DEVELOPMENT OF NATIONAL HYDROGRAPHY DATASET, WATERSHED BOUNDARIES AND GIS-BASED WATER QUALITY/QUANTITY DATA ANALYSIS SYSTEM FOR TURKEY

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ABSTRACT

DEVELOPMENT OF GIS-BASED NATIONAL HYDROGRAPHY DATASET, SUB-BASIN BOUNDARIES, AND WATER QUALITY/QUANTITY DATA ANALYSIS SYSTEM FOR TURKEY

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Computerized data visualization and analysis tools, especially Geographic Information Systems (GIS), constitute an important part of today's water resources development and management studies. In order to obtain satisfactory results from such tools, accurate and comprehensive hydrography datasets are needed that include both spatial and hydrologic information on surface water resources and watersheds. If present, such datasets may support many applications, such as hydrologic and environmental modeling, impact assessment, and construction planning.

The primary purposes of this study are production of prototype national hydrography and watershed datasets for Turkey, and development of GIS-based tools for the analysis of local water quality and quantity data. For these purposes national hydrography datasets and analysis systems of several counties are reviewed, and based on gained experience; 1) Sub-watershed boundaries of 26 major national basins are derived from digital elevation model of the country by using raster-based analysis methods and these watersheds are named according to coding system of the European Union, 2) A prototype hydrography dataset with built-in connectivity and water flow direction information is produced from publicly available data sources, 3) GIS based spatial tools are developed to facilitate navigation through streams and watersheds in the hydrography dataset, and 4) A state-of-the art GIS-based stream flow and water quality data analysis system is developed, which is based on the structure of nationally available data and includes advanced statistical and spatial analysis capabilities. All datasets and developed tools are gathered in a single graphical user-interface within GIS and made available to the end-users.

Keywords: GIS, Turkey, hydrography dataset, watershed boundaries dataset, water quality data, stream flow data, geographical database, data analysis system

ÖZ

TÜRKİYE İÇİN CBS TABANLI ULUSAL HİDROGRAFİK VERİ SETİ,
ALT HAVZA SINIRLARI VE SU KALİTESİ/KANTİTE VERİ
ANALİZ SİSTEMİ GELİŞTİRİLMESİ

Girgin, Serkan

Yüksek Lisans, Jeodezik ve Coğrafik Bilgi Teknolojileri

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Bilgisayar tabanlı veri analizi ve görselleştirme araçlar, özellikle de Coğrafi Bilgi Sistemleri (CBS), günümüzde su kaynaklarının geliştirilmesi ve yönetimi çalışmalarında önemli bir yer tutmaktadır. Ancak, bu araç ve sistemlerden doğru sonuçlar elde edebilmek için, su kaynaklarının ve havzalarının gerek coğrafi gerekse hidrolojik özelliklerini yüksek doğruluk ve tam bir bütünlük içerisinde veren hidrografik veri setlerine ihtiyaç vardır. Mevcut oldukları taktirde bu veri setleri, hidrolojik ve çevresel modelleme, etki değerlendirmesi, ve yapı planlaması gibi birçok uygulama alanını destekleyebilir.

Bu çalışmanın amaçları, Türkiye için su kaynakları ile ilgili çalışmalarda kullanılabilecek prototip hidrografi ve havza sınırları veri setlerinin hazırlanması, ve yerel su kalitesi ve kantite verilerinin incelenmesi için CBS destekli analiz araçlarının geliştirilmesidir. Bu amaçlar doğrultusunda: 1) 26 büyük ulusal havzaya ait alt havzaların sınırları sayısal yükseklik modeli kullanılarak CBS ortamında belirlenmiş ve Avrupa Birliği havza kodlama sistemine göre isimlendirilmiş; 2) Kendi içinde su akış yönü ve akarsular arasındaki bağlantılar gibi bilgiler bulunan prototip bir hidrografik veri seti herkesin kullanımına açık veri kaynakları kullanılarak hazırlanmış ve kalite kontrolleri yapılmış; 3) Elde edilen veri setleri içerisinde akarsular ve havzalar arasında su akış yönünde ve tersi yönde analizi sağlayacak araçlar CBS ortamında geliştirilmiş; ve 4) Ulusal veri kaynaklarının yapısına uygun olarak dizayn edilmiş ve ileri düzeyde mekansal ve istatistiksel analiz özellikleri içeren CBS tabanlı bir akım ve su kalitesi verisi analiz sistemi geliştirilmiştir. Elde edilen veri setleri ve geliştirilen araçlar CBS ortamında ortak bir grafik kullanıcı arabirim altında toplanarak son kullanıcıların hizmetine sunulmuştur.

Anahtar Kelimeler: CBS, Türkiye, hidrografik veri seti, havza sınırları veri seti, su kalitesi verisi, akım verisi, coğrafik veri tabanı, veri analiz sistemi

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LIST OF ABBREVIATIONS

AEA	Albers Equal Area
AVHRR	Advanced Very High Resolution Radiometer
DAFIF	Digital Aeronautical Flight Information File
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DIAM	Defense Intelligence Agency Manual
DIGEST	Digital Geographic Information Exchange Standard
DLG	Digital Line Graph
DMA	U.S. Defense Mapping Agency
DOD	U.S. Department of Defense
DTED	Digital Terrain Elevation Data
ED-50	European Datum 1950
EPRSDA	General Directorate of Electrical Power Resources Survey and Development Administration
ERICA	European Rivers and Catchments
ESRI	Environmental Systems Research Institute
EU	European Union
FACC	Feature and Attribute Coding Catalog
FOIA	Freedom of Information Act
HUC	Hydrologic Unit Code
GCM	Republic of Turkey General Command of Mapping
GLCC	Global Land Cover Characteristics
GDRS	General Directorate of Rural Services
GIS	Geographical Information System

JNC	Jet Navigation Chart
JOG	Joint Operational Graphics
LCC	Lambert Conformal Conic
MSL	Mean Sea Level
NGDC	U.S. National Geophysical Data Center
NHD	National Hydrography Dataset
NIMA	U.S. National Imagery and Mapping Agency
NOAA	U.S. National Oceanic and Atmosphere Administration
ONC	Operational Navigation Chart
R2V	Raster to Vector
RF	Reach File
SHW	General Directorate of State Hydraulic Works
SRTM	Shuttle Radar Topography Mission
SRTM30	SRTM 30-Arc Seconds Global Elevation DEM
TIN	Triangular Irregular Networks
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VMAP-0	Vector Map Level 0
VMAP-1	Vector Map Level 1
VPF	Vector Product Format
WGS84	World Geodetic System 1984

CHAPTER 1

INTRODUCTION

Water quality and quantity data are crucial elements of water resources related studies. Although data collection is the essential first step, it is only the starting point. In order to solve the problems related with water resources effectively without spending excess time, the data should also be organized such that its form is appropriate for already existing data analysis methods and tools. For example, after the development and publication of methods for deriving and using duration curves, there remains the need for presenting the data so that duration curves can be readily prepared (Langbein and Iseri, 1983). Hence as stated by Langbein and Iseri (1983), the following steps should be followed prior to any kind of analysis: collection of data, development of methods of using the data; and processing the data into convenient form.

For today's highly computerized surface hydrology studied, several datasets are needed to show the location and connectivity of natural and man-made features such as rivers, lakes, canals and reservoirs. The essential datasets, which can be termed together as hydrography datasets, can be listed as follows:

- Natural drainage channels
- Man-made channels
- Lakes and reservoirs
- Coastline

A watershed dataset showing the delineations of water drainage areas can also be added to this list. All these datasets can be used in their basic forms for mapping purposes by presenting the spatial relationships both between these features and others, such as monitoring sites and topography. But once the analysis requirements of the users are put clearly forward, datasets can be provided that can go far beyond simple mapping. For example it is possible to provide datasets that provide catchment characteristics such as catchment area, drainage density, and stream length, or datasets that provide stream characteristics such as stream slope and order with respect to different ordering methods. Moreover, specially designed datasets can provide navigational information both in up and downstream directions, which may help to identify the pollution sources or identify the areas that can be affected from these sources. Such datasets are not just useful for surface hydrology but they are also very valuable for environmental management and modeling purposes. Some of the possible applications can be listed as follows:

<u>Geocoding of water-related data:</u> A hydrography dataset may provide means to relate several different kinds of data (e.g. pollution or hydrometric data) to water features.

<u>Hydrologic and environmental modeling:</u> Flow direction and connectivity data together with stream flow and velocity information can be used for hydrologic modeling in the stream network. If water quality and pollution data exists, environmental modeling may be possible as well.

<u>Map making:</u> Positional and descriptive data in the dataset can be used for making different kind of maps. Especially rich set of attribute data found in the hydrography dataset can be used to create various thematic maps, each presenting different hydrologic properties of water features.

<u>Data maintenance:</u> Unique identifiers and other methods encoded in the dataset help to solve technical problems of cooperative data maintenance when many organizations try to improve and update the collections of geographic data.

One important characteristic of the hydrography datasets is hydrologically-validiness. Most of the time, the traditional maps have the aim of showing the physical relationships of features and places in an easy to interpret manner. Therefore the aesthetics is the primary concern. However in GIS, useful datasets are the ones that support various spatial analyses, not the ones that are visually better. A hydrologically-valid hydrographical dataset needs to demonstrate connectivity, including pathways through lakes. It must be able to provide catchment characteristics with confidence and must demonstrate consistency between complementary layers. These mandatory features can be summarized as follows (Flavin et al., 1998):

- Cleanliness and completeness of layers
- Connectivity of drainage network, and closed lake shores
- Connectivity with coastline
- Consistency with political boundaries where water features define the boundary
- Consistency between rivers, lakes, coast and catchment boundaries
- Continuity in transboundary areas

Many countries in the World have their own national hydrography and watershed datasets, which can be review as example datasets.

1.1. Example Hydrography and Watershed Datasets

One of the earliest efforts in the development of digital hydrography datasets is the hydrographic database of the surface waters of U.S., which is called River Reach File (RF) and developed by U.S. Environmental Protection Agency (USEPA). The development of RF dates back to early 70’s and it has progressed through four versions (USEPA, 1994). Development date, scale and number of reaches in each RF version are summarized in Table 1.1. Also for a selected watershed, last three RF versions are shown in comparison in Figure 1.1.

Table 1.1. Reach File versions

RF Version	Production date	Scale	Number of Reaches
RF1-A	1973 – 1975	1:2,500,000	Few thousands
RF1	1978 – 1982	1:250,000	68,000
RF2	1988	1:250,000	170,000
RF3	1988 – 1997	1:100,000	3,100,000

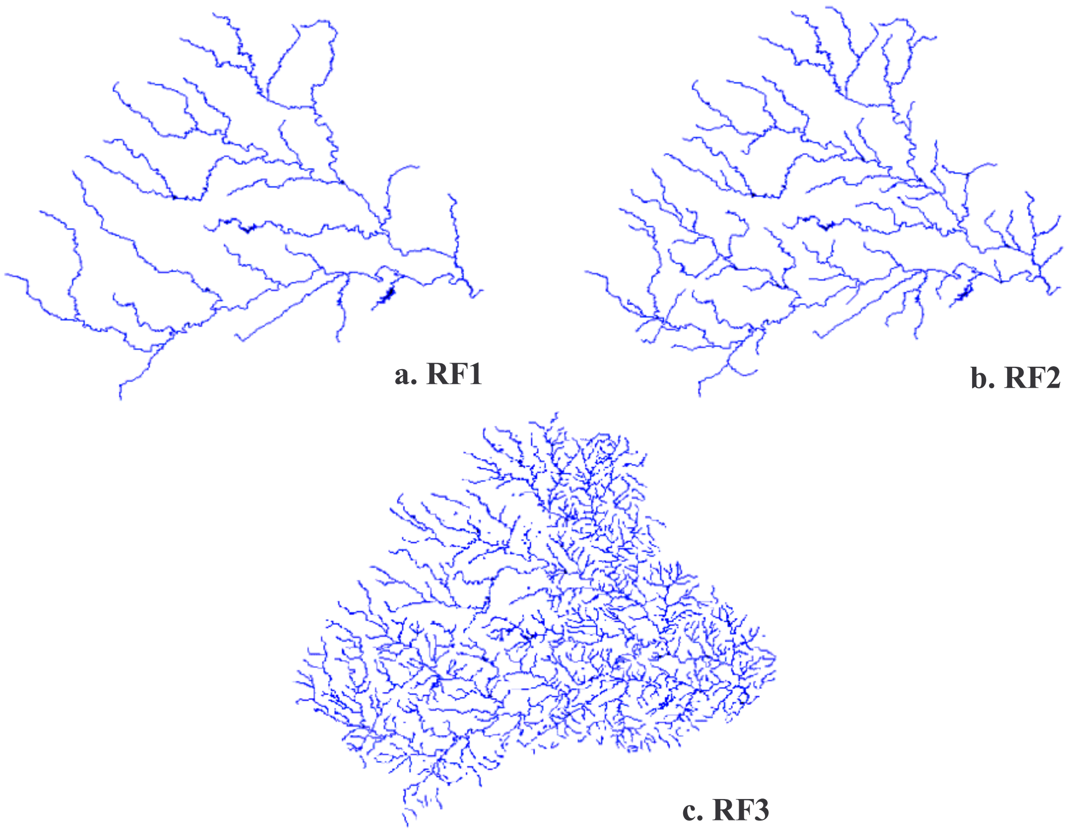


Figure 1.1. Comparison of different RF versions

The structure and content of the RF are created primarily to establish hydrologic ordering, to perform hydrologic navigation for modeling applications, and to provide a unique identifier for each surface water feature. A key characteristic of the RF is its attributes, which define the connected stream network regardless of the presence of topologic continuity. The attributes also include unique identifier, flow direction and hydraulic characteristics for each stream reach (USEPA, 1994).

Starting from 1980's, RF was used by USEPA for performing water quality modeling on whole river basins for all of the hydrologic regions in the conterminous U. S. The unique reach code assigned to each reach has been used to link a number of USEPA national databases to surface waters, e.g. STORET Water Quality Database, Facility Discharge Database, and Drinking Water Intakes Database. The Reach File has also been used by the U. S. Geological Survey (USGS) and U.S. National Oceanic and Atmospheric Administration (NOAA) as the hydrography backbone for several of their programs and applications (Horn et al., 1994).

In 1997, RF3 was "frozen" so that efforts could be focused on building the next generation hydrography database, which is a combined map and routing system called the National Hydrography Dataset (NHD).

The NHD is the result of recent cooperative efforts of USEPA and USGS. It combines elements of USGS digital line graph (DLG) hydrography files and the USEPA RF3 (USGS, 2000). The NHD supersedes RF3 and DLG files by incorporating them, not by replacing them. The same data are presented in a new, more flexible format; they are expanded and refined. General characteristics of NHD can be listed as follows:

- It is a feature-based dataset that interconnects and uniquely identifies the stream segments or "reaches" that make up the Nation's surface water drainage system.
- Unique reach codes (originally developed by the USEPA) are provided for networked features and isolated water bodies.
- The reach code structure is designed to accommodate higher resolution data.
- Common identifiers uniquely identify every occurrence of a feature.
- It is currently based on the content of the USGS 1:100,000-scale data, giving it accuracy consistent with those data.
- Names with Geographic Names Information System (GNIS) identification numbers are included for lakes, other water bodies, and many stream courses.

- It provides flow direction and centerline representations through surface water bodies.

The NHD data are available for downloading by watershed basis from the USGS (URL 1.1). A set of GIS-based tools are also developed to facilitate navigation through the NHD, and reach-indexing auxiliary data (URL 1.2).

In addition to RF and NHD, U.S. also has a standardized hydrologic unit system, referred to as the Hydrologic Unit Code (HUC) system that was developed by the USGS. HUC system divides U.S. into successively smaller hydrologic units, which are classified into six levels: regions, sub-regions, basins, sub-basins, watersheds and sub-watersheds.

The underlying concept is a topographically defined set of drainage areas organized in a nested hierarchy by size (Seaber et al., 1987). The units are defined along natural hydrologic breaks based on land surface and surface water flow, and they are generally subdivided into 5 to 15 units from one level to the next. A 2 to 12 digit unique code based on its level in the classification identifies each hydrologic unit. Average unit size and number of units for each level are summarized in Table 1.2 (Legleiter, 2001). Since the development of last two HUC levels are still continuing, estimates are given for these levels. HUC hierarchy is also illustrated in Figure 1.2.

Table 1.2. Size and number of hydrologic units

Level	Name	Digits	Average Size (km^2)	Number of Units
1	Region	2	459,880	21
2	Sub-region	4	43,512	222
3	Basin	6	27,443	352
4	Sub-basin	8	1,820	2,149
5	Watershed	10	163 – 1,012 *	22,000 *
6	Sub-watershed	12	41 – 163 *	160,000 *

* Estimate

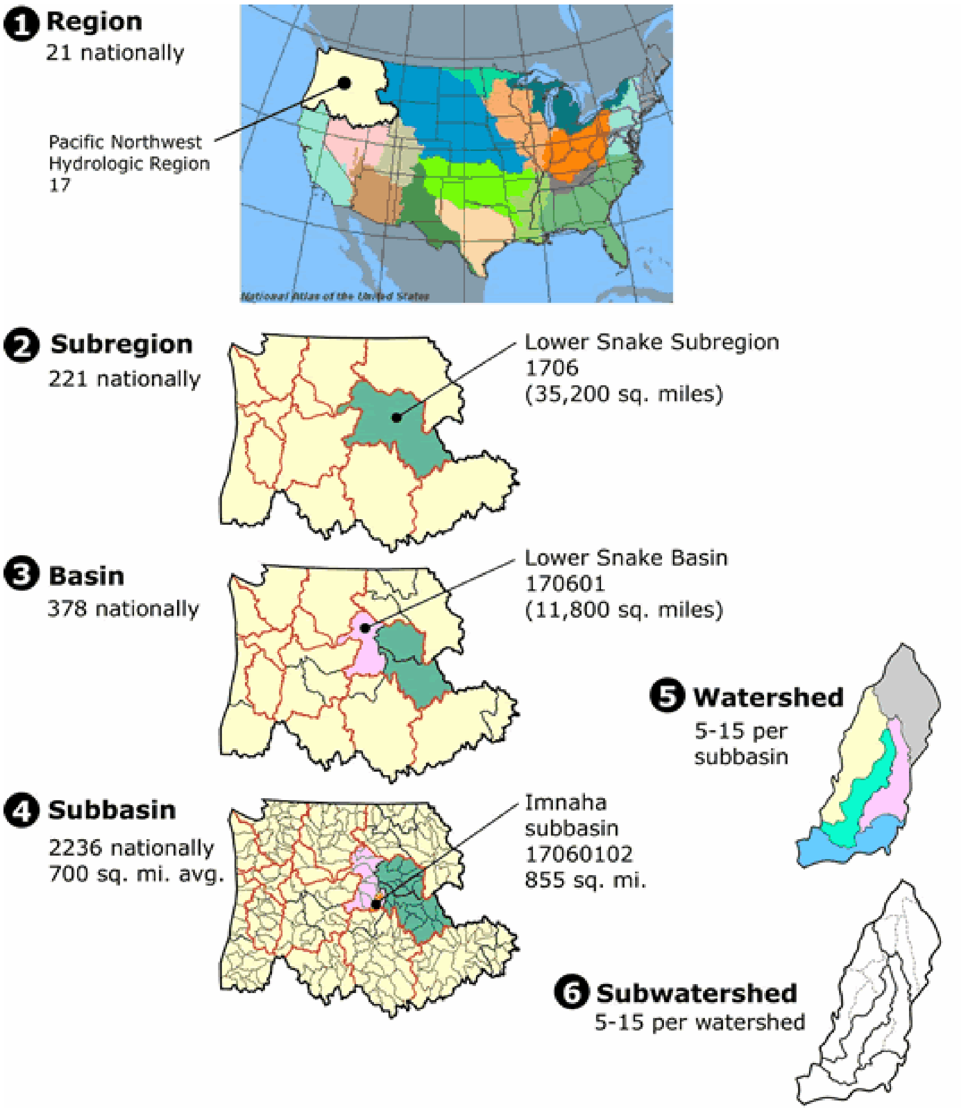


Figure 1.2. Hydrologic unit hierarchy (Legleiter, 2001)

In Europe, many countries have their own national hydrography and watershed datasets. For selected European countries, availabilities of these datasets at different scales are summarized in Table 1.3 and 1.4 (taken from Morris and Kronvang, 1994).

Table 1.3. Availability of digital hydrography data in European countries

Country	Map Scale (x 1:1000) (* = partially available)							
	1:25	1:50	1:100	1:200	1:250	1:400	1:500	1:1000
Austria	*	X					X	
Belgium					X			
Denmark	X		X					
Finland		*	*	X		*		
France		*	*				X	X
Germany	*	*		*				X
Greece			*					X
Italy					X		X	
Netherlands		X			X			
Norway		X			X			X
Portugal							X	
Spain	*			X				
Sweden		X			X			
Switzerland	X			X				
U. K.		*			X			

Table 1.4. Availability of digital watershed boundary data in European countries

Country	Map Scale (x 1:1000) (* = partially available)							
	1:25	1:50	1:100	1:200	1:250	1:400	1:500	1:1000
Austria	*	X						
Belgium								
Denmark	X		X					
Finland		X						
France	*	*	*					
Germany	*	*						
Greece			*					
Italy								
Netherlands		X						
Norway		X						
Poland				*				
Spain	*							
Sweden		X						
Switzerland				X				
U. K.		X						

In addition to national datasets of individual countries, the European Union (EU) also recently developed a common hydrography and catchment dataset, which is called European Rivers and Catchments (ERICA). ERICA is a hydrologically-valid digital database of EU that includes rivers, canals, lakes, coastlines and catchment boundaries (Flavin et al., 1998). In this quality-controlled and validated dataset that is developed on the GIS, each river stretch is uniquely identified and includes flow direction. All stretches are node matched and flow paths are continuous through lakes. All individual feature sets are mutually consistent, including automatically derived catchment boundaries, and both local and English names (if present) are made available for features. In order to identify catchments, the dataset uses ERICA Coding System (ERICA-CS), which is a combination of Norwegian and German coding systems and includes a marine code, a marine border code, a series of nested catchment codes and a catchment size indicator for each catchment. Two different versions of ERICA are available: 1/1.000.000 scale ERICA-1M which covers the whole Europe and 1/250.000 scale medium resolution ERICA which is currently available only for two pilot catchments.

1.2. Situation in Turkey

Turkey is a country which forms a bridge between two continents, Europe and Asia. It is surrounded by three international seas (Black Sea, Aegean Sea, and Mediterranean Sea) and also has an interior sea (Sea of Marmara). It has a varying geography, which is mainly mountainous, and has several important water resources within its region. A summary of land and water resources of Turkey is given in Table 1.5 (URL 1.3). As shown this table, Turkey has an average precipitation of 642 mm, which results in a total water potential of 501 km^3. 186 km^3 of this potential becomes surface runoff, but only approximately half of it (95 km^3) can be used for water supply and irrigation. As runoff per capita this value is equal to 1475 m^3, which shows that Turkey is not too water-poor but also not water-rich compared with the World average (SHW, 2001). Therefore, development and protection of water resources reflects great importance.

Table 1.5. Land and water resources of Turkey

Land Resources (million ha)	
Area of Turkey (projected)	77.95
Agricultural Land	28.05
Irrigable Land	25.85
Economically Irrigable Land	8.50
Precipitation	
Mean (arithmetic) Annual Precipitation	642.6 mm
Mean Annual Volume of Precipitation	501.0 km^3
Surface Waters	
Annual Surface Runoff	186.05 km^3
Annual Surface/Rainfall Ratio	0.37
Annual Depletible Volume	95.00 km^3
Actual Annual Utilization	33.90 km^3
Groundwater	
Annual Available Groundwater Reserve	13.66 km^3
Actual Annual Utilization	6.23 km^3

In order to assess problems related with water resources development, and to study and plan required works, Turkey is divided into major basins and water resources management regions. The history of water resources management regions goes back to the beginning of the Republic and even older. Figure 1.3 illustrates the management regions in 1925.

