielded sustainable solutions with positive aggregate net present value. Dredging has the highest aggregate net benefit. However, there is an important point here. Maximum dredging height in RESCON solution is 30 m. Borcka dam has height of 86 m from river bed. In market, dredging equipment allowing dredging operation up to 150 m depth is available (Roovers, 1989). This means net benefit calculated by RESCON should be revised. However, this requires a proffessional study which is not our concern. Total removal with HSRS is not possible because maximum sediment evacuation capacity of HSRS solution (29 404 m^3) is very low compared to annual sediment deposition (7 779 020 m^3). For trucking reservoir should be emptied. However, this is an energy dam and could not possibly be emptied for a long time. Under the light of this conclusions flushing is economically the best solution. It requires no interruption in service.

Long term capacities for flushing, dredging and trucking are 193 200 773 m^3 (46.1%), 366 363 144 m^3 (87.4%) and 399 229 929 m^3 (95.3%), respectively. For Phase I, frequency of removal for flushing, dredging and trucking are 3 years, 8 years and 12 years, respectively. In Phase II, flushing and dredging requires annual removal operation. On the other hand, trucking requires 10 years of frequency of removal for phase II. Using these comparisons, it can be concluded that dredging and trucking seems to be best options. From physical applicability point of view trucking should be investigated more deeply. Since, it is required to remove 65 733 570 m^3 of sediment for one trucking event in phase II. Increasing frequency of trucking events will reduce this amount but lower frequencies for trucking could not be accepted especially for an energy dam like Borcka. This amount is quite big for a trucking event. Sediment amount removed per dredging event is 6 573 357 m^3. This amount is logical because a dredging equipment has an annual sediment removal capacity of 11 000 000 m^3 normally.

As a result, sediment removal policy for Borcka Dam should be prepared since it has a half life of 32 years. This is not an acceptable situation.

4.3.4 Ivriz Dam

Ivriz Dam is located on 10km southeast of Ereğli, Konya (Figure 4.4). Main purpose of the dam is irrigation and flood control. Construction of the dam was completed in 1993. The dam has a big siltation problem. In the area surrounding the reservoir has no green cover. A research has been carried out by Sönmez and Dinçsoy (2002) presenting possible methods to prevent sediment inflow and their cost for Ivriz dam. In this work sediment inflow calculations have been made using GIS (Geographic Information System) technology and USLE (Universal Soil Loss Equation). There is no sediment measurement done by State Hydraulic Works and other governmental or private institutions. The capacity of the dam is 80 hm^3 and height from river bed is 65 m.

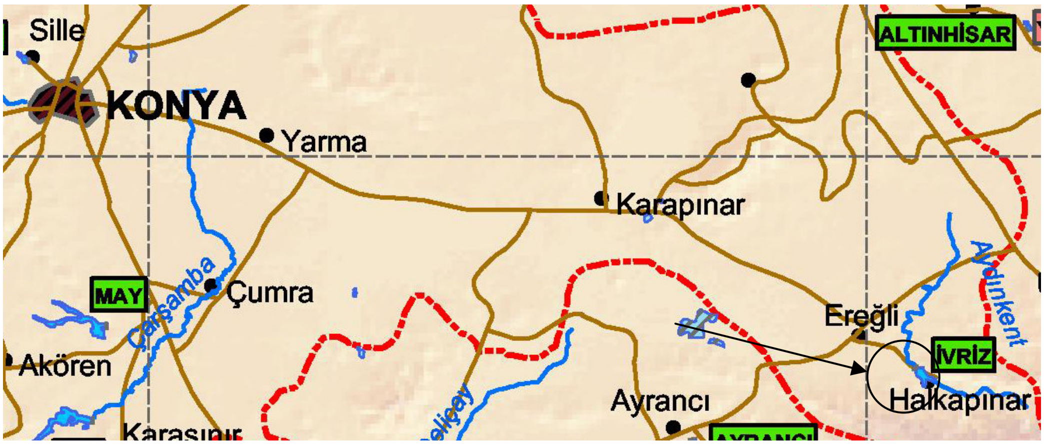


Figure 4.4 Location of Ivriz Dam

4.3.4.1 Evaluation of Ivriz Dam RESCON Results

All the strategies except HSRS have yielded sustainable solutions with positive aggregate net present value. Capacity of HSRS (3 926 m^3/year) is less than annual sediment inflow (252 000 m^3/year). “Do nothing” option has the highest aggregate net benefit. However, this is dam constructed for irrigation purposes and bottom outlet of the dam is close to river bed elevation. Therefore, maximum capacity loss is 8% of the total capacity. In order flushing to be feasible 57% capacity loss is required but this is not acceptable for this dam. Dredging and trucking are possible solutions for Ivriz dam.

Long term capacities for dredging and trucking are 73 653 030 m^3 (92.1%) and 78 535 314 m^3 (98.2%), respectively. Approximate number of years until the dam is sustained at long term capacity for dredging and trucking is 26 years. Total number of years from construction is 26+(2002-1993)=35 years. 2002 is the year at which the report of Dönmez and Dinçsoy (2002) was prepared and 1993 is the construction completion year. In report of Dönmez and Dinçsoy (2002) depletion of 8% capacity was 26 years. The two results are close enough. Sediment removed in phase I is “N/A” for dredging and trucking since long term capacity has already been exceeded for dredging and trucking. 26 years of time also indicates the length of phase I. For phase II dredging requires annual operation and trucking requires removal operation every 21 years. Sediment removed per dredging event is 244 114 m^3 which is quite a low amount of sediment for ordinary dredging equipment. As for trucking sediment removed per trucking event is 5 126 398 m^3. This amount of sediment can be trucked if enough number trucks are available. 21 year-of-removal frequency is quite good from serviceability point of view.

As a conclusion, sediment removal operations can sustain a great amount of capacity for Ivriz dam. This capacity gain results in economical outcome as well as continuity of aggriculture.

CHAPTER 5

CONCLUSION

The program RESCON has been run for four of the reservoirs of Turkey. These dams are Çubuk I Dam, Bayındır Dam, İvriz Dam and Borçka Dam. In section 4. RESCON results for these four dams have been evaluated. Comparisons between the results of RESCON and previous works have been made. It is observed that results of RESCON and those of previous works are in good aggreement. In section 4, while evaluating results applicability of the sediment removal techniques have also been discussed. In Table 5.1 RESCON results for the tested reservoirs can be seen. Table 5.1 shows the sustainable solutions for each reservoir with a descending order of aggregate net present value. Physically unacceptable solutions are excluded in this table such as trucking 65 733 570 m^3 of sediment from Borcka reservoir.

Table 5.1 RESCON Results for Tested Reservoirs

Reservoir	Sustainable?	Technologies (in order of Net Present Value)
Cubuk I	Sustainable	Dredging / HSRS / Trucking
Bayındır	Sustainable	HSRS / Dredging / Trucking
Borcka	Sustainable	Dredging / Flushing
Ivriz	Sustainable	Flushing / Dredging / Trucking

It can be concluded that RESCON results are acceptable for the tested reservoir. When evaluating RESCON results physical applicability should be kept in mind all the time.

Normally bathymetric surveys should be made by DSI for each reservoir of Turkey every 5 years in order to monitor sedimentation. As can be seen from Table 4.1 bathymetric survyes have not been made for every reservoir and the surveys that have been made have not 5-year intervals. In order to carry out sediment removal operations these surveys are essential but there are not enough data taken. If maps given in Appendix H are examined number of sediment observation stations of EIE are not enough. Therefore, sediment data may not be available for every reservoir. This situation has economical reasons. Since sediment sampling is an expensive task and monitoring every creek/river is not possible.

Water capacity of Turkey is being depleted and new dams are constructed. Erosion and deforestation in Turkey is very high. Due to deforestation and uncontrolled tree cut very large amount of sediment deposits in reservoirs and damage the economy. These means constructing new dams is not enough and sediment management is crucial.

Using RESCON is the first step for sedimentation mangagement for a reservoir. After gathering required data for RESCON, program is run and results are obtained. Program gives sustainable and non-sustainable solutions with their economical values. Once these results have been obtained user of the program should evaluate the results. For example, construction of new tunnels for flushing may be required or reservoir may be too long for sediment bypassing. Trucking may not be possible due to amount of sediment deposited in a reservoir. Evaluation of downstream conditions, existence of fisheries, local conditions for successful removal operations, cost of dredging if depth is more than 30m is the responsibility of the user. Whether existing bottom outlet can be used for flushing or sediment bypassing or not is another key point. Economical values of all the strategies require quite economical knowledge. Hydraulics knowledge is required to evaluate technical results. Therefore, the user should be as proffessional as possible.

After evaluation of results, the most probable method for a site is selected and more detailed calculations are made to find out more precise technical results. When detailed calculations are made, investment expenses and operation expenses may be decided.

All these calculations are site specific and should be practiced on dam basis. Gathering required data, using it to find out the possible strategy to be used, economical calculations take time. However, once a policy for a reservoir has been prepared it can provide a sustainable solution and efficient use of existing water resources becomes possible.

As a conclusion, RESCON should be used as a prefeasibility tool for preparing a sustainable reservoir sedimentation management policy.

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APPENDIX A

Table A.1 Dams In Operation in Turkey

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
A.KARAÖREN	+				ANKARA	1977
ADIGÜZEL		+	+	+	DENİZLİ	1989
AVŞAR		+		+	MANİSA	1977
AĞCAŞAR				+	KAYSERİ	1986
AHILI(ÇİPİ)				+	KIRIKKALE	1980
AHİKÖY I			+			1999
AHİKÖY II			+			2000
AHMETBEY				+	KIRKLARELİ	2000
AHMETLER				+	UŞAK	1998
AKALAN				+	BURSA	1988
AKBELEN				+	TOKAT	1994
AKÇAOVA				+	AYDIN	1995
AKKAYA				+	NİĞDE	1967
AKKÖY				+	KAYSERİ	1967
AKÖREN				+	KONYA	1990
AKSU				+	ÇORUM	1981
AKYAR	+				ANKARA	1999
ALACA				+	ÇORUM	1984
ALAÇATI	+				İZMİR	1997
ALAKIR		+		+	ANTALYA	1971
ALİBEY	+	+			İSTANBUL	1983
ALİDEMİRCİ				+	BALIKESİR	1989
ALMUS		+	+	+	TOKAT	1966
ALPAGUT				+	ÇANAKKALE	1990
ALTINAPA	+			+	KONYA	1967
ALTINHİSAR				+	NİĞDE	1989
ALTINKAYA			+		SAMSUN	1988
ALTINTAŞ (MESUDİYE)				+	UŞAK	1993
ALTINYAZI		+		+	EDİRNE	1967
APA				+	KONYA	1962

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
ARAÇ-TUZAKLI				+	KASTAMONU	2000
ARBETE				+	MARDİN	1981
ARIKLIKAŞ				+	OSMANİYE	1999
ARMAĞAN				+	KIRKLARELİ	1997
ARMUTALAN				+	BALIKESİR	2003
ARMUTLU	+				YALOVA	1999
ARPAÇAY		+		+	KARS	1983
ARTOVA				+	TOKAT	1986
ASARTEPE				+	ANKARA	1980
ASLANBEYLİ				+	ESKİŞEHİR	1988
ASLANTAŞ		+	+	+	OSMANİYE	1984
AŞ. DALAMAN-BEREKET			+			2001
ATABEY				+	ISPARTA	1992
ATAKÖY			+		TOKAT	1977
ATATÜRK			+	+	ŞANLIURFA	1992
ATİKHİSAR				+	ÇANAKKALE	1973
AVCIPINAR				+	SİVAS	1985
AYDOĞMUŞ				+	KONYA	1989
AYHANLAR	+			+	NEVŞEHİR	2003
AYRANCI				+	KARAMAN	1958
AYVALI I				+	ESKİŞEHİR	1994
AYVALI (AMASYA)				+	AMASYA	1990
BADEMLİ				+	BURDUR	1997
BAĞARASI				+	ISPARTA	1989
BAHÇELİK	+			+	KAYSERİ	2003
BAKACAK				+	ÇANAKKALE	1998
BALCI				+	ISPARTA	1998
BALÇOVA	+				İZMİR	1980
BALIKLI				+	KİLİS	1996
BARANDA				+	ANTALYA	1978
BARLA				+	ISPARTA	2000
BAŞAĞIL				+	EDİRNE	1978
BATMAN			+	+	BATMAN	1998

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	**Domestic & Indutrial Water Supply**	**Flood Control**	**Energy**	**Irrigation**	**Location**	**In Operation**
BAYAT				+	AFYON	1991
BAYINDIR	+	+			ANKARA	1965
BAYIRLI				+	AMASYA	1991
BAYRAKTAR		+		+	İZMİT	1984
BAYRAMİÇ				+	ÇANAKKALE	1996
BAYRAMŞAH				+	TEKİRDAĞ	1979
BEDİRKALE				+	TOKAT	1995
BELENLİ				+	BURDUR	1989
BELPINAR				+	TOKAT	1984
BERDAN	+		+	+	İÇEL	1984
BEREKET I			+			1998
BEREKET II			+			1998
BERKE			+		ADANA	2001
BEYKONAK				+	EDİRNE	1978
BEYKÖY			+			2000
BEYLER				+	KASTAMONU	1992
BEYLİK				+	ESKİŞEHİR	1985
BIÇKIDERE		+		+	İZMİT	1978
BIYIKALİ				+	TEKİRDAĞ	1987
BİRECİK			+	+	ŞANLIURFA	2000
BİRKAPILI			+		İÇEL	2004
BOĞAZDERE				+	SİVAS	1984
BORÇAK				+	BİLECİK	1997
BOSTANCILAR	+			+	KARABÜK	1983
BOZDOĞAN				+	ÇORUM	1979
BOZKIR		+		+	NİĞDE	1981
BOZTEPE (EDİRNE)				+	EDİRNE	1985
BOZTEPE (TOKAT)				+	TOKAT	1983
BUCUK				+	ANKARA	1988
BULCUK				+	KONYA	1993
BULDAN		+		+	DENİZLİ	1967
BURCUN				+	BURSA	1985
BÜLBÜLDERE				+	EDİRNE	1982

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
BÜYÜKAKÖZ				+	TOKAT	1991
BÜYÜKÇEKMECE	+	+			İSTANBUL	1987
BÜYÜKORHAN				+	BURSA	1992
CANILLI				+	ANKARA	1991
CEFFAN				+	BATMAN	1995
CEMALETTİN				+	SİNOP	1988
CEVİZLİ				+	ANTALYA	1979
CEYHAN-MARAŞ			+			1958
CİHANBEYLİ				+	KONYA	1989
CİP				+	ELAZIĞ	1965
ÇAĞÇAĞ III			+			1968
ÇAKMAK	+				SAMSUN	1988
ÇALI				+	BURSA	2001
ÇAMALAN				+	ANKARA	1993
ÇAMBAŞI II				+	ORDU	1997
ÇAMGAZİ				+	ADIYAMAN	1999
ÇAMKÖY					BALIKESİR	1991
ÇAMLICA I			+			1998
ÇAMLIDERE	+				ANKARA	1985
ÇAMLIGÖZE			+		SİVAS	1997
ÇAN KÜÇÜKLÜ				+	ÇANAKKALE	1994
ÇAT				+	MALATYA	1997
ÇATAK	+				KASTAMONU	1992
ÇATAK(AYDIN)				+	AYDIN	1999
ÇATALAN	+	+	+		ADANA	1996
ÇATMAPINAR				+	ESKİŞEHİR	1995
ÇATÖREN				+	ESKİŞEHİR	1987
ÇAVDARHİSAR		+		+	KÜTAHYA	1990
ÇAVDIR				+	BURDUR	1996
ÇAVUŞKÖY				+	EDİRNE	1984
ÇAYBOĞAZI				+	ANTALYA	2000
ÇAYGELDİ				+	MUŞ	1999
ÇAYGÖREN		+		+	BALIKESİR	1971
ÇAYHAN				+	KONYA	1994

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
ÇAYKÖY-AKSU			+	+	BOLU	1989
ÇAYKÖY-GÖNLÜK				+	BOLU	1997
ÇERTE				+	KÜTAHYA	1997
ÇEŞTEPE				+	ANKARA	1984
ÇETİNCE				+	ISPARTA	2002
ÇILDIR			+			1975
ÇİFTEVİ				+	AKSARAY	1994
ÇİFTLİKKÖY				+	EDİRNE	2002
ÇİFTLİKÖZÜ				+	KONYA	2001
ÇİĞDEM				+	KASTAMONU	1981
ÇİTLİ				+	AMASYA	1990
ÇOĞUN				+	KIRŞEHİR	1975
ÇORUM	+			+	ÇORUM	1977
ÇUBUK I	+	+			ANKARA	1936
ÇUBUK II	+				ANKARA	1964
ÇUKURÇİMEN				+	KONYA	1981
ÇUKURHİSAR				+	ESKİŞEHİR	1990
DAMSA				+	NEVŞEHİR	1971
DANACI				+	KIRIKKALE	1979
DARLIK	+				İSTANBUL	1988
DEDEÇAM				+	ISPARTA	1993
DEĞİRMENCİ		+		+	EDİRNE	1978
DEĞİRMENLİ				+	BALIKESİR	1991
DELİCE				+	SİVAS	1996
DELİİLYAS				+	SİVAS	1993
DEMİRCİÖREN				+	ÇANKIRI	1979
DEMİRDÖVEN				+	ERZURUM	1995
DEMİRKÖPRÜ		+	+	+	MANİSA	1960
DEMİRTAŞ				+	BURSA	1983
DERBENT			+		SAMSUN	1990
DEREKÖY (BURDUR)				+	BURDUR	1981
DEREKÖY (SAMSUN)				+	SAMSUN	2000

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
DEREKÖY (ZONGULDAK)	+				ZONGULDAK	1988
DEREYALAK				+	ESKİŞEHİR	1991
DERİNÖZ				+	AMASYA	2002
DERME-KAPULUK			+			1951
DESTEK				+	AMASYA	2000
DEŞTİĞİN				+	KONYA	1995
DEVEGEÇİDİ				+	DİYARBAKIR	1972
DİCLE			+	+	DİYARBAKIR	1997
DİKENLİ		+		+	ANTALYA	1989
DİNAR II			+			2000
DİRSEKLİ				+	ŞIRNAK	1968
DİVANBAŞI				+	SAMSUN	1987
DODURGA		+		+	ESKİŞEHİR	1977
DOĞANCI I	+				BURSA	1983
DOĞANHİSAR				+	KONYA	1995
DOĞANKENT I			+			1971
DOĞANKENT II			+			1971
DOĞANTEPE				+	AMASYA	1986
DOKUZDERE		+		+	EDİRNE	1978
DOKUZYOL				+	KARAMAN	1993
DÖRT EYLÜL	+			+	SİVAS	2003
DUMANLI				+	ÇANKIRI	1977
DUMLUCA				+	MARDİN	1991
DURAĞAN		+		+	SİNOP	1986
DURUÇAY				+	SAMSUN	2001
DUTLUCA				+	TOKAT	1990
EDİL				+	SİNOP	1991
EĞREKKAYA	+				ANKARA	1992
EKŞİLİ		+		+	ANTALYA	1990
ELMALI II	+				İSTANBUL	1955
EMEK				+	VAN	1989
ENGİL			+			1968
ENNE	+				KÜTAHYA	1972
ERENKÖY I				+	ESKİŞEHİR	1994

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
ERKMEN				+	AFYON	1991
ERZİNCAN				+	ERZİNCAN	1997
ESKİKADIN				+	EDİRNE	1979
ESPİYELİ				+	SİNOP	1974
EŞEN II-GÖLTAŞ			+			2002
EVCİ YENİKIŞLA				+	ÇORUM	1969
EVLİYATEKKE				+	KONYA	1994
EVREN (KÖPRÜDERE)				+	ANKARA	1999
EYMİR				+	BURSA	1990
FEHİMLİ				+	YOZGAT	1988
FETHİYE			+			1999
FETİYE				+	ESKİŞEHİR	2004
FINDIKLI				+	ÇANAKKALE	1990
GAYT				+	BİNGÖL	1991
GAZİBEY				+	SİVAS	1992
GAZİHALİL				+	EDİRNE	2004
GAZİLER			+			2002
GEBERE				+	NİĞDE	1941
GEDİKSARAY				+	AMASYA	1993
GELİNGÜLLÜ				+	YOZGAT	1993
GERMEÇTEPE				+	KASTAMONU	1985
GEVEN				+	ÇORUM	1976
GEYİK	+				MUĞLA	1988
GEYKOCA				+	ÇORUM	1981
GEZENDE			+		İÇEL	1990
GİRLEVİK I			+			1963
GİRLEVİK II+MERCAN			+			2001
GÖDET				+	KARAMAN	1988
GÖKÇE	+				İSTANBUL	1988
GÖKÇEADA	+			+	ÇANAKKALE	1983
GÖKÇEDOĞAN				+	ÇORUM	1992
GÖKÇEKAYA			+		ESKİŞEHİR	1972
GÖKPINAR				+	DENİZLİ	2001