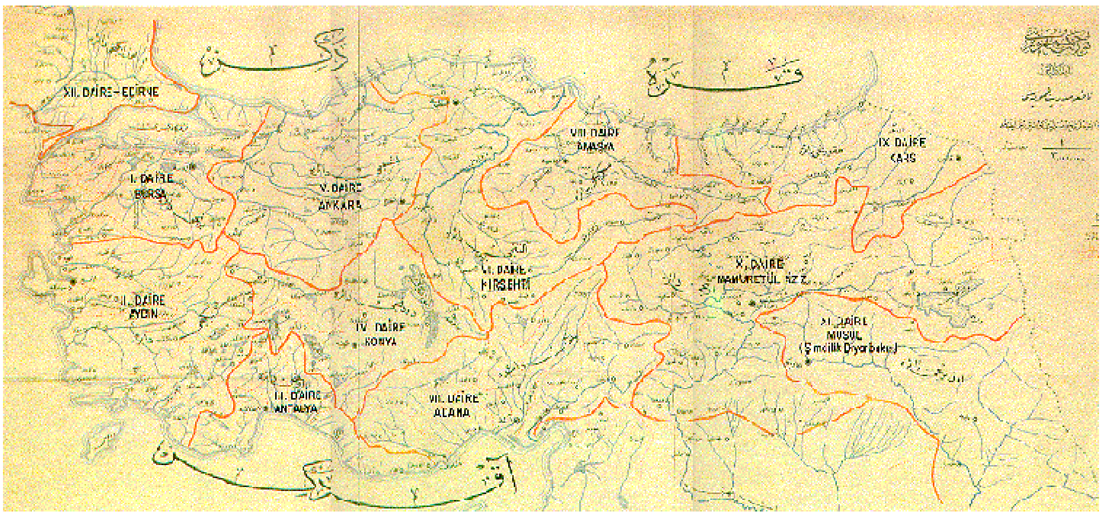


Figure 1.3. Water resources management regions of Turkey in 1925 (URL 1.4)

Today, there exist 26 officially defined major hydrologic regions (i.e. basins) that cover the whole country. These basins belong to different river systems separated with natural divides. Their boundaries are determined in a way that they generally include main rivers of Turkey and their contributory branches. Also there exist coastal basins that include small streams draining to the same sea, and closed basins that drain to inland water bodies. Geographic distribution of watersheds and their names are given in Figure 1.4.

Four of the basins (Burdur Lakes, Akarçay, Konya Closed, and Van Lake) are closed basins, whereas seven of the remaining are coastal basins (North Black Sea, West Black Sea, Marmara, North Aegean, West Mediterranean, Antalya and East Mediterranean). Six basins (Meriç, Asi (Orontes), Fırat (Euphrates), Dicle (Tigris), Aras, Çoruh) have physical boundaries that are beyond the country boundaries and hence they could be classified as cross-boundary basins. The classifications of the watersheds are also indicated in Figure 1.4.

In order to give a general idea about the characteristics of national basins, their surface area, mean annual precipitation and total surface runoff values are summarized in Table 1.6. Data given this table are also illustrated in Figure 1.5 as a comparison bar chart.

As it can be seen from Figure 1.5, the largest basin of Turkey is the Fırat Basin, which belongs to Euphrates river that is the most important water course of Mesopotamia together with Tigris river. Although yearly precipitation of Fırat Basin is lower than the country average, it has the maximum surface runoff due to its size. Lowest precipitation is observed in Konya Closed Basin, whereas the maximum is seen in North Black Sea Basin. For the majority of the basins, the amount of precipitation that becomes surface runoff is low. The country average is 37%.

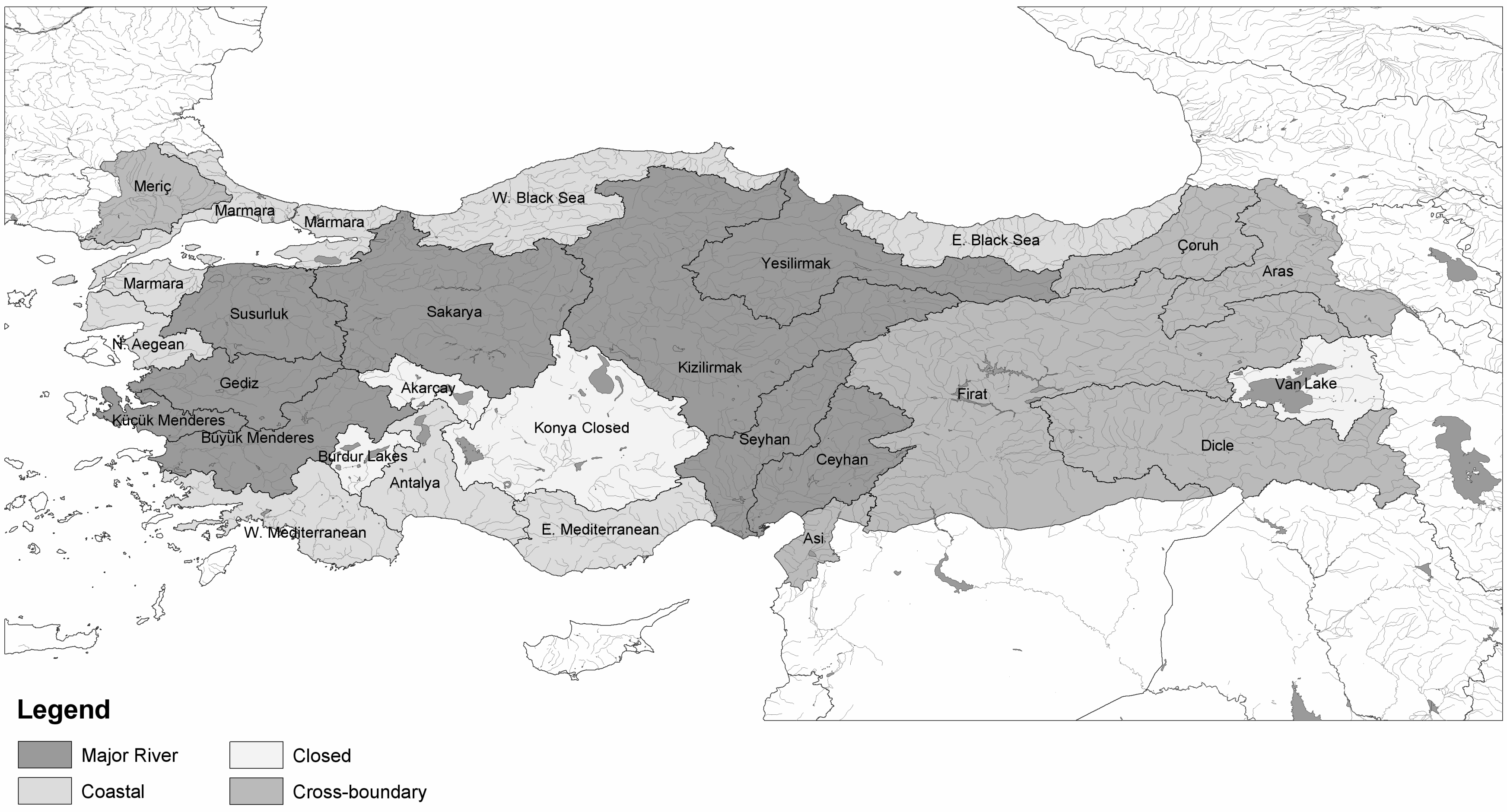


Figure 1.4. 26 major national basins of Turkey

Table 1.6. General information on 26 major national basins (SHW, 2001)

Watershed	Surface area (km^2)	Yearly mean precipitation (mm)	Yearly surface runoff (km^3)
Meriç	14,560	604.0	1.33
Marmara	24,100	728.7	8.33
Susurluk	22,399	711.6	5.43
North Aegean	10,003	624.2	2.09
Gediz	18,000	603.0	1.95
Küçük Menderes	6,907	727.4	1.19
Büyük Menderes	24,976	664.3	3.03
West Mediterranean	20,953	875.8	8.93
Antalya	19,577	1000.4	11.06
Burdur Lakes	6,374	446.3	0.50
Akarçay	7,605	451.8	0.49
Sakarya	58,160	524.7	6.40
West Black Sea	29,598	811.0	9.93
Yeşilırmak	36,114	496.5	5.80
Kızılırmak	78,180	446.1	6.48
Konya Closed	53,850	416.8	4.52
East Mediterranean	22,048	745.0	11.07
Seyhan	20,450	624.0	8.01
Asi	7,796	815.6	1.17
Ceyhan	21,982	731.6	7.18
Fırat	127,304	540.1	31.61
East Black Sea	24,077	1198.2	14.90
Çoruh	19,872	629.4	6.30
Aras	27,548	432.4	4.63
Van Closed	19,405	474.3	2.39
Dicle	57,614	807.2	21.33

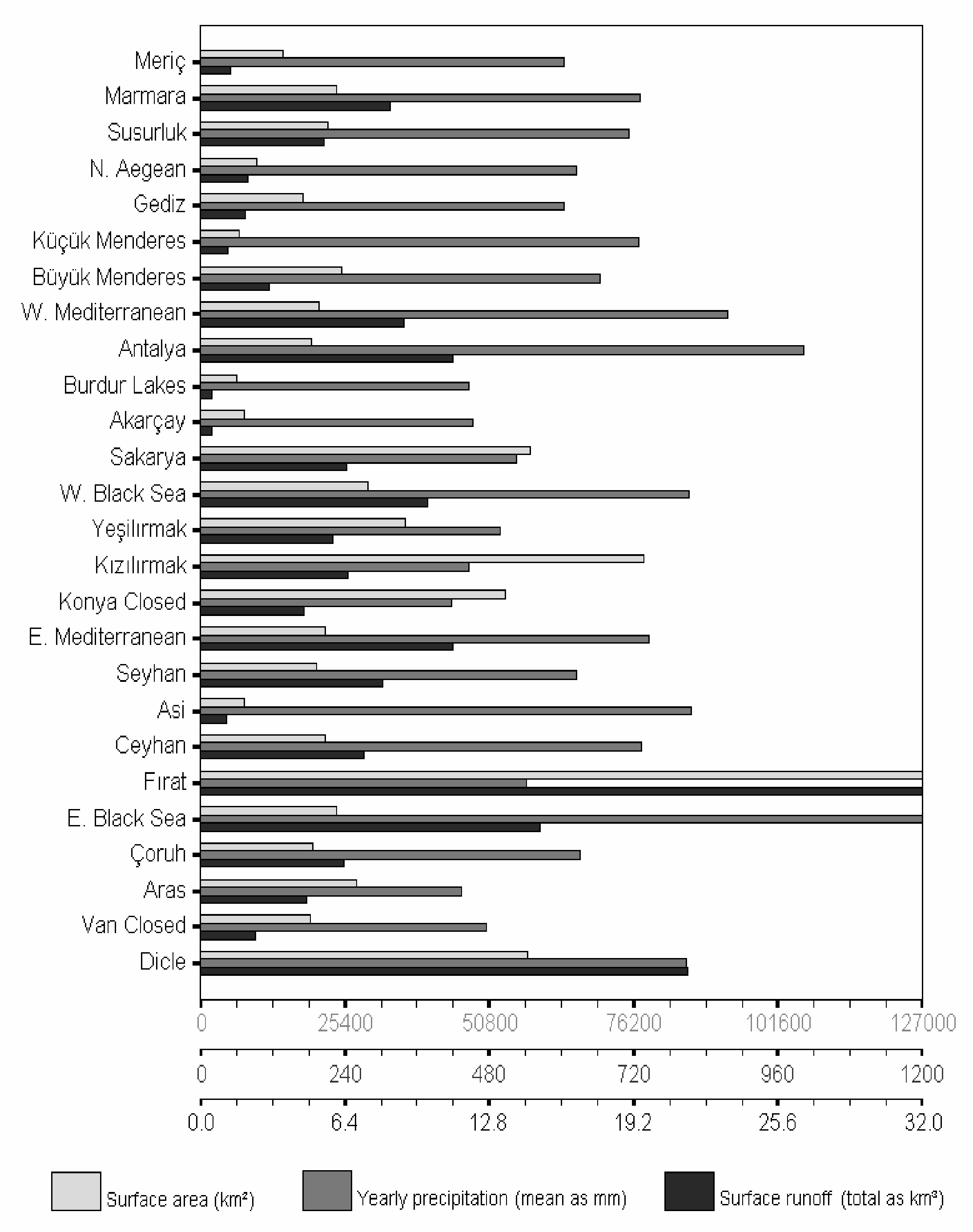


Figure 1.5. Comparison of 26 major national basins

The surface areas of the major basins range from 6,374 km^2 to 127,304 km^2, the average being approximately 30,000 km^2. The size distribution is given in Figure 1.6 as a histogram. As it can be seen from this figure, only two basins have surface area larger than 70,000 km^2, and approximately 70% of the basins have surface area smaller than 25,000 km^2. However, these sizes are quite large especially for local water resources related studies like non-point source water pollution modeling. If compared with nested watershed classification of U.S. that divides water management regions of U.S. into successively smaller hydrologic units, the average size of major national basins corresponds to the third level (basins), below which another level resides (sub-basins) with an average size of 1800 km^2. In U.S., even the sub-basins are found to be too large to adequately serve many water-resource investigations, resource analysis and management needs (Legleiter, 2001). Two additional classification levels are currently under development in order to solve this problem. Similar watershed size levels and nested classifications are also observed in many other countries (Morris and Kronvang, 1994). Shortly, it can be concluded that the existing major basin of Turkey are very large for effective integrated water resources management and development. Determination of a series of small-sized, standardized sub-basins would be definitely beneficial for future studies.

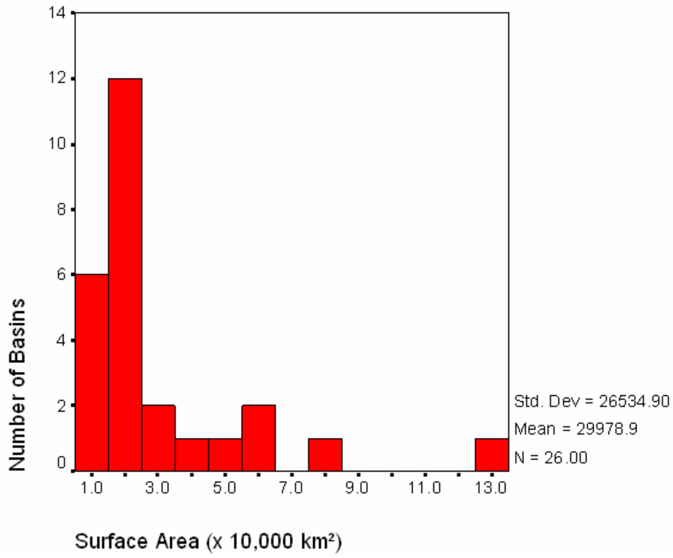


Figure 1.6. Histogram of surface areas of the major basins

In addition to watershed boundaries dataset, there is also a need for national hydrography dataset. Although maps showing the nation's surface water resources are available at different scales and in digital form, a hydrography dataset that has the features mentioned at the beginning does not exists. Such a national dataset is definitely a must for systematic studies and to form a backbone for cooperation between the institutions and directorates that are related with water resources development and protection. Once the datasets are developed, a further step may be development computer-aided tools for the analysis of water related data. For quite a long time, several governmental institutions are collecting huge amount of water quality and quantity data in Turkey. However, data analysis, modeling and visualization tools specially designed to satisfy the local needs are very limited. In order to facilitate water resources related studies, such tools should be developed, which combine advanced spatial, statistical and hydrologic analysis methods in a user-friendly environment, should be developed as soon as possible. GIS, with its comprehensive spatial data analysis and visualization capabilities, forms a very suitable framework for such purposes.

1.3.Objectives of the Study

The primary purposes of this study, which aims to contribute the efforts to put away these deficiencies, are development of proto-type national hydrography and watershed datasets that can be used to support water resources related studies, and development of analysis tools for local hydrometric and water quality data. Four main parts of the study can be listed as follows:

1. Development of a prototype national hydrography dataset that covers nation's water courses and inland water bodies.

2. Determination of watershed boundaries beyond 26 large national basins, which can be used as cataloging units for hydrographic features, by a digital elevation model (DEM) based automated delineation technique.

3. Development of GIS-based spatial tools that facilitate analyses on produced national watershed and hydrography datasets.

4. Development of state-of-the-art GIS-based stream flow and water quality data analysis system that is based on the structure of nationally available data.

Following the order given above, in Chapter 2 currently available national and international map sources for hydrography dataset development are reviewed and alternatives are evaluated to select the ultimate map source. Evaluation of national and international DEM sources that can be used for the study and justification of the final DEM that will be used to determine the watershed boundaries are also given in this chapter. National water quantity (stream flow) and quality data sources are summarized and the formats of available data are examined as well. In Chapter 3, national hydrography dataset development process is explained in detail, including accuracy check and hydrological attribute assignment steps. Determination of sub-basin boundaries is described in Chapter 4. Development of GIS-based water quantity and quality analysis system, which is based on data types given in Chapter 2, is explained in Chapter 5. Finally, conclusions and recommendations for future studies are given in Chapter 6.

CHAPTER 2

REVIEW AND EVALUATION OF DATA SOURCES

All three major objectives of the study, i.e. production of national hydrography dataset, delineation of national sub-basins and development of water quality/quantity analysis systems, heavily depend on different kinds of data related with surface water resources of Turkey. For national hydrography dataset, maps showing the locations and shapes of water courses and water bodies are required as the initial data. For automatic delineation of sub-basins, elevation data should be provided, which is used as the primary input to the delineation algorithms. Similarly, the structure of the water quality and quantity analysis system should be based on the format of available water quality and quantity data that is collected nation-wide. Certainly, quality and completeness of the data sources used for the study directly affect the results that will be obtained at the end. Hence, selection of the data sources is a very important step, which requires special attention and care. As many as possible data sources should be evaluated and they should be compared to each other before selecting a dataset for the final analysis, so that positive and negative sides of the datasets can be clearly put forward and the most appropriate dataset could be determined.

In this chapter, available map sources for the production of national hydrography dataset, digital elevation models for the delineation of national sub-basins, and water quality/quantity data for the development of GIS-based analysis system are summarized and evaluation of the alternatives are given in detail.

2.1. Hydrography Map Sources

Development of a national hydrography dataset can be divided into three major steps, which are: 1) production of a digital geographical database of water related features, 2) entry of attribute data that define hydrological and hydrographical properties of the features, and 3) assessment of positional and attribute accuracies. Essential elements for the first step of the dataset development are maps of water courses and inland water bodies, which show delineation of water features. Scale, accuracy and up-to-datedness of these maps directly affect the quality of the resulting hydrography dataset. Therefore selection of source maps is an important step and necessitates special attention.

In order to evaluate available data sources and to determine the ones suitable for the study, designation of solid evaluation criteria at the beginning is very useful for the rest of the study. The criteria determined for this purpose can be listed in the order of their priorities as follows:

1. <u>Public availability:</u> One of the primary aims of the study is development of a national hydrography dataset that will be publicly available in order to be used for hydrological, water resources protection and development, mapping, and other similar purposes easily without any constraints. There exist map resources that are superior in quality but copyrighted, which make distribution of such maps and their derivatives restricted. This is especially the case for maps produced by General Command of Mapping (GCM), which is the national mapping agency of Turkey.

2. <u>Cost:</u> Although cost should have lower priority in evaluation of map sources, and technical criteria should have precedence, it became one of the most important criteria since the study could not have any financial support. Especially large scale maps in digital format are very costly and require a

huge budget. Although such maps and datasets were also reviewed for study, public domain, costless alternatives should have to be preferred.

3. Map format: Data sources, which are in the form of conventional paper maps, should be first converted into digital vector maps so that they could be used for the hydrography dataset production. This conversion step is inevitable for data sources, which are unique and available only as paper maps. However if there exist alternative digital vector maps to paper maps, then these maps should be preferred to reduce time and labor requirements. Even, loss in quality and accuracy, and decrease in scale could be acceptable in the favor of digital maps up to a limit, if such a choice should have to be done.

4. Map scale and accuracy: Obviously, one of the most important criteria in base map selection is scale and accuracy of the maps. Maps that have larger scale and better accuracy, and that are more complete with respect to presence of features, should be preferred as much as possible.

5. Labor requirement: Labor requirement is also another important factor for the study. Man hours devoted to the study is naturally limited, like the time period in which the study should be completed. As stated in map format criteria, maps available in vector format reduce the labor requirement significantly, since the most time consuming step of data preparation, i.e. feature digitization, was already completed. Other factors affecting required labor time are mainly related with map accuracy and completeness. As number of features in the maps increases (with the decrease in map scale) and their completeness decreases, time required for accuracy checks and corrections increases correspondingly. Therefore, higher accuracy map sources should be preferred as much as possible.

There are many map sources available, that can be used for the development of national hydrography dataset. These map sources range from conventional paper maps to digital vector maps, from general purpose topographic maps to special maps containing only hydrographic features, or from national maps prepared by local mapping agencies to international public domain maps prepared by foreign organizations. In the following sections, first a selected set of available map sources will be reviewed. Starting from national ones; scale, extent, type, accuracy and characteristics of both national and international map sources will be explained in detail and their positive/negative sides will be highlighted. Then, comparison of these resources will be given and justification of selected resource will be made based on the evaluation criteria stated above.

2.1.1. National Map Sources

National map sources that can be used for hydrography dataset can be divided into two groups: general purpose maps prepared by the national mapping agency, and water resources specific maps prepared by related governmental organizations (e.g. General Directorate of State Hydraulic Works). Information on both types of map sources are given below.

2.1.1.1. Maps of General Command of Mapping

In Turkey, General Command of Mapping (GCM) bounded to Ministry of National Defense is the organization which is responsible from map production. GCM serves for all mapping needs of ministries, and governmental and public organizations up to 1:5,000 scale, and it is the only authority that has the right to prepare and publish maps having smaller scales. In order to fulfill their special needs, 1:5,000 and larger scale maps can be prepared by other governmental organizations as well.

Up to present, GCM had produced many historical, topographic, and thematic maps having both national and regional coverage. Among these maps, 1:25,000-1:250,000 scale topographic map series and smaller scale (up to 1:1,000,000) Ground and Air Joint Operational Graphics (JOG) are the most widely used, hence important products of GCM. Samples of 1:25,000 and 1:250,000 topographic maps are given in Figure 2.1a and 2.1b respectively.

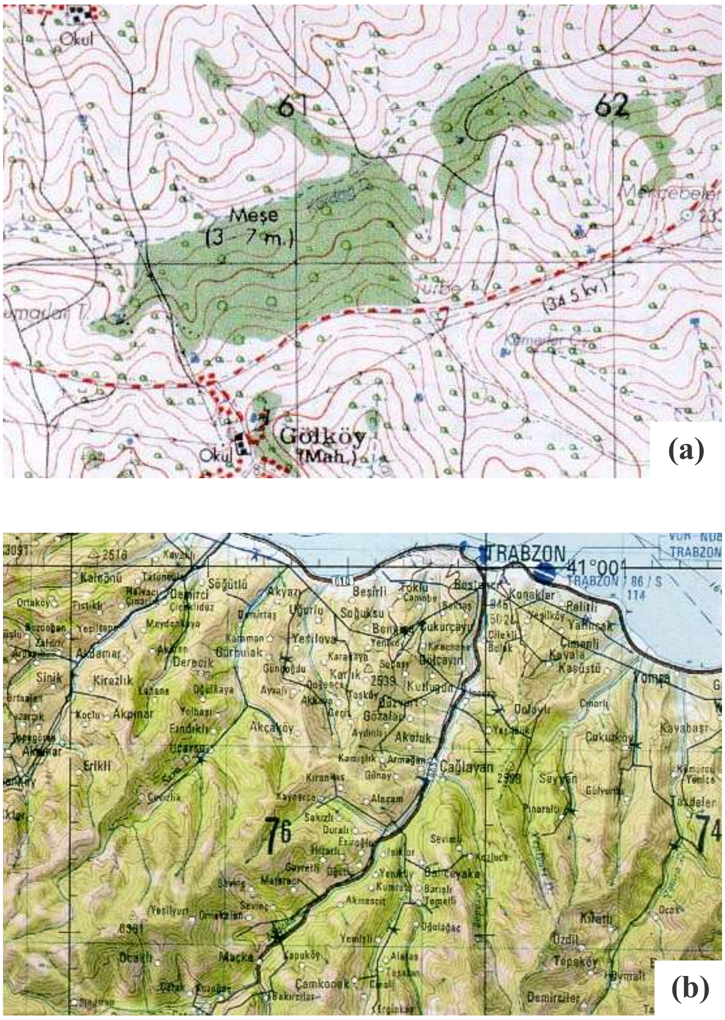


Figure 2.1. Detail from a) 1:25,000, b) 1:250,000 scaled topographic maps of GCM

Detailed information on these maps, including source, production method, projection, datum, and accuracy are summarized in Table 2.1. As indicated in the Table 2.1, air photogrammetry was used to produce largest scale (1:25,000) maps and smaller scales were obtained by cartographic transformation and scaling. Depending on the scale of the map series, Gauss-Kruger, Universal Transverse Mercator and Lambert Conformal Conic map projections were used with European Datum 1950 (ED50) as the reference datum. 1:100,000 and larger scale maps are classified products of GCM and they are not publicly available. These maps can be obtained on project or study basis after a written permission, and should be returned to GCM at the end of the project or study.

Table 2.1. Maps produced by General Command of Mapping

Maps	**Series**	**Source**	**Production[1]**			**Projection[2]**	**Datum**	**Accuracy[3]**		**Availability**	**Media[4]**	
			P	**C**	**V**			**Hor.**	**Ver.**		**P**	**R**
Topographic Maps												
1:25,000 Topographic	K-816	Air photo	✓			TM (G-K)	ED-50	5	2.5	Classified	✓	✓
1:50,000 Topographic	K-716	K-816		✓		TM (G-K)	ED-50	10	5	Classified	✓	✓
1:100,000 Topographic	K-613	K-716		✓		TM (G-K)	ED-50	20	10	Classified	✓	✓
1:250,000 JOG Ground	JOG 1501-G	K-613			✓	UTM	ED-50	50	25	Unclassified	✓	✓
1:500,000 JOG Ground	1404	JOG 1501-G		✓		LCC	ED-50	-	-	Unclassified	✓	✓
1:1,000,000 JOG Ground	1301	1404		✓		LCC	ED-50	-	-	Unclassified	✓	✓
Air Maps												
1:250,000 JOG Air	JOG 1501-A	K-613			✓	UTM	ED-50	50	25	Unclassified	✓	
1:500,000 JOG Air	TPC	JOG 1501-A		✓		LCC	ED-50	-	-	Unclassified	✓	
1:1,000,000 JOG Air	ONC	TPC		✓		LCC	ED-50	-	-	Unclassified	✓	
Digital Maps												
1:25,000 Elevation	YUKPAF-25	K-816	R2V			UTM	ED-50	-	5	Classified	ArcInfo	
1:250,000 Elevation	YUKPAF-250	JOG 1501-G	R2V			UTM	ED-50	-	50	Unclassified	ArcInfo	
1:25,000 Topographic[*]	TOPO-25	K-816	R2V			UTM	ED-50	?	?	Classified	ArcInfo	
1:250,000 Topographic[*]	TOPO-250	JOG 1501-G	R2V			UTM	WGS84	?	?	Unclassified	ArcInfo	

[1] Production methods: P = Photogrammetry, C = Cartographic transformation, V = Cartographic transformation or direct production from VMAP
R2V = Scanning to raster followed by vector transformation
[2] Projections: TM (G-K) = Transverse Mercator (Gauss-Kruger), UTM = Universal Transverse Mercator, LCC = Lambert Conformal Conic.
[3] Accuracies are given in meters.
[4] Media: P = Paper, R = Raster (digital), ArcInfo = ArcInfo coverage
[*] Production of these maps are still continuing

In addition to traditional paper maps, digital maps are also available from GCM. All topographic map series were scanned in the past and they are currently available in raster format (RASTER-xxx series). However, digital maps in vector format are limited to only two scales, 1:25,000 and 1:250,000. Elevation contour maps, which are subsets of topographic maps, and gridded digital terrain elevation data (DTED) created from these contour maps are available for the whole nation. Production of vector topographic maps for the same scales is still continuing, however tiles produced so far can be obtained on request. Detailed information on the production status can be obtained from GCM. Unlike paper maps, GCM charges money for digital maps. The number of map tiles needed to cover the whole country, unit price of a single tile for the year of 2003, and total price are given in Table 2.2 for different series.

Table 2.2. Cost of digital GCM maps for Turkey

Map series	Number of tiles	Unit cost ($)[1]	Total cost ($)[1]
RASTER-25	5,547	27	147,920
RASTER-50	1,455	27	38,800
RASTER-100	393	27	10,480
RASTER-250	71	27	1,898
RASTER-500	18	27	480
TOPO-25	5,547	333	1,849,000
TOPO-250	71	666	47,000
YUKPAF-25	5,547	83	462,250
YUKPAF-250	71	133	9,467

[1] 1 US dollar = 1,500,000 TL

As shown in Table 2.2, total cost of 1:25,000 scale digital maps including vector and DTED is well over two million U.S. dollars. Working at this scale nation-wide requires a huge budget that is very difficult to support. Although similar scales are currently in use for nation-wide hydrologic studies in several countries (e.g. United States), it is practically not possible to use this scale in Turkey, except for local studies. All other topographic map series, with the exception of 1:250,000 scale, are available in raster format only and need to be converted into vector format either by heads-up digitizing or raster-to-vector (R2V) conversion followed by manual editing. In either way, vector data production will be a labor extensive and time consuming task, especially if numbers of tiles for each map series are considered. Hence, the only scale that is suitable for near future hydrological studies is 1:250,000. However, it should be noted that production of 1:250,000 scale vector maps are still continuing.

In addition to topographic map series, there is also “Map of Administrative Units of Turkey” published by GCM in 1998, which has a scale of 1:1,000,000. Although the main aim of the map, which consists of 3 sheets, is to show the administrative unit boundaries and settlements of Turkey, it has also good quality hydrography and road network layers. No information is given on the projection system used, but it seems to be Lambert Conformal Conic. The map includes a latitude-longitude grid with one degree interval, which can be used for georeferencing purposes. Although complete copyright information is not given, it is simply stated on the map that all rights are reserved by the GCM. GCM has a very strict copyright policy in general, which restricts public redistribution of maps (both original and value-added) by third-party persons and organizations. This map is also not an exception and can only be used for referencing purposes.

2.1.1.2. Maps of Other National Governmental Organizations

In addition to topographic maps of GCM, there also exist specific maps published by governmental organizations that have responsibilities related with water resources development. Two General Directorates of the Ministry of Energy and Natural Resources, which are State Hydraulic Works (SHW) and Electrical Power Resources Survey and Development Administration (EPRSDA), major institutions in this area.

Map of “Dams, Power stations and Irrigation Establishments in Turkey” was prepared by SHW in 1992 (SHW, 1992). As its name implies, the primary aim of the map is to show water resources related works conducted by SHW. These include dams, hydro-electrical power plants, surface and ground water irrigation systems (irrigation ponds and channels), regulators, tunnels, and flood controlling structures.

In addition to already existing works, the ones that are under construction and in planning phase at that time were also indicated on the map. As supplementary information, boundaries of provinces, SHW regions, and watersheds are present. A sample from the map, which consists of three separate sheets, is given in Figure 2.2.

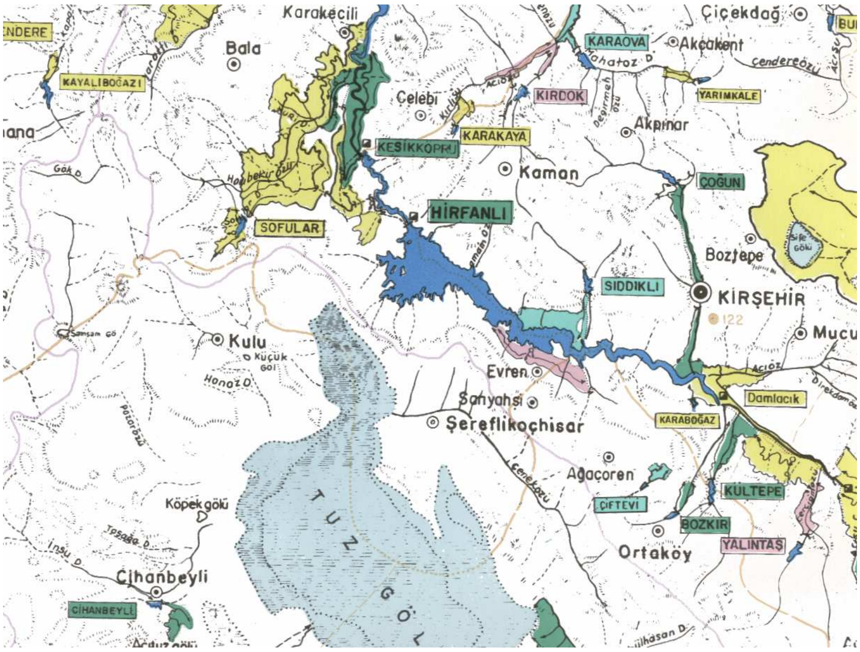


Figure 2.2. Detail from "Dams, Power stations and Irrigation Establishments in Turkey" map of SHW

"Dams, Power stations and Irrigation Establishments in Turkey" map also includes water courses and inland water bodies layer. However, the quality of this layer is poor and especially linear features could not be easily distinguished. Dams that will be constructed in future have the same symbology with already existing dams and natural lakes; hence they can not be differentiated from each other. No map projection information is given except the scale, which is 1:800,000. The map has reference marks at the borders, but there is no grid on the map. Therefore, georeferencing of the map is not easy as well.

Discharge monitoring yearbooks published yearly by SHW contain maps that show the nation-wide distribution of monitoring stations belonging to SHW. Not only the stations that are in operation at that time, but also stations that are closed beforehand are indicated on these maps. The maps are organized in terms of national watersheds and there are 13 map sheets most of which including more than one watershed. The maps show hydrography as well, but unfortunately map projection used by the maps is not specified and the maps do not have any grid. Moreover, the boundaries of the watersheds are not consistent to each other. Usually two map sheets belonging to neighboring watersheds could not be overlaid, because the boundaries are drawn differently in each map. Even though they are termed as maps in the bulletins, they are actually closer to being sketches. Mosaicking of these maps is very difficult, and for some parts of the country significant amount of loss in accuracy is inevitable. Nevertheless they are valuable sources, especially for validation purposes. In this study, maps belonging to 1994 Discharge Monitoring Yearbook published in 1999 are used for such purposes.

EPRSDA also publishes discharge monitoring yearbooks, which are similar to their SHW counterparts. Like SHW yearbooks, these yearbooks include maps that show the nation-wide distribution of stream flow monitoring stations belonging to EPRSDA. The characteristics and quality of EPRSDA maps are alike to SHW maps; hence comments given in the previous paragraph are also valid for these maps. Since accurate location information on EPRSDA monitoring stations do exist in several different documents, there was no need for the information encoded in the maps. Therefore, these maps were not used for the study.

2.1.1.3. National Commercial Map Sources

In Turkey, there are several commercial vendors who are marketing data for use in GIS. Although majority of the products that are marketed are satellite images, several digital maps are also available. İşlem GIS Corporation founded in 1984 markets 1:250,000 scale digital vector maps of Turkey, which are based on 1:250,000 scale maps of GCM. The maps are available as separate thematic layers including settlements, roads, railroads, streams, lakes, provinces and districts. Hence only required thematic layers could be purchased with a lower cost, which is not possible for digital maps of GCM. Pricing is done according to requested extent of the map.

Currently, İşlem vector maps are the only datasets available from national sources, which cover the whole country and have a scale of 1:250,000. Streams and lakes layers of these datasets could be used to produce national hydrography dataset. However there are two obstacles. The first one is related with copyright. Since İşlem dataset is based on GCM maps, they are subjected to strict copyright restrictions of GCM. Even the purchase of these maps could not be done directly. In order to purchase vector maps, first paper copies should be purchased from GCM. Then vector maps could be obtained from İşlem under the name of "digitizing service". A hydrography dataset that will be based on maps that are such restricted will definitely suffer from similar problems. Another obstacle related with İşlem datasets is their cost. Since they are commercial products, their costs are high and require an adequate budget. However, as a part of their partnership relations with academic institutions, İşlem GIS Corporation supported the study and supplied 1:250,000 map layers related with hydrography for internal use of the study without any cost. These layers are used for validation purposes.

2.1.2. International Map Sources

In addition to national map sources, there are also international map sources that can be used for the production of hydrography dataset. Mainly, these sources are general purpose vector maps having global extent. The Digital Chart of the World, its successor Vector Map Level 0, and larger scale Vector Map Level 1 are such datasets, all produced by U. S. National Imagery and Mapping Agency. These map sources are explained in the following sections.

2.1.2.1. Digital Chart of the World

The Digital Chart of the World (DCW) is a comprehensive, publicly available 1:1,000,000 scale vector database of the world in geographic coordinate system. It is the first unclassified map series that provides consistent, continuous global coverage of geographic features, attribute data, descriptive text, and metadata that can be used in conjunction with GIS software (URL 2.1). It was originally produced by

Environmental Systems Research Institute (ESRI) for the U.S. Defense Mapping Agency (DMA, now NIMA).

The DCW data are primarily based on the DMA Operational Navigation Chart (ONC) series that are produced by the United States, Australia, Canada, and the United Kingdom (URL 2.2). The ONCs have a scale of 1:1,000,000, and they were designed to meet the needs of pilots and air crews in medium- and low-altitude flight navigation and to support military operational planning. Therefore, the selection of ground features is based on the requirement for rapid visual recognition of significant details seen from a low perspective angle (URL 2.3). Data for the Antarctic region are based on 1:2,000,000 scale Jet Navigation Charts (JNCs). Several additional sources have been used to complete the data set. The DMA's Digital Aeronautical Flight Information File (DAFIF) was the primary source for the airport data in the aeronautical layer. An Advanced Very High Resolution Radiometer (AVHRR) image is the source for the data in the Vegetation layer, which is only available for the U.S. The Defense Intelligence Agency Manual (DIAM) 65-18 is the source for the Geopolitical codes and the ocean boundaries information contained in the Political and Oceans layer (ESRI, 1993).

The database contains more than 1.7 gigabytes of data on four CD-ROMs, organized in 17 thematic layers including over 200 attributes. Some of the major layers are hypsography, drainage, roads, railroads, utility lines (pipelines and communication lines), populated places, political boundaries, aeronautical features, vegetation, and data quality overlays (URL 2.1). Also additional layers are available in several commercial versions, which may be of use in interpreting the DCW data sets like tile name reference, ONC compilation date, and gazetteer layers (URL 2.4). A complete description of dataset contents is available from DCW Data Dictionary (ESRI, 1993). The development of the Digital Chart of the World is thoroughly described in Military Specification Document (DOD, 1992). A sample map that is based on DCW is given in Figure 2.3.

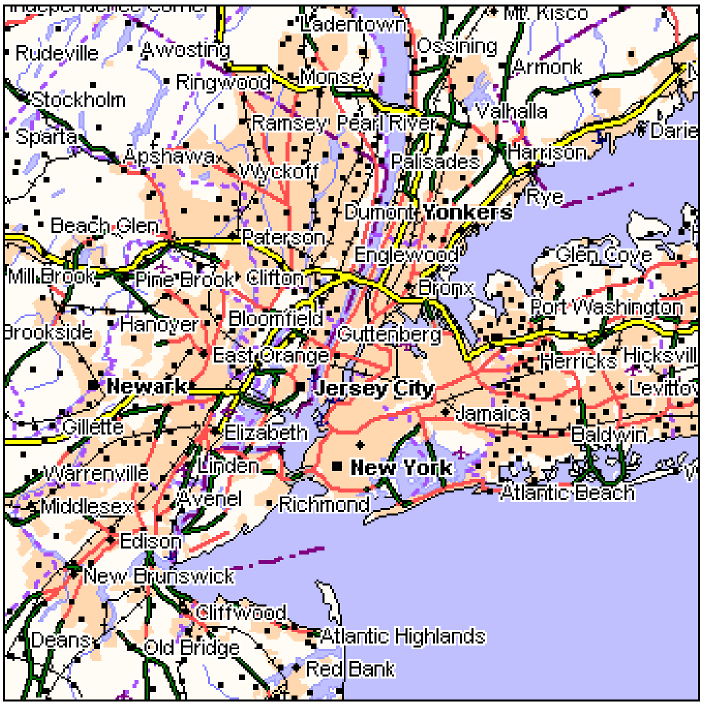


Figure 2.3. Sample DCW map

The DCW data are broken up into tiles, each representing 5 degree latitude by 5 degree longitude portion of the earth. There are 2094 tiles in total (URL 2.5). Antarctica is an exception, where data are very sparse and each tile has dimensions of 90 degree by 35 degree. The dataset is also logically divided into 15 degree rows and columns to be used in naming the tiles. Each physical five degree tile has a four digit name, two of which are letters indicating the 15 degree tile column and row, and other two are numbers indicating the 5 degree column and row in the 15 degree tile (URL 2.6). In order to uniquely identify each layer and item, other naming conventions are used. The layer naming convention uses a two digit identifier to specify the type of layer. This is followed by an indicator specifying the type of features in the layer. For instance the roads layer is named RDLINE. The RD for roads and the LINE for the line feature type. The item names are uniquely identified by two characters representing the theme, two characters representing the type of feature it is associated with, and several characters describing the contents. For example, the "type" item in the political and oceans layer associated with lines is "POLNTYPE". The 'PO' for the theme, the 'LN' for line features, and the 'TYPE' to describe the item (URL 2.7).

The first version of the Digital Chart of the World was released in 1992 in the Vector Product Format (VPF), which is the U. S. Military Standard (MIL-STD-2407) and compliant with the international Digital Geographic Information Exchange Standard (DIGEST). Since then it has been translated into most major GIS formats, such as ARC/INFO, MapInfo, Atlas and Intergraph, and distributed to thousand of GIS users world-wide (Langaas, 1995). DCW data are also downloadable from Internet as ARC/INFO coverages and export files that are clipped to individual country borders (URL 2.8, URL 2.9). This wide availability made DCW an invaluable data source for GIS users world-wide concerned with military, scientific, and educational applications on regional, continental and global level.

Despite the usefulness of DCW, many users have discovered various types of imperfections in several of the coverages in different thematic layers included in the database (Langaas, 1995). Complaints about the DCW data quality have often been centered upon positional accuracy, logical consistency and completeness issues. Detailed accuracy information and product specifications of DCW can be found in DCW Data Dictionary (ESRI, 1993), DCW Documentation (DOD, 1992) and Metadata files (URL 2.10). Product specifications of ONCs (DMA, 1987) are also very informative in this respect. Briefly, it can be stated that with 90% confidence limits the horizontal and vertical accuracies are 485 to 2,225 meters and 50 to 640 meters respectively. The arcs in the database were digitized so that there was at least one vertex every 1.4 cm with respect to the original paper maps (URL 2.10). Data up-to-datedness varies from place to place depending on the currency of the ONC charts, which is in the range of the mid 1960s to the early 1990s (URL 2.3). The dataset is also well documented with respect to data quality. There are attribute tables for many of the features that give status information for individual primitives in the database, and DQNET layer describes the data quality of individual layers and characteristics of each map sheet used in the compilation of the DCW database.

2.1.2.2. Vector Map Level 0

An updated and improved version of the DCW is U.S. National Imagery and Mapping Agency's (NIMA) Vector Map Level 0 (VMAP-0). VMAP-0, which is the fifth edition of the DCW, has replaced the DCW in U.S. military and government usage for detailed thematic maps. The product is dual named to show its lineage to the original DCW, while positioning the revised product within a broader family of VMAP products. Like its ancestor, VMAP-0 is a 1:1,000,000 scale vector base map of the world that is based primarily on ONCs. The data structure is VPF and data are organized in thematic layers similar to DCW with several updates. Thematic layer groups and sub layers of VMAP-0 are summarized in Table 2.3. Availabilities of sub layers for Turkey are indicated with checkmarks in the third column of the table. Complete specifications of VMAP-0 can be found in Military Specification Document (MIL-V-89039) (DOD, 1995).

Major updates of VMAP-0 over DCW according to Metadata Document (NIMA, 2000) are as follows: ONCs, which had been revised since production of the first version of DCW, were digitized and corresponding sections of VMAP-0 were updated. Using an overlay and/or buffer process, names from the GeoNet Names Server (GNS) database were assigned to VMAP-0 populated place polygon features. First order administrative boundaries (provinces) are added to the dataset from ESRI ArcWorld global database. Daily AVHRR images were averaged for a two week time period of 1994 and these averaged images, their rates of change, elevation information, and other data were used to produce a single land classification image of the whole world. Vegetation coverage that is available in DCW for North America only is replaced with vector version of this classification image that is clipped according to coastlines. All data attribute coding of VMAP-0 was done according to Feature and Attribute Coding Catalog (FACC) of DIGEST. The Type/Status codes used in DCW were mapped into the FACC coding scheme. Different from DCW, data were tiled into two sizes: 15 degrees x 15 degrees for predominately land tiles and 30 degrees x 30 degrees for ocean tiles.

Table 2.3. Thematic layers of VMAP 0

Thematic Layer	Sub Layer	Available	Sub Layer Type
Boundaries	Political Boundaries	✓	Point, Line, Area
	Barrier	✓	Line
	Coast	✓	Line
	Depth	✓	Line
	Ocean/Sea	✓	Area
Data Quality	Data Quality	✓	Area, Line
Elevation	Elevation	✓	Point
	Contour	✓	Line
Hydrography	Danger	✓	Point, Line
	Miscellaneous	✓	Point, Line
	Aqueduct/Canal/Flume/Penstock	✓	Line
	Water Course	✓	Line
	Inland Water	✓	Area
Industry	Extraction	✓	Point, Area
	Miscellaneous Industry	✓	Point
	Storage	✓	Point
	Fishery Industry	✓	Area
Physiography	Cut/Fill		Line
	Landform		Line
	Ground	✓	Area
	Land Ice	✓	Area
	Sea Ice		Area
Population	Built-Up Area	✓	Point, Area
	Miscellaneous Population	✓	Point, Area
Transportation	Airport	✓	Point
	Railroad Yard		Point
	Transportation Structures		Node
	Miscellaneous Transportation		Line
	Railroad	✓	Line
	Road	✓	Line
	Trails and Tracks	✓	Line
	Transportation Structures	✓	Line
Utilities	Utility	✓	Point, Line
	Pipeline	✓	Line
Vegetation	Firebreak		Line
	Hedge		Line
	Cropland	✓	Area
	Grassland	✓	Area
	Oasis		Area
	Orchard		Area
	Marsh/Swamp	✓	Area
	Trees	✓	Area
	Tundra	✓	Area
	Vegetation Void Collection		Area

Metadata document also includes information on attribute accuracy, logical consistency, completeness, and positional (both vertical and horizontal) accuracy reports. According to these reports, overall horizontal accuracy is 2040 m, whereas overall vertical accuracy is 152.4 m, both at a 90% confidence interval. However, it should be noted that overall accuracy analysis was performed on one chart only in the prototyping phase. Related with completeness it is stated that “VMAP-0 features depicted on the ONC source materials have been captured and have valid attribute codes assigned to them. All attribute codes were reviewed against their sources. Also all data were found to be topologically correct, and no overshoot, undershoot, and duplicate features are present” (NIMA, 2000). This is however questionable as it will be discussed in the Chapter 3.

2.1.2.3. Vector Map Level 1

Actually, VMAP-0 is not the only vector dataset that is available globally. Its next level, VMAP Level 1 (VMAP-1), which is based primarily on 1:250,000 scale NIMA Joint Operation Graphics (JOGs), was also already produced. VMAP-1 has a resolution that is 4 times better than VMAP-0 and includes information collected from nearly 10,000 map sheets (URL 2.11). As the map series name implies (JOG 1501), these maps are similar to 1:250,000 scale topographic maps of GCM.

The content and format of VMAP-1 is specified in NIMA MIL-V-89033 VMAP military specification main document and its appendix (NIMA, 1995). The dataset has metric unit of measure and its horizontal and vertical datums are WGS84 and Mean Sea Level (MSL) respectively. Like VMAP-0, VMAP-1 products are also organized into thematic layers. Each thematic layer is stored as a single coverage within a VPF library. There are two reference coverages and ten thematic coverages in the data library level. Some of the thematic layers are political boundaries, coastlines, elevation contours, hydrography, vegetation cover, road, rail and utility networks.

The global extent of VMAP-1 consists of multiple regional databases and is divided into a rather complex mosaic of 234 geographic zones, each being available on a single CD-ROM. However at the present time, NIMA is only releasing selected areas of the VMAP-1 dataset (Figure 2.4), even though the whole dataset has been de-classified, is in the public domain, and could be made available via FTP.

Some of the excuses given include the protection of cartographic monopolies of it's overseas partners, that it is not ready for the public to see it, that their security office has not approved it, and that NIMA is afraid the public might "misuse" it (URL 2.11). There are protests, especially from U.S., against limited release of VMAP-1, and NIMA is accused of ignoring Freedom of Information Act (FOIA) petitions to release the data.