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
GÖKSU				+	DİYARBAKIR	1991
GÖKSU-YERKÖPRÜ			+	+	DİYARBAKIR	1959
GÖLBAŞI		+		+	BURSA	1938
GÖLCÜK				+	BURSA	1995
GÖLKÖY		+		+	BOLU	1970
GÖLOVA		+		+	SİVAS	1988
GÖLYERİ				+	BURDUR	1997
GÖNEN		+	+	+	BALIKESİR	1996
GÖZEBAŞI				+	ADIYAMAN	1990
GÖZEGÖL				+	DİYARBAKIR	1964
GÜLDERE				+	SAMSUN	1993
GÜLDÜREK				+	ÇANKIRI	1988
GÜLÜÇ	+				ZONGULDAK	1966
GÜMELEKÖY				+	KÜTAHYA	1993
GÜMÜŞLER				+	NİĞDE	1967
GÜNEYKÖY				+	UŞAK	1996
GÜRGENLİK (YAPRAKLI)				+	ÇANKIRI	1981
GÜVEN	+			+	SAMSUN	1989
GÜZELHİSAR	+				İZMİR	1981
GÜZELOĞLAN				+	SİVAS	1980
GÜZELYURT (AKSARAY)				+	AKSARAY	1994
GÜZELYURT (MALATYA)				+	MALATYA	1999
HACIDEDE	+			+	SAMSUN	2000
HACIHIDIR				+	ŞANLIURFA	1989
HACILAR-GÖKPINAR			+			2003
HAKKIBEYLİ				+	ADANA	1998
HALHALCA				+	BURSA	1998
HALİLAN				+	DİYARBAKIR	1981
HALKAPINAR				+	BALIKESİR	1983
HANCAĞIZ				+	GAZİANTEP	1988
HANKÖY				+	ESKİŞEHİR	1985

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
HARMANCIK				+	SİVAS	1994
HASAN UĞURLU			+		SAMSUN	1981
HASANAĞA				+	BURSA	1984
HASANCIK				+	ADIYAMAN	1993
HASANLAR		+	+	+	BOLU	1972
HATİPLER				+	ANTALYA	2001
HAZAR I			+			1957
HAZAR II			+			1967
HELVADERE				+	AKSARAY	1990
HIDIRBEYLİ				+	AYDIN	1998
HIDIRLIK				+	ÇORUM	1995
HİRFANLI			+		KIRŞEHİR	1959
HİSARARDI				+	ISPARTA	1989
HÖYÜK				+	ÇORUM	1979
ILICA				+	ANKARA	1976
IŞIKTEPE				+	ELAZIĞ	1996
İBECİK				+	AMASYA	2000
İBİRLER				+	BALIKESİR	1988
İĞDİR				+	ANKARA	1985
İKİZCETEPELER	+	+		+	BALIKESİR	1990
İLEYDAĞI				+	ISPARTA	1984
İMİRLER				+	AMASYA	1995
İMRANLI				+	SİVAS	2002
İNANLI				+	TEKİRDAĞ	1983
İNCECİK				+	KAHRAMAN MARAŞ	1984
İNCESİ (SELKAPANI)				+	KAYSERİ	2000
İNEGAZİLİ				+	ÇORUM	1976
İNEGÖL KURŞUNLU				+	BURSA	2003
İNGÖLÜ				+	GİRESUN	1999
İVRİNDİ-KORUCU				+	BALIKESİR	2002
İVRİZ				+	KONYA	1985

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	**Domestic & Indutrial Water Supply**	**Flood Control**	**Energy**	**Irrigation**	**Location**	**In Operation**
K.DOĞANCA				+	EDİRNE	2001
K.KALECİK				+	ELAZIĞ	1974
KABALAR				+	KASTAMONU	1975
KADIKÖY				+	EDİRNE	1992
KADIKÖY (DERBENT)		+		+	EDİRNE	1972
KADIKÖY (KARABÜK)				+	KARABÜK	1982
KADINCIK I			+			1971
KADINCIK II			+			1974
KALECİK				+	OSMANİYE	1985
KANDIRA ARIKLAR				+	KOCAELİ	2003
KANGAL (BOZARMUT)				+	SİVAS	2000
KANLIDERE				+	YOZGAT	1979
KANLIPINAR				+	ESKİŞEHİR	1978
KAPIKAYA (ERZURUM)				+	ERZURUM	1979
KAPULUKAYA			+		KIRIKKALE	1989
KARAAĞA				+	KONYA	2000
KARAAĞAÇ				+	UŞAK	1990
KARAAHMET				+	ANKARA	1980
KARAAHMETLİ				+	UŞAK	1991
KARABÜK				+	SAMSUN	1996
KARACA				+	SİNOP	2000
KARACAÖREN I			+		BURDUR	1989
KARACAÖREN II			+		BURDUR	1993
KARACAÖREN (AFYON)				+	AFYON	2000
KARACAÖREN (BALIKESİR)				+	BALIKESİR	1988
KARAÇOMAK	+	+		+	KASTAMONU	1974
KARADERE (ÇANKIRI)				+	ÇANKIRI	1990
KARAGÜNEY				+	ANKARA	1983

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
KARAHÖYÜK				+	ADIYAMAN	1996
KARAİDEMİR		+		+	TEKİRDAĞ	1980
KARAKAYA			+		DİYARBAKIR	1987
KARAKOL				+	BALIKESİR	1985
KARAMANLI (BURDUR)				+	BURDUR	1973
KARAMANLI (HATAY)				+	HATAY	2000
KARAOVA				+	KIRŞEHİR	1997
KARAÖREN (ÇANKIRI)				+	ÇANKIRI	1981
KARAÖREN (ESKİŞEHİR)				+	ESKİŞEHİR	1971
KARASATI				+	EDİRNE	1995
KARKAMIŞ			+		ŞANLIURFA	1999
KARTALKAYA	+	+		+	KAHRAMAN MARAŞ	1972
KAVAKAYAZMA				+	EDİRNE	1997
KAVAKDERE (EDİRNE)				+	EDİRNE	1983
KAVAKLI				+	BALIKESİR	1996
KAYABELEN				+	AFYON	1991
KAYABOĞAZI		+		+	KÜTAHYA	1987
KAYAKÖY			+			1956
KAYALIKÖY		+		+	KIRKLARELİ	1986
KAYAPA				+	BURSA	1998
KAYI II				+	ESKİŞEHİR	1995
KAYI III		+		+	ESKİŞEHİR	1998
KAYMAZ				+	ESKİŞEHİR	1977
KAZAN				+	MUĞLA	1995
KEBAN			+		ELAZIĞ	1975
KELKAYA				+	ESKİŞEHİR	1986
KEMER		+	+	+	AYDIN	1958
KEMERİZ				+	SİVAS	1991
KEPEKTAŞ				+	ELAZIĞ	2002
KEPEZ I			+			1961

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
KEPEZ II			+			1986
KERAMETTİN				+	EDİRNE	1988
KESİKKÖPRÜ			+	+	ANKARA	1966
KESİKSUYU				+	ADANA	1971
KESKİN		+		+	ESKİŞEHİR	1997
KESTEL				+	İZMİR	1988
KEŞAN-ÇAMLICA				+	EDİRNE	2002
KILDIR				+	SİVAS	1992
KILIÇKAYA			+		SİVAS	1989
KINIK				+	ADIYAMAN	1989
KIRKA				+	AFYON	1989
KIRKAT				+	BATMAN	1985
KIRKLAR				+	AFYON	1997
KIRKLARELİ	+	+		+	KIRKLARELİ	1995
KIRKÖY				+	ANKARA	1982
KISIK			+			1993
KIZIK(AKYURT)				+	ANKARA	1970
KIZIK(TOKAT)				+	TOKAT	2000
KIZILCAPINAR	+			+	ZONGULDAK	1993
KIZILDAMLAR				+	BİLECİK	2001
KIZILİNİŞ				+	KAHRAMAN MARAŞ	1994
KIZILSU		+			BURDUR	1965
KIZLARKALESİ				+	GÜMÜŞHANE	1998
KİRAZDERE	+				KOCAELİ	1999
KİTİ			+			1966
KOCAAVŞAR				+	BALIKESİR	1994
KOCABEY				+	BALIKESİR	1989
KOCADERE				+	EDİRNE	1979
KOCAŞ				+	ESKİŞEHİR	1990
KOÇKÖPRÜ			+		VAN	1991
KORKUTELİ				+	ANTALYA	1975
KORUKLU				+	EDİRNE	1986
KORULUK				+	GÜMÜŞHANE	2004
KOVADA I			+			1960

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
KOVADA II			+			1971
KOVALI				+	KAYSERİ	1988
KOYUNLU				+	NİĞDE	1995
KOYUNYERİ				+	ÇANAKKALE	1988
KOZAĞACI (ANTALYA)		+		+	ANTALYA	1989
KOZAĞACI (BURDUR)				+	BURDUR	1985
KOZAN				+	ADANA	1972
KOZANSIKI				+	SAMSUN	1990
KOZÇEŞME				+	ÇANAKKALE	1997
KOZLU	+				ZONGULDAK	1986
KOZLUÖREN				+	BURSA	1994
KOZVİRAN				+	UŞAK	2000
KÖKLÜCE			+			1988
KÖMEVİRAN				+	SİVAS	1971
KÖRKÜLER				+	ISPARTA	1998
KÖSENÇAYIRI				+	KASTAMONU	1986
KÖSRELİK				+	ANKARA	1968
KÖYCEĞİZ				+	ERZURUM	1985
KRALKIZI			+	+	DİYARBAKIR	1997
KULA				+	MANİSA	2002
KUMDERE				+	EDİRNE	1985
KUMTEPE				+	NEVŞEHİR	1990
KUNDUZLAR				+	ESKİŞEHİR	1983
KURTBEY				+	EDİRNE	1974
KURTBOĞAZI	+			+	ANKARA	1967
KURTDERE				+	İZMİT	1979
KURUCAGÖL				+	SİVAS	1983
KURUÇAY				+	KÜTAHYA	1985
KUZAYCA				+	YOZGAT	1997
KUZGUN			+	+	ERZURUM	1995
KÜÇÜKHÖYÜK				+	SİVAS	1985
KÜÇÜKLER				+	UŞAK	2002
KÜLTEPE				+	KIRŞEHİR	1983
KÜPDERE				+	EDİRNE	1987

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
KÜRTÜN			+		GÜMÜŞHANE	2002
LADİK				+	KONYA	1995
MADRA				+	BALIKESİR	1997
MAHSUTLU				+	SİVAS	1982
MAMASIN	+			+	AKSARAY	1962
MANAVGAT			+		ANTALYA	1988
MART				+	ÇANKIRI	1991
MARUF (ÇANKIRI)				+	ÇANKIRI	1999
MARUF(SİNOP)				+	SİNOP	1990
MAY				+	KONYA	1987
MAY(PEYNİRLİ)				+	KONYA	1991
MECİDİYE (EDİRNE)				+	EDİRNE	1981
MECİDİYE (KONYA)				+	KONYA	1985
MEDİK				+	MALATYA	1975
MENZELET			+	+	KAHRAMAN MARAŞ	1989
MERCAN				+	EDİRNE	1986
MERİÇ MERKEZ				+	EDİRNE	1974
MERKEZ PULLAR				+	KÜTAHYA	2003
MERKEZ ŞARKÖY	+				TEKİRDAĞ	1981
MERKEZ YASSIÇAL				+	AMASYA	2003
MOLU			+			2000
MORÇİÇEK				+	VAN	1999
MUMCULAR				+	MUĞLA	1989
MURGUL			+			1951
MURSAL				+	SİVAS	1991
MURTAZA				+	NİĞDE	1992
MUSAÖZÜ				+	ESKİŞEHİR	1969
MUZALIDERE				+	EDİRNE	1983
NERGİZLİK		+		+	ADANA	1995

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
NİSİ				+	SİNOP	1998
OLUR ÜRÜNLÜ				+	ERZURUM	1996
ONAÇ I		+			BURDUR	1967
ONDOKUZ MAYIS	+			+	SAMSUN	-
ONDOKUZ MAYIS II	+				SAMSUN	1997
ORTAKÇILAR				+	KARABÜK	1981
ORTAKÖY				+	AMASYA	1979
OSMANCIK				+	KONYA	1988
OSMANLI				+	EDİRNE	1994
OVACIK				+	BALIKESİR	1993
OYMAPINAR			+		ANTALYA	1984
ÖMERKÖY				+	ESKİŞEHİR	1989
ÖMERLİ	+				İSTANBUL	1972
ÖRENCİK				+	ANKARA	1993
ÖREN				+	ISPARTA	1997
ÖRENLER				+	AFYON	1992
ÖZALP GÖLEGEN				+	VAN	2003
ÖZLÜCE			+		BİNGÖL	1998
PALANDÖKEN (GEDİKÇAY)				+	ERZURUM	1989
PALANDÖKEN (LEZGİ)	+			+	ERZURUM	2001
PAMUK			+			2004
PAMUKOVA-KAREL			+			2000
PAŞA				+	AMASYA	1993
PATNOS				+	AĞRI	1991
PERŞEMBE YAYLASI				+	ORDU	1994
PINARLI (AFYON)				+	AFYON	1993
PINARLI (ÇORUM)				+	ÇORUM	1980
POLAT				+	MALATYA	1989

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
PORSUK (ERZURUM)				+	ERZURUM	1984
PORSUK (ESKİŞEHİR)		+		+	ESKİŞEHİR	1972
POSTALLI				+	NİĞDE	2003
SAHLİ				+	SİVAS	1985
SAKIZ				+	KASTAMONU	1976
SARAYKÖY				+	ÇANKIRI	1972
SARAYÖZÜ				+	AMASYA	1989
SARIBEYLER				+	BALIKESİR	1985
SARIBUĞDAY				+	AMASYA	1990
SARICAALİ				+	KIRKLARELİ	1990
SARIÇAL				+	SİVAS	1989
SARIMEHMET				+	VAN	1991
SARIMSAKLI				+	KAYSERİ	1968
SARIYAHŞİ				+	AKSARAY	1989
SARIYAR-H. POLATKAN			+		ANKARA	1956
SAZLIDERE	+				İSTANBUL	1996
SEFERİHİSAR				+	İZMİR	1993
SEKİÖREN				+	ESKİŞEHİR	2002
SELEVİR		+		+	AFYON	1965
SERBAN				+	AFYON	1994
SEVİŞLER					MANİSA	1981
SEYDİKÖY (ULUDERE)				+	ÇANKIRI	1996
SEYDİM I	+				ÇORUM	1973
SEYDİM II	+				ÇORUM	1976
SEYHAN I		+	+	+	ADANA	1956
SEYHAN II			+			1992
SEYİTLER				+	AFYON	1964
SIDDIKLI				+	KIRŞEHİR	1998
SIHKE				+	VAN	1958
SIR			+		KAHRAMAN MARAŞ	1991
SIZIR			+			1961

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
SİLLE		+		+	KONYA	1960
SİNCAN				+	ÇORUM	1989
SOFUHALİL				+	KIRKLARELİ	1983
SOĞUKSU				+	BALIKESİR	1994
SORGUN				+	ISPARTA	2000
SÖĞÜT-DEREBOYU (ZEVYE)				+	BİLECİK	2004
SÖĞÜT (BURDUR)				+	BURDUR	1997
SÖĞÜT (KÜTAHYA)				+	KÜTAHYA	1983
SÖVE				+	BALIKESİR	1992
SUAT UĞURLU			+		SAMSUN	1981
SUÇATI			+			2000
SUĞLA DEPOLAMASI					KONYA	2003
SULTANKÖY				+	EDİRNE	1993
SULTANSUYU				+	MALATYA	1992
SUSUZ					ANKARA	1992
SÜLOĞLU		+		+	EDİRNE	1980
SÜRGÜ				+	MALATYA	1969
SÜTÇÜLER			+			1998
ŞABANÖZÜ-ÖDEK				+	ÇANKIRI	2002
ŞAHİNBURGAZ				+	BALIKESİR	1994
ŞAHİNLER				+	İZMİT	1991
ŞAMLI				+	BALIKESİR	1997
ŞEHİTLER				+	ISPARTA	1998
ŞEREFİYE				+	SİVAS	1996
ŞERİFBABA				+	MARDİN	1974
ŞEYHLİ				+	KAYSERİ	1992
ŞEYTANDERE				+	İZMİT	1983
TADIM				+	ELAZIĞ	1993
TAHTAKÖPRÜ		+		+	HATAY	1975
TAHTARLI	+				İZMİR	1996

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
TAKMAK				+	UŞAK	1984
TAŞÇILAR				+	KASTAMONU	1983
TAŞMANLI				+	SİNOP	1975
TAŞOLUK (AFYON)				+	AFYON	1998
TATLARİN				+	NEVŞEHİR	1966
TAVAKLI (ALEMŞAH)				+	ÇANAKKALE	2000
TAVAS				+	DENİZLİ	1997
TAYFUR	+				ÇANAKKALE	1985
TEFENNİ				+	BURDUR	1991
TEKİR				+	KAYSERİ	1990
TELME				+	GÜMÜŞHANE	1992
TEMREZLİ				+	TEKİRDAĞ	1994
TERCAN			+	+	ERZİNCAN	1989
TINAZTEPE				+	AFYON	1991
TOHMA-MEDİK			+		MALATYA	1998
TOPÇAM (AYDIN)		+		+	AYDIN	1984
TOPLUKONAK				+	GİRESUN	1994
TORTUM I			+		ERZURUM	1960
TÜRKMENLİ				+	EDİRNE	1997
ULUAĞAÇ				+	NİĞDE	1998
ULUBORLU		+		+	ISPARTA	1984
ULUDAĞ UNİ.YOL.ÇAT				+	BURSA	2003
ULUKÖY (AMASYA)				+	AMASYA	1983
ULUKÖY (ÇANAKKALE)				+	ÇANAKKALE	1993
ULUÖZ				+	TOKAT	1991
UNİVERSİTE I	+				SAMSUN	1980
UŞAKPINAR				+	BURSA	1999
UZGAÇ				+	EDİRNE	1997
UZUNLU		+		+	YOZGAT	1989
ÜÇBAŞ				+	ANKARA	1969

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
ÜÇÇAM				+	ESKİŞEHİR	2002
ÜÇPINAR				+	KİLİS	2001
ÜÇTEPE				+	SİVAS	1972
ÜRKMEZ				+	İZMİR	1989
ÜSKÜP				+	KIRKLARELİ	1990
Y.KARPUZLU				+	EDİRNE	1995
Y.MUHACİR				+	EDİRNE	1993
YAĞLIPINAR				+	ANKARA	1967
YAĞMURCA				+	EDİRNE	1991
YAHYASARAY				+	YOZGAT	1990
YAKACIK				+	AMASYA	2000
YALINTAŞ				+	NEVŞEHİR	1994
YALVAÇ				+	ISPARTA	1973
YAPIALTIN				+	SİVAS	1977
YAPILDAK				+	ESKİŞEHİR	1992
YAPRAKLI				+	BURDUR	1990
YARSELİ				+	HATAY	1989
YASSIALAN				+	SAMSUN	2001
YAYLADAĞ				+	HATAY	1998
YAYLAKAVAK				+	AYDIN	1996
YEDİKIR				+	AMASYA	1985
YELTEN				+	ANTALYA	1993
YENİCE(BURSA)				+	BURSA	1995
YENİCE (ESKİŞEHİR)			+		ESKİŞEHİR	1999
YENİHAYAT	+				ÇORUM	1997
YENİKÖY				+	AMASYA	1986
YENİKÖY				+	KIRŞEHİR	2004
YENİCEKÖY I				+	KÜTAHYA	1997
YEŞİLBÜK				+		1986
YEŞİLÇAT				+	AFYON	1988
YILDIZ				+	SİVAS	1998
YUKARIKARTAL				+	ESKİŞEHİR	1971
YUKARISÖĞÜT				+	ESKİŞEHİR	1988
YUMURTACI				+	KASTAMONU	1976

Table A.1 Dams In Operation in Turkey (continued)

Name of Dam	Domestic & Indutrial Water Supply	Flood Control	Energy	Irrigation	Location	In Operation
YÜREĞİR			+			1972
ZERNEK			+	+	VAN	1988
ZİNCİDERE				+	KAYSERİ	1991
ZÜLFİKAR				+	GAZİANTEP	1990

Table A.2 Classification of Dams For Single Purpose

	Number of Reservoirs	% of Reservoirs
Total Number of Reservoirs in Operation	**603**	100,00
# of Reservoirs Functioning For Dom.&Ind. Water Supply	55	9,12
# of Reservoirs Functioning For Flood Control	54	8,96
# of Reservoirs Functioning For Energy	92	15,26
# of Reservoirs Functioning For Irrigation	491	81,43
# of Reservoirs Functioning For Environmental Protection	2	0,33
# of Functioning For Fishering	2	0,33

Table A.3 Classification of Dams For Multi Purpose

Multipurpose Functions	Number of Reservoirs	% of Reservoirs
Dom.&Ind. Water Supply+Flood Control	4	0,66
Dom.&Ind. Water Supply+Flood Control+Energy	1	0,17
Dom.&Ind. Water Supply+Flood Control+Irrigation	4	0,66
Flood Control+Energy+Irrigation	8	1,33
Dom.&Ind. Water Supply+Energy+Irrigation	1	0,17
Dom.&Ind. Water Supply+Irrigation	14	2,32
Flood Control+Irrigation	35	5,80
Energy+Irrigation	12	1,99