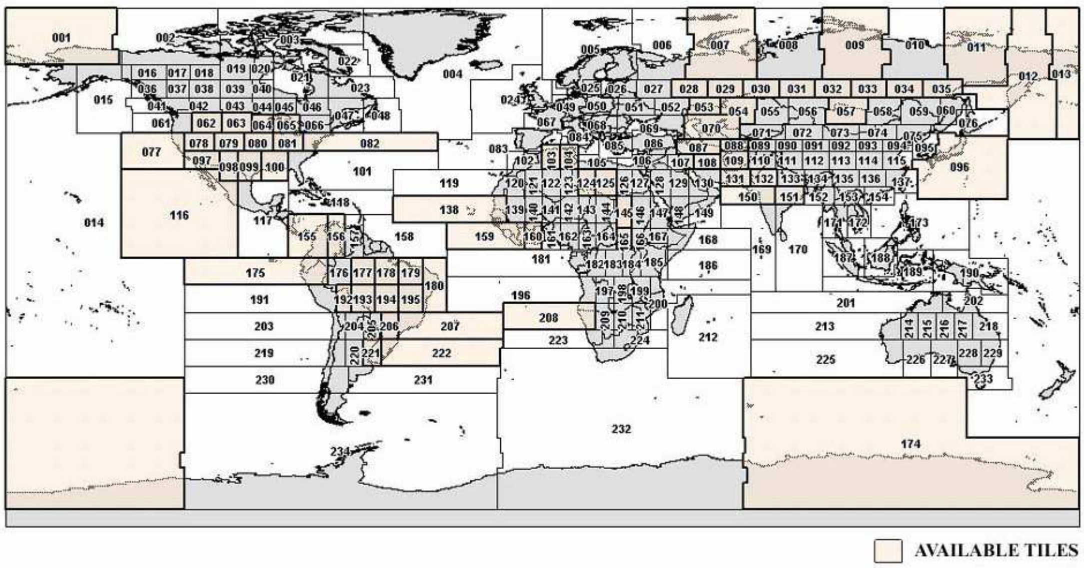


Figure 2.4. Publicly available VMAP-1 coverages (as of 2003)

Anyhow, if VMAP-1 will be released fully to the public, it will be a fundamental part of the next generation of global digital maps, together with 3-arc seconds SRTM digital elevation dataset, which will be described in the Section 2.2.

2.1.3. Evaluation of Map Sources

As stated in Section 2.1, map sources explained so far are evaluated based on several criteria, which are designated to be important for the study. These criteria can be listed shortly as cost, public availability and copyright restriction, map format, accuracy, scale and labor requirement. Comparison of map sources with respect to these criteria are given in Table 2.4 in tabular form. The table includes all map sources mentioned until now, except 1:100,000 and larger scale topographic maps of GCM, which are classified products and hence not publicly available.

As it can be seen from Table 2.4, maps from national institutions (both military and commercial) are superior in map scale and accuracy, and they are also available as digital vector maps. However, copyright restrictions limit the usage of these maps and prevent public distribution of end products that are based on these sources. High cost is a drawback as well. All these make these map sources less preferential for the study. VMAP-1 dataset of NIMA has the same quality as national 1:250,000 scale maps and its status has been set to public domain a long time ago. But, parts of the dataset that cover Turkey are still not accessible, and when it will be available (or if it will be available or not) is currently unknown. Hence, this dataset could not be an alternative. Among the remaining sources, maps of SHW and EPRSDA are on paper and their accuracies are questionable. Especially the maps found in yearbooks are closer to sketches rather than scaled maps having known projections, and it is a very difficult task to convert them to accurate vector datasets. Their approximate scale (1:800,000) is also not significantly better than the scale of other remaining alternative sources, which is 1:1,000,000.

Digital Chart of the World (DCW) and its successor VMAP-0 datasets, both distributed by NIMA, are the data sources that attract attention. They are well documented and peer-reviewed vector map datasets with known accuracies, and are publicly and freely available.

Table 2.4. Comparison of vector map sources

Map Source	Scale	Format	Cost	Labor Requirement	Accuracy	Public Availability
GCM Topographic Maps	1:250,000	Vector*	High	Low	High	Copyrighted
İşlem Thematic Maps	1:250,000	Vector	High	Low	High	Copyrighted
Vector Map Level 1 (VMAP-1)	1:250,000	Vector	None	Low	High	Available**
GCM Topographic Maps	1:500,000	Raster	Medium	High	High	Copyrighted
SHW Map of Dams	1:800,000	Paper	None	High	Medium	Unknown
GCM Administrative Map	1:1,000,000	Vector	Medium	Low	Medium	Copyrighted
Digital Chart of the World (DCW)	1:1,000,000	Vector	None	Low	Medium	Available
Vector Map Level 0 (VMAP-0)	1:1,000,000	Vector	None	Low	Medium	Available
SHW/EPRSDA Yearbook Maps	Unknown	Paper	None	High	Low	Unknown

* Production is still continuing; hence partially available
** Available only for selected part of the world (currently not for Turkey)

Although their 1:1,000,000 scale seems to be low, taking into account the facts that current hydrography dataset of the European Union has a scale of 1:1,000,000 and that the studies related with hydrography dataset production in U.S. started with 1:2,500,000 scale maps, this scale is found to be acceptable as a starting map scale for the study that aims to produce a prototype national hydrography dataset for Turkey. Hence, VMAP-0 that is an updated version of DCW has been selected as the base dataset for the study.

All other maps and datasets, including 1:250,000 scale İşlem dataset, "Map of Dams, Power Stations and Irrigation Establishments in Turkey" from SHW and "Administrative Units of Turkey" map of GCM, are used for validation and correction purposes, which are also important parts of the study. In order to validate the hydrography dataset and determine missing or excess stream lines, a reference map that is more up-to-date or that has a larger scale is needed. A newer digital dataset, which has a scale same as VMAP 0, currently does not exist. But 1:250,000 scale river network dataset has a better scale; hence it includes more detail compared to VMAP 0. Also since the source for 1:250,000 scale river network dataset is 1:250,000 scale national topographic maps prepared by the General Command of Mapping, its accuracy is also higher. Therefore it is a good dataset to be used for validating national hydrography dataset that will be based on VMAP-0 hydrography layer. If 1:250,000 scale river network dataset will be selected for the production of national hydrography dataset, in that case another reference dataset would be required, which is currently not available.

Selection of VMAP-0 dataset also reduced the process overhead of the study. The number of stream lines in VMAP-0 hydrography layer is 4,219 for Turkey. In 1:250,000 scale river network provided for the study by İşlem GIS Corporation, this number is 46,804. That means approximately 11 times more data that should be processed. Since a large proportion of the processing is done manually, time requirement increases dramatically. Also probability to make mistakes rises. Therefore more strict quality assessment is needed, which necessitates additional study time. Although additional time that will be spent will most probably result in a better hydrography dataset in return, first the usefulness and success of a national hydrography dataset should be proved in a practical time period so that additional time requirement becomes reasonable. Thus, a small scale prototype national hydrography dataset that can be developed in a short time is better to begin with. This is another reason why VMAP-0 hydrography layer is selected for the study.

2.2. Digital Elevation Data Sources

There are several elevation data types that are available to be used in GIS. Vector contour maps, gridded (raster) elevation models, and triangular irregular networks (TINs) can be listed as the widely used ones. Among these data types, raster elevation models are generally more common and especially available in global extent, since their production and analysis methods are easier. Elevation data from different sources, having different extends and scales, can be easily merged in raster format by using simple, fully computerized resampling methods. However, this is not the case for vector data. Simplification of larger scale maps is required in order to prevent non-uniform feature distribution and inconsistencies in the resulting map. Vector simplification can not be fully automatized and is very subjective to cartographer. Especially, if too many maps each prepared by different organizations should be merged together (which is the case for development of global elevation maps), this task gets to be much more complicated. Therefore, gridded elevation models are preferred in such cases. Also elevation models obtained from satellite interferometry, which gained importance and started to be used intensively, are in raster format. This as well facilitates use of gridded elevation models for analysis purposes.

Due to aforementioned reasons, it is decided to use a gridded DEM for the study. Both national and international data sources are examined and evaluated to select the best alternative for the study. In the following sections first, different gridded DEM sources and their characteristics are summarized. Then selection of the chosen dataset is justified.

2.2.1. National DEM Sources

In Turkey, DEMs covering the whole country can be obtained only from GCM. Although there exist many topographic map series of GCM, available digital elevation datasets are limited to only two grid spacings, which are 3-arc seconds (DTED-1) and 1-arc second (DTED-2). General information on sources of these datasets, and their availabilities are given in Table 2.5 (URL 2.12).

Table 2.5. Digital Elevation Models produced by General Command of Mapping

Dataset	Series	Source	Availability
3-arc seconds (1^o x 1^o tiles)	DTED-1	YUKPAF-250	Unclassified
1-arc second (7.5’ x 7.5’ tiles)	DTED-2	YUKPAF-25	Classified

1-arc second dataset is available as 7.5 x 7.5 minute tiles, whereas 3-arc seconds dataset is available in 1 x 1 degree tiles; both in DTED format. They are in geographic projection system and datum is WGS84. Horizontal and vertical accuracies for both datasets are given as 130 and 30 meters respectively. Sources of DTED-1 and DTED-2 datasets are 1:250,000 and 1:25,000 contour maps, which are based on topographic maps. Vector-to-grid conversion was conducted by spatial interpolation. Like other digital datasets, GCM charges money for DTEDs as well. Table 2.6 summarizes number of tiles that are required to cover the whole country, their unit and total costs for DTED-1 and DTED-2 (URL 2.13).

Table 2.6. Cost of GCM digital elevation datasets for Turkey

Map series	Number of tiles	Unit cost ($)[1]	Total cost ($)[1]
DTED-1	71	133	9,467
DTED-2	5547	93	517,720

[1] 1 US dollar = 1,500,000 TL

Unlike vector maps, productions of which are still continuing, digital elevation data were completed for the whole country. However, DTED-2 which has a grid spacing comparable to 1/25,000 scale maps is a classified product; hence is not publicly available. Only GCM elevation data that can be used for the study is DTED-1. But there exists some technical problems, which prevents DTED-1 dataset to be used for hydrologic purposes. These problems will be examined in detail in Section 2.2.3, where all elevation models are evaluated.

2.2.2. International DEM Sources

Starting from mid-1980's, a number of global elevation datasets are developed and made available to the public by several national and international research groups and organizations. A short list of such global elevation datasets are given in Table 2.7.

As it can be seen from the table, grid spacing of global elevation models has increased from 10-minutes to 30-arc seconds in less than two decades. This corresponds to twenty folds improvement in the resolution, which is very noteworthy. Currently, global elevation models with smaller grid spacing like 3-arc seconds are under development and will be available to public in a recent time. Presence of such datasets will definitely widen the application areas of global elevation models and contribute significantly to scientific studies. In order to illustrate the improvement in data quality, samples from three datasets having 5-minute, 30-arc seconds, and 3-arc seconds grid spacing are given in Figure 2.5.

In the following sections, major global elevation models listed in Table 2.7 will be explained in detail to show how they are progressed in time and to form a background for data source evaluation and selection steps of the study.

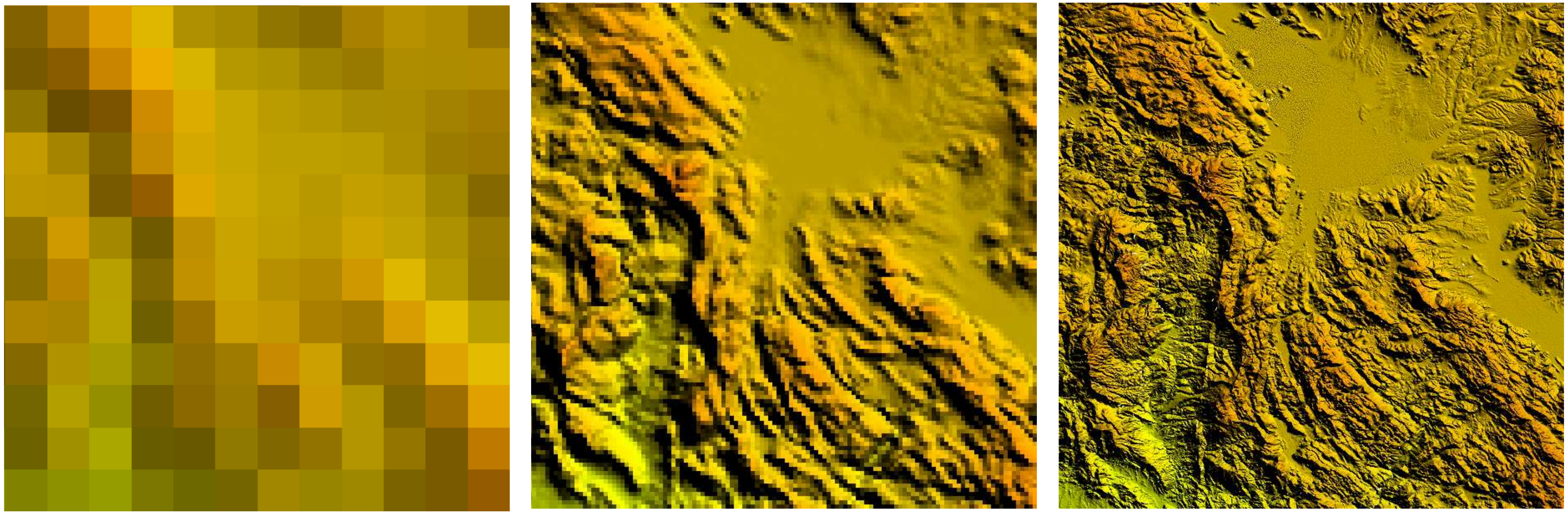
Table 2.7. Publicly available global digital elevation models

DEM	Date	Grid Spacing	Type	Coverage	Organization	Grid size[1]	Grid Dimensions
FNOC 10’	1984	10-minute	Topography	Global	FNOC	18.55 km	1080 x 2160
ETOPO5	1988	5-minute	Relief	Global	NGDC	9.28 km	2160 x 4320
TerrainBase	1994	5-minute	Relief	Global	NGDC/WDC-A	9.28 km	2160 x 4320
DTED-0	1996	30-arc seconds	Topography	Partial	NIMA	928 m	**
GTOPO30	1996	30-arc seconds	Topography	Global	USGS	928 m	21600 x 43200
GLOBE	1999	30-arc seconds	Topography	Global	NGDC	928 m	21600 x 43200
ETOPO2	2001	2-minute	Relief	Global	NGDC	3.71 km	5400 x 10800
SRTM30	2003	30-arc seconds	Topography	Global	NASA/NIMA	928 m	21600 x 43200
SRTM 3”	2003[2]	3-arc seconds	Topography	Partial	NASA/NIMA	92.8 m	**

[1] Although grid sizes are constant in degree units, they are not constant in metric units, since distances between longitudes decrease as going from equator to poles. Grid sizes given in this column are at the equator.

[2] Will be available at the end of 2003.

** Grid dimensions could not be given for partial coverage DEMs



(a) 5-minutes (TerrainBase) (b) 30-arc seconds (GTOPO30) (c) 3-arc seconds (SRTM)

Figure 2.5. Comparison of different grid sized digital elevation models

2.2.2.1. FNOC Global DEM

One of the first digital elevation models available to public is 10-minute (~9.27 km at equator) global elevation model of Fleet Numerical Oceanographic Center (FNOC) that is developed in 1984 (URL 2.14). The main sources of the data were the U.S. Department of Defense (DOD) Operational Navigation Charts (ONC) at a scale of 1:1,000,000. Where ONCs were not available, other maps such as the Jet Navigation Charts and World Aeronautical Charts were used. The dataset do not include bathymetry and coded values are in terms of 100 foot contour intervals (URL 2.15) (Figure 2.6).

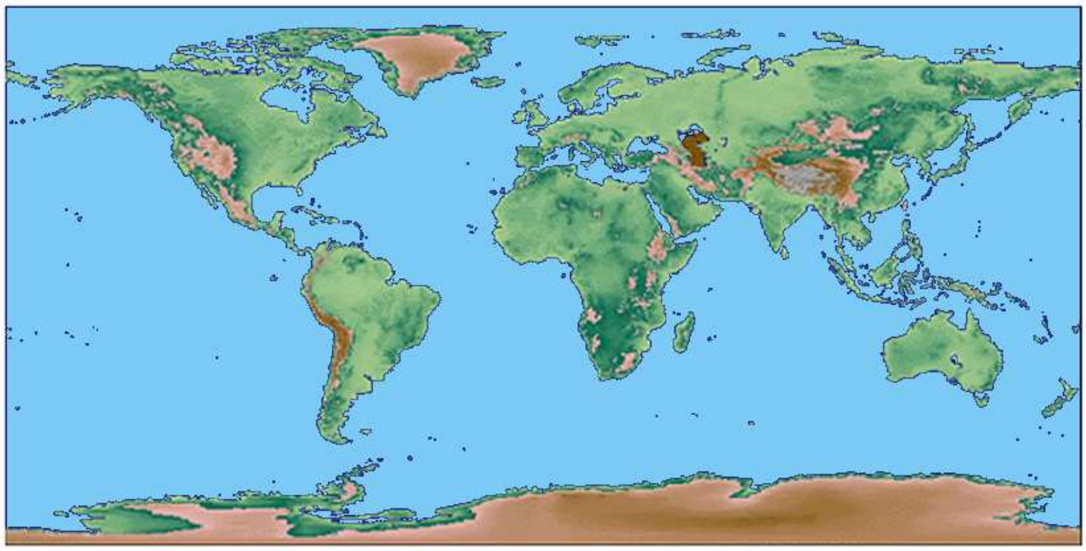


Figure 2.6. FNOC Global Elevation Model

2.2.2.2. ETOPO5 Global DEM

ETOPO5, which is made available in 1988 by National Geophysical Data Center (NGCD), evolved from a 5-minute global terrain model that was initially developed in 1985 at Washington University (URL 2.16). The model is a mosaic of five different source models, the grid spacings of which range between 30-arc seconds to 10-minutes. For North America 30-arc seconds, and for Europe, Mediterranean region, Japan, Korea and Australia, and New Zealand 5-minutes datasets are utilized.

For all remaining land areas FNOC 10-minute grid is used. ETOPO5 also includes bathymetry data from U.S. Naval Oceanographic Office's Digital Bathymetric Data Base 5-minutes (DBDB5) (URL 2.17). Elevations are given in meters. The dataset had been periodically corrected; hence several different versions are available. It had been an important terrain data resource for a broad array of users, and was very popular at that time (URL 2.16) (Figure 2.7).

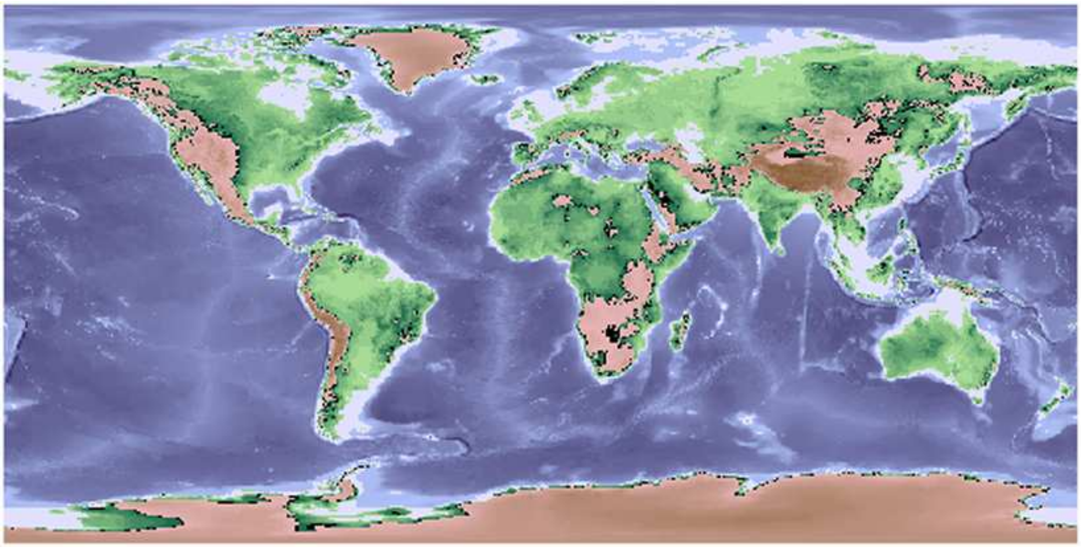


Figure 2.7. ETOPO5 Global Relief Model

2.2.2.3. TerrainBase Global DEM

As a result of a project conducted by NHGC and World Data Centers–A for Solid Earth Geophysics and for Marine Geology and Geophysics, TerrainBase CD-ROM has been published in 1994, which was containing a large collection of digital terrain models available at that time (Row and Hastings, 1994). In addition to more than 20 regional models, a new global model was also introduced. Extent and grid spacing of TerrainBase global elevation model were the same as ETOPO5. But it has significant improvements in the amount and quality of source data that were used for global model development. In addition to five models used in ETOPO5, ten other sources were included and documentation has been redesigned and extended. Although the model contains many significant artifacts, it provides substantial improvements in quality, structure and documentation over its predecessors (Row et al., 1995). An important characteristic of TerrainBase is its design as an "evolving" dataset. 'Update of dataset as new sources having better quality will be available' was one of the primary objectives of the project that was stated explicitly. In this respect, it differs from FNOC 10-minute and ETOPO5 datasets.

2.2.2.4. GTOPO30 Global DEM

A major progress, which provided a new level of detail in global topographic data, was the development of GTOPO30 (Figure 2.8). GTOPO30 that was developed over a 3 year period through a collaborative effort led by staff at the U.S. Geological Survey's EROS Data Center (EDC) and completed in late 1996, is the first 30-arc seconds (approximately 1 km at equator) global DEM that is publicly available (USGS, 1997a). GTOPO30 is based on data derived from 8 different elevation sources, including vector and raster data sets. Two major data sources were U.S. National Imagery and Mapping Agency's (NIMA) Digital Terrain Elevation Data (DTED) raster topographic database with a horizontal grid spacing of 3-arc seconds and hypsography layers of 1:1,000,000 scale Digital Chart of the World (DCW) vector cartographic dataset. Approximately 80% of GTOPO30 was derived from these two sources. A complete listing of data sources and their descriptions, extents and supporting organizations can be found from GTOPO30 Documentation (USGS, 1997b).

For the production of GTOPO30, raster sources were resampled using a set of generalization methods, and topographic information from vector sources was converted into raster grids using special gridding programs. Resulting raster datasets were merged into a global dataset and clipped according to coastlines to separate land and ocean areas. During merging process overlapping area are interpolated to obtain a smooth transition between different sources. The generalized raster sources had the highest priority while merging, followed by the grid derived from DCW that had the highest priority among the vector sources.

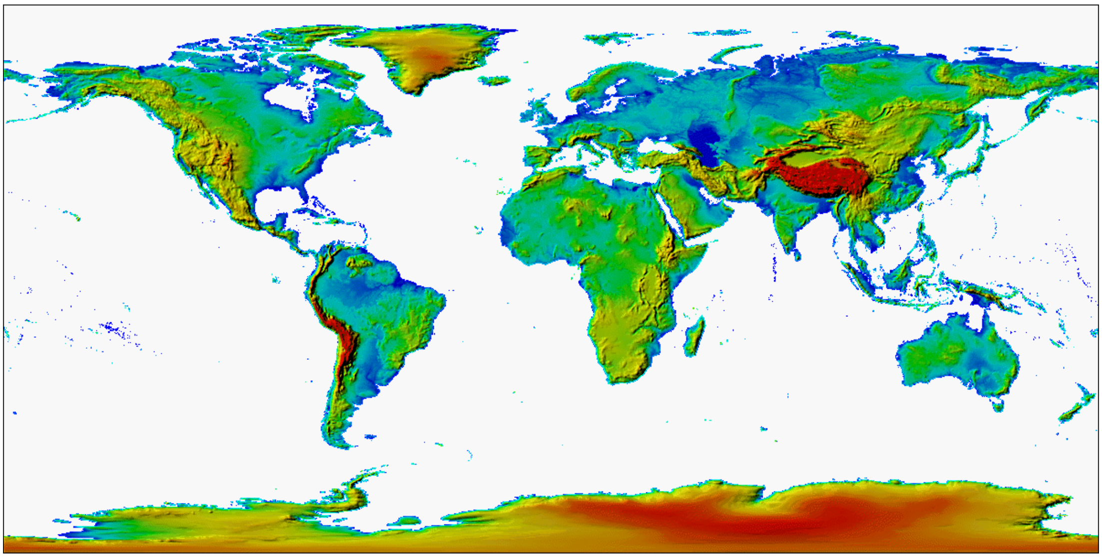


Figure 2.8. GTOPO30 Global Elevation Model

Detailed information on raster and vector source processing, DEM merging, topographic detail and accuracy, and known artifacts are given in GTOPO30 documentation (USGS, 1997b). Although accuracy of dataset differs from part to part depending on the source that is used to derive the grid elevations, its vertical accuracy ranges between 9 m to 300 m, except Antarctica where the accuracy is highly variable.

To facilitate electronic distribution, GTOPO30 has been divided into tiles with no overlap. The area from 60 degrees south latitude to 90 degrees north latitude is covered by 27 tiles, with each tile covering 50 degrees of latitude and 40 degrees of longitude. Antarctica (south of 60 degrees south latitude) is covered by 6 tiles, with each tile covering 30 degrees of latitude and 60 degrees of longitude (Figure 2.9).

Data for each tile are provided in a set of 8 files, which are: digital elevation model data, header file for DEM, world file containing georeferencing information, statistics file, projection information file, shaded relief image, source map, and header file for source map. The base file is digital elevation model data file; the others are made available as supplementary information.

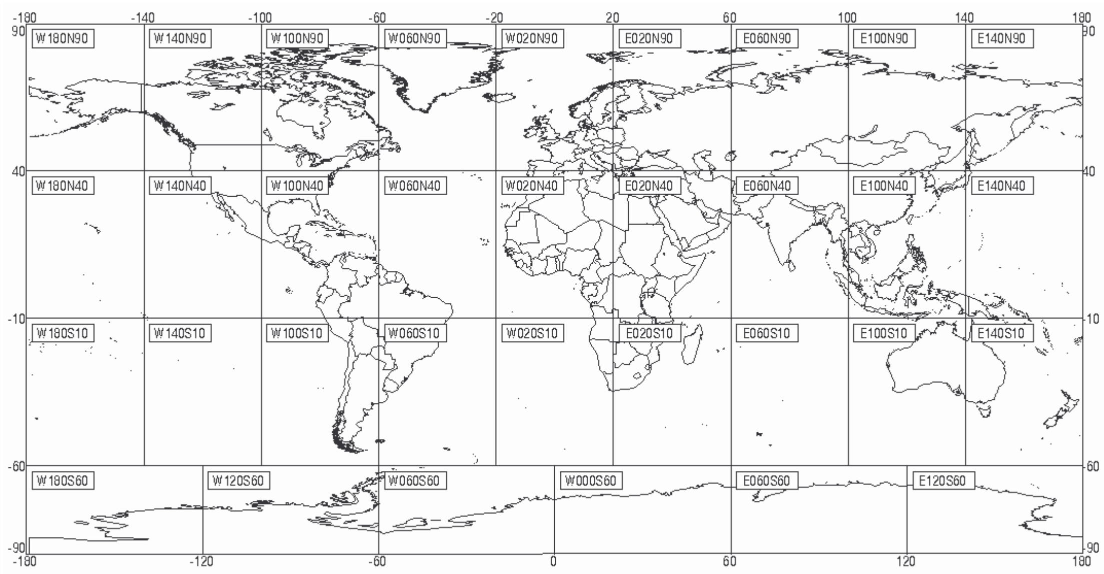


Figure 2.9. Tiles of GTOPO30

GTOPO30 data were used for many regional and continental applications world-wide, such as climate modeling, continental-scale land cover mapping, extraction of drainage features for hydrologic modeling (Danielson, 1996; Verdin and Greenlee, 1996), and geometric and atmospheric correction of medium and coarse resolution satellite image data (Gesch, 1994; JPL, 1997).

2.2.2.5. GLOBE Global DEM

The successor of GTOPO30 is Global Land One-kilometer Base Elevation (GLOBE) dataset that is released in 1996 (Figure 2.10) (GLOBE Task Team and others, 1999). GLOBE is designed, openly peer-reviewed, implemented, and documented by a global consortium of scientists and organizations. Like TerrainBase, one of the aims of GLOBE was being an ongoing program of data collection, with enhancement of the data base and documentation for as long as the data are useful. It has a project Web site and online documentation, which includes detailed information on general characteristics of dataset, development history, data sources, applied data processing methods, assembly of global dataset, imperfections, horizontal and vertical accuracy, data format, and data distribution (Hastings and Dunbar, 1999).

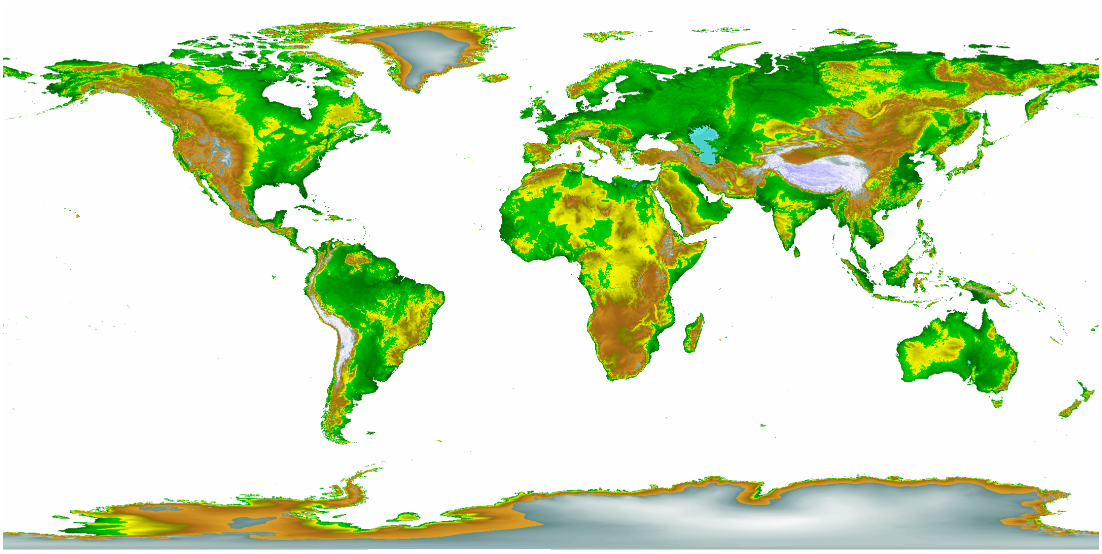


Figure 2.10. GLOBE Global Elevation Model

Similar to TerrainBase that had the same grid spacing as its precursor ETOPO5 but used more data sources, GLOBE has the grid spacing of 30-arc seconds that is the same as GTOPO30, but the number of sources that are used to derive global elevations are much more in GLOBE Six gridded DEMs, and five cartographic sources, were adapted for use in GLOBE. Several of these sources were processed in more than one way to create 30-arc seconds grids. This resulted in 18 combinations of source/lineage used in GLOBE (Hastings and Paula, 1999) (Figure 2.11).

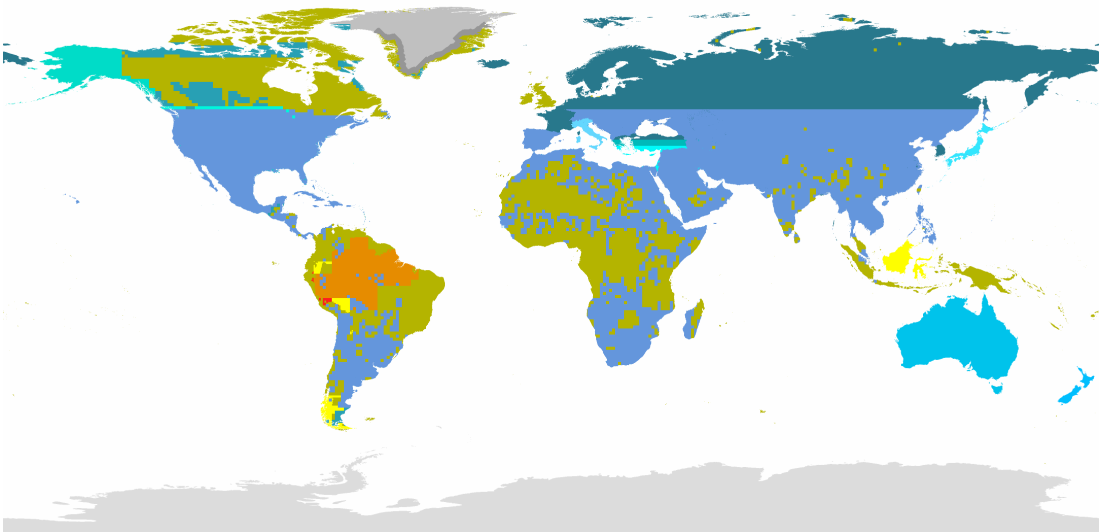


Figure 2.11. Source lineage map of GLOBE

Two different GLOBE distributions are available: Best Available Data (B.A.D.) version, and Globally Only Open-Access Data (G.O.O.D.) version. The former includes copyrighted data that are made available for distribution by GLOBE with restrictions, while the latter do not contain any restricted data. Both of the versions are distributed as tiles shown in Figure 2.12.

```
                 180W      90W       0         90E       180E
North Pole  90N+---------+---------+---------+---------+
               |         |         |         |         |
               |    A    |    B    |    C    |    D    |
               |         |         |         |         |
            50N+---------+---------+---------+---------+
               |         |         |         |         |
               |    E    |    F    |    G    |    H    |
               |         |         |         |         |
Equator       0+---------+---------+---------+---------+
               |         |         |         |         |
               |    I    |    J    |    K    |    L    |
               |         |         |         |         |
            50S+---------+---------+---------+---------+
               |         |         |         |         |
               |    M    |    N    |    O    |    P    |
               |         |         |         |         |
South Pole  90S+---------+---------+---------+---------+
```

Figure 2.12. Tiling diagram of GLOBE

Primary source of GLOBE is GTOPO30; hence most of accuracy information is the same as GTOPO30. But accuracy of data is higher for regions, where better quality sources than GTOPO30 are used, like Japan, Italy and Australia. Complete accuracy information is given in GLOBE Documentation (Hastings and Paula, 1999).

Until very recently, GLOBE was the best global elevation model that is publicly available. However, this situation changed as products of Shuttle Radar Topography Mission (SRTM) are started to be released.

2.2.2.6. SRTM30 Global DEM

The SRTM data resulted from a collaborative effort by the U.S. National Aeronautics and Space Administration (NASA) and the U.S. National Imagery and Mapping Agency (NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry (USGS, 2003). The objective of this project was to produce digital topographic data for 80% of the Earth's land surface (all land areas between 60º north and 56° south latitude that equates to 119.56 million km^2), with data points located every 1-arc second on a latitude/longitude grid (30 meters at equator). A complete description of the SRTM mission can be found in Farr and Kobrick (2000), but a short description is given below in order to provide basic information.

SRTM instrument was the primary payload on the STS-99 mission of the Space Shuttle Endeavour, which launched on February 11, 2000 and flew for 11 days. The instrument consisted of space-borne imaging radar hardware and antenna that were located in the shuttle's payload bay, a space station-derived 60 m long mast that was the longest rigid structure ever deployed in space, and an additional antenna at the end of the mast (USGS, 2003). The two antennas formed an interferometer with a 60 meter long baseline from which two radar images were simultaneously captured. The instrument operated virtually uninterrupted during the whole flight and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times (Figure 2.13). The goal was to image each terrain segment at least twice from different angles (on ascending and descending orbit passes) to fill in areas shadowed from the radar beam by terrain (USGS, 2003).

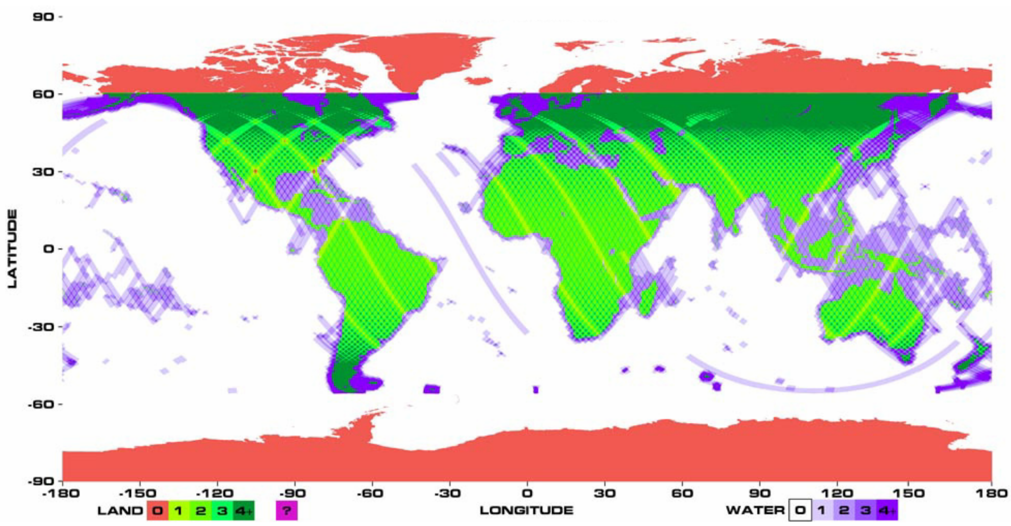
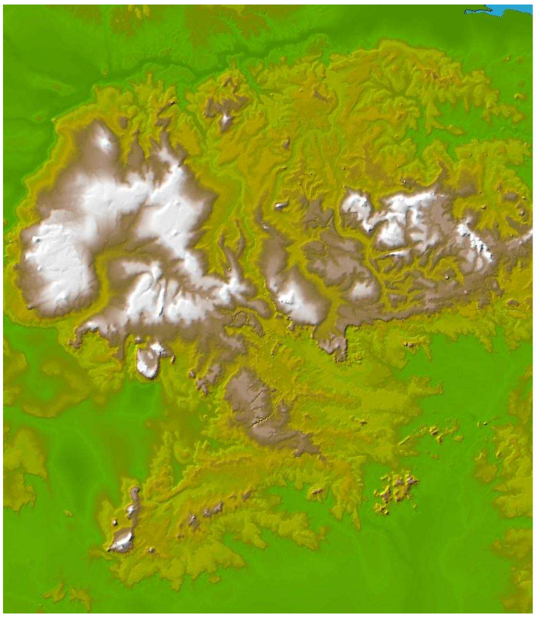


Figure 2.13. SRTM coverage map showing number of images captured for each land segment

SRTM radar contained two types of antenna panels, C-band and X-band. The near global coverage DEMs are made from the C-band radar data. These data were processed at the Jet Propulsion Laboratory in a time period of two years and are being distributed through the USGS's EROS Data Center. Data from the X-band radar are used to create slightly higher resolution DEMs but without the global coverage of the C-band radar. The SRTM X-band radar data are being processed and distributed by the German Aerospace Center (URL 2.18). Data collection and processing methods applied in SRTM ensured that the SRTM generated topographic maps have the same characteristics (URL 2.19). The absolute vertical accuracy of the C-band data is estimated to be 16 meters at 90% confidence interval. With this high accuracy, near-global coverage, and superior resolution, SRTM data become the most complete high-resolution digital topographic database of Earth that has ever assembled (URL 2.20) and the mission itself may regarded to be one of the best geospatial collection works in the history of mapping (URL 2.21). The base dataset is under control of NIMA, who is using it to update and extend their DTED products, especially DTED Level 2 which has the same grid spacing. Distribution of base dataset is restricted, but its several products will be publicly available.

As a part of data processing process, 1-arc second base data were averaged 3 x 3 and a 3-arc seconds dataset was produced. Currently this dataset is publicly available for North and South America. Other continents will also be released systematically to the public and scientific community by mid 2004 (URL 2.18). This dataset can be designated as herald of a new era, since a new level of detail will be added to the current publicly available global elevation models.

Further 10 x 10 averaging of 3-arc seconds data resulted in another dataset with 30-arc seconds grid spacing that is similar to GTOPO30 and its successor GLOBE. However, unlike these datasets, which were compiled from various data sources and hence have non-uniform accuracy and quality, radar interferometry based SRTM data has the same characteristics at all locations. Also as stated previously, the accuracy of SRTM data is much higher. One drawback of SRTM 30-arc seconds data is its not global but near-global coverage. There exist locations as well, where SRTM data are missing. This is especially the case for high mountainous areas, where shadowing effect is observed. In order to overcome these problems, a hybrid dataset called SRTM30 has been created by combining averaged SRTM data with GTOPO30 such that grid cells contained SRTM data where SRTM data were valid and GTOPO30 data where SRTM data were missing. As stated in its documentation, SRTM30 can be considered to be "either an SRTM data set enhanced with GTOPO30, or as an upgrade to GTOPO30, which greatly improves accuracy of GTOPO30 between 60 degrees north and 60 degrees south of equator" (USGS, 2003). Increase in accuracy is illustrated in Figure 2.14 (URL 2.20).



a. GTOPO30

b. SRTM30

Figure 2.14. Comparison of GTOPO30 and SRTM30

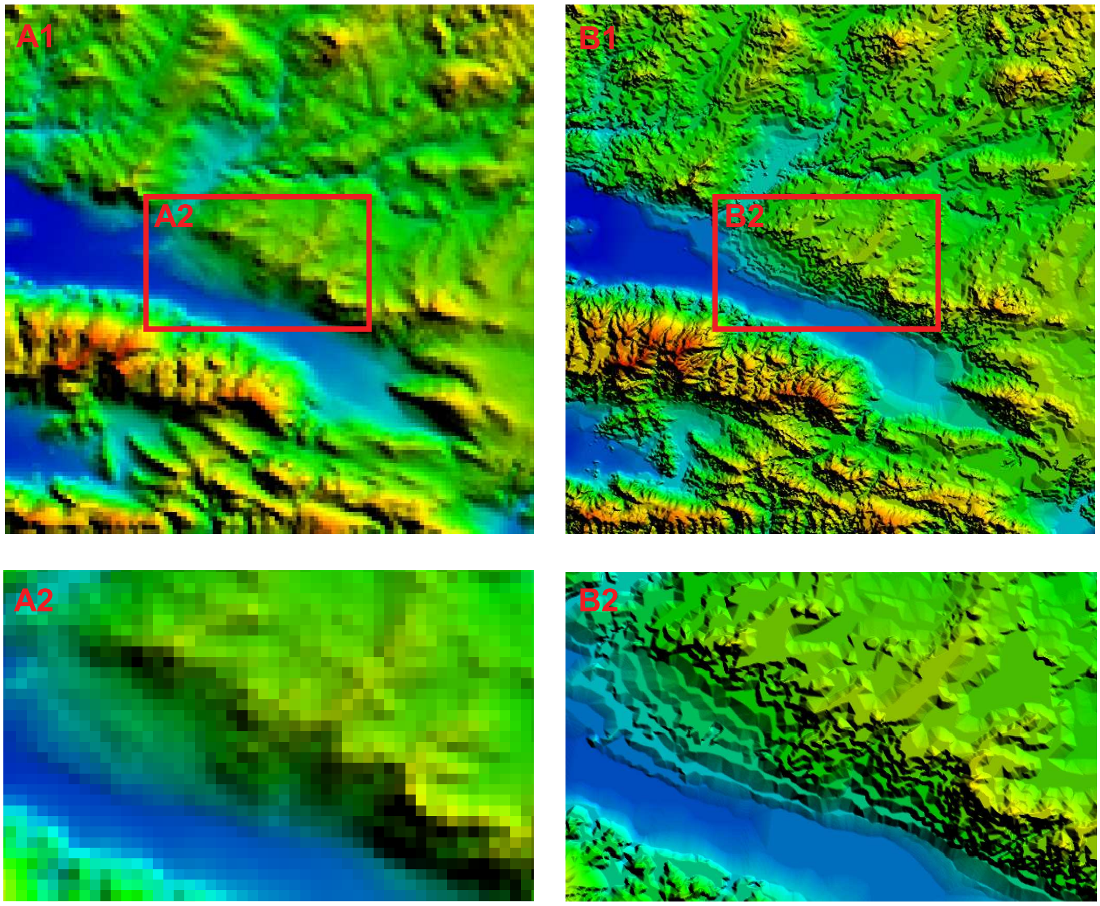
SRTM30 has been divided into the same tiles as GTOPO30. However, since no SRTM data are available below 60 degree south latitude, Antarctica tiles were not generated. For each tile, 4 new files are available in SRTM30 in addition to 8 files that were included in GTOPO30. These new files contain cell-by-cell information on number of valid SRTM points used in averaging, standard deviation of elevations, and difference between SRTM30 and GTOPO30. Also color coded shaded relief image in JPEG format is made available.

2.2.3. Evaluation of DEM Sources

As described so far, there exist both national and international DEM sources that can be used for the study. Although grid spacing of GCM DEMs are superior to publicly available global sources, there exists several problems. Putting the financial burdens aside, which are also important and should be taken into consideration, there exist much more important troubles that are related with the production of GCM datasets.

One important technical problem of 3-arc seconds DTED-1 dataset is improper interpolation of elevation data, which resulted in terracing effects. It is well known that the sources for GCM DTEDs are vector contour maps that are extracted from topographic maps. There are several methods available to produce gridded elevation data from vector contours, like inverse distance weighting, local and global polynomial interpolation, radial basis functions, kriging and cokriging. All these techniques are known to be smooth interpolators, resulting in continuous gradients between data points. However, if DTED-1 tiles of GCM are examined, it can be easily noticed that many unnaturally flat areas exist that are artifacts of vector-to-raster interpolation. This situation is illustrated in Figure 2.15 with comparison to SRTM30 dataset.

In Figure 2.15, DTED-1 and SRTM30 DEMs are given for a geographical area located between 28-29^{o} east longitudes and 38-39^{o} north latitudes. Some portions of the DEMs are also enlarged to show the details. Since SRTM30 has a grid spacing of 30-arc seconds, which is ten times coarser than 3-arc seconds DTED-1, DTED-1 results in a sharper and more comprehensive view. However, if detailed sections are examined, flat zones are observed in DTED-1, where hill slopes are present in SRTM30. Even, it can be said that majority of the DTED-1 grid cells belong to flat areas. Such flat zones are definitely not natural, and they seem to be resulting from improper interpolation.



A1: SRTM30, A2: SRTM30 detail B1: DTED1, B2: DTED1 detail

Figure 2.15. Comparison of SRTM30 and DTED-1 DEMs

The situation can be made clearer by examining the histogram of both DEMs, which show the distribution of grid cells with respect to their counts per elevation value. Histograms generated for SRTM30 and DTED-1 DEMs given in Figure 2.15 are shown in Figure 2.16. Histogram of SRTM30 shows a continuous distribution of elevation values, and no elevation value has an excess count of grid cells compared with others. However, in the histogram of DTED-1, a series of high and low peaks are observed instead of a continuous distribution. The elevation values corresponding to these peaks show a specific pattern: high peaks are at elevations that are folds of 100, and low peaks are at elevations that are folds of 50. In the lower end of the histogram there are also peaks at elevations that are folds of 25.