APPENDIX B

CHECK OF Wt/MAR FOR TESTED RESERVOIRS

In order to calculate water yield Gould’s gamma distribution is used and the equation that is used in RESCON to calculate water yield is:

$$W_t = \frac{4 \cdot S_t \cdot V_{in} - Zpr^2 \cdot sd^2 + 4 \cdot Gd \cdot sd^2}{4 \cdot \left(S_t + \frac{Gd}{V_{in}} \cdot sd^2 \right)} = w(S_t) \tag{B.1}$$

In order to find until where above equation is valid rearrangement can be made for easy calculation as follows:

$$W_t = \frac{4 \cdot S_t \cdot V_{in} - Zpr^2 \cdot sd^2 + 4 \cdot Gd \cdot sd^2}{4 \cdot \left(\frac{S_t \cdot V_{in}}{V_{in}} + \frac{Gd \cdot sd^2}{V_{in}} \right)} = w(S_t) \tag{B.2}$$

$$W_t = \frac{4 \cdot S_t \cdot V_{in}^2 - Zpr^2 \cdot sd^2 \cdot V_{in} + 4 \cdot Gd \cdot sd^2 \cdot V_{in}}{4 \cdot \left(S_t \cdot V_{in} + Gd \cdot sd^2 \right)} = w(S_t) \tag{B.3}$$

$$W_t = \frac{4 \cdot S_t \cdot V_{in}^2 + 4 \cdot Gd \cdot sd^2 \cdot V_{in} - Zpr^2 \cdot sd^2 \cdot V_{in}}{4 \cdot S_t \cdot V_{in} + 4 \cdot Gd \cdot sd^2} = w(S_t) \tag{B.4}$$

$$\frac{W_t}{V_{in}} = 1 - \frac{Zpr^2 \cdot sd^2}{4 \cdot S_t \cdot V_{in} + 4 \cdot Gd \cdot sd^2} = w(S_t) \tag{B.5}$$

Critical St is the value that makes $\frac{W_t}{V_{in}} = 1 - \frac{Zpr^2 \cdot sd^2}{4 \cdot S_t \cdot V_{in} + 4 \cdot Gd \cdot sd^2} = 0{,}4$

$$\frac{Zpr^2 \cdot sd^2}{4 \cdot S_t \cdot V_{in} + 4 \cdot Gd \cdot sd^2} = 0{,}6 \tag{B.6}$$

$$\frac{Z_{pr}{}^{2} \cdot sd^{2}}{2.4} - \left[Gd \cdot sd^{2}\right] = S_{t} \cdot V_{in} \tag{B.7}$$

$$S_{t} = \frac{Zpr^{2} \cdot sd^{2}}{2.4V_{in}} - \frac{Gd \cdot sd^{2}}{V_{in}} \tag{B.8}$$

Table B.1 Calculation of Critical St for Tested Reservoirs

Dam	**Zpr**	**sd(m^3)**	**Vin**	**Gd**	**St(m^3)**
Çubuk I	2.33	6 550 000	65 500 000	1.50	499 137
Borçka	2.33	565 500 000	5 655 000 000	1.50	43 093 456
İvriz	2.33	10 400 000	104 000 000	1.50	792 523
Bayındır	2.33	390 000	3 900 000	1.50	29 720
Capacity Ratio For Wt/Vin=0,4					
7.03					%
10.29					%
0.99					%
0.42					%
Reservoir Capacities					
Çubuk I	7 100 000				m^3
Borçka	418 950 000				m^3
İvriz	80 000 000				m^3
Bayındır	7 000 000				m^3

Description of Variables	
Zpr	Standardized Normal Variate at pr*100%
sd	Standard Deviation of Annual Run-off
Vin	Mean Annual Run-off (includes all sources to reservoir)
Gd	Gould's Correction Factor

APPENDIX C

SENSITIVITY ANALYSIS FOR TARBELA DAM MADE BY RESCON TEAM

Table C.1 Geometric Parameters for Tarbela Dam

Parameter Description	**Parameter Symbol**
Original (initial) capacity of the reservoir	S_0
Existing storage capacity of the reservoir	S_e
Reservoir length at the normal pool elevation	L
Representative bottom width for the reservoir	W_{bot}
Minimum bed elevation just upstream of dam	El_{min}
Water surface elevation at flushing gates during flushing	El_f
Elevation of top water level in reservoir (normal pool)	El_{max}
Available head = normal pool elevation minus tail water elevation	h
Representative side slope for the reservoir	SS_{res}

Table C.2 Physical Parameters Varied In Addition To Geometry Changes

Parameter Description	**Parameter Symbol**	**Range of Values**
Mean annual sediment inflow mass	M_{in}	0.1-3.0% of inflow
Multiplier for reservoir and its sediment (Tsinghua University Method)	Y	180, 300, 650, 1600 (depending on site)
Representative discharge passing through reservoir during flushing	Q	10-3 000m3/s (depending on site)
Frequency of flushing events	N	1-15 year intervals
Duration of flushing after complete drawdown	T_f	1 day-2 months
Coefficient of Variation of Annual Run-off volume	C_v	0.1-2.0
Number of pipes used for hydrosuction sediment removal	NP	1-3 pipes
Pipe diameter for hydrosuction	D	1-3.5 feet

Table C.3 Constant Parameters In Sensitivity Analysis for Tarbela Dam

Parameter Description	**Parameter Symbol**
Density of in-situ reservoir sediment.	r_d
Estimated reservoir water temperature.	T
Sediment type category to be removed by hydrosuction (medium sand/smaller or gravel).	Type
Reservoir similar to Chinese reservoirs? “3”: if reservoir sediments are significantly larger than median grain size (d50)=0,1mm or if the reservoir has been impounded for more than 10 years without sediment removal. Use “1”: if otherwise. A value of “3” was used throughout the analysis.	ANS
Is reservoir yield ever used for hydroelectric power?	HP
Sediment type for Brune Curve calculations.	Brune Curve

Table C.4 Assumed Constant Removal Parameters for Tarbela Dam

Parameter Description	Parameter Symbol	Assumed Value
Acceptable probability of failure to provide reservoir yield in a given year (as decimal).	pr	0,01
Maximum fraction of total yield that is allowed to be used in HSRS operations.	YA	1
Maximum percent of capacity loss allowable at any time in reservoir. Allowable loss must be greater than the existing loss.	cl	75%
Percent of accumulated sediment dredged per event.	ASD	80%
Percent of accumulated sediment trucked per event.	AST	80%
Concentration by weight of sediment removed to water removed by traditional dredging.	Cw	30%

Table C.5 Economic Parameter Assumptions for Tarbela Dam

Parameter Description	**Parameter Symbol**	**Assumed Value**
If dam being considered is an existing dam enter 0. If the dam is a new construction project, enter 1.	E	0
Unit Cost of Construction. This cost is estimated using S_0 specified in Reservoir Geometry.	c	Default Calculation
Cost of Dam Construction. The default cost is estimated as unit cost of construction times initial reservoir storage volume (C2 = S0*c*E).	C2	Default Calculation
Reservoir (Dam) Operation and Maintenance Coefficient	omc	0.01
Dam Salvage Value Coefficient	a	0
Discount Rate (decimal)	r	0.05
Price of Net Reservoir Yield.	P1	\$0.01/m^3
Unit Value of Water Used released downstream during actual flushing operations (water lost during drawdown is internally assigned a value of zero).	PF	\$0.005/m^3
Unit value of water released downstream of dam in river by hydrosuction operations.	PH	\$0.005/m^3
Unit value of water used in dredging operations.	PD	\$0.005/m^3
Unit cost for hydrosuction operations expressed as \$/m3 of sediment removed.	CH	\$5/m^3
Unit cost of traditional dredging	CD	Default Calculation

Table C.6 Sensitivity to Value of Unit Reservoir Yield (P1=\$0.1/m3 to P1=\$0.2/m3), Tarbela Dam

Possible Strategies	**Technique**	**Change in NPV (\$ 1000 million)**	**Change in NPV (%)**
Non-sustainable(Decommissioning)-with No Removal	N/A	138.4	100
Non-sustainable(Decommissioning)-with Partial Removal	HSRS	138.4	100
Non-sustainable(Run-off-River)-with No Removal	N/A	138.7	100
Non-sustainable(Run-off-River)-with Partial Removal	HSRS	138.7	100
Sustainable	Flushing	139.2	100
Sustainable	HSRS	N/A	N/A
Sustainable	Dredging	142.3	101
Sustainable	Trucking	138.8	115

	Change in LTC(million m^3)	**Change in LTC(%)**
Long term reservoir capacity for Flushing	0	0
Long term reservoir capacity for HSRS	N/A	N/A
Long term reservoir capacity for Dredging	+1.089	31
Long term reservoir capacity for Trucking	+405	6

Table C.7 Sensitivity to Discount Rate (r reduced from 5% to 3%), Tarbela Dam

Possible Strategies	**Technique**	**Change in NPV ($ 1000 million)**	**Change in NPV (%)**
Non-sustainable(Decommissioning)-with No Removal	N/A	70.2	51
Non-sustainable(Decommissioning)-with Partial Removal	HSRS	70.2	51
Non-sustainable(Run-off-River)-with No Removal	N/A	72.2	52
Non-sustainable(Run-off-River)-with Partial Removal	HSRS	72.2	52
Sustainable	Flushing	81.7	59
Sustainable	HSRS	N/A	N/A
Sustainable	Dredging	89.1	63
Sustainable	Trucking	37.9	31

	Change in LTC(million m^3)	**Change in LTC(%)**
Long term reservoir capacity for Flushing	0	0
Long term reservoir capacity for HSRS	N/A	N/A
Long term reservoir capacity for Dredging	2 025	33
Long term reservoir capacity for Trucking	270 056	4

Table C.8 Sensitivity to Operation and Maintenance Coefficient (omc=0.01 to omc=0.05), Tarbela Dam

Possible Strategies	**Technique**	**Change in NPV ($ 1000 million)**	**Change in NPV (%)**
Non-sustainable(Decommissioning)-with No Removal	N/A	-1.801	-1.3
Non-sustainable(Decommissioning)-with Partial Removal	HSRS	-1.801	-1.3
Non-sustainable(Run-off-River)-with No Removal	N/A	-1.830	-1.3
Non-sustainable(Run-off-River)-with Partial Removal	HSRS	-1.830	-1.3
Sustainable	Flushing	-1.830	-1.3
Sustainable	HSRS	N/A	N/A
Sustainable	Dredging	-1.830	-1.3
Sustainable	Trucking	-1.830	-1.5

Table C.9 Sensitivity to Cost of Removal Parameters (S2, PH, CD, CT) (S2 increased from 0.5 to 0.75), (PH decreased from $0.005 to $0.003) (CD decreased from $2.62 to $2.00/m3), (CT decreased from $50 to $40/m3), Tarbela Dam

Possible Strategies	**Technique**	**Change in NPV ($ 1000 million)**	**Change in NPV (%)**
Non-sustainable(Decommissioning)-with No Removal	N/A	0	0
Non-sustainable(Decommissioning)-with Partial Removal	HSRS	0.2	0
Non-sustainable(Run-off-River)-with No Removal	N/A	0	0
Non-sustainable(Run-off-River)-with Partial Removal	HSRS	0.2	0
Sustainable	Flushing	1 367.2	1.0
Sustainable	HSRS	N/A	N/A
Sustainable	Dredging	264.6	0.2
Sustainable	Trucking	3 310.16	2.7

	Change in LTC(million m^3)	**Change in LTC(%)**
Long term reservoir capacity for Flushing	0	0
Long term reservoir capacity for HSRS	N/A	N/A
Long term reservoir capacity for Dredging	810	13
Long term reservoir capacity for Trucking	135	2

APPENDIX D

Table D.1 Dams with Sediment Measurements in Turkey

DSİ REGION	NAME OF DAM	OPERATIN G LEVELS		RESERVOIR VOLUME (hm^3)					
				MEASUREMENT YEAR					
				1	2	3	4	5	6
I	GÖLBAŞI			1969	1977				
		MAX	128,50	11,8	12,7				
		MIN	119,00	5,3	5,1				
	DOĞANCI			1983	1987	1992			
		MAX	333,00	38,1	36,9	42,5			
		MIN	312,00	11,1	11,1	14,6			
II	DEMİRKÖPRÜ			1971	1977				
		MAX	475,00	1060,2	1060,2				
		MIN	460,00	280,5	290,8				
	MARMARA			1969	1976				
		MAX	79,20	320,5	320,7				
		MIN	73,60	27,2	28,8				
	SEVİŞLER			1976	1986				
		MAX	162,10	126,5	120,5				
		MIN	126,50	8,1	7,1				
	BULDAN			1972	1976	1986			
		MAX	500,00	54,6	54,7	44,8			
		MIN	471,00	5,2	3,6	3,0			
	AFŞAR			1977	1986				
		MAX	259,25	91,3	83,9				
		MIN	236,75	6,4	5,2				
III	PORSUK			1970	1976	2001			
		MAX	892,85	517,4	465,0	454,4			
		MIN	860,05	17,5	19,0	16,2			
IV	ALTINAPA			1974	1979				
		MAX	1250,0	24,0	18,9				
		MIN	1239,5	2,2	1,2				
	BEYŞEHİR			1962	2000				
		MAX	1125,40	5263,1	5337,6				
		MIN	1121,03	2591,4	2411,3				

Tablo D.1 Dams with Sediment Measurements in Turkey (continued)

DSİ REGION	NAME OF DAM	OPERATING LEVELS		RESERVOIR VOLUME (hm^3)					
				MEASUREMENT YEAR					
				1	2	3	4	5	6
IV	SİLLE			1969	1974	1979			
		MAX	1267,86	3,0	2,7	2,5			
		MIN	1253,50	0,4	0,1	0,0			
	ÇAVUŞÇU			1971	1977	1980			
		MAX	1027,90	178,8	177,5	184,1			
		MIN	1021,60	19,7	18,2	22,6			
	APA			1967	1972	1977			
		MAX	1054,04	167,2	166,9	171,6			
		MIN	1034,34	6,7	6,8	6,5			
	GÜMÜŞLER			1967	1978				
		MAX	1352,00	3,8	4,0				
		MIN	1335,00	0,1	0,0				
	GEBERE			1941	1965	1977			
		MAX	1720,30	2,7	2,4				
		MIN	1707,00	0,5	0,0	2,5			
	AYRANCI			1958	1966	1977	1980		
		MAX	1193,00	30,1	30,9	31,7	30,9		
		MIN	1170,00	1,3	1,1	1,6	0,7		
	MAMASIN			1973	1978	1982	1991		
		MAX	1107,19	165,8	185,8	173,4	154,6		
		MIN	1084,46	5,7	5,5	6,5	5,0		
V	HİRFANLI			1969	1972	1977			
		MAX	851,00	6218,6	6224,3	5750,0			
		MIN	842,00	4126,6	4129,1	3705,3			
	HASANLAR			1972	1977	1978			
		MAX	255,50	50,9	50,6	50,6			
		MIN	227,50	4,4	2,8	2,8			
	KESİKKÖPRÜ			1974	1979				
		MAX	785,55	97,4	88,1				
		MIN	772,48	37,9	31,1				

Tablo D.1 Dams with Sediment Measurements in Turkey (continued)

DSİ REGION	NAME OF DAM	OPERATING LEVELS		RESERVOIR VOLUME (hm^3)					
				MEASUREMENT YEAR					
				1	2	3	4	5	6
V	SARIYAR			1951	1970				
		MAX	475,00	1901,2	1698,6				
		MIN	465,00	859,5	756,6				
	KURTBOĞAZI			1967	1975	1980	1985	1998	
		MAX	961,00	102,7	95,2	93,9	96,8	92,1	
		MIN	931,00	8,7	6,4	7,1	8,0	5,8	
	ÇUBUK I			1936	1943	1967	1973	1983	
		MAX	907,61	9,6	5,9	6,1	5,9	5,6	
		MIN	895,71	0,4	0,0	0,1	0,0	0,0	
	ÇUBUK II			1964	1973	1978	1983		
		MAX	1113,0	25,0	22,7	23,8	22,4		
		MIN	1074,0	1,9	0,6	0,6	0,3		
	BAYINDIR			1965	1970	1980			
		MAX	986,5	8,1	7,0	6,6			
		MIN	972,0	1,0	0,7	0,4			
VI	SEYHAN			1966	1971	1976	1980	1986	1991
		MAX	67,50	1238,8	1029,2	924,4	883,5	878,9	865,4
		MIN	49,00	300,0	221,2	149,5	138,9	159,5	159,9
	KALECİK			1985	1991				
		MAX	535,00	38,8	32,5				
		MIN	493,00	3,1	1,3				
	KOZAN			1972	1976				
		MAX	274,00	168,4	148,0				
		MIN	224,00	4,0	0,4				
	MEHMETLİ			1975	1986				
		MAX	203,00	54,9	59,2				
		MIN	170,00	3,6	3,6				
VII	ALMUS			1972	1977				
		MAX	804,5	1007,2	1006,8				
		MIN	767,37	151,5	151,5				

Tablo D.1 Dams with Sediment Measurements in Turkey (continued)

DSİ REGION	NAME OF DAM	OPERATING LEVELS		RESERVOIR VOLUME (hm^3)					
				MEASUREMENT YEAR					
				1	2	3	4	5	6
IX	SÜRGÜ			1971	1975	2001			
		MAX	1309,60	75,4	67,9	70,1			
		MIN	1288,50	10,7	8,8	8,7			
	ÇİP			1968	1971	1976			
		MAX	1004,50	7,1	7,0	6,0			
		MIN	997,00	1,8	1,5	1,1			
X	DEVEGEÇİDİ			1972	1977	1980			
		MAX	757,00	202,3	207,5	219,1			
		MIN	739,50	7,3	7,5	7,2			
XI	ALTINYAZI			1973	1978	1997			
		MAX	39,20	38,7	38,9	36,8			
		MIN	27,50	3,2	2,8	2,1			
	KADIKÖY			1966	1975	1997			
		MAX	82,00	65,1	65,6	56,5			
		MIN	63,45	3,2	2,3	1,0			
	KARAİDEMİR			1980	1997				
		MAX	104,40	122,5	111,6				
		MIN	91,80	10,5	6,5				
	SÜLOĞLU			1980	1983	1997			
		MAX	202,80	51,4	50,2	45,3			
		MIN	177,00	3,2	3,3	2,2			
XII	DAMSA			1971	1975				
		MAX	1225,00		7,1				
		MIN	1212,00	2,9	0,6				
	SARIMSAKLI			1972	1977				
		MAX	1205,00	32,0	34,8				
		MIN	1183,00	3,4	2,5				
	BOZKIR			1967	1972				
		MAX	1126,30	6,1	5,9				
		MIN	1109,30	0,8	0,8				

Tablo D.1 Dams with Sediment Measurements in Turkey (continued)

DSİ REGION	NAME OF DAM	OPERATING LEVELS		RESERVOIR VOLUME (hm^3)					
				MEASUREMENT YEAR					
				1	2	3	4	5	6
XII	TATLARIN			1972	1976				
		MAX	1151,00	1,5	2,2				
		MIN	1143,65	1,0	0,9				
	ÇOĞUN			1973	1978				
		MAX	1106,30	23,4	22,6				
		MIN	1094,25	2,9	2,3				
XIII	KORKUTELİ			1967	1979				
		MAX	1065,50	38,9	40,2				
		MIN	1039,00	3,4	3,3				
	OYMAPINAR			1984	1989				
		MAX	184,00	349,6	296,7				
		MIN	166,00	264,9	220,2				
XIV	ÖMERLİ			1966	1979				
		MAX	62,00	388,3	357,0				
		MIN	46,00	120,7	121,7				
	DURUSU			1973	1977	1982			
		MAX	4,50	199,8	204,7	186,3			
		MIN	1,00	102,6	98,6	42,1			
XVII	SELEVİR			1966	1977				
		MAX	1092,50	74,7	60,7				
		MIN	1075,50	9,9	4,7				
XVIII	YALVAÇ			1974	1979				
		MAX	1183,85	13,1	12,1				
		MIN	1168,00	1,6	1,1				
	SEYİTLER			1962	1974	1979			
		MAX	1047,75	38,2	36,7	38,0			
		MIN	1036,50	5,2	3,9	4,6			
XIX	KILIÇKAYA			1989	1995				
		MAX	850,00	1400,1	1400,4				
		MIN	815,00	275,1	267,6				

Tablo D.1 Dams with Sediment Measurements in Turkey (continued)