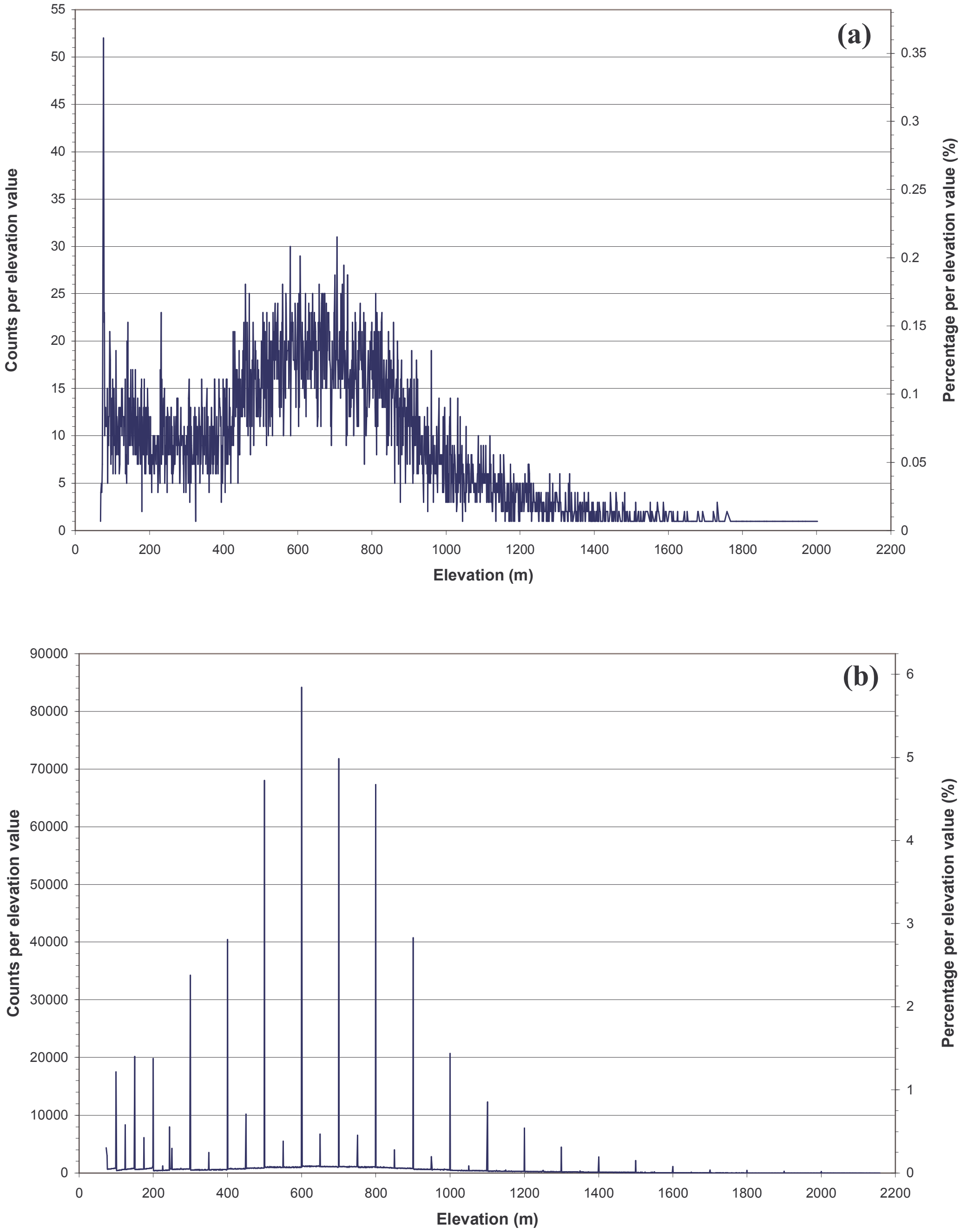


Figure 2.16. Histograms of a) SRTM30, b) DTED-1 for 28-29° E/38-39° N

These values show one-to-one match with elevations of contours that are used to produce DTED-1 grids. Hence, it can be concluded that the gridding technique used to create DEMs had definitely favored the elevations of source contours and instead of a smooth interpolation, values of elevation contours are given to the majority of neighboring cells. This resulted in unnatural flat zones nearby the contours. Taking the shapes of the flat zones and observed phenomena into account, it can be deduced that in order to produce DTED-1 datasets, first contour vectors were converted to TIN, and then these networks were gridded. Only such a methodology could result in DEMs similar to GCM DTED-1. Actually, this is the fastest method to obtain grids from vector contours, and hence may be preferred by GCM to cope with high number of tiles that should be processed.

Current flow direction/flow accumulation algorithms that are using gridded elevation models do not perform well in flat areas, since the flow direction could not be determined precisely. In addition to natural flat areas, if enormous numbers of unnatural flat zones are also present in a DEM, than the flow directions and drainage network resulting from these directions will be inaccurate, even unrealistic for most of the time. Therefore, use of such datasets should be prevented if possible.

Although grid spacing of GCM DTED-1 dataset is superior to alternative 30-arc seconds datasets, the problem related with its production mentioned above makes it unsuitable for use in the study. Use of this dataset for other hydrologic applications is also not recommended. 3-arc seconds SRTM dataset, which will be available by the mid of 2004, has the same grid spacing with GCM DTED-1 and since it is based on satellite interferometry it is safe from interpolation errors. Hence, it could be a good alternative to work with. Up to that time, 30-arc seconds global elevation datasets are the best sources for accurate digital elevation data.

As stated in the review of digital elevation models, there exist several 30-arc seconds global elevation datasets. However, GLOBE dataset that is based on cartographic sources and SRTM30 that is based on satellite interferometry are representatives of the latest developments, and they are superior to other available datasets. Until recently, GLOBE dataset was the "best" 30-arc seconds DEM, and definitely the dataset that should be selected to work with. But SRTM30 dataset, with its uniform accuracy and high quality data source, superceded this dataset as stated before and illustrated in Figure 2.14. In addition to that, SRTM30 also showed that GLOBE dataset has more problems than just accuracy and dataset production techniques caused inappropriate results for the part covering Turkey.

For the production of GLOBE dataset, 18 different combinations of source/lineage were used. 5 of these 18 combinations, short descriptions of which are given in Table 2.8, are observed in the study area as shown in Figure 2.17.

Table 2.8. Description of the GLOBE source/lineage combinations for Turkey

Source Code	Source/Lineage
0	Sea/Ocean
1	DTED Level 0 discrete (spot) 30" DEM, sampled from the southwestern corner of the 30" GLOBE grid cell
2	DTED-based 30" median DEM from USGS/GTOPO30
6	DTED-based 30" "breakline" DEM from USGS/GTOPO30
7	DTED-based DEM. Linear blending between classes 2 and 6

Figure 2.17. GLOBE source/lineage map for Turkey

Although GLOBE DEM of Turkey has a single source, which is DTED, it does not have uniform characteristics since different resampling methods are applied to different parts of the country. During the construction of the GLOBE, the DEMs for Eurasia that is based on median resampling and Africa that is based on breakline resampling favoring ridges and valleys were mosaicked along 39^o North latitude, and 59^o East longitude. The data were linearly blended along a 2-degree-wide zone centered along these lines. Thus at 40^o North, median derivations were used (Class 2), at 38^o North breakline methods were used exclusively (Class 6), and at 39^{o}N 50% weighting of both of these methods was used (Class 7) (Hastings and Dunbar, 1999). Because Turkey extends between 36 - 42^o North latitudes, all these three resampling methods are observed. Although the mosaicking of Class 2 and Class 7 DEMs resulted in a smooth transition, which is not distinguishable, the transition from Class 7 to Class 6 DEMs is very sharp as it can be seen from Figure 2.18.

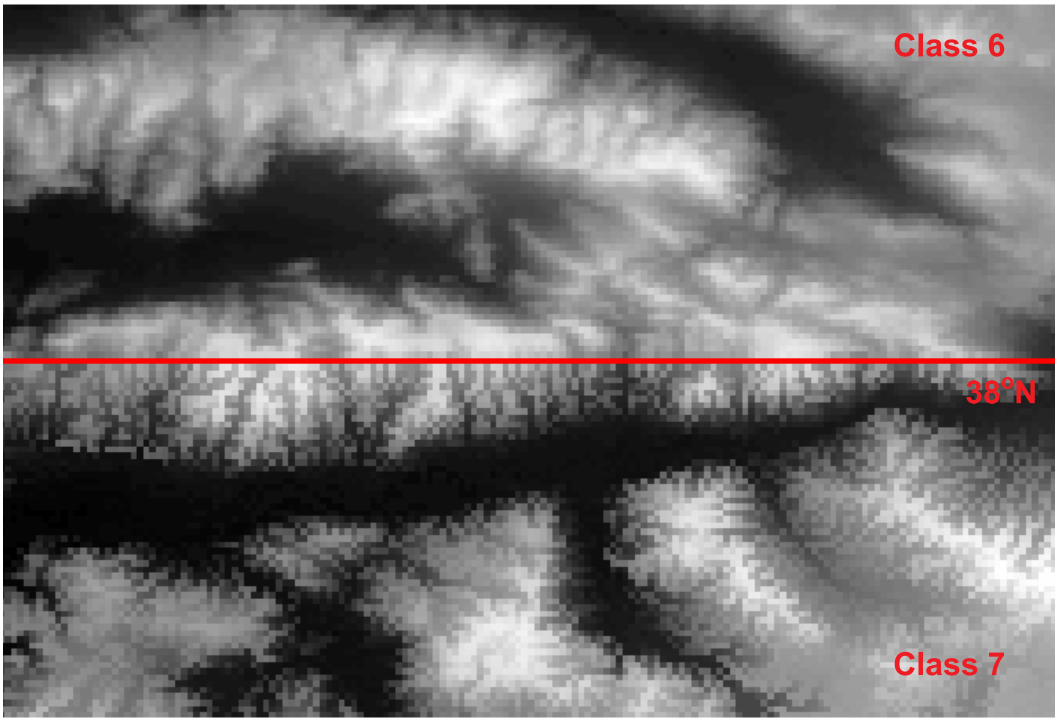


Figure 2.18. Difference in GLOBE DEM between two sources, Class 6 and Class 7

In addition to presence of DEMs with different characteristics, there also exists another problem, which is 30 arc-seconds (one grid cell) shift of Class 6 and Class 2 DEMs to the west. This shift is easily observable in GIS when both SRTM and GLOBE DEMs are visualized on top of each other. Although it is not so easy to realize this shift on paper, a set of elevation values are given in Figure 2.19 to illustrate this phenomena. Since the sources are different, elevation values are not the same for two grids; however their order of magnitude could give an idea. Portions of grids with gray background are the ones that correspond to each other.

1210	1187	1126	1088	1118
1193	1149	1104	1115	1125
1177	1135	1107	1114	1105
1068	1050	1067	1055	958
1000	951	946	966	944

SRTM DEM

1175	1105	1100	1111	1115
1146	1099	1108	1122	1130
1122	1101	1103	1112	1093
1009	1052	1030	903	889
916	912	911	904	971

GLOBE DEM

Figure 2.19. Left shift of DEM grid cells in GLOBE DEM

This shift in grid cells directly affects the analyses that are based on digital elevation data, e.g. flow direction and accumulation calculations, determination of watershed boundaries. Its effect in the location of drainage lines are illustrated in Figure 2.20. As it can be seen from this figure, shift of DEM cells also results in shift of drainage lines that are based on DEM. If GLOBE DEM is used for flow direction calculations, obtained drainage lines do not coincide exactly with reference stream lines. However, if SRTM30 DEM is used, stream and DEM-based drainage lines are found to be matching to each other.

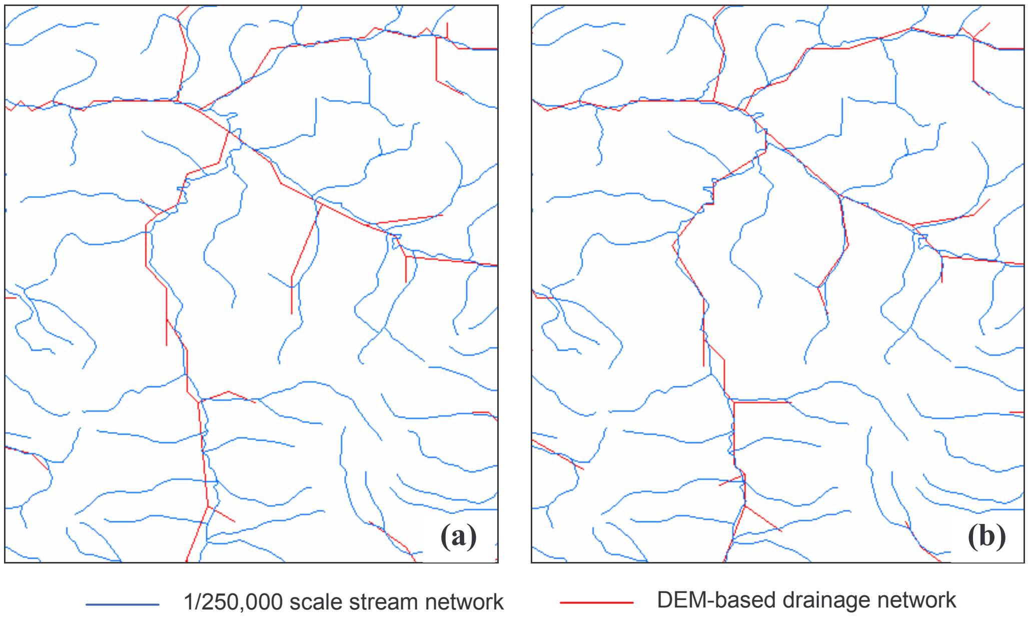


Figure 2.20. Drainage network obtained from a) GLOBE, b) SRTM30

Taking these drawbacks into account, use of GLOBE DEM is not recommended for hydrologic applications in Turkey. In this study, SRTM30 dataset is used as the base elevation data for all DEM based analyses.

2.3. Water Quality and Quantity Data Sources

Unlike some other countries, in Turkey there exists no single organization that is responsible for monitoring of water resources. Instead, several organizations are collecting hydrological data for the needs of the country. Leading organizations in this area can be listed as follows:

- General Directorate of State Hydraulic Works (SHW),
- General Directorate of Electrical Power Resources Survey and Development Administration (EPRSDA), and
- General Directorate of Rural Services (GDRS).

General Directorate of State Meteorological Works (SMW) can also be added to the list in terms of meteorological data.

Different monitoring studies, including measurements of stream flows, water levels in lakes and reservoirs, sediment and water quality parameters, snow depths and meteorological conditions are being conducted by these organizations. Within the scope of this study, attention is given to the stream flow and water quality monitoring studies. Lake monitoring stations, snow monitoring stations, meteorological stations, and data collected by these types of stations are not studied explicitly.

In this section, general information on SHW, EPRDA and GDRS are given, stream flow and water quality monitoring studies of these organizations are summarized, and format of the collected data, for which an analysis system is developed as a part of the thesis study, is described in details.

2.3.1. General Directorate of State Hydraulic Works

General Directorate of State Hydraulic Works (SHW), which is founded in 1953, is one of the primary managerial state water agencies. The directorate that is bound to the Ministry of Energy and Natural Resources is charged by the law to develop water resources of the country. SHW's main objectives are to prepare feasibility studies for the development of water resources, to design required projects, and to construct and operate hydraulic facilities. Specific duties of the directorate can be listed as follows:

- Carrying out surveys for river basin management,
- Preparing master plans and feasibility reports,
- Executing technically and economically feasible water resources projects,
- Constructing dams and hydroelectric power plants,
- Building of irrigation and drainage systems,
- Constructing and operating flood-control structures,
- Modeling of hydraulic structures,
- Performing ground water studies,
- Developing and administering all the stages of water supply and treatment works for settlements over 100,000 population.

In order to supply data needed for its duties, SHW collects hydrometeorological data throughout the whole country. Stream flows and sediment concentrations along the nation's water courses are monitored by gauging stations. Also water quality parameters are measured by water quality monitoring stations; water levels in lakes and reservoirs are measured by lake monitoring stations; rainfall, temperature, evaporation, humidity and similar meteorological measurements are done by meteorological stations; and water levels at the wells that are drilled for research and study purposes are monitored periodically. Number of stations operated by SHW is not constant and according to data needs it changes from year to year. By the end of 2002, there were 1139 stream flow gauging, 115 lake monitoring, 392 meteorology and 115 snow monitoring stations operated by SHW (URL 2.22). Monitoring studies are executed by Directorate of Observations Department of the Directorate of Research and Planning Office, and study and planning units of regional directorates.

Raw data collected at the gauging stations are processed by the hydrologists of SHW and final data are published as yearbooks. In these yearbooks stream flow gauging stations that are in operation at that year are listed with respect to watersheds and for each station detailed information is given separately. All data and information related with a gauging station are summarized in a single page under the following sections: General information, water year summary, daily stream flows, and monthly flow summaries. A sample page from SHW yearbooks is illustrated in Figure A.1.

In a yearbook, the followings are provided as general information on a station:

- Geographic location (latitude/longitude and description)
- Drainage area (km^2)
- Approximate Elevation (m)
- Recording period (starting and ending date)

Latitude and longitude information are given for most of the stations down to seconds level. However, quality of data is poor and there are many cases at which given location do not reflect the actual geographic location. This can be easily seen from Figure 2.21, which is generated by using latitude/longitude information extracted from 1994 Discharge Monitoring Yearbook that is published in 1999 (SHW, 1999). According to extracted data, 140 out of 1206 stations are found to be outside of the country boundaries of Turkey. This value corresponds to approximately 11.6% of total number of stations, which is actually quite high. From this figure, it can be concluded that numerical location data given in yearbooks are not reliable. Therefore other sources should be used to map SHW gauging stations.

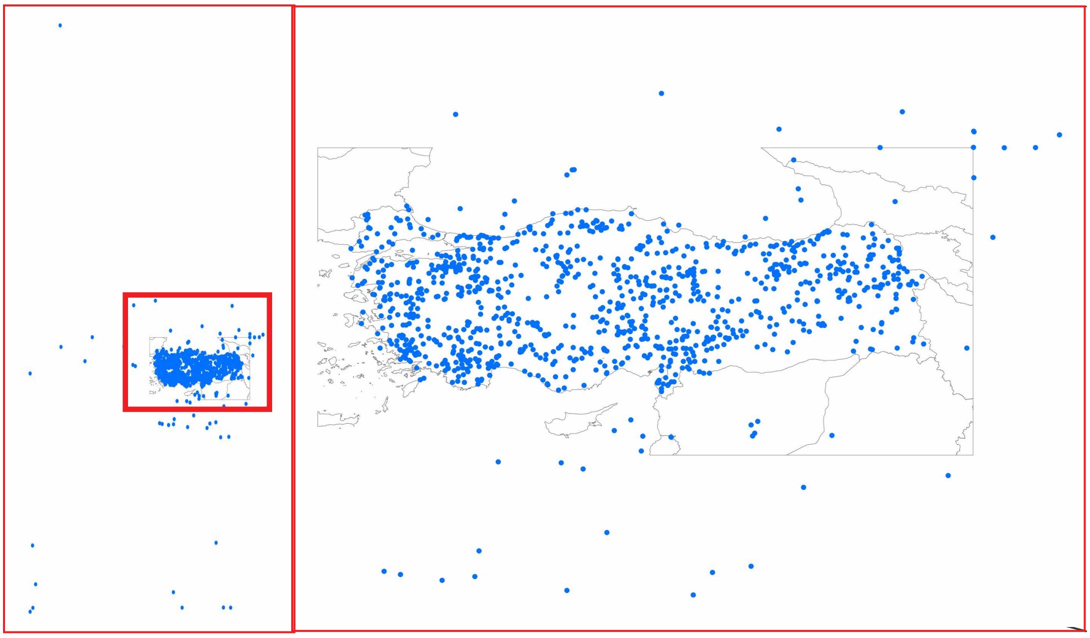


Figure 2.21. Distribution of SHW gauging stations according to 1994 yearbook data

The quality of drainage area data is also very questionable. Different drainage areas are found to be stated in different yearbooks for many gauging stations, although textual location descriptions were the same. Since change in drainage area can only be possible when the station is moved to another location, which was not the case, it can be concluded that quality of drainage area information is also low. Other studies dealing with stream flow gauging stations found similar results as well (Kulga and Dizdar, 1994). Another problem related with yearbooks is the presence of a long time lag between the data collection and publication. For example, yearbook of 1994 water year could be published in 1999. With data collection and processing technologies available today, this should be definitely done in a much shorter time period. There are many examples in the world, that show the possibility of stream flow data analysis and publication in short time periods. Stream flow data are published even in real-time through the Internet in several countries (URL 2.23).

As a summary of stream flow conditions at the gauging stations, average, maximum, and minimum stream flows are given in the yearbooks both for the water year and the whole recording period. Occurrence dates of maximum and minimum flows are also specified. The last information given before the daily stream discharges is the rating curve table. Critical points of the rating curve, that is used to convert water level measurements to discharge values for that water year, are tabulated in this table. Water levels are given in centimeters and discharges are given in m^3/s (Figure A.1).

Daily discharge values are also given in tabular form. Columns in daily discharge table are representing months in the water year, whereas rows are representing the days in a month. A water year, for which daily discharge data are given, typically starts on October, 1st of the previous year and ends on September, 30th of the stated year. Daily discharge table for a water year is complete and there exists no missing data. Daily discharge values given in the table are average values that are calculated from a set of values measured in a day. For stations having automatic level gauging devices (i.e. limnigraphs), average value is calculated from the graph of measurements. Today, most of the gauging stations operated by SHW are equipped with such devices; therefore values given in recent yearbooks are this kind. However, there are also gauging stations at which discharges are measured one or two times in a day. For such stations, daily average gauge height that is used to calculate daily average discharge is found by averaging gauging heights measured at that day, and the days before and after.

At the bottom of a yearbook page, daily discharges are summarized for each month. Six different monthly summaries are available, which are listed below:

- Maximum discharge (m^3/s): Maximum stream flow observed in a month. Maximum discharge is determined from instantaneous measurements if the station has an automatic stage recorder.
- Minimum discharge (m^3/s): Minimum stream flow observed in a month. Like maximum discharge value, it is computed from instantaneous measurements.
- Average discharge (m^3/s): Average of daily mean discharges
- Yield of the basin ($L/s/km^2$): Shows discharge per unit drainage area. It is calculated by dividing the average discharge (in L/s) by the drainage area of the station.
- Flow depth (mm): Height of monthly total flow over the drainage area of the station in mm.
- Total volume of flow (million m^3): Total monthly flow in million m^3.

Finally, yearly total values are given at the bottom of the page in three different units, as million m^3, mm, and $L/s/km^2$. The locations of gauging stations are also indicated on maps that are prepared for each watershed. Although yearbooks include information only on gauging stations that are in operation at that water year, locations of closed gauging stations as well are indicated on these maps (Figure A.2).

Another source for flow gauging station maps is “Album of Discharge Monitoring Network” published by SHW in 1988 (SHW, 1988). This album, which is prepared to be used instead of 1:800,000 scaled “Hydrometric Monitoring Network” map of Turkey, includes maps that are organized in terms of watersheds. The locations of gauging stations operated by SHW as well as by EPRSDA in each watershed are indicated on these maps. Different symbols are used to differentiate owners of stations from each other. Stations that are not in operation are also specified (Figure A.3).

In addition to maps, the album also includes detailed information on SHW gauging stations, especially on their working periods. The stations are sorted with respect to their station numbers, and for each station the following data are given in tabular form: name, opening date, closure date, SHW region, station hardware, drainage area, elevation, 1:100,000 scale map index, and latitude/longitude. The table also includes columns for each water year starting from 1960 till 1999 (columns up to 1988 are actually used). Start and end points of a recording period at a gauging station are noticed with ‘x’ marks in water year columns, and a line is drawn in-between. If a station has several recording periods that are separated with periods of no data collection, each period is marked individually. Water years before 1960 are also indicated in a separate column as textual information (Figure A.4). By using this table one can easily determine time periods with available data for a gauging station. The album, together with maps and tables, is a very useful and handy source of information, particularly for gauging station locations. However, after 15 years it definitely became outdated and requires an update to reflect the current situation of the stream flow monitoring network.

In addition to stream flow gauging studies, SHW also conducts water quality monitoring studies, which were started in 1979. The number of water quality stations, which was 65 at the beginning, is reported to be 1090 by the end of the year 2002 (Baltacı, 2003). Quality Control branches of Regional Directorates are sampling and analyzing water quality parameters at these stations according to Technical Methods and Sampling Principles Bulletin of Water Pollution Control Regulation (Official Gazette No. 20748, 1991). It should be noted that the term ‘water quality monitoring station’ does not mean that a station building exists physically. It is just used to emphasize the locations of sampling points.

Water quality monitoring studies undertaken by SHW can be divided into four classes: general water quality, ground water quality, drinking water and project specific. The aim of general water quality monitoring studies is to determine quality of water bodies and differentiate polluted parts from unpolluted ones. 6, 4, or 2 samplings are done at general water quality monitoring stations in a year, and following parameters are analyzed: stream flow, temperature, pH, electrical conductivity, chlorine, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total alkalinity, dissolved oxygen, biological oxygen demand, total organic compounds, ortho-phosphate, sulfate, total dissolved solids, and suspended solids. Drinking water monitoring stations are located on water bodies that are planned or already in use for drinking water supply. At these stations, heavy metals and drinking water quality related parameters are also measured besides general water quality parameters. Water quality measurements are conducted at selected ground water wells to monitor changes in ground water quality. Ground water quality monitoring stations have their own set of water quality parameters, which differs from general and drinking water quality stations. Complete listings of water quality parameters analyzed at general, drinking and ground water quality monitoring stations are given in Appendix B. Stations that could not be classified in three types mentioned so far are operated for data needs of different projects, which aim to develop water resources in a specific area or to solve problems related to water resources. Therefore parameters analyzed at such stations differ from station to station and a common list can not be given.