DSİ REGION	NAME OF DAM	OPERATING LEVELS		RESERVOIR VOLUME (hm^3)					
				MEASUREMENT YEAR					
				1	2	3	4	5	6
XX	KARTALKAYA			1967	1974	1980	1985	1989	
		MAX	717,70	206,5	193,1	180,8	180,2	169,8	
		MIN	684,50	5,9	5,6	0,6	0,4	0,0	
XXI	IŞIKLI			1975	1982	1990	1998		
		MAX	820,60	225,7	197,1	222,3	212,9		
		MIN	817,50	51,9	33,9	50,4	46,2		
	KEMER			1968	1974	1979	1989	1998	
		MAX	287,45	457,0	407,1	389,4	372,5	358,5	
		MIN	248,65	125,0	85,7	79,3	66,8	57,6	
	MUMCULAR			1989	1994				
		MAX	60,00	18,2	19,4				
		MIN	40,00	1,0	1,8				
	TOPÇAM			1985	1992				
		MAX	110,70	79,5	83,5				
		MIN	81,70	6,8	9,8				
XXV	ÇAYGÖREN			1971	1978	1983			
		MAX	271,50	171,8	165,6	159,5			
		MIN	242,00	17,0	14,8	14,0			
	ATIKHİSAR			1977	1983				
		MAX	61,00	55,5	52,5				
		MIN	38,00	1,0	0,9				
	SARIBEYLER			1985	1990				
		MAX	238,37	19,8	19,9				
		MIN	216,50	1,1	1,0				

APPENDIX E

BAYINDIR DAM USER INPUTS AND RESCON RESULTS

Table E.1 Bayındır Dam Input Data

Parameter	Unit	Value	Source
Reservoir Geometry			
S_0	m^3	7 000 000	(Yılmaz, 2003)
S_e	m^3	5 170 000	(Yılmaz, 2003)
W_{bot}	m	105.0	Measured from drawings (Dams in Turkyey, 1991)
SS_{res}		2.0	Measured from drawings (Dams in Turkyey, 1991)
El_{max}	m	985.0	Dams in Turkyey (1991)
El_{min}	m	960.0	Dams in Turkyey (1991)
El_f	m	970	Assumed due to not knowing bottom outlet sill elevation
L	m	3 000	Measured from map
Water Characteristics			
V_{in}	m^3	3 900 000	(Yılmaz, 2003)
Sediment Characteristics			
M_{in}	metric tonnes	63 500	(Yılmaz, 2003)
Removal Parameters			
Q_f	m^3/s	5	Bottom outlet capacity, (Dams in Turkyey, 1991)
Economic Parameters			
r	decimal	0.08	Koyuncu (2005)
Mr	decimal	0.03	Koyuncu (2005)
P1	$\$/m^3$	0.35	Koyuncu (2005)
omc	$\$/m^3$	0.085	Koyuncu (2005)
CD	$\$/m^3$	3.00	Koyuncu (2005)
CT	$\$/m^3$	2.62	Koyuncu (2005)

Table E.2 Economic Results for Bayındır Dam

Possible Strategies	**Technique**	**Aggregate Net Present Value**
Do nothing	N/A	0.000
Nonsustainable (Decommissioning) with Partial Removal	HSRS	Partial Removal with HSRS is technically infeasible. See Total Removal with HSRS
Nonsustainable (Run-of-River) with No Removal	N/A	-1 500 402
Nonsustainable (Run-of-River) with Partial Removal	HSRS	Partial Removal with HSRS is technically infeasible. See Total Removal with HSRS
Sustainable	Flushing	-1 499 060
Sustainable	HSRS	-2 978 471
Sustainable	Dredging	-4 310 891
Sustainable	Trucking	-4 932 516

Table E.3 Economic Conclusion for Bayındır Dam

Strategy yielding the highest aggregate net benefit:	Do nothing
Technique yielding the highest aggregate net benefit:	N/A
The highest aggregate net benefit is: $	0.000E+00

Table E.4 Nonsustainable (Decommission) for Bayındır Dam

# of years until Partial Removal Option with HSRS is practiced:	Not applicable	years
# of years until retirement for Decommission-with no Removal Option:	0	years
# of years until retirement for Decommission: Partial Removal Option with HSRS:	Not applicable	years
Remaining reservoir capacity at retirement for Decommission-with No Removal Option:	5 170 000	m^3
Remaining reservoir capacity at retirement for Decommission: Partial Removal Option with HSRS:	Not applicable	m^3

Table E.5 Annual Fund Results for Bayındır Dam

Annual Retirement Fund Payment for nonsustainable options: Decommission	0	$
Annual Retirement Fund Payment for nonsustainable options: Partial Removal with HSRS	Not applicable	$

Table E.6 Nonsustainable (Run-of-River) for Bayındır Dam

# of years until Partial Removal Option with HSRS is practiced:	Not applicable	years
Approximate # of years until dam is silted for Run-of-River-with No Removal Option:	114	years
Approximate # of years until dam is silted for Run-of-River-with Partial Removal Option:	Not applicable	years

Table E.7 Long Term Capacity Values for Bayındır Dam

Long term reservoir capacity for Flushing	1 313 957	m^3
Long term reservoir capacity for HSRS	5 124 196	m^3
Long term reservoir capacity for Dredging	5 122 034	m^3
Long term reservoir capacity for Trucking	5 717 487	m^3

Table E.8 Phase I Lengths for Bayındır Dam

Approximate # of years until dam is sustained at long term capacity for Flushing	86	years
Approximate # of years until dam is sustained at long term capacity for HSRS	2	years
Approximate # of years until dam is sustained at long term capacity for Dredging	2	years
Approximate # of years until dam is sustained at long term capacity for Trucking	2	years

Table E.9 # of Flushing Events in Phase I, Bayındır Dam

Approximate # of Flushing events until dam is sustained at long term capacity	0	times

Table E.10 Frequency of Removal for Bayındır Dam

Strategy	Technique	Cycle/Phase	Frequency of Removal (years)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	Not applicable
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	Not applicable
Sustainable	Flushing	Phase I	No Flushing occurs
Sustainable	Flushing	Phase II	1
Sustainable	HSRS	Annual cycle	1
Sustainable	Dredging	Phase I	2
Sustainable	Dredging	Phase II	1
Sustainable	Trucking	Phase I	2
Sustainable	Trucking	Phase II	14

Table E.11 Sediment Removed per Event for Bayındır Dam

Strategy	Technique	Cycle/Phase	Sediment Removed (m^3)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	Not applicable
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	Not applicable
Sustainable	Flushing	Phase I	0
Sustainable	Flushing	Phase II	45 804
Sustainable	HSRS	Annual cycle	45 804
Sustainable	Dredging	Phase I	N/A
Sustainable	Dredging	Phase II	45 804
Sustainable	Trucking	Phase I	N/A
Sustainable	Trucking	Phase II	641 257

Table E.12 Optimal Values of ASD/AST and CLF/CLD/CLT, Bayındır Dam

Technique	ASD/AST(%)	CLF/CLD/CLT
Flushing(Phase I)	N/A	82
Flushing(Phase II)	1	
HSRS	2	27
Dredging(Phase I)	N/A	27
Dredging(Phase II)	2	
Trucking(Phase I)	N/A	27
Trucking(Phase II)	34	

Table E.13 Technical Comments for Bayındır Dam

Average expected concentration of sediment to water flushed per flushing event:	51 547	ppm
Average expected concentration of sediment to water released downstream of dam per hydrosuction event:	1 412	ppm
Average expected concentration of sediment to water removed from reservoir per dredging event:	300 000	ppm
Note: Because reservoir is dewatered prior to a trucking event and river is diverted during a trucking event, material removed is moist sediment (negligible water)		

Table E.14 Number of Truck Loads Required to Complete Sustainable Sediment Trucking Removal Option, Bayındır Dam

Truck Model Number	m^3/Truck Load	Number of Loads (Phase I)	Number of Loads (Phase II)
769D	16.2	N/A	39 584
771D	18.0	N/A	35 625
773D	26.0	N/A	24 664
775D	31.0	N/A	20 686
777D	42.1	N/A	15 232
785B	57.0	N/A	11 250
789B	73.0	N/A	8 784
793C	96.0	N/A	6 680

Table E.15 Number of Dredges Required to Complete Sustainable Sediment Dredging Removal Option, Bayındır Dam

Volume Removed per Dredge (m^3/Dredge)	No. of Dredges (Phase I)	No. of Dredges (Phase II)
11 000 000	N/A	1

Table E.16 Unit Cost of Sediment Removal for Bayındır Dam

	Phase I	Phase II
Unit Cost of Dredging($/$m^3$)	N/A	3.00
Unit Cost of HSRS($/$m^3$)	1.94	

APPENDIX F

BORCKA DAM USER INPUTS AND RESCON RESULTS

Table F.1 Borcka Dam Input Data

Parameter	**Unit**	**Value**	**Source**
Reservoir Geometry			
S_0	m^3	418 950 000	Borcka Introductory Booklet (2003)
S_e	m^3	418 950 000	Borcka Introductory Booklet (2003)
W_{bot}	m	385.0	Borcka Introductory Booklet (2003)
SS_{res}		1.0	Borcka Introductory Booklet (2003)
El_{max}	m	187.0	Borcka Introductory Booklet (2003)
El_{min}	m	103.0	Borcka Introductory Booklet (2003)
El_f	m	113	Assumed due to not knowing bottom outlet sill elevation
L	m	30 500	Borcka Introductory Booklet (2003)
Water Characteristics			
V_{in}	m^3	5 655 000 000	Borcka Introductory Booklet (2003)
Sediment Characteristics			
M_{in}	metric tonnes	10 501 677	Borcka Introductory Booklet (2003)
Removal Parameters			
Q_f	m^3/s	287	Borcka Introductory Booklet (2003)
Economic Parameters			
r	decimal	0.095	Koyuncu (2005)
Mr	decimal	0.03	Koyuncu (2005)
P1	$\$/m^3$	0.18	Koyuncu (2005)
omc	$\$/m^3$	0.1	Koyuncu (2005)
CD	$\$/m^3$	3.00	Koyuncu (2005)
CT	$\$/m^3$	2.62	Koyuncu (2005)

Table F.2 Economic Results for Borcka Dam

Possible Strategies	Technique	Aggregate Net Present Value
Do nothing	N/A	7 488 543 414
Nonsustainable (Decommissioning) with Partial Removal	HSRS	7 488 918 784
Nonsustainable (Run-of-River) with No Removal	N/A	7 490 195 435
Nonsustainable (Run-of-River) with Partial Removal	HSRS	7 490 570 806
Sustainable	Flushing	7 368 404 656
Sustainable	HSRS	Total Removal with HSRS is technically infeasible. See Partial Removal with HSRS
Sustainable	Dredging	7 590 185 391
Sustainable	Trucking	7 208 603 765

Table F.3 Economic Conclusion for Borcka Dam

Strategy yielding the highest aggregate net benefit:		Sustainable
Technique yielding the highest aggregate net benefit:		Dredging
The highest aggregate net benefit is:	$	7.590E+09

Table F.4 Nonsustainable (Decommission) for Borcka Dam

# of years until Partial Removal Option with HSRS is practiced:	1	years
# of years until retirement for Decommission-with no Removal Option:	63	years
# of years until retirement for Decommission: Partial Removal Option with HSRS:	63	years
Remaining reservoir capacity at retirement for Decommission-with No Removal Option:	4 828 508	m^3
Remaining reservoir capacity at retirement for Decommission: Partial Removal Option with HSRS:	6 499 638	m^3

Table F.5 Annual Fund Results for Borcka Dam

Annual Retirement Fund Payment for nonsustainable options: Decommission	551 682	$
Annual Retirement Fund Payment for nonsustainable options: Partial Removal with HSRS	551 682	$

Table F.6 Nonsustainable (Run-of-River) for Borcka Dam

# of years until Partial Removal Option with HSRS is practiced:	1	years
Approximate # of years until dam is silted for Run-of-River-with No Removal Option:	64	years
Approximate # of years until dam is silted for Run-of-River-with Partial Removal Option:	64	years

Table F.7 Long Term Capacity Values for Borcka Dam

Long term reservoir capacity for Flushing	193 200 773	m^3
Long term reservoir capacity for HSRS	Not applicable	m^3
Long term reservoir capacity for Dredging	366 363 144	m^3
Long term reservoir capacity for Trucking	399 229 929	m^3

Table F.8 Phase I Lengths for Borcka Dam

Approximate # of years until dam is sustained at long term capacity for Flushing	56	years
Approximate # of years until dam is sustained at long term capacity for HSRS	Not applicable	years
Approximate # of years until dam is sustained at long term capacity for Dredging	8	years
Approximate # of years until dam is sustained at long term capacity for Trucking	12	years

Table F.9 # of Flushing Events in Phase I, Borcka Dam

Approximate # of Flushing events until dam is sustained at long term capacity	14	times

Table F.10 Frequency of Removal for Borcka Dam

Strategy	Technique	Cycle/Phase	Frequency of Removal (years)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	1
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	1
Sustainable	Flushing	Phase I	3
Sustainable	Flushing	Phase II	1
Sustainable	HSRS	Annual cycle	Not applicable
Sustainable	Dredging	Phase I	8
Sustainable	Dredging	Phase II	1
Sustainable	Trucking	Phase I	12
Sustainable	Trucking	Phase II	10

Table F.11 Sediment Removed per Event for Borcka Dam

Strategy	Technique	Cycle/Phase	Sediment Removed (m^3)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	26 954
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	26 954
Sustainable	Flushing	Phase I	10 165 604
Sustainable	Flushing	Phase II	6 573 357
Sustainable	HSRS	Annual cycle	Not applicable
Sustainable	Dredging	Phase I	N/A
Sustainable	Dredging	Phase II	6 573 357
Sustainable	Trucking	Phase I	N/A
Sustainable	Trucking	Phase II	65 733 570

Table F.12 Optimal Values of ASD/AST and CLF/CLD/CLT, Borcka Dam

Technique	ASD/AST(%)	CLF/CLD/CLT
Flushing(Phase I)	Varies	55
Flushing(Phase II)	3	
HSRS	N/A	N/A
Dredging(Phase I)	N/A	13
Dredging(Phase II)	13	
Trucking(Phase I)	N/A	19
Trucking(Phase II)	83	

Table F.13 Technical Comments for Borcka Dam

Average expected concentration of sediment to water flushed per flushing event:	86 091	ppm
Average expected concentration of sediment to water released downstream of dam per hydrosuction event:	199	ppm
Average expected concentration of sediment to water removed from reservoir per dredging event:	300 000	ppm
Note: Because reservoir is dewatered prior to a trucking event and river is diverted during a trucking event, material removed is moist sediment (negligible water)		

The physical maximum limit for removal of sediment with trucking, MT, specified in the User Input page, is being exceeded. Decrease AST or increase MT.

Table F.14 Number of Truck Loads Required to Complete Sustainable Sediment Trucking Removal Option, Borcka Dam

Truck Model Number	m^3/Truck Load	Number of Loads (Phase I)	Number of Loads (Phase II)
769D	16.2	N/A	4 057 628
771D	18.0	N/A	3 651 865
773D	26.0	N/A	2 528 214
775D	31.0	N/A	2 120 438
777D	42.1	N/A	1 561 367
785B	57.0	N/A	1 153 221
789B	73.0	N/A	900 460
793C	96.0	N/A	684 725

Table F.15 Number of Dredges Required to Complete Sustainable Sediment Dredging Removal Option, Borcka Dam

Volume Removed per Dredge (m^3/Dredge)	No. of Dredges (Phase I)	No. of Dredges (Phase II)
11.000.000	N/A	1

Table F.16 Unit Cost of Sediment Removal for Borcka Dam

	Phase I	Phase II
Unit Cost of Dredging($/$m^3$)	N/A	3.00
Unit Cost of HSRS($/$m^3$)	6.18	

APPENDIX G

IVRIZ DAM USER INPUTS AND RESCON RESULTS

Table G.1 Ivriz Dam Input Data

Parameter	**Unit**	**Value**	**Source**
Reservoir Geometry			
S_0	m^3	80 000 000	DSI Web Page (2005)
S_e	m^3	75 122 000	Sönmez and Dinçsoy (2002)
W_{bot}	m	75.0	Measured from Drawings (Dams in Turkey, 1991)
SS_{res}		2.0	Measured from Drawings (Dams in Turkey, 1991)
El_{max}	m	1155.0	DSI Web Page (2005)
El_{min}	m	1114.8	DSI Web Page (2005)
El_f	m	1121	Assumed due to not knowing bottom outlet sill elevation
L	m	32 000	Sönmez and Dinçsoy (2002)
Water Characteristics			
V_{in}	m^3	104 000 000	Sönmez and Dinçsoy (2002)
Sediment Characteristics			
M_{in}	metric tonnes	340 200	Sönmez and Dinçsoy (2002)
Removal Parameters			
Q_f	m^3/s	55	Sönmez and Dinçsoy (2002)
Economic Parameters			
r	decimal	0.08	Koyuncu (2005)
Mr	decimal	0.03	Koyuncu (2005)
P1	$\$/m^3$	0.35	Koyuncu (2005)
omc	$\$/m^3$	0.10	Koyuncu (2005)
CD	$\$/m^3$	3.00	Koyuncu (2005)
CT	$\$/m^3$	2.62	Koyuncu (2005)

Table G.2 Economic Results for Ivriz Dam

Possible Strategies	Technique	Aggregate Net Present Value
Do nothing	N/A	43 347 725
Nonsustainable (Decommissioning) with Partial Removal	HSRS	43 333 978
Nonsustainable (Run-of-River) with No Removal	N/A	43 347 725
Nonsustainable (Run-of-River) with Partial Removal	HSRS	43 333 978
Sustainable	Flushing	43 347 011
Sustainable	HSRS	Total Removal with HSRS is technically infeasible, See Partial Removal with HSRS
Sustainable	Dredging	41 485 803
Sustainable	Trucking	38 115 009

Table G.3 Economic Conclusion for Ivriz Dam

Strategy yielding the highest aggregate net benefit:	Do nothing
Technique yielding the highest aggregate net benefit:	N/A
The highest aggregate net benefit is: $	4.335E+07

Table G.4 Nonsustainable (Decommission) for Ivriz Dam

# of years until Partial Removal Option with HSRS is practiced:	322	years
# of years until retirement for Decommission-with no Removal Option:	324	years
# of years until retirement for Decommission: Partial Removal Option with HSRS:	323	years
Remaining reservoir capacity at retirement for Decommission-with No Removal Option:	907 001	m^3
Remaining reservoir capacity at retirement for Decommission: Partial Removal Option with HSRS:	910 600	m^3

Table G.5 Annual Fund Results for Ivriz Dam

Annual Retirement Fund Payment for nonsustainable options: Decommission	0	$
Annual Retirement Fund Payment for nonsustainable options: Partial Removal with HSRS	0	$

Table G.6 Nonsustainable (Run-of-River) for Ivriz Dam

# of years until Partial Removal Option with HSRS is practiced:	326	years
Approximate # of years until dam is silted for Run-of-River-with No Removal Option:	328	years
Approximate # of years until dam is silted for Run-of-River-with Partial Removal Option:	327	years

Table G.7 Long Term Capacity Values for Ivriz Dam

Long term reservoir capacity for Flushing	47 065 739	m^3
Long term reservoir capacity for HSRS	Not applicable	m^3
Long term reservoir capacity for Dredging	73 653 030	m^3
Long term reservoir capacity for Trucking	78 535 314	m^3

Table G.8 Phase I Lengths for Ivriz Dam

Approximate # of years until dam is sustained at long term capacity for Flushing	137	years
Approximate # of years until dam is sustained at long term capacity for HSRS	Not applicable	years
Approximate # of years until dam is sustained at long term capacity for Dredging	26	years
Approximate # of years until dam is sustained at long term capacity for Trucking	26	years

Table G.9 # of Flushing Events in Phase I, Ivriz Dam

Approximate # of Flushing events until dam is sustained at long term capacity	0	times

Table G.10 Frequency of Removal for Ivriz Dam

Strategy	Technique	Cycle/Phase	Frequency of Removal (years)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	1
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	1
Sustainable	Flushing	Phase I	No Flushing occurs
Sustainable	Flushing	Phase II	1
Sustainable	HSRS	Annual cycle	Not applicable
Sustainable	Dredging	Phase I	26
Sustainable	Dredging	Phase II	1
Sustainable	Trucking	Phase I	26
Sustainable	Trucking	Phase II	21

Table G.11 Sediment Removed per Event for Ivriz Dam

Strategy	Technique	Cycle/Phase	Sediment Removed (m^3)
Nonsustainable-with Partial Removal	HSRS	Annual cycle	3 599
Run-of-River (Nonsustainable)-with Partial Removal	HSRS	Annual cycle	3 599
Sustainable	Flushing	Phase I	0
Sustainable	Flushing	Phase II	244 114
Sustainable	HSRS	Annual cycle	Not applicable
Sustainable	Dredging	Phase I	N/A
Sustainable	Dredging	Phase II	244 114
Sustainable	Trucking	Phase I	N/A
Sustainable	Trucking	Phase II	5 126 398

Table G.12 Optimal Values of ASD/AST and CLF/CLD/CLT, Ivriz Dam

Technique	ASD/AST(%)	CLF/CLD/CLT
Flushing(Phase I)	N/A	41
Flushing(Phase II)	1	
HSRS	1	N/A
Dredging(Phase I)	68	8
Dredging(Phase II)	4	
Trucking(Phase I)	N/A	8
Trucking(Phase II)	89	

Table G.13 Technical Comments for Ivriz Dam

Average expected concentration of sediment to water flushed per flushing event:	19 471	ppm
Average expected concentration of sediment to water released downstream of dam per hydrosuction event:	40	ppm
Average expected concentration of sediment to water removed from reservoir per dredging event:	300 000	ppm
Note: Because reservoir is dewatered prior to a trucking event and river is diverted during a trucking event, material removed is moist sediment (negligible water)		

Table G.14 Number of Truck Loads Required to Complete Sustainable Sediment Trucking Removal Option, Ivriz Dam

Truck Model Number	m^3/Truck Load	Number of Loads (Phase I)	Number of Loads (Phase II)
769D	16.2	N/A	316 444
771D	18.0	N/A	284 800
773D	26.0	N/A	197 169
775D	31.0	N/A	165 368
777D	42.1	N/A	121 767
785B	57.0	N/A	89 937
789B	73.0	N/A	70 225
793C	96.0	N/A	53 400

Table G.15 Number of Dredges Required to Complete Sustainable Sediment Dredging Removal Option, Ivriz Dam

Volume Removed per Dredge (m^3/Dredge)	No. of Dredges (Phase I)	No. of Dredges (Phase II)
11.000.000	N/A	1

Table G.16 Unit Cost of Sediment Removal for Ivriz Dam

	Phase I	Phase II
Unit Cost of Dredging($/$m^3$)	N/A	3.00
Unit Cost of HSRS($/$m^3$)	46.31	

APPENDIX H

MAPS OF BASINS IN TURKEY

There are 26 catchment areas in Turkey. These are given in Figure H.1 ~ Figure H.32.

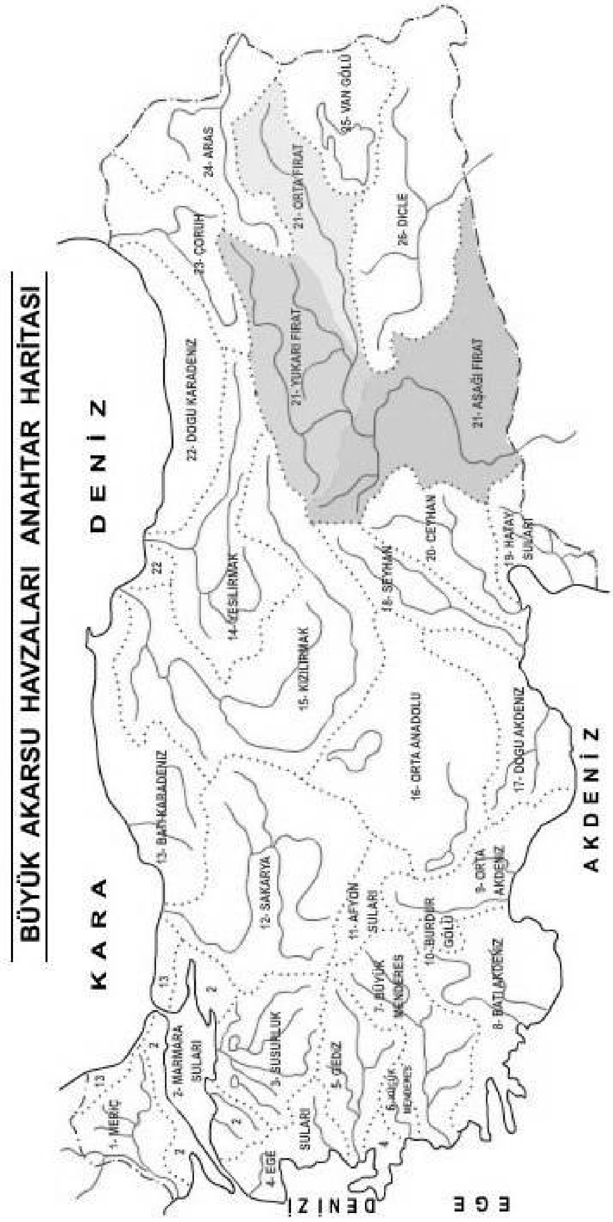

Figure H.1 Layout of Basins of Tureky

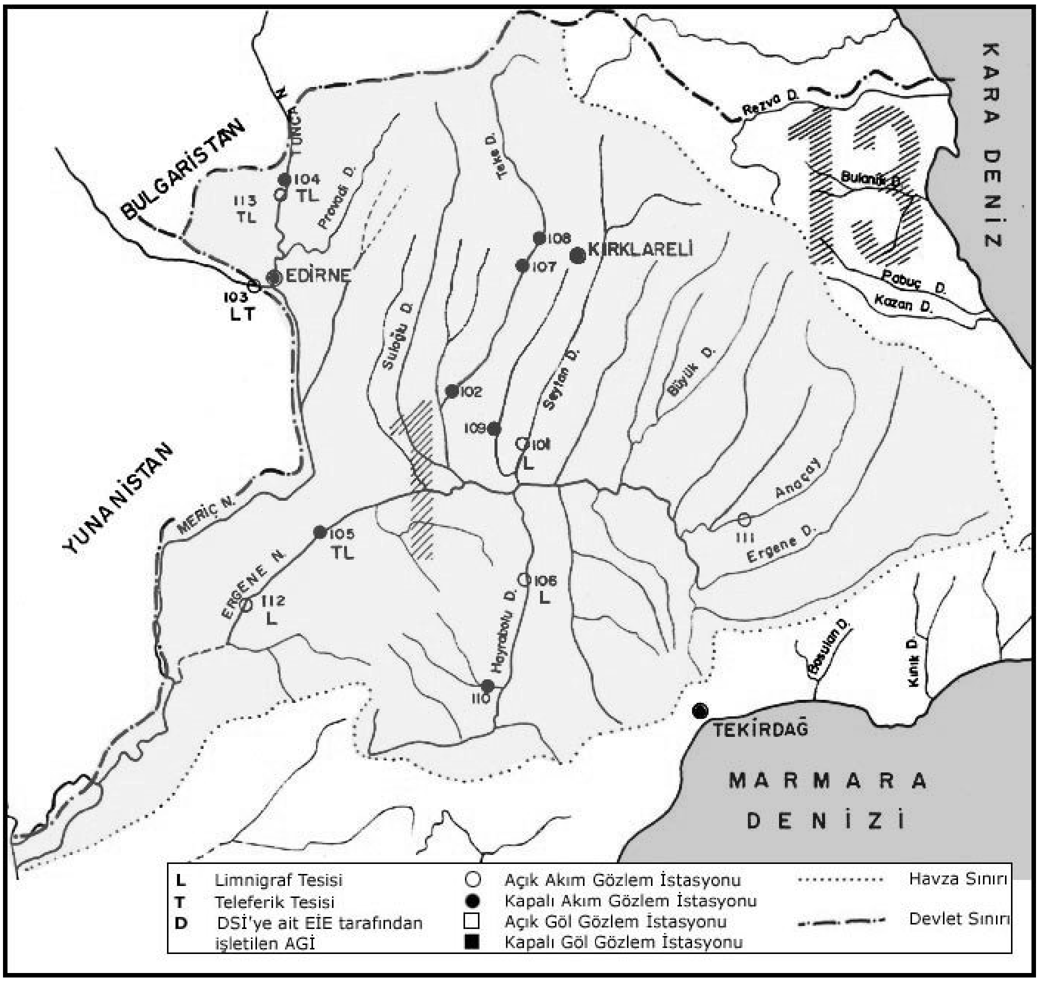

Figure H.2 Meric Basin (Basin #1)

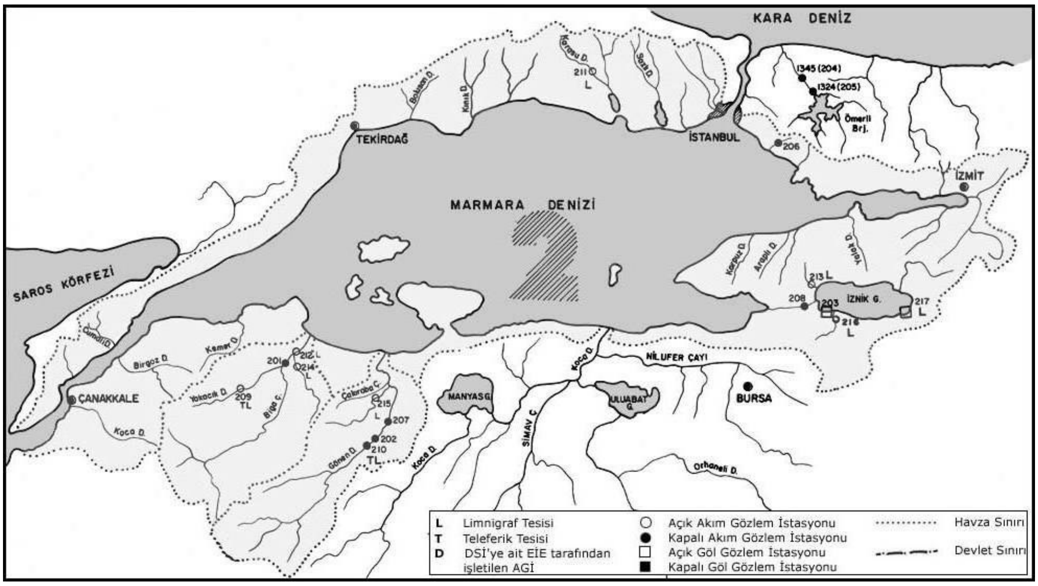

Figure H.3 Marmara Basin (Basin #2)

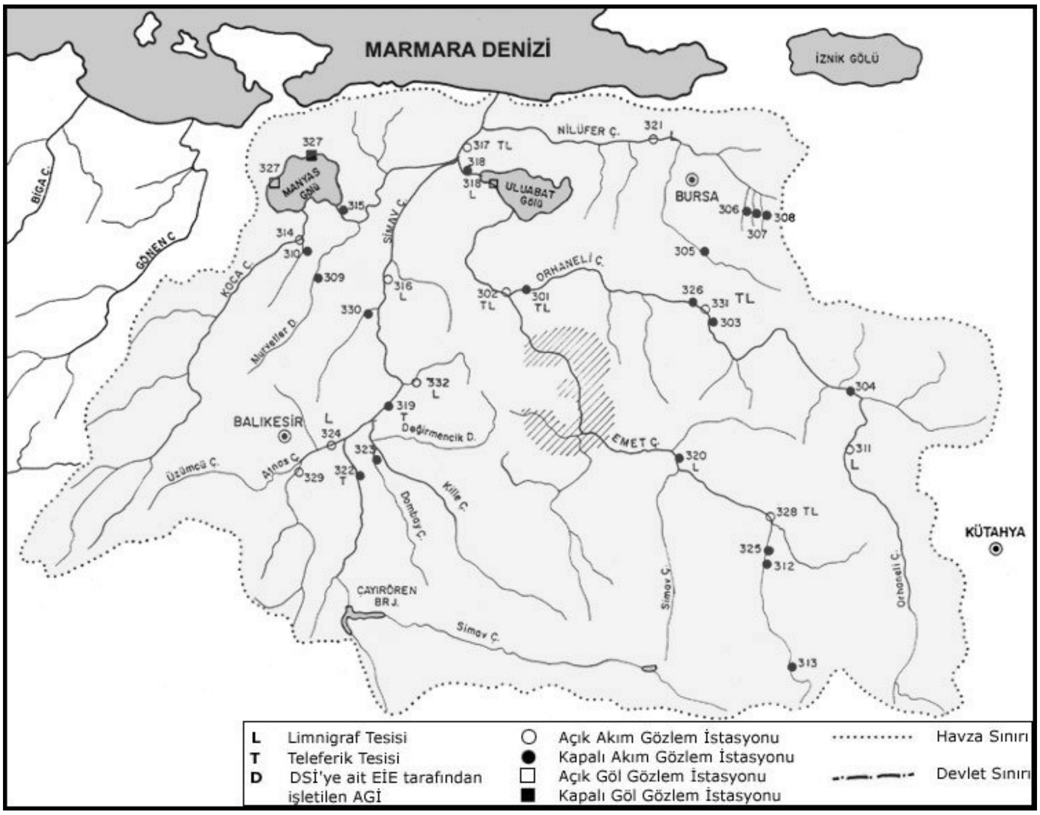

Figure H.4 Susurluk Basin (Basin #3)

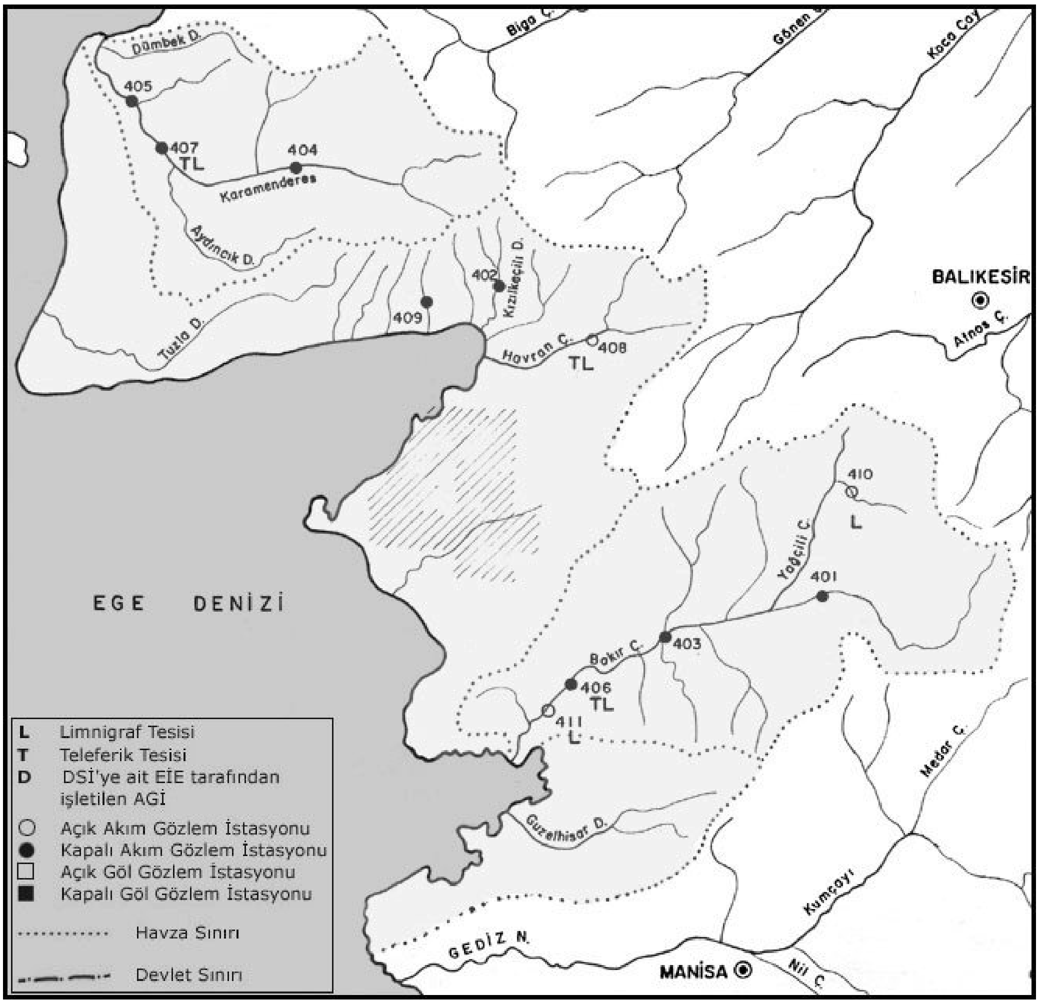

Figure H.5 Aegean Basin (Basin #4)

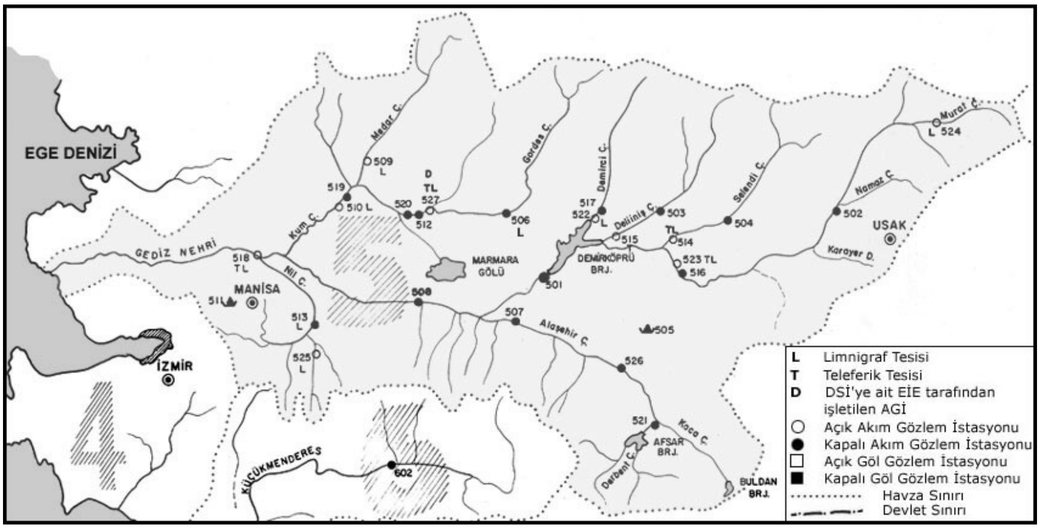

Figure H.6 Gediz Basin (Basin #5)

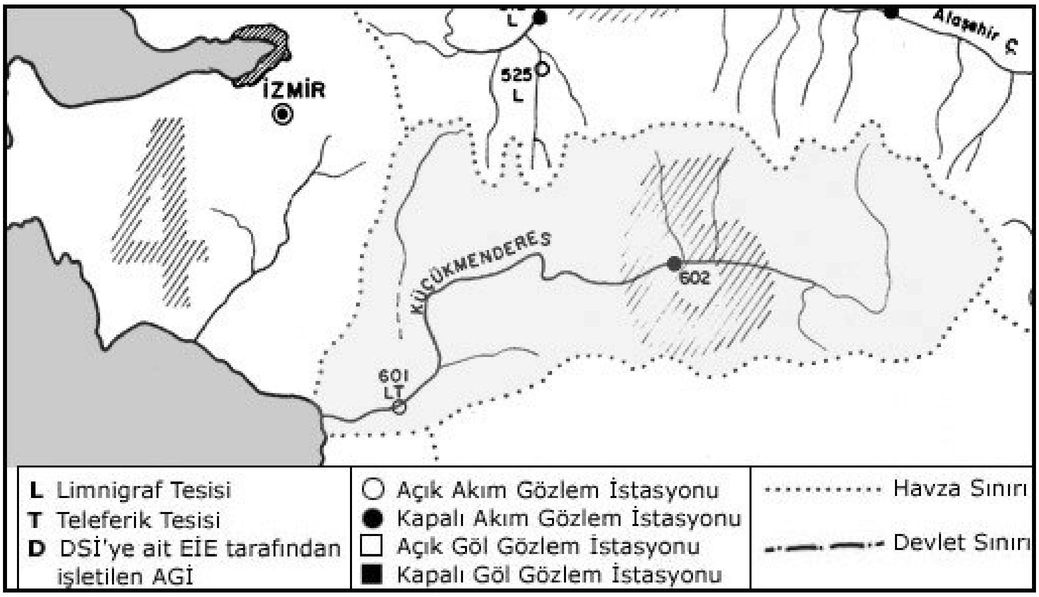

Figure H.7 Small Meander Basin (Basin #6)

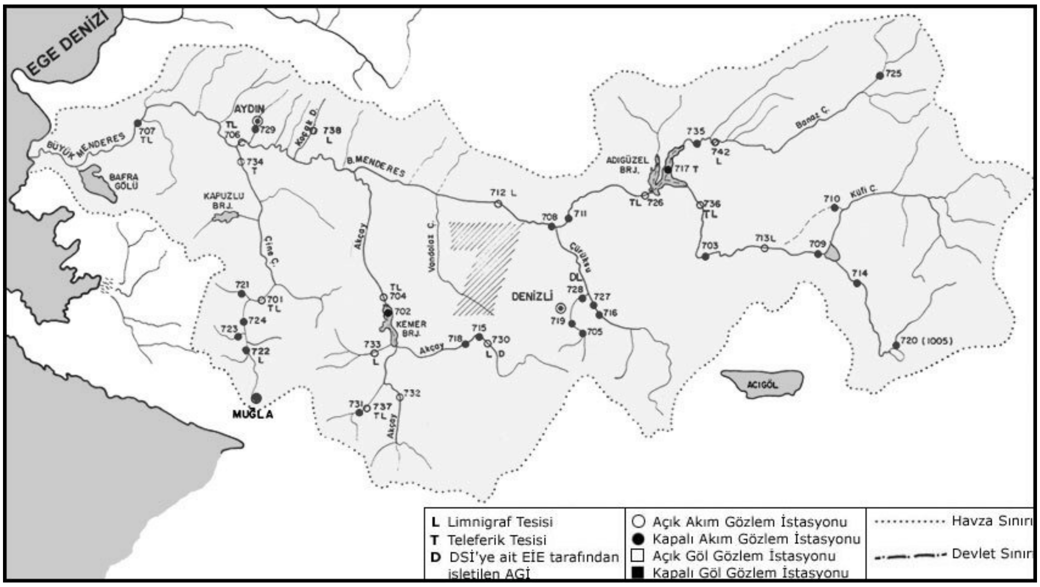

Figure H.8 Great Meander Basin (Basin #7)