Current distribution of water quality stations is as follows: 62% general water quality, 30% drinking water, 6% ground water quality, and 2% project specific (Baltacı, 2003). According to data needs, number of samplings and locations of sampling stations are planned yearly and a water quality monitoring works plan is prepared for the whole country. A sample page from this plan is given in Figure A.5.

Until 1987, SHW published water quality data in the form of yearbooks. Actually only two yearbooks exist, one for 1981-1982 that is published in 1985 and the other for 1983-1984 that is published in 1987 (SHW, 1987). A yearbook begins with a list of water quality stations that are operated in the period of the yearbook. In the introduction part, general information regarding to data collection and analysis methods are given. For each station, its number, name, and region are indicated. If the location of the station coincides with a stream flow gauging station, the owner of the gauging station and its identification number are also given. No geographical information is present (i.e. latitude/longitude) except the textual location description of the station. However maps are available for each watershed, which show the location of water quality monitoring stations (Figure A.6). Measured data are given in tabular form for each station and for each year separately. All measured data for a single parameter were not made available and just monthly averages are provided. Number of samples collected for the parameter in a year is indicated in the first column of the table (Figure A.7).

Since 1987, no water quality yearbook is published by SHW. Water quality data can be obtained from Drinking Water and Sewerage Directorate of SHW on station basis or water quality management reports prepared by the same directorate for different watersheds at different dates can be used. A map showing the distribution of current water quality sampling stations is also not publicly available. Studies are underway to develop a database system to store water quality data in a format that is compatible with EU (Baltacı, 2003).

2.3.2. General Directorate of Electrical Power Resources Survey and Development Administration

Second largest stream flow monitoring station network of Turkey is being operated by the General Directorate of Electrical Power Resources Survey and Development Administration (EPRSDA). EPRSDA is an investor governmental organization that is founded in 1935. The directorate, which is bound to the Ministry of Energy and Natural Resources, carries out engineering services related with electrical energy production. Main tasks of EPRSDA can be listed as follows:

- Conducting research on water resources to determine if they are suitable for electrical energy production,
- Making hydrological studies and geotechnical surveys,
- Executing engineering services and design studies for dams and hydro electrical power plants,
- Making researches and studies for new and renewable energy resources (e.g. wind power, solar energy),
- Conducting surveys and studies for the rational use of energy resources.

Since 1935, EPRSDA has been collecting stream flow data through the nation's water courses. In addition to stream flow measurements, sediment and water quality monitoring studies are also being conducted since 1962 and 1970 respectively. Currently there are 284 stream flow monitoring, 11 lake monitoring, 49 snow monitoring, 192 monthly stream flow observation, 353 yearly stream flow observation, 65 monthly lake monitoring and 14 meteorology stations (968 in total) are in operation by 11 Hydrometric Region Directorates of EPRSDA (URL 2.24).

Directorate of Hydrologic Surveys Office is responsible from set-up and operation of monitoring stations. Data collected by stream flow gauging stations are published yearly as yearbooks. Format of published discharge yearbooks are very similar to yearbooks published by SHW (EPRSDA, 1996a). A list of gauging stations that are in operation is given at the beginning, which is followed by stream flow data for each gauging station that are grouped by watersheds. Stream flow data layout is also the same with SHW layout (Figure A.8). The only difference is presence of 'Remarks' section, in which comments and opinions of the hydrologist that processed the data are given. Maps showing the locations of gauging stations are given at the end of each chapter, which are dedicated to separate watersheds. Closed gauging stations are also indicated on these maps (Figure A.9). In addition to these maps, sample hydrographs of selected gauging stations are also given in yearbooks to illustrate the flow characteristics in that water year. A single representative hydrograph is present for each watershed (Figure A.10).

In addition to 'Water Year Discharges' yearbooks published periodically, monthly discharge summaries are also published by EPRSDA as separate books titled 'Monthly Average Discharges'. In each 5 years an updated edition of this book is published. The latest one, which is published recently, covers a time period of 1935 to 2000 (EPRSDA, 2003). A lot of information is available from the web page of EPRSDA as well. General information on all types of monitoring stations operated by EPRSDA (stream flow, lake, snow, etc.) are made available for download as separate Excel sheets that are grouped according to watersheds (URL 2.25). The Excel sheets related with stream flow gauging stations include detailed information on each gauging station, including its name, station number, opening and closing dates, type of gauge, drainage area, elevation, code numbers of map tiles at 1:250,000 and 1:25,000 scales, and geographic coordinates in degrees. Also general remarks exist for several stations. A sample Excel sheet is illustrated in Figure A.11. Although majority of these information are also available in discharge yearbooks, Excel sheet are handier since they are already in digital form and they include not only the stations in-operation but that are also closed in time. The accuracy of station coordinates given in these Excel sheets found to be quite accurate and consistent with the maps given in discharge yearbooks. A map of stream flow gauging stations, which is prepared by using latitude/longitude information given in the Excel sheets, shows a perfect match with actual maps as shown in Figure 2.22. Another set of Excel sheets include information on data availability. In these sheets water years are indicated, for which stream flow data are available at each gauging station. This kind of information is very useful, especially to determine if data is available for a study period or not. A sample from these sheets is given in Figure A.12.

Figure 2.22. Distribution of EPRSDA gauging stations according to Excel sheets

In addition to stream flow measurements, water quality analyses are also conducted at selected gauging stations of EPRSDA since 1970. Currently there are 92 gauging stations at which water quality is measured (URL 2.26). Typically, water samples are taken monthly and several water quality parameters are measured in these samples according to TS 266 and SHW Water Analysis Handbook standards (EPRSDA, 1996b). For special cases, there may be also more than one sampling in a month, but this is very rare.

EPRSDA measures the same water quality parameters at all stations. The list of analyzed water quality parameters is as follows:

- Stream flow at the time of sampling,
- Water temperature,
- Electrical conductivity,
- pH,
- Total Suspended Solids
- Salinity,
- Carbonate (CO_3^{--}),
- Bicarbonate (HCO_3^{-}),
- Sulfate (SO_4^{--}),
- Chlorine (Cl^{-}),
- Sodium (Na^{+}),
- Potassium (K^{+}),
- Calcium + Magnesium (Ca^{++} + Mg^{++})
- Total hardness,
- Boron.

For some stations, total organic material concentration is also analyzed. As it can be realized from the list, water quality analyses of EPRSDA focus on hardness causing cations/anions and sediment, and do not include biological and chemical parameters related with water pollution. Sediment concentration is very important to calculate effective life of a dam, and also together with hardness, which results in calcification, is very important for mechanical parts that are used in hydro-electrical power plants (HEPPs) to produce energy. Sulfate has corrosive effects on concrete, which is the main construction material of the dams. This is why only such a limited set of water quality parameters are measured by EPRSDA, which is interested on water resources mainly for building of HEPPs.

Water quality measurements are published periodically by EPRSDA in "Water Quality Data for Surface Waters in Turkey" books. In these books, the latest being published in 1996, information on both water quality stations that are in operation at that time and that are closed previously are given (EPRSDA, 1996b). The stations are grouped according to watersheds and for each station its name, station number, location, drainage area, approximate elevation, and sampling period are specified. Mean discharge and maximum/minimum electrical conductivities are also given for the sampling period, and remarks on the station are indicated. All water quality measurements from the start of sampling period till the evaluation time of the book (e.g. end of 1994 for 1996 book) are given in tabular form sorted by the date of sampling (Figure A.13). In addition to individual measurements, monthly summaries of all measurements for the sampling period are also presented in a separate table (Figure A.14). In this monthly summary table, stream flow and temperature are found by taking the average of measurements directly. However, flow-weighted averages are calculated for other water quality parameters. Number of samples used to calculate average values for each month are indicated in a separate column. At the end of each watershed section, a map is provided that shows watershed boundaries, important water courses and location of water quality monitoring stations (Figure A.15).

2.3.3. General Directorate of Rural Services

General Directorate of Rural Services (GDRS) is another organization, which collects data related with water resources. The GDRS, affiliated to the Prime Ministry, is responsible for land use, infrastructure and water resources development in rural areas. Main duties of the directorate related with water sector are to provide services to the farmers for efficient use of soil and water resources, and to protect and develop these resources in a sustainable manner. Other duties of the general directorate include determining essential criteria for construction, maintenance and operation of water and sewerage services in the rural areas; to provide tap and drinking water to villages; and to construct and operate water distribution systems to meet water demands of up to 500 L/s.

Different from previously mentioned organizations (SHW and EPRSDA), GDRS do not gather nation-wide data but collects data only in small sized watersheds that are located within the service boundaries of its research institutes. There are 21 watersheds monitored by 10 research institutes (Ankara, Tarsus, Menemen, Eskişehir, Konya, Tokat, Samsun, Şanlıurfa, Erzurum and Kırklareli) (GDRS, 1993). Typically in each watershed, there exist a stream flow gauging station located at the outlet of the watershed and several meteorological stations that are distributed uniformly within the watershed. For larger watersheds there may be more than one gauging station. Hydrometeorological data recorded at the watersheds are published periodically as yearbooks, which are titled "Rainfall-Runoff Yearbook of GDRS Research Institute Watersheds". In these yearbooks, daily stream flow data and corresponding monthly summaries are given in the same format as SHW and EPRSDA yearbooks (Figure A.16). Additionally, rainfall data measured at meteorological stations are given in the format of State Meteorological Works (SMW). Detailed information on each watershed is also made available, including area; perimeter length; maximum, minimum and average elevation; average slope; aspect; shape indices; total length, density and maximum order of branches; length and slope of main channel; and curve number (Figure A.17). Although a general map showing location of watersheds in Turkey does not exist in the yearbooks, maps are provided for each watershed on which locations of runoff and rainfall monitoring stations are indicated (Figure A.18). No information related with water quality can be obtained from yearbooks published by GDRS.

CHAPTER 3

DEVELOPMENT OF HYDROGRAPHY DATASET

In order to develop a national hydrography dataset for Turkey, hydrography thematic layer of VMAP-0 has been used. This thematic layer consists of several sub-layers, which are listed in Table 3.1 with their short descriptions.

Table 3.1. Sub-layers of hydrography thematic layer of VMAP-0

Sub-layer	Type	Description
Watrcrsl	Line	Water courses including streams and rivers
Inwatera	Area	Inland water bodies
Aquecanl	Line	Aqueducts, canals, penstocks
Dangerp	Point	Danger causing point features, e.g. rocks and wrecks
Dangerl	Line	Danger causing linear features, e.g. reefs
Miscp	Point	Miscellaneous point features, e.g. islands, rapids, springs
Miscl	Line	Miscellaneous linear features, e.g. dams/weirs, seawalls
Hydrotext	Text	Annotations

The most important sub-layers of hydrography thematic layer are Watrcrsl and Inwatera, which include natural streams and rivers, and natural and constructed inland water bodies respectively. These two sub-layers form the basis of the national hydrography dataset as it will be explained in detail in the forthcoming sections. Aquecanl sub-layer includes man-made water courses like aqueducts and canals. Dangerp and Dangerl sub-layers include features that may cause danger to sea transportation. Among different types of point danger features, only rocks are present in the area covered by Turkey, and no linear danger feature exists. Miscp and Miscl sub-layers include hydrography related miscellaneous point and line features. As linear features only dams/weirs, and as point features islands and springs/waterholes are present in these sub-layers for Turkey. The last sub-layer, Hydrotext, includes textual annotations and is totally a supplementary sub-layer. In addition the hydrography sub-layers mentioned so far, political boundaries and coastline sub-layers from boundaries thematic layer of VMAP-0 are also used for the study. A sample map showing hydrography thematic layer of VMAP-0 is given in Figure 3.1. The numbers of features in each sub-layer for the area covered by Turkey are also counted and tabulated in Table 3.2.

For ease of reference, attribute lists of sub-layers and their pre-defined values are extracted from Vector Map Level 0 Performance Specification (MIL-V-89039) document of NIMA (DOD, 1995), and summarized in Appendix C.

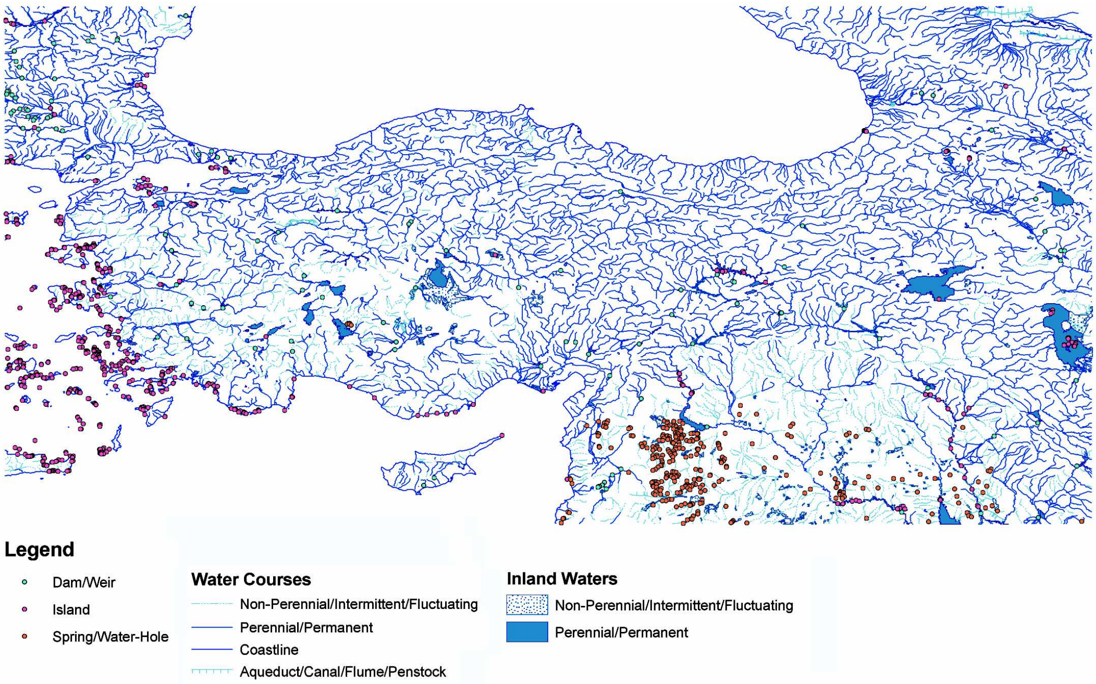


Figure 3.1. Hydrography thematic layer of VMAP 0

Table 3.2. Number of features in VMAP-0 hydrography sub-layers

Sub-layer	Number of Features
Watrcrsl	4219
Inwatera	351
Aquecanl	26
Dangerp	11
Dangerl	0
Miscp	292
Miscl	3

As stated previously, Watrcrsl and Inwatera sub-layers include features, which are crucial for the development of hydrography dataset. However, the features presented in other sub-layers are not mandatory, and provide information that can be termed as supplementary in general. Hence, these sub-layers are left in their original state and no correction/validation studies are conducted for these sub-layers. Such studies are done extensively for water courses and inland water bodies sub-layers, and will be explained in detail. But first, a short review of VMAP-0 hydrography thematic map in terms of quality and accuracy will be given with comparison to available reference sources.

3.1. Evaluation of Available Reference Maps

As indicated in the Chapter 2, map sources available from local institutions are not suitable to be used as primary data sources for the study according to pre-determined criteria. However, they can be used as reference maps in data correction and validation steps. For this purpose, first the quality and accuracy of these maps should be clarified. Although information related with these maps was given in Chapter 2, no special emphasis was given at that time to their hydrography layers. Since these layers are primary concern of the study, in this section first, they will be reviewed in detail, and then their qualities will be tried to be identified, at least relative to each other.

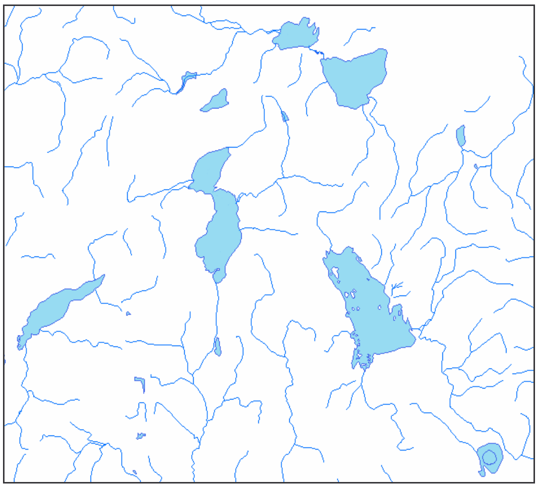
Local map sources that are used as reference can be listed as follows:

- "Administrative Units of Turkey" map of GCM
- "Dams, Power Plants and Irrigation Establishments of Turkey" map of SHW
- Watershed maps found in daily discharge yearbooks of SHW
- 1:250,000 scale thematic map of İşlem GIS Corporation

In order to compare these maps, first a study area should be determined, which is small enough to facilitate the comparison and also in which as many as possible different hydrographic features are present. After a preliminary examination, Beyşehir Lakes region is selected for this purpose.

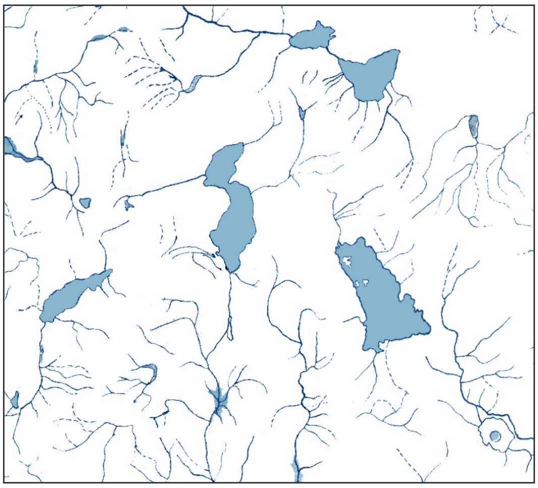
All reference maps, except 1:250,000 scale dataset, were available at the beginning as paper maps only, which makes the comparison difficult. Therefore, first their parts that include the study area are scanned and converted to raster images. Then features, which are not related with hydrography, are deleted from the images by manual editing. Since the maps were including many of such features, this step was very time consuming. But at the end, very clear raster hydrography layers are obtained, which can be compared easily. Originals of scanned maps and obtained raster hydrography layers are given in Appendix D. All hydrography layers, including vector datasets, are also shown side by side in Figure 3.2.

In general, as the scale of the source maps gets larger, the stream line density increases as expected. The details of features also get finer. If two 1:1,000,000 scale maps (VMAP-0 and GCM map) are compared, differences are observed in the stream features shown on the maps. This is fairly predictable, since the sources and production aims of the maps are completely different. However, stream line densities are found to be similar to each other, which reveal that feature generalizations applied in the maps are appropriate to their scale. Distribution of stream lines seems to be more uniform in VMAP-0.

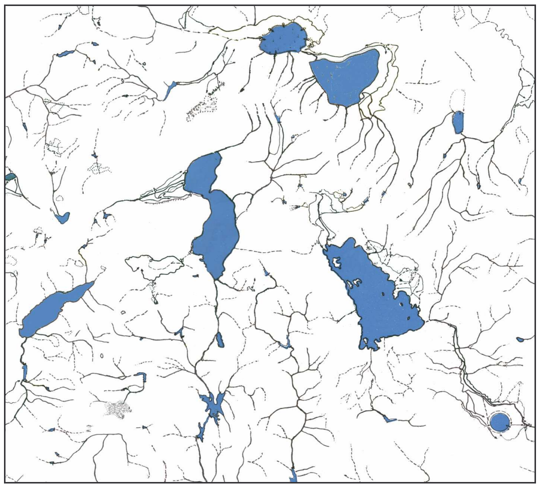


(a) VMAP-0 (1:1,000,000 scale)

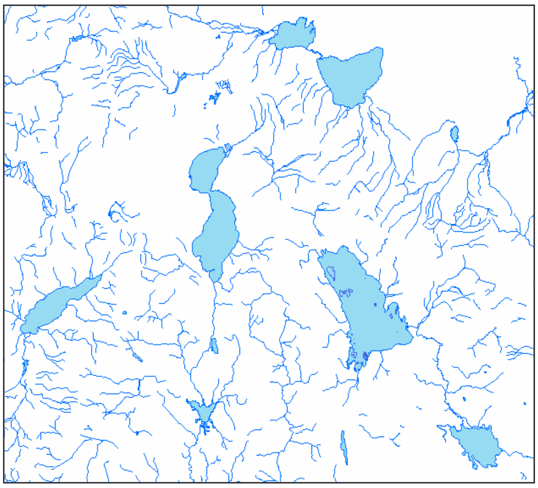
(b) GCM Map (1:1,000,000 scale)



(c) SHW Yearbook (~1:800,000 scale)



(d) SHW Map (1:800,000 scale)



(e) İşlem Dataset (1:250,000 scale)

Figure 3.2. Comparison of hydrography layers from different map sources

1:800,000 scale maps of SHW include more stream line features, especially first-order reaches, compared with 1/1,000,000 scale maps. At first sight, “Dams, Power Plants and Irrigation Establishments of Turkey” map seems to have a higher stream line density compared to the collection of maps found in discharge yearbooks, which has the same scale. The density is even comparable to that of 1:250,000 scale map. However, this situation is misleading since SHW map includes not only existing but also planned water works, which will be present in the future. Also different from other maps, this map involves irrigation systems as well. It is not easy to differentiate these additional features from other ones; hence they can not be removed from the map, which resulted in a higher density. But anyhow, this map is a good source to be used as a reference.

The highest stream line density is observed in 1:250,000 scale thematic map of İşlem GIS Corporation. However, this map includes many small stream segments, which are not connected to any stream network. Majority of these streams are connected to main stream channels or lakes in other map sources; hence there may be some problems related with the quality of 1:250,000 scale map. This map should be carefully used for feature correction and validation purposes.

Independent from map source, large natural inland water bodies seem to be accurately presented in all map sources. But shapes of small-sized lakes and especially dams are generally varying from map to map. Use of a single reference that is the most up-to-date among the available ones for such features may prevent possible confusion.

In general, hydrography layers of maps that are available at hand are found to be accurate and in better quality compared with VMAP-0 hydrography layer. Certainly, these maps can be used as references for correction and validation water courses and inland water bodies of VMAP-0 dataset.

3.2. Correction and Validation of Inland Water Body Features

Inland water bodies sub-layer of VMAP-0 includes three different types of features: perennial (permanent) inland waters, non-perennial (intermittent) inland waters, and lands subject to intermittent inundation. Perennial inland waters include natural lakes and constructed dams. These features are also found in other map sources; hence, they can be easily validated. However, non-perennial inland waters and inundation areas are unique features of VMAP-0 and neither SHW hydrography maps nor GCM administrative map include these hydrography feature types. Therefore no validation could be possible for these kinds of features. Since non-perennial features are not essential elements of a hydrography dataset, these features are extracted from inland water sub-layer and put into another sub-layer as supplementary data. Remaining features of inland water sub-layer are examined in detail, and correction and validation tasks are carried out.

The examination showed that the majority of permanent inland water bodies are correctly represented in VMAP-0 inland water sub-layer, i.e. their shapes and locations are accurate. Even small natural lakes, which are not shown in 1:1,000,000 scale map of GCM, are present in VMAP-0. However, there also exist several problems, which can be listed as follows:

- Missing water bodies: Although natural lakes are found in excess amount, some dams are absent in VMAP-0 inland water sub-layer. Not only small sized but some large-sized dams are also found to be missing. But this is especially the case for recently constructed dams, and the problem is most probability related with the up-to-datedness of VMAP-0. Compilation dates of ONC maps covering Turkey dates back to 1970s. Even though these maps were revised in time, latest revisions incorporated to VMAP-0 were done at the end of 1980s as indicated in data quality layer of the dataset. Since water resources development of Turkey has been accelerated in the last decades, many dams were built since the last revision dates of the maps. Hence, these dams are missing from VMAP-0.

- Unnamed water bodies: Attribute table of inland water sub-layer of VMAP-0 includes a name field, in which local names of water bodies were entered. Approximately half of the water bodies in Turkey were already named, however the remaining ones were indicated as “Unknown”. Actually majority of these unnamed water bodies do have names, which could be found in local sources.

- Feature delineations that differ from generally accepted boundaries: Delineations of features naturally differ from map to map. Scale, source, generalization methods used for mapping, and even cartographer’s personal preferences may affect the shapes of features in the resulting map. If several maps should be compared to each other, which is the case for validation of VMAP-0 hydrography layer with local map sources, this fact should be taken into consideration and small differences should be accepted to be not existent. However in VMAP-0 there are some inland water bodies, delineations of which differ significantly from generally accepted ones found in national reference map sources. Especially, inland waters that are permanent but have fluctuating shore lines are among these bodies. The Salt Lake, which is illustrated in Figure 3.3, is a typical example

The followings have been done to correct already mentioned problems of VMAP-0 inland waters sub-layer.