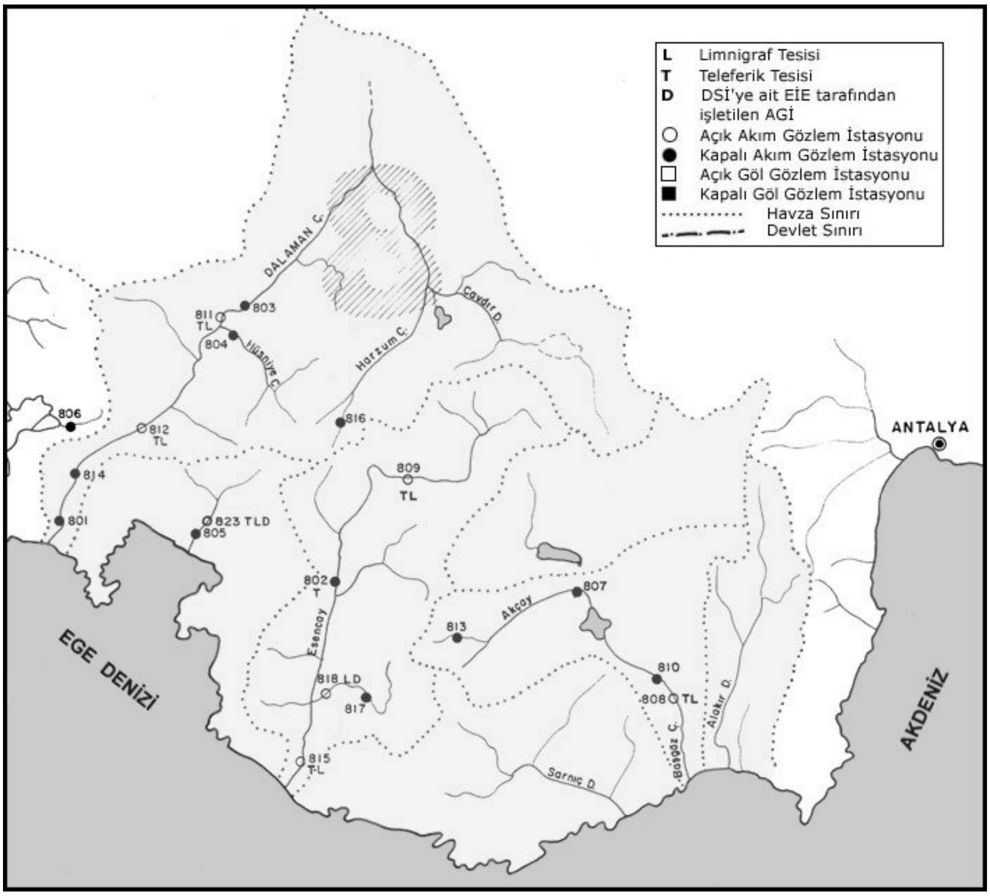

Figure H.9 West Mediterranean Basin (Basin #8)

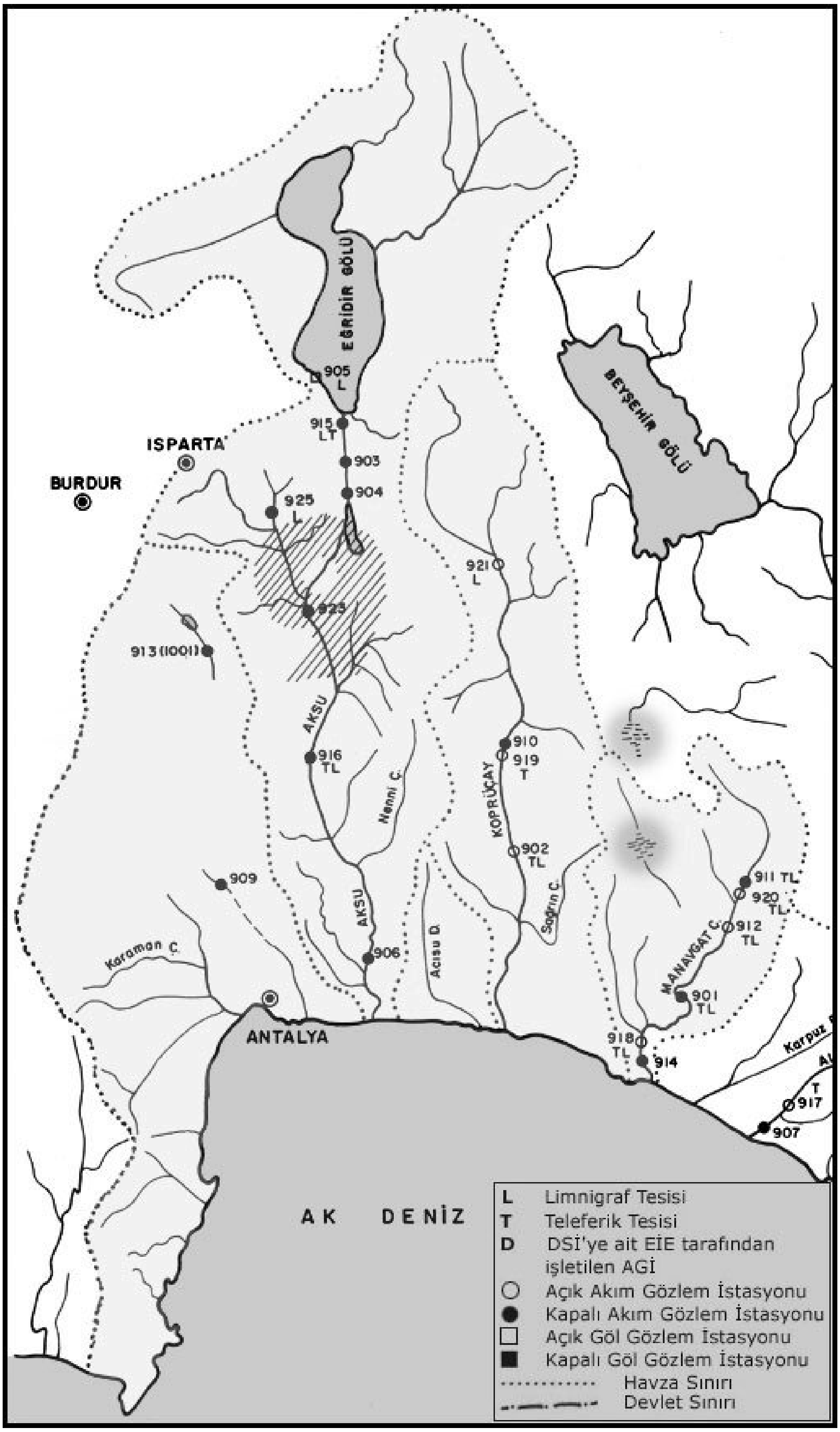

Figure H.10 Middle Mediterranean Basin (Basin #9)

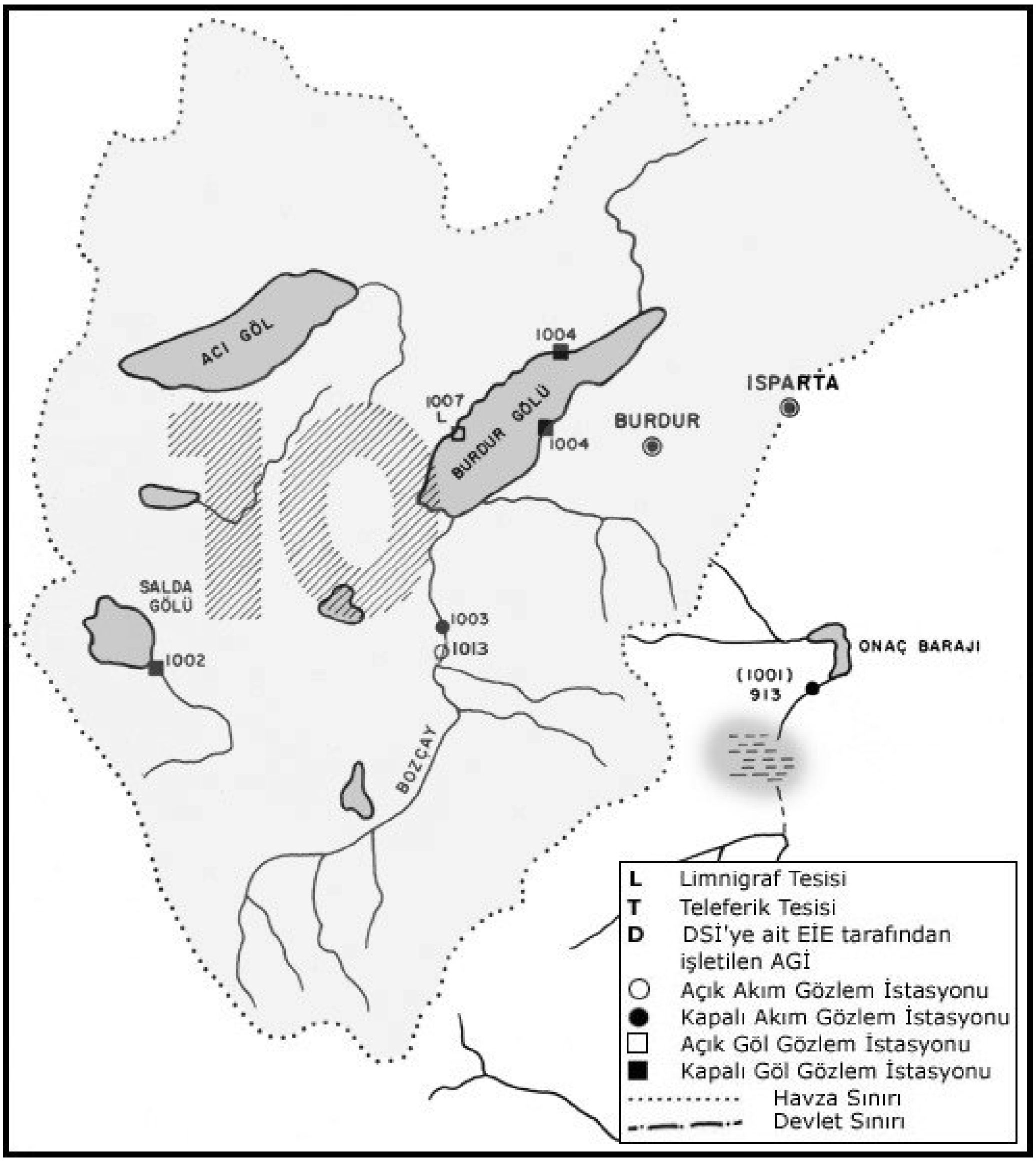

Figure H.11 Burdur Lake Basin (Basin #10)

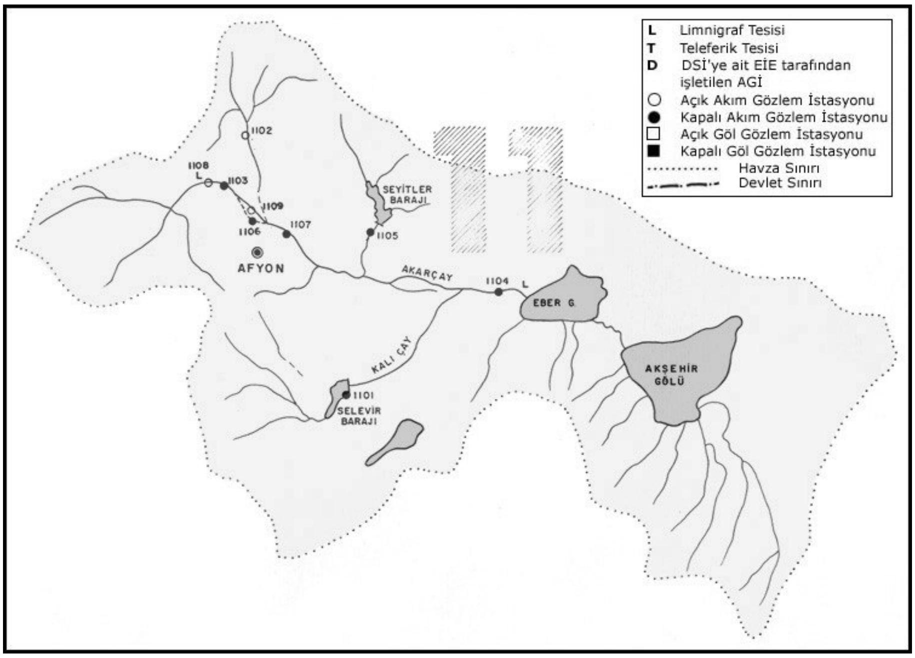

Figure H.12 Afyon Basin (Basin #11)

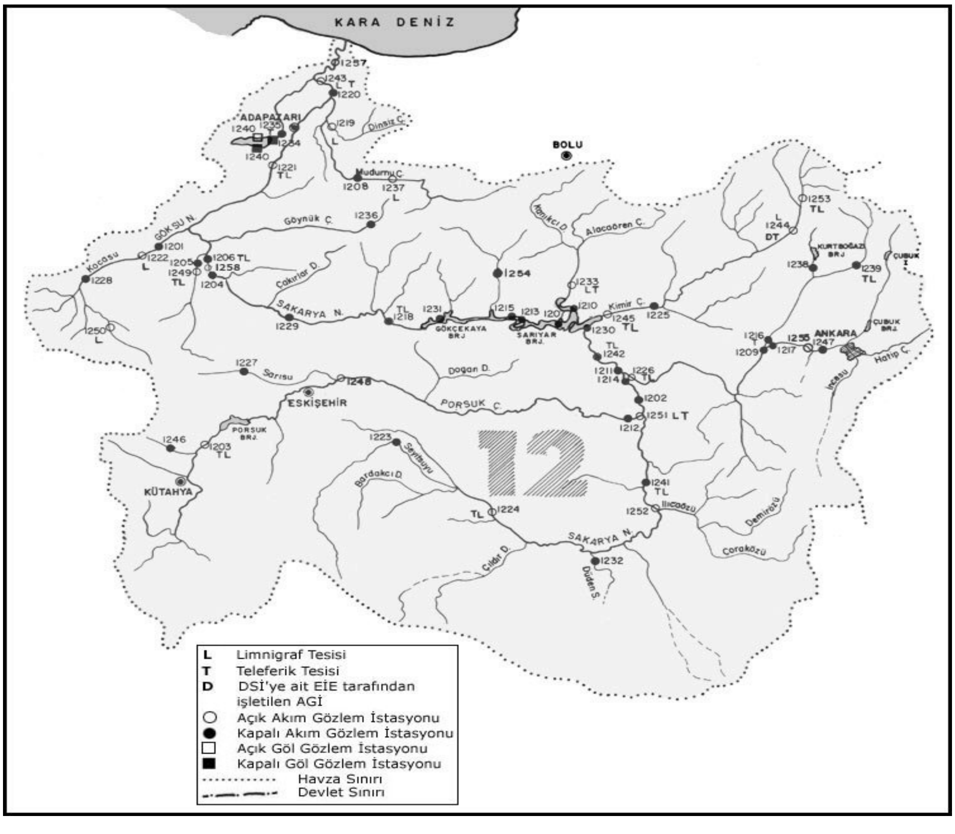

Figure H.13 Sakarya Basin (Basin #12)

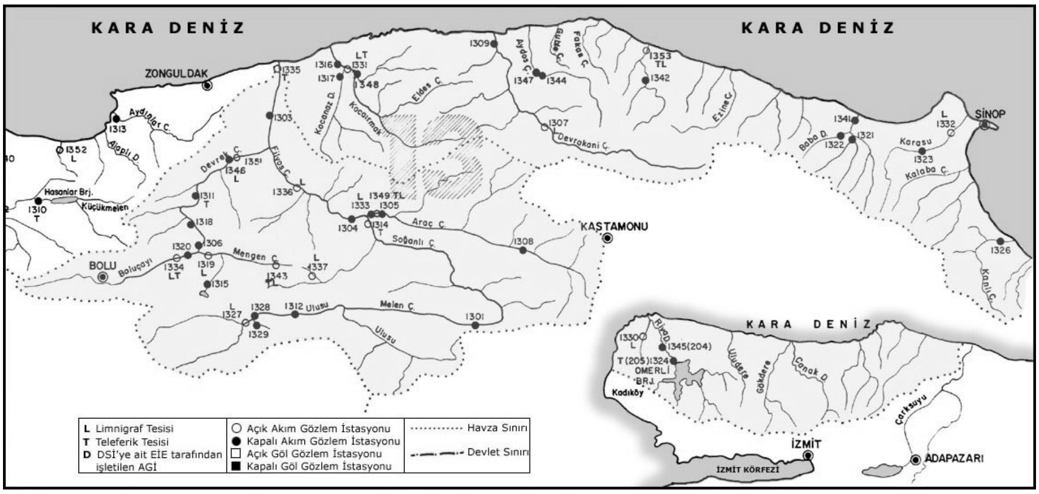

Figure H.14 West Black Sea Basin – Anatolian Part (Basin #13)

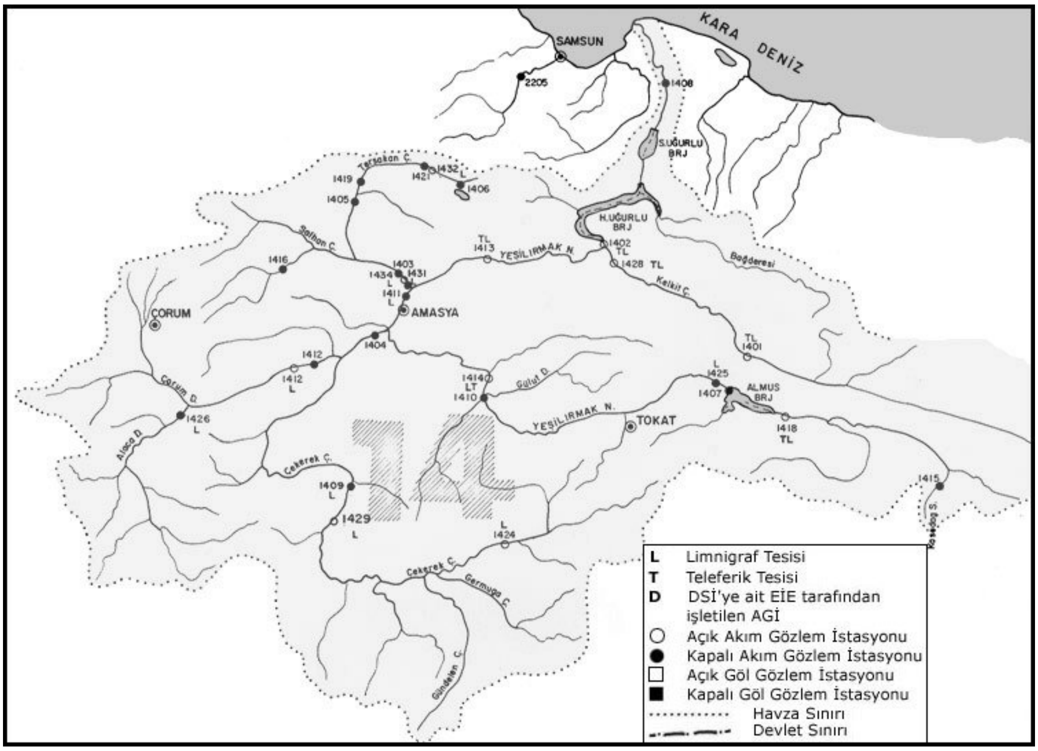

Figure H.15 West Yesilirmak Basin (Basin #14)

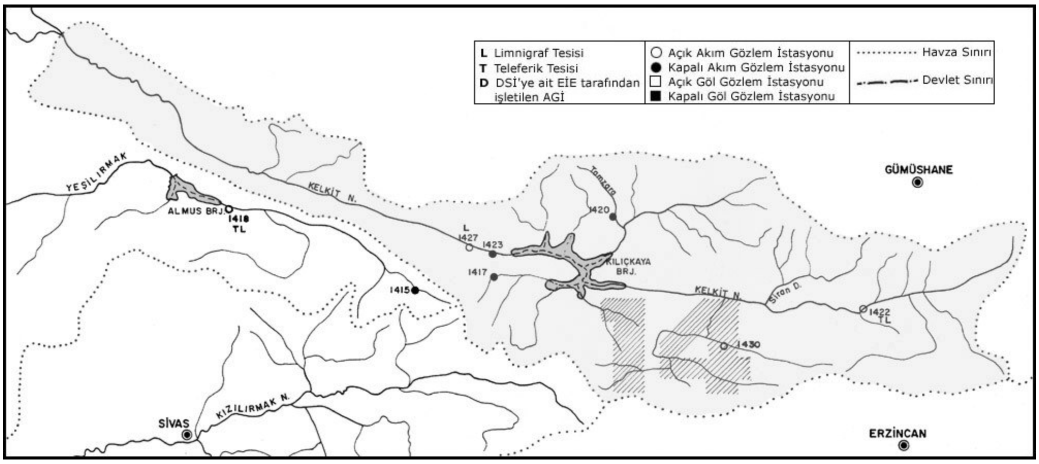

Figure H.16 East Yesilirmak Basin (Basin #14)

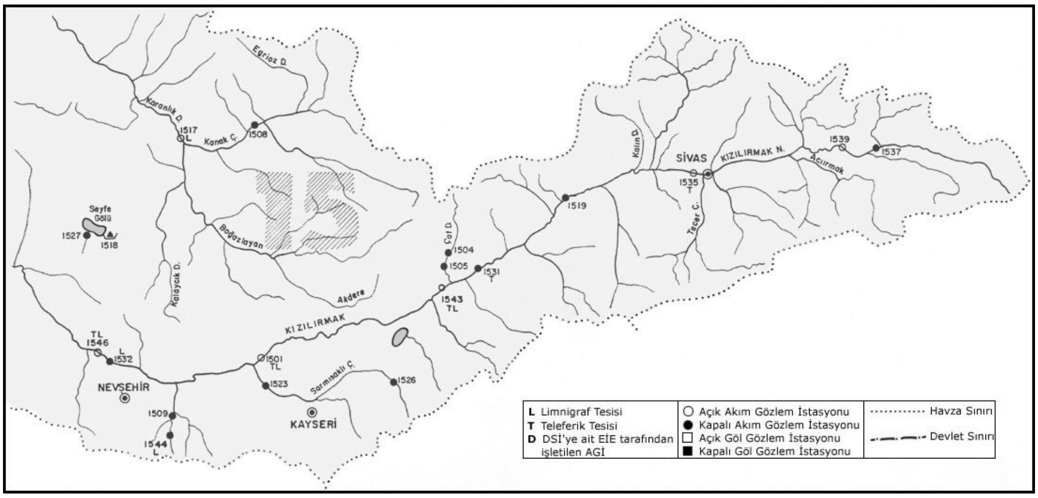

Figure H.17 South Kizilirmak Basin (Basin #15)

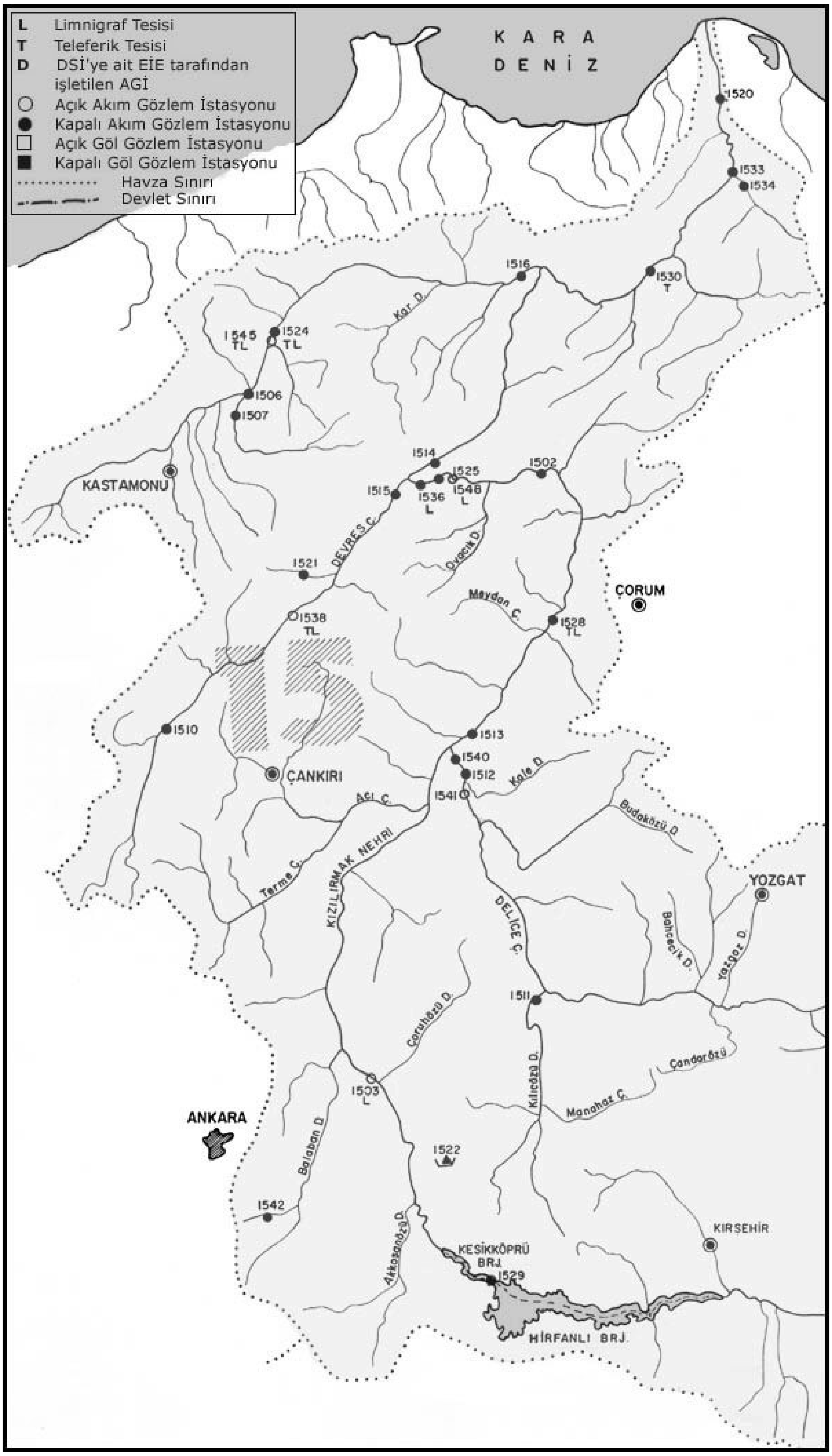

Figure H.18 North Kizilirmak Basin (Basin #15)

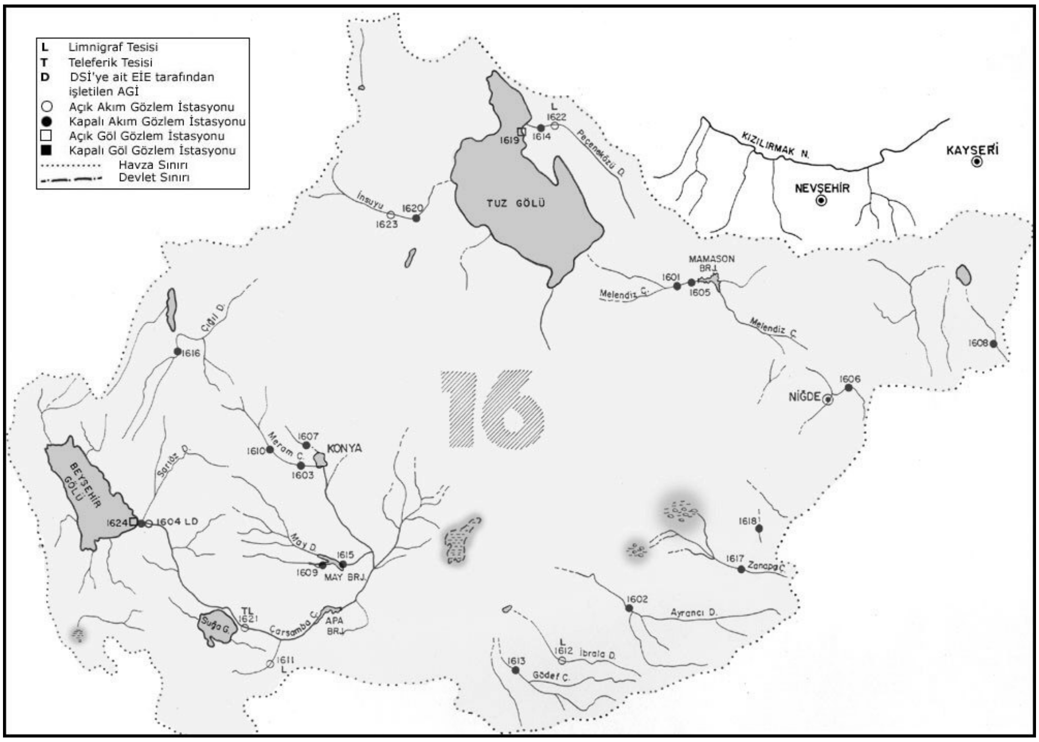

Figure H.19 Middle Anatolian Basin (Basin #16)

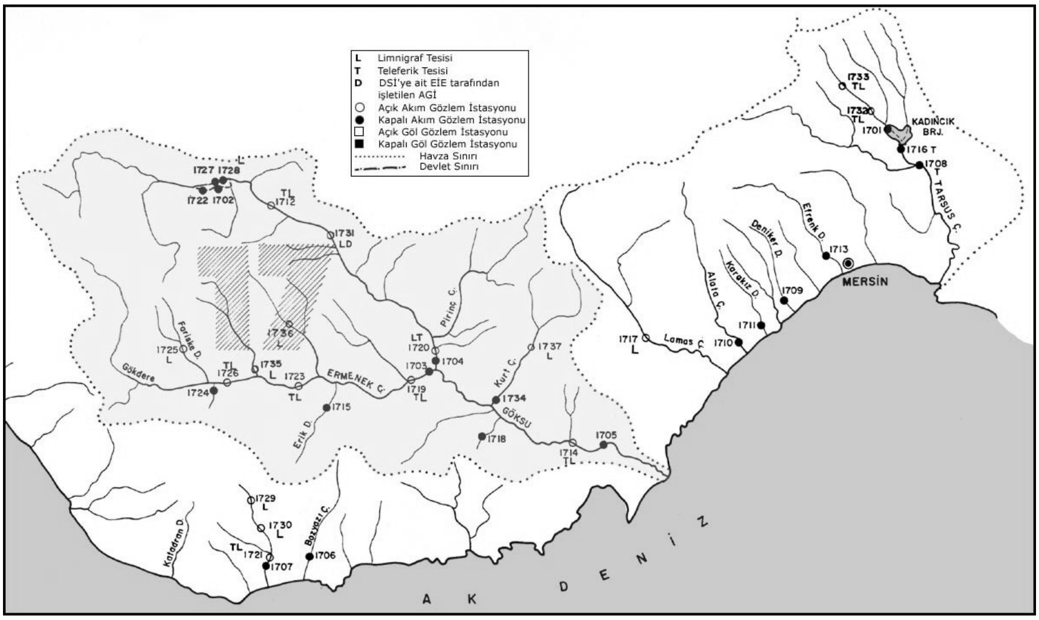

Figure H.20 East Mediterranean Basin (Basin #17)

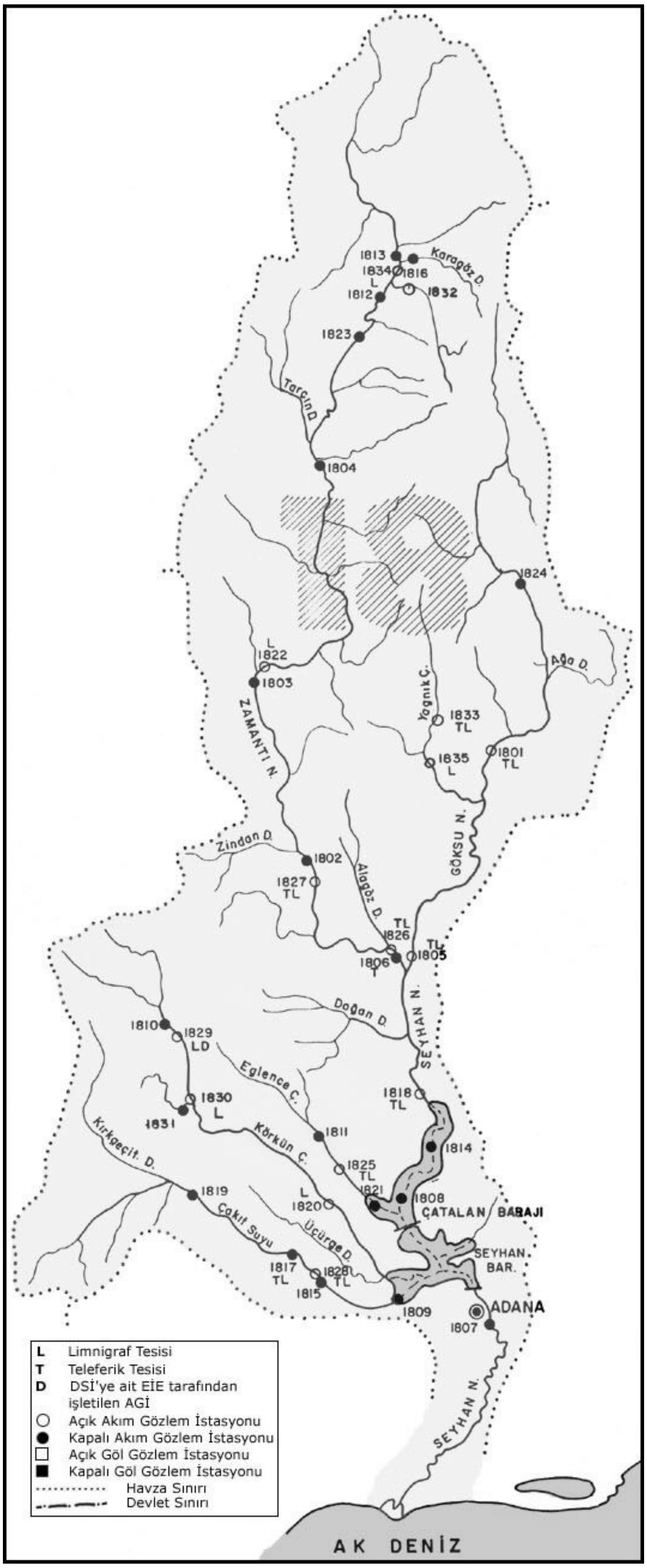

Figure H.21 Seyhan Basin (Basin #18)

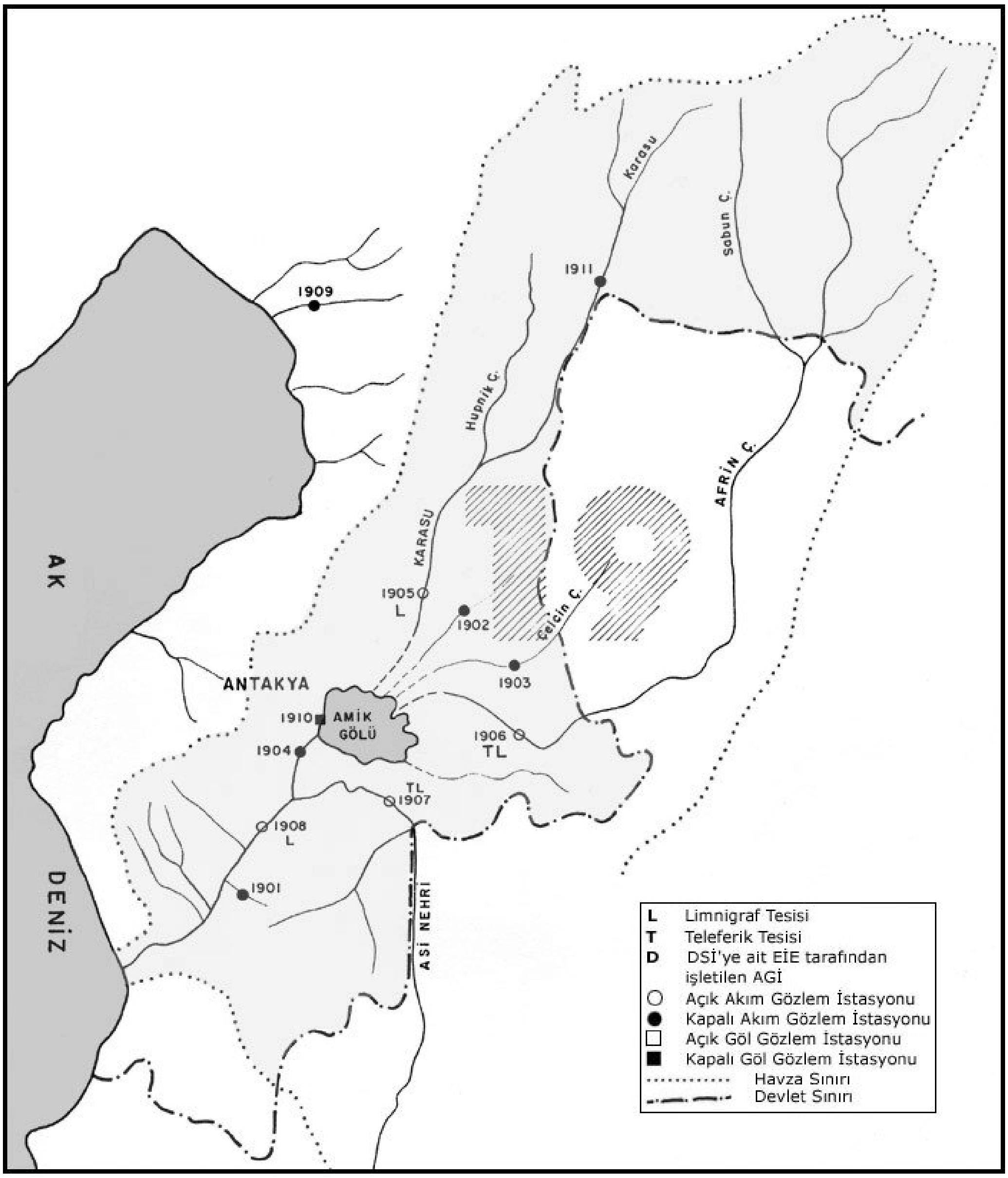

Figure H.22 Hatay Basin (Basin #19)

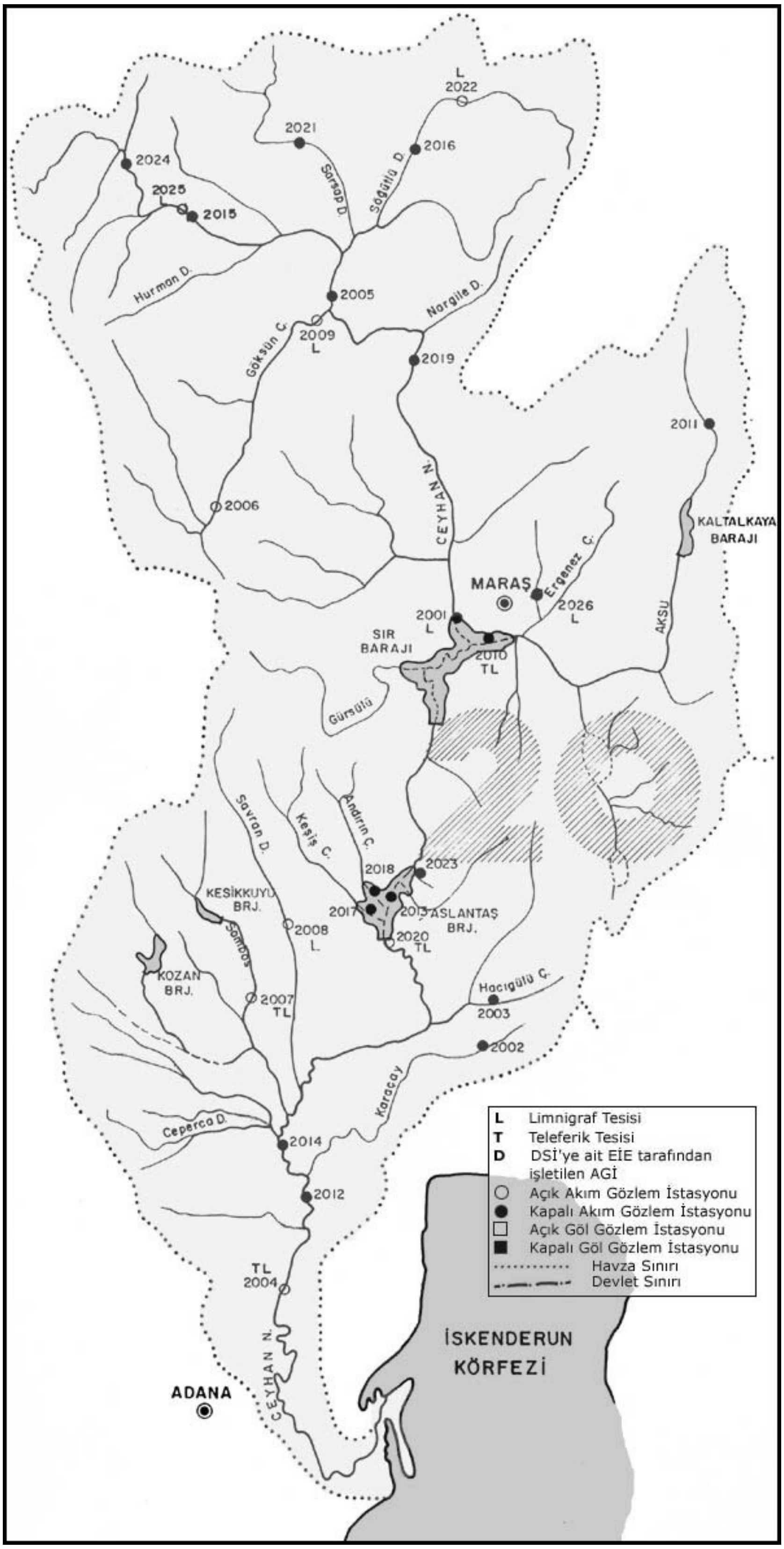

Figure H.23 Ceyhan Basin (Basin #20)