Water bodies shown in all three reference maps are examined and the ones that are missing from VMAP-0 are determined. By manual digitizing, these missing water bodies are added to VMAP-0 dataset. 1:1,000,000 scale map published by GCM in 1998 is used as the primary reference for this task, since it is the most up-to-date source that is available.

(a) VMAP-0 (only permanent features)

(b) VMAP-0 (all inland water features)

(c) 1:250,000 scale İşlem dataset

Figure 3.3. Representation of the Salt Lake in VMAP-0 and reference dataset

In order to fill in the names of unnamed water bodies, first a list of such water bodies is prepared. Then for each water body in the list, its counterpart is searched in reference maps. If an unnamed water body is found to be present in any of the reference sources and a name for the water body is explicitly indicated, then that name is taken and entered to attribute table of VMAP-0. If the water body is present in more than one reference maps and its name varies from map to map, then the name indicated on the most recently published map is used. The names of water bodies, for which no name could be found from reference maps, are left as

"Unknown". Once all unnamed water bodies are processed, names of water bodies originating from VMAP-0 are also validated as an additional step in naming process. If the name found in any reference map differs from the name indicated in VMAP-0 attribute table, then VMAP-0 name is changed with the one stated in local reference.

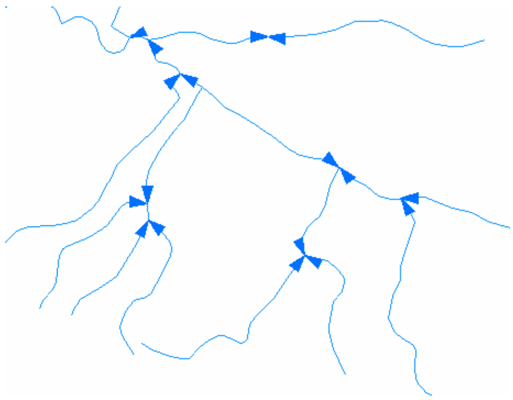
As the last step of validation and correction of inland water bodies sub-layer, the boundaries of water bodies that differ significantly from their corresponding delineations given in reference maps are edited manually and they are updated to reflect generally accepted boundaries.

3.3. Correction and Validation of Water Course Features

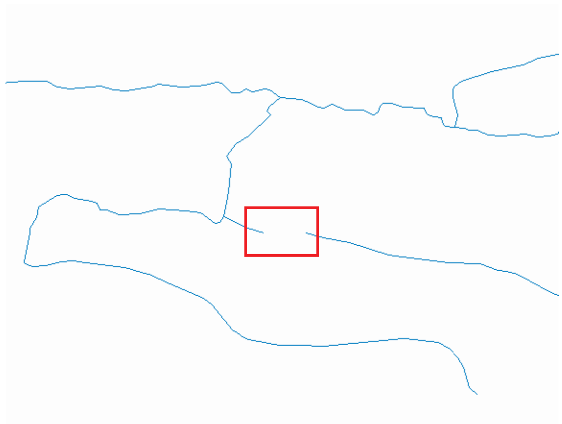
Natural streams and rivers, which form the basis of the hydrography dataset, are found in water courses sub-layer of VMAP-0. In addition to delineations of streams and rivers, sub-layer also includes an attribute table containing textual information. However, this attribute table is very limited and the only attribute related with hydrologic characteristics of features is their seasonality, i.e. whether they are perennial (permanent) or non-perennial (intermittent, fluctuating). There is no discrimination between minor and major streams, and no information is present on their length, order, and connectivity. A closer look to the dataset also reveals existence of some geometric and hydrologic problems, which can be listed as follows:

- Mixed stream line directions
- Missing stream lines
- Excess stream lines
- Discontinuity of stream lines at intersection points
- Discontinuity of stream lines through inland water bodies
- Shift in location of stream lines

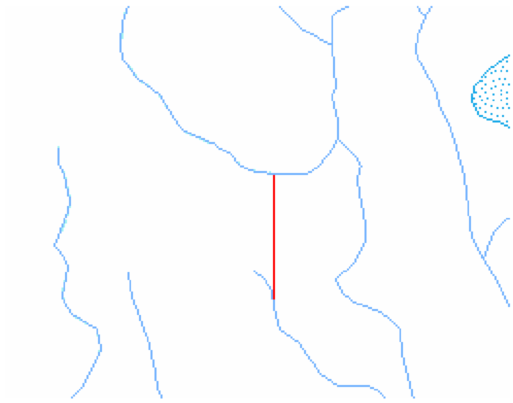
Each of these problems is illustrated separately in Figure 3.4a through Figure 3.4f with actual samples from the dataset.



(a) Mixed stream line directions

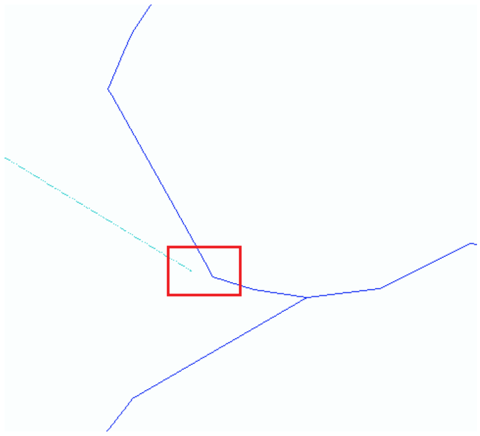


(b) Missing stream lines

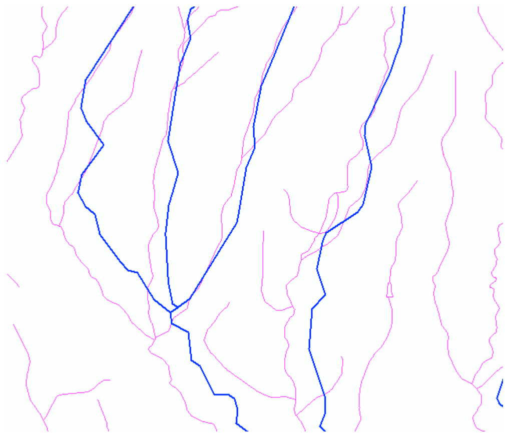


(c) Excess stream lines

(d) Discontinuity of stream lines through inland water bodies



(e) Discontinuity of stream lines at intersection points



(f) Location shift in stream lines

Figure 3.4. Hydrologic problems of VMAP 0 Hydrography Layer

Solving the problems requires a systematic approach and step-by-step processing of the dataset. The order in which the problems are dealt with is important, and it is determined that the order should be as follows for a satisfactory and efficient correction and validation process.

1. Correction of wrong stream line directions
2. Establishment of connectivity through inland water bodies
3. Establishment of connectivity at stream line intersections
4. Addition of missing stream lines
5. Removal of excess stream lines
6. Entry/Update of textual attribute data

Following the order given above, majority of the problems are solved and a better quality hydrography dataset is obtained through the study. Complete descriptions of the problems are given below, and solution techniques used for each problem are explained in detail. Additional discussion is also present on completeness of attribute data.

3.3.1. Mixed stream line directions

In order to have a hydrography dataset that can be used for hydrologic ordering and up-stream/down-stream navigation, each stream line should have a direction that is consistent with actual flow direction of the stream. Alternatively, this information could be encoded in the attribute table as well. However, VMAP-0 water courses sub-layer neither includes such a field in its attribute table, nor care has been paid to the stream line directions during the development of the dataset. As shown in Figure 3.5, majority of stream lines have wrong directions, which differ from direction of actual water flow in these streams.

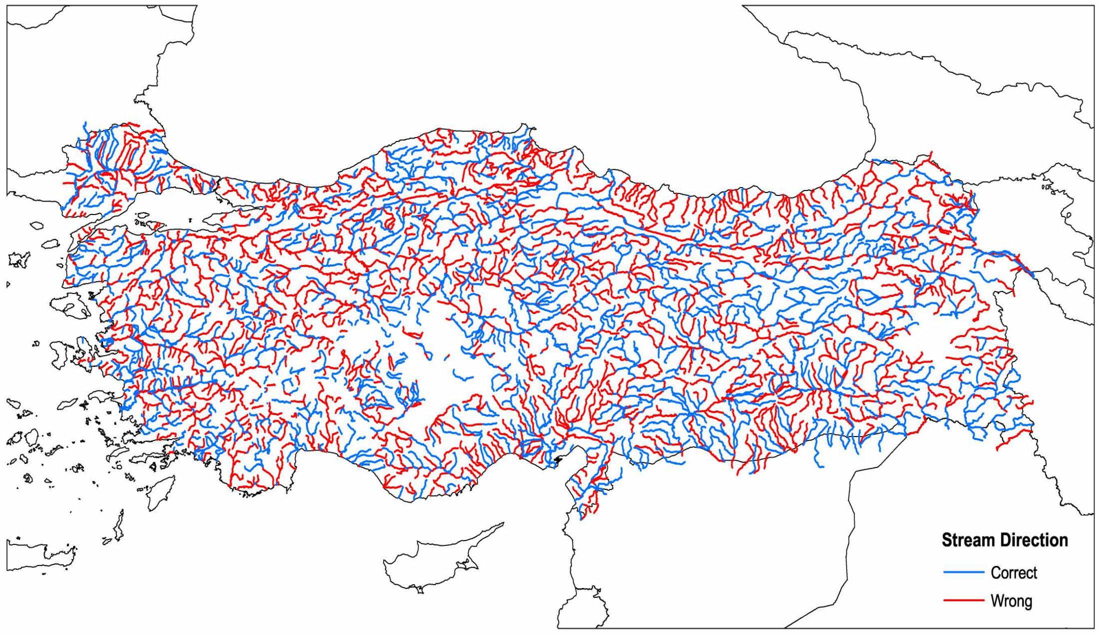


Figure 3.5. Geographic distribution of stream lines with wrong flow direction

In order to correct the directions of stream lines, all stream lines are visually checked and the ones having wrong direction are flipped manually. An arrow headed cartographic line symbol is used for the presentation of stream lines, so that the directions can easily be visualized. Stream lines, which are part of a stream network draining to a sea or inland water body, are oriented such that their direction will always point to the drainage point. No attention has been paid to any other criteria. However, for small stream reaches, which exist as separate features and do not drain to any water body, elevations of starting and ending points are used to determine the flow direction. Line flipping is done in ArcView 3.2 GIS and FlipLine extension v1.3 by Quantitative Decisions (2000) is used, which orients a polyline in the direction pointed out by the user. At the end of the process, valid directions are assigned to all stream lines that had wrong directions originally in VMAP-0. A sample line flipping process is illustrated in Figure 3.6.

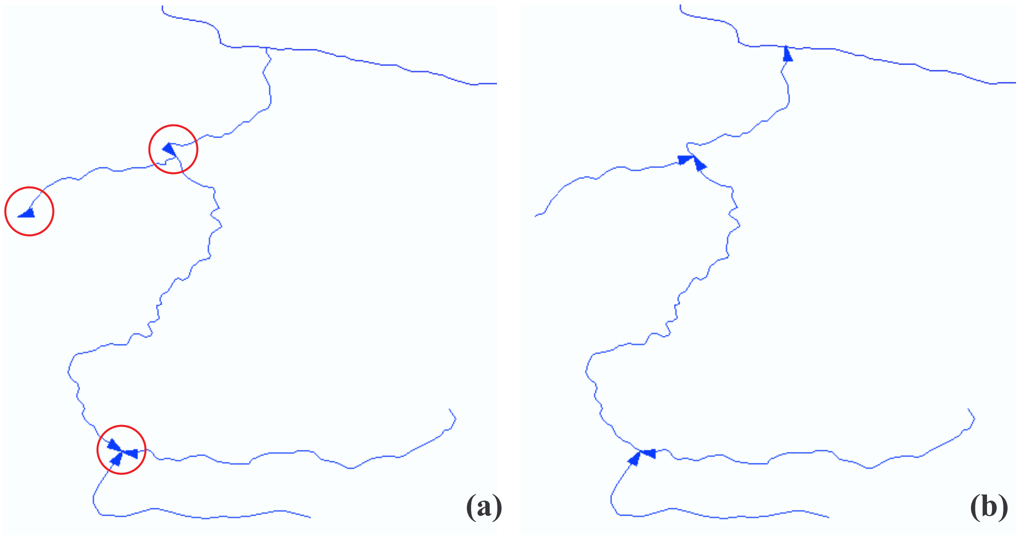


Figure 3.6. A stream having reaches with (a) wrong, (b) correct directions

3.3.2. Discontinuity of stream lines through inland water bodies

Inland water bodies can be grouped into two based on their positions in the drainage network: inland waters that are "on" the stream network and inland waters that act as a "sink" in the stream network (Figure 3.7).

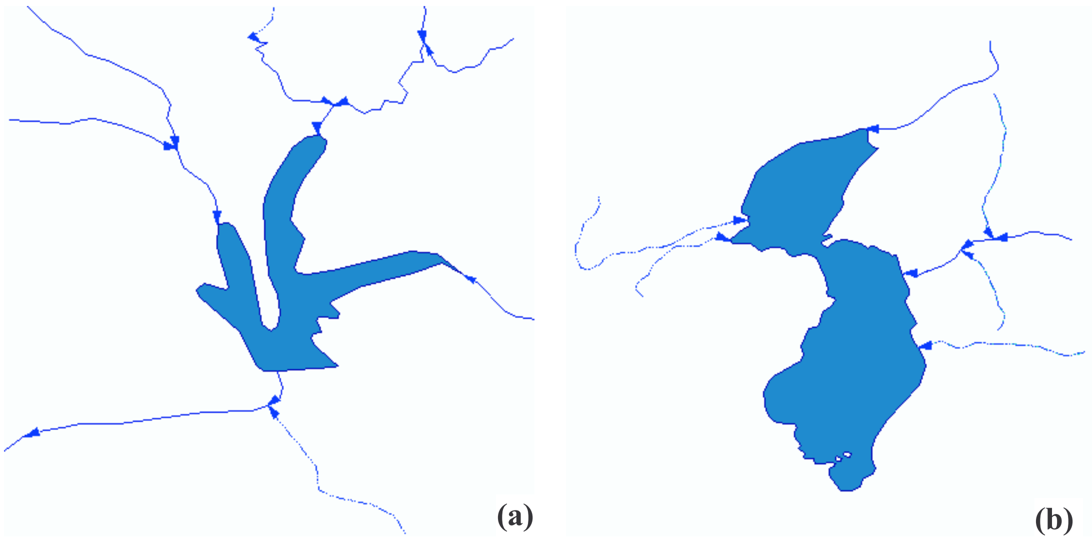


Figure 3.7. Inland water bodies (a) on-stream, (b) sink

For inland waters that are on the stream network, water flows into the water body from one or more inlets, moves through it and leaves the body from one or more outlets again in the form of streams. Dams are typical examples of such inland waters. Large rivers that are represented as area features instead of line features in large scale maps can also be regarded as “on-stream” inland waters. Inland waters that act as sinks in the stream network have one or more inlet, but they have no outlet, at least not as a surface water stream. Water bodies that are located at the center of closed basins are in this group. Water that is found in such water bodies is not fresh, but salty or soda water if they do not have any outlet from the bottom. Salt Lake and Van Lake are two examples of this kind. If there is an outlet from the bottom of the water body, which may be the case under carstic geography, then the water may be fresh. Lake Beyşehir can be given as an example. Independent from their water characteristics, these water bodies are end points of stream network from hydrography dataset point of view.

Since inland water bodies that act as sinks are end points of a stream network, the streams flowing to these bodies can be left as they are, without any further processing. However, since the water flow is continuous through the water bodies that are on the stream network, streams flowing to these bodies should be somehow connected to the outlet points in order to maintain the continuity of the stream network. Otherwise up-stream/down-stream navigation will not be possible along the streams that have inland water bodies on their way.

In order to solve this continuity problem, all inland water bodies in the hydrography layer of VMAP-0 are examined, and artificial stream lines are added to each water body that is on the stream network. While adding artificial stream lines, forms of water bodies are taken into consideration and artificial lines are drawn to approximate actual water flow in the water body as much as possible. Addition of artificial lines to the inland water bodies is illustrated in Figure 3.8.

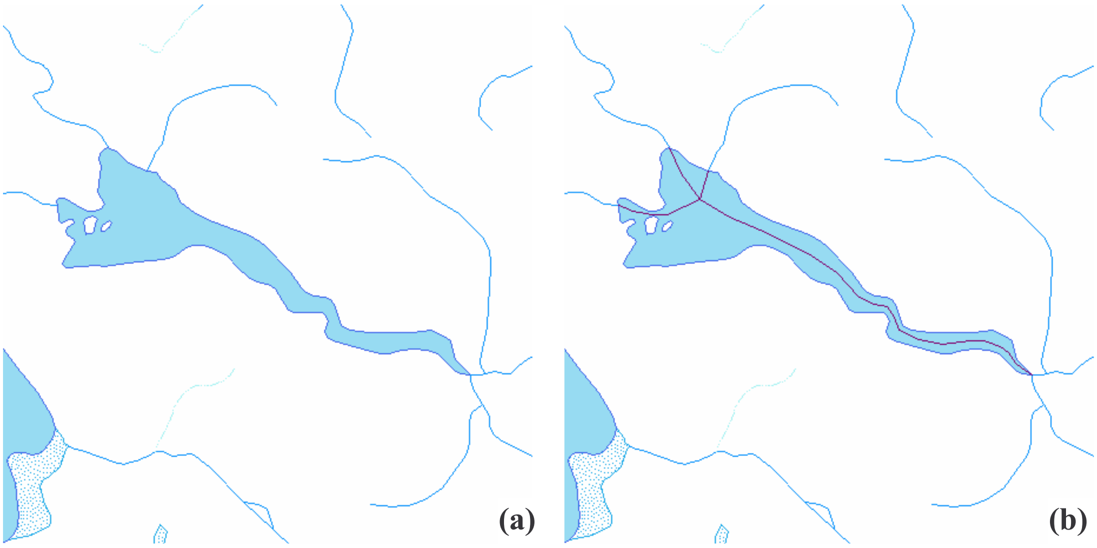


Figure 3.8. Inland water body (a) without, and (b) with artificial stream line

For the whole country a total number of 249 artificial stream lines are added to VMAP-0 water courses sub-layer. The geographic distribution of these artificial stream lines is given in Figure 3.9.

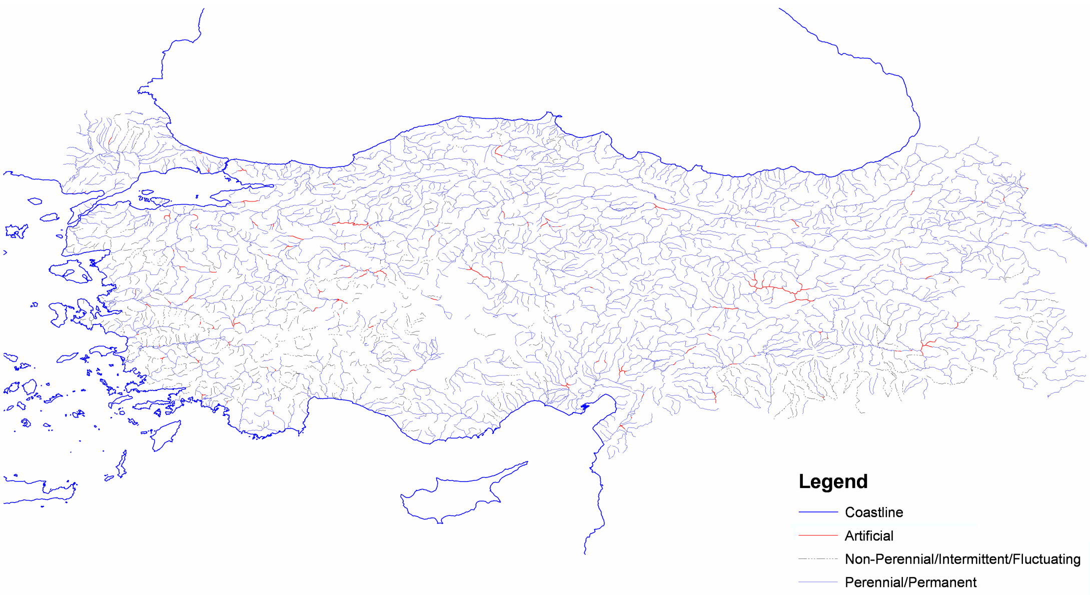


Figure 3.9. Distribution of artificial stream lines

3.3.3. Discontinuity of stream lines at intersection points

Once invalid flow directions are corrected and continuity of stream network through the inland water bodies is established, the only probable obstacle that remains against complete up-stream/down-stream navigation is presence of discontinuities at intersection points of the stream lines. In order to navigate spatially through stream lines by following the starting and ending points of streams, the stream network should consist of separate reaches that are connected to each other by means of nodes at their intersection points. A topologically correct dataset has always this property. However, since VMAP-0 datasets do not have topological structures, connectivity at nodes is not supported at all locations and there exist some discontinuities. These discontinuities may be classified into two main groups: physically separated stream lines, and presence of vertices at intersection points instead of nodes. Both cases are illustrated in Figure 3.10.

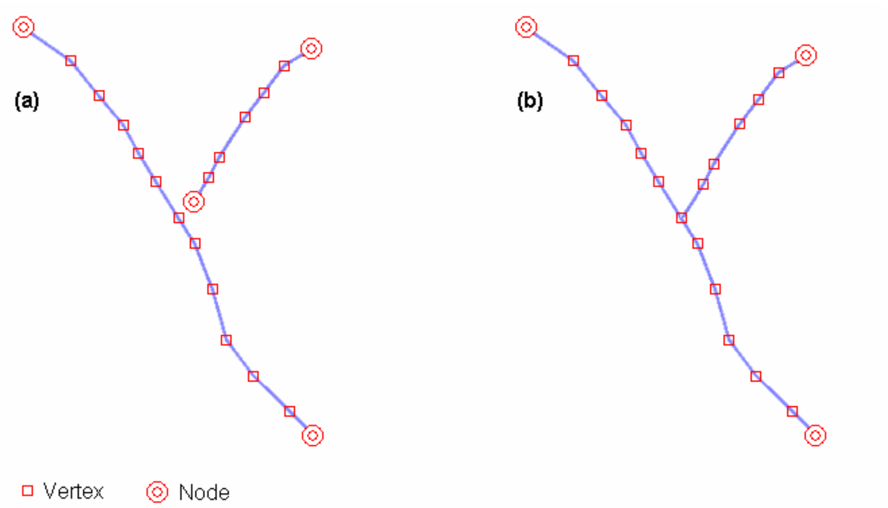


Figure 3.10. Discontinuity due to (a) separate reaches, (b) intersection at vertexes

Since discontinuities at intersection points are in micro level, it is very difficult to determine discontinuous stream lines just by manual inspection. Therefore, a semi-automated discontinuity checking method is applied in the study. For this purpose, Aselect Connect AVENUE script developed by Heines (2001) is utilized. This script selects all features located in up-stream or down-stream direction of a selected feature in the network based on user's preferences. A stream network having correct line directions is the only requirement of the script, which was obtained in the previous steps of the study already.

In order to determine discontinuity points, first by using location based feature selection commands of ArcView 3.2, all stream reaches intersecting with coastlines, inland water bodies and country boundaries are selected. Then these reaches are used as an input to Aselect Connect script, and all up-stream reaches of these reaches are determined. Since stream lines used as input constitute all possible stream network end points in Turkey, selected up-stream reaches should theoretically cover the whole country. If a stream line is not selected by the script, then this reach should be either a small reach, which is independent in nature, or a reach with connectivity problems that are mentioned above. Taking this fact into consideration, features that are not selected are examined in detail and if the reason is found to be incorrect intersection then intersections of these lines are corrected. At each intersection point, main stream reach is divided into two parts by inserting a node and end point of subsidiary stream is moved and snapped to this node for the correction. At the end of this step, most of the discontinuity problems of VMAP-0 water course sub-layer are solved.

3.3.4. Missing stream lines

When comparing a map with another reference map, it is fairly possible to have missing features, even if the maps have the same scales. If the number of such features is not too much, then the differences could be acceptable. However, missing stream lines at critical locations may result in important problems. For example, if a stream reach that should be located on the main channel of a stream network is missing, then continuity of the network will be broken and up-stream/down-stream parts could not be related to each other. This situation is illustrated