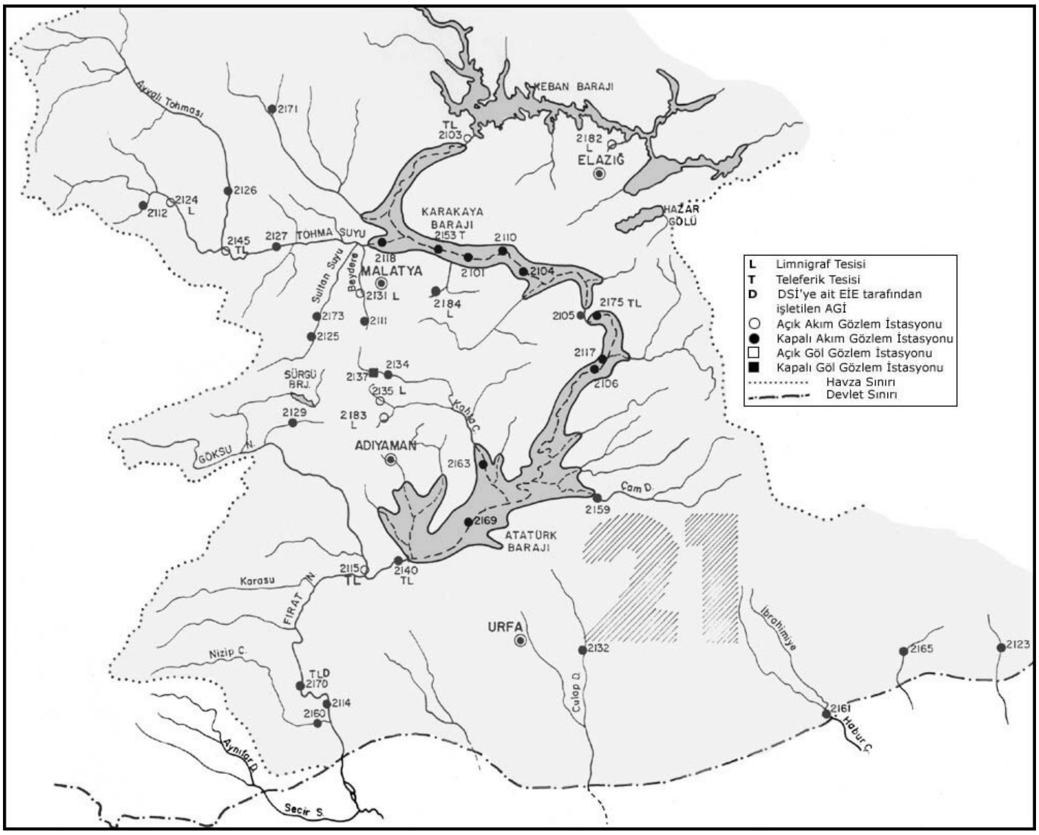

Figure H.24 Lower Euphrates River Basin (Basin #21)

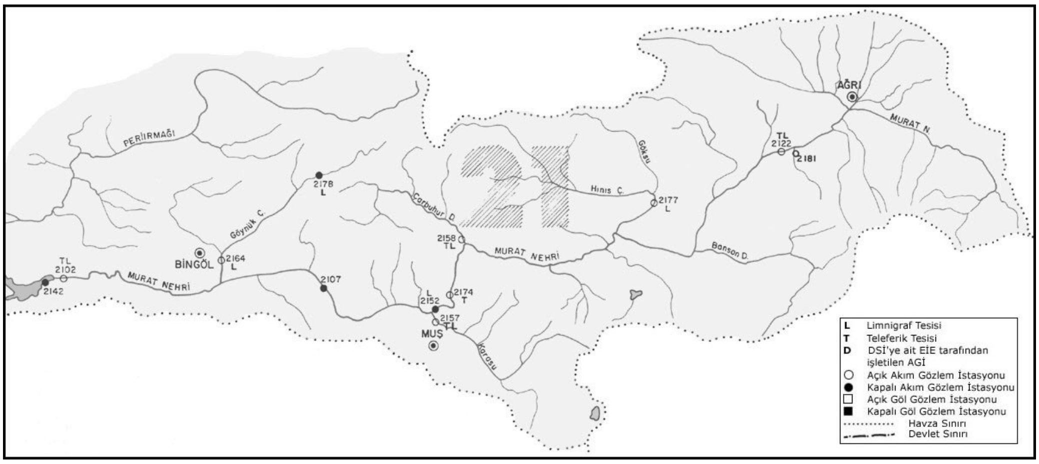

Figure H.25 Middle Euphrates River Basin (Basin #21)

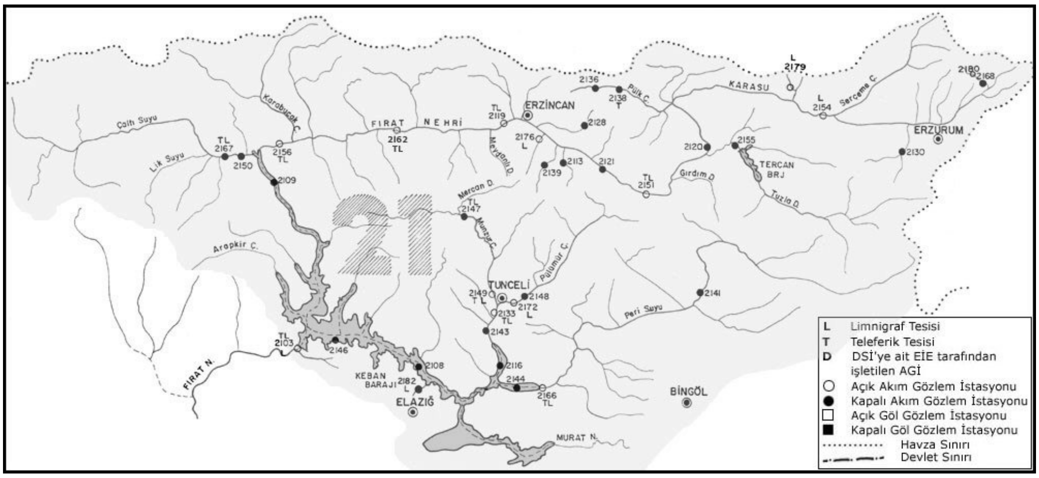

Figure H.26 Upper Euphrates River Basin (Basin #21)

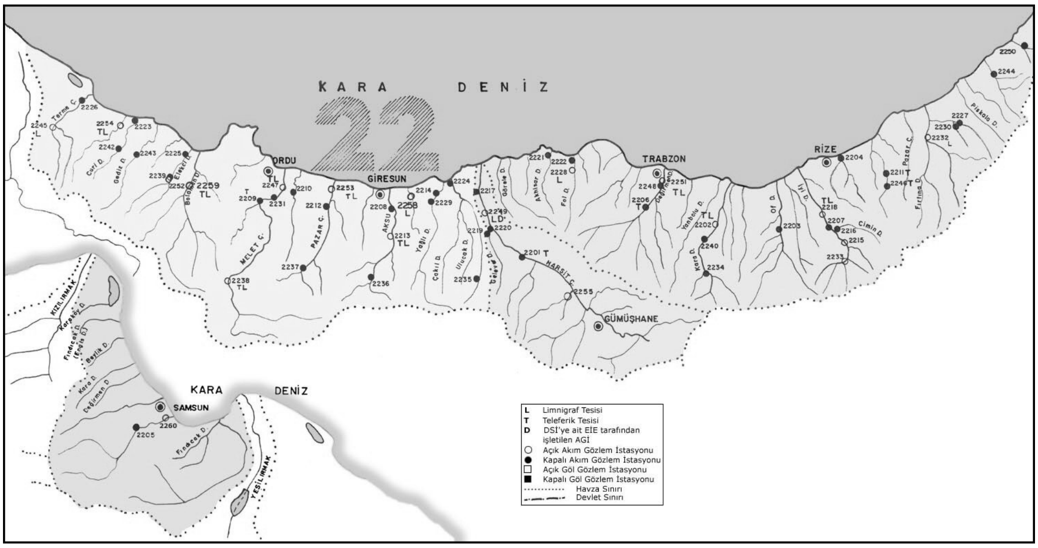

Figure H.27 East Black Sea Basin (Basin #22)

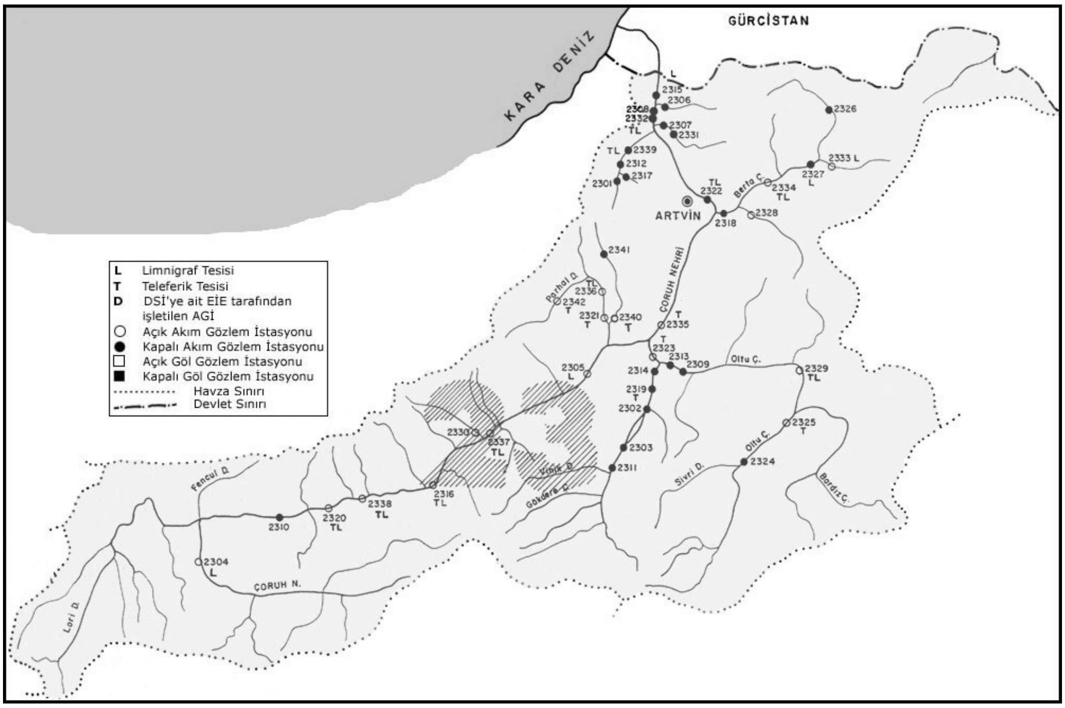

Figure H.28 Coruh Basin (Basin #23)

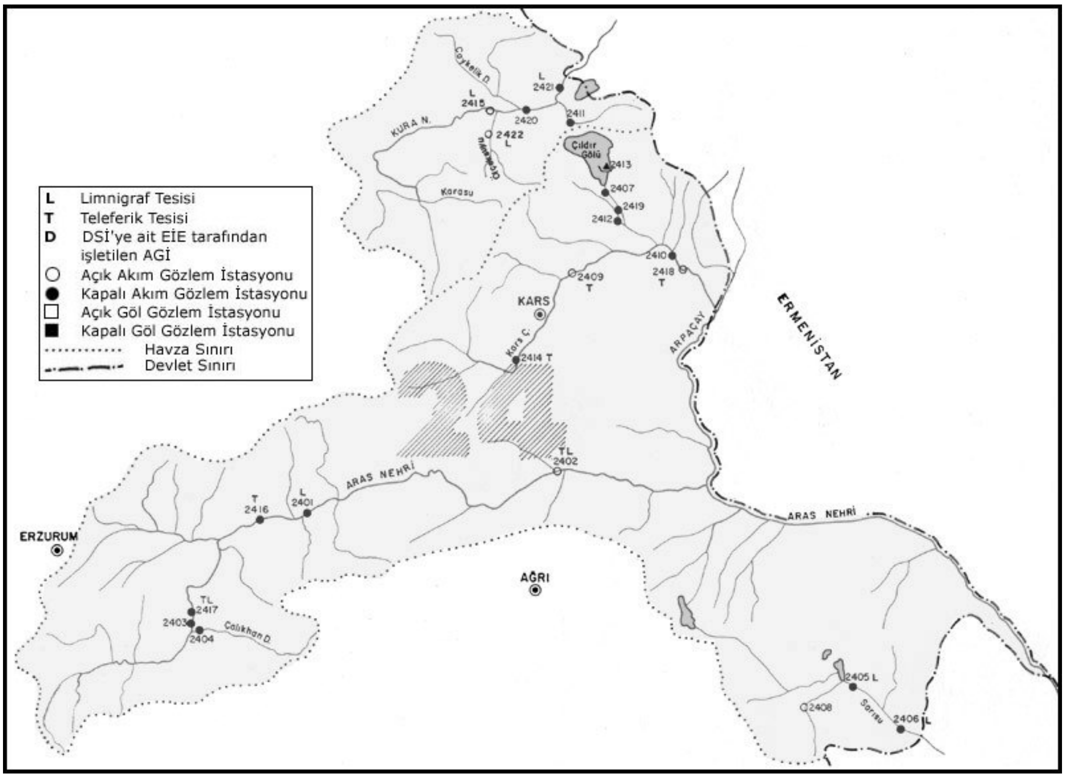

Figure H.29 Aras Basin (Basin #24)

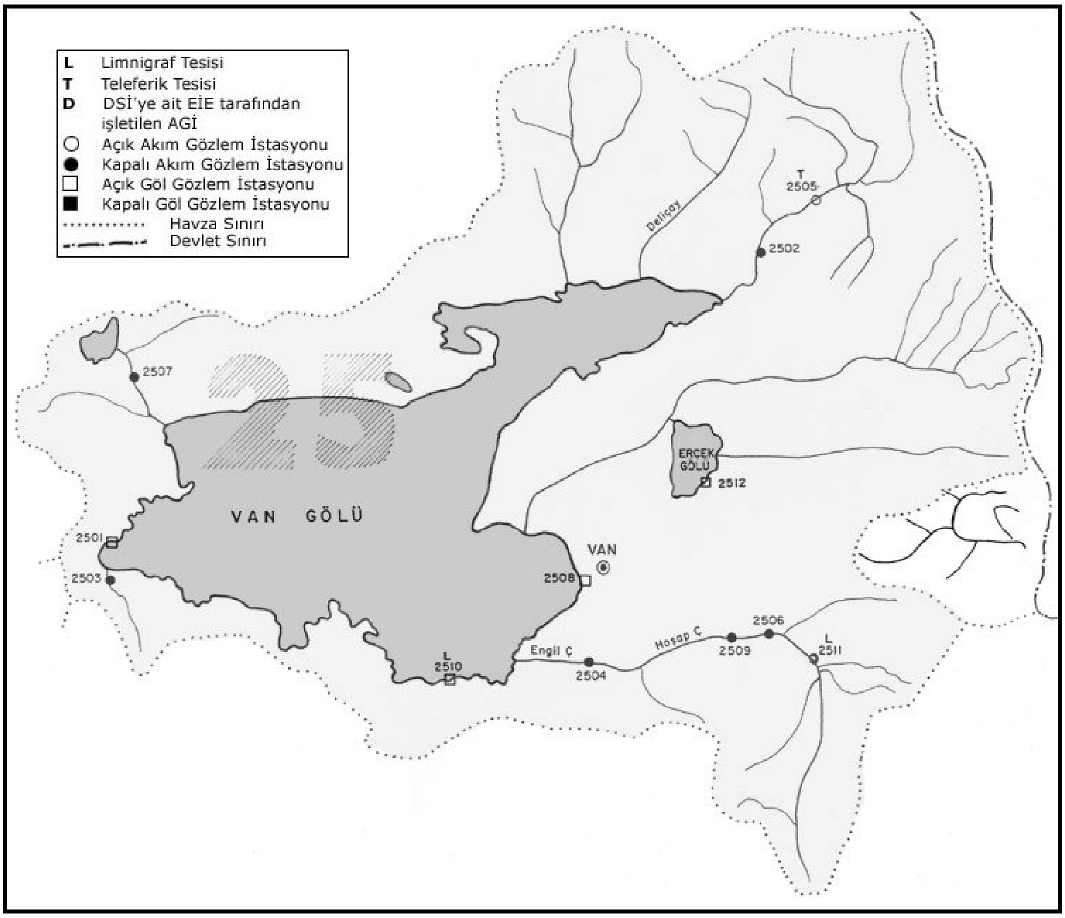

Figure H.30 Van Lake Basin (Basin #25)

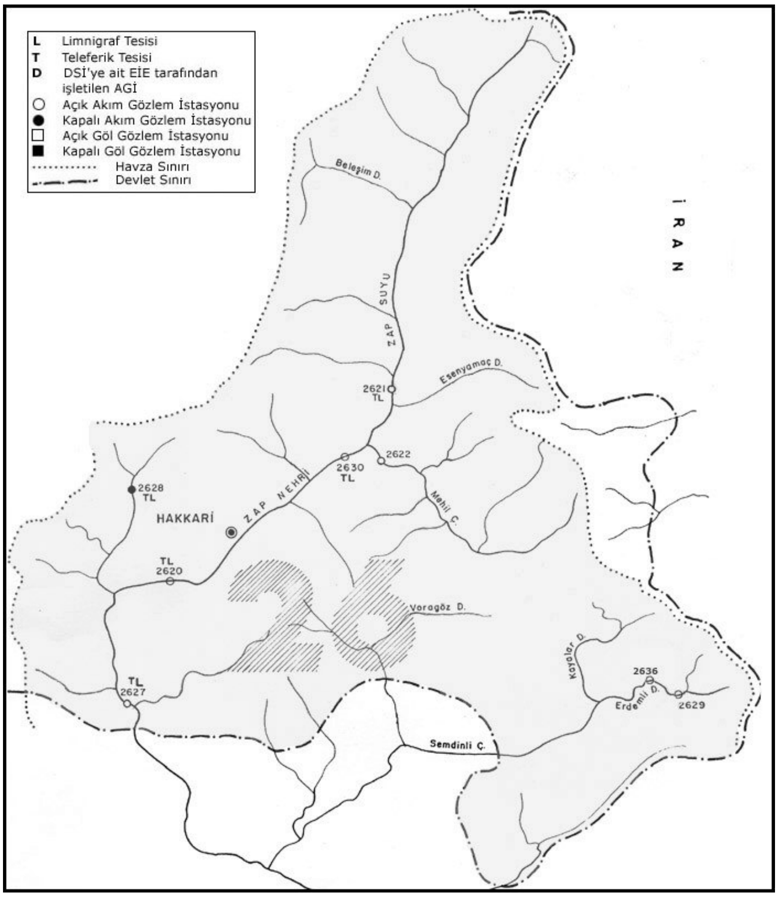

Figure H.31 Tigris River Basin (Basin #26)

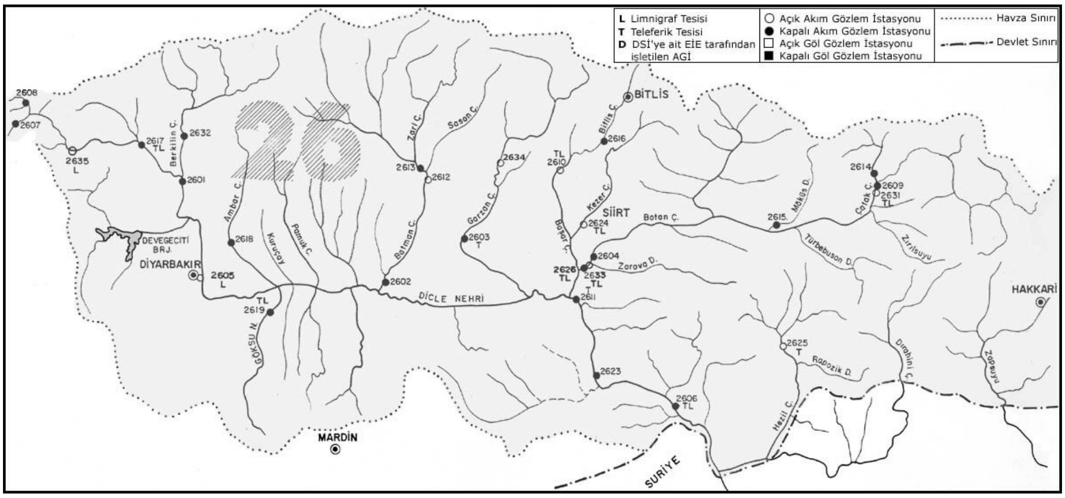

Figure H.32 Tigris-Zapsuyu Basin (Basin #26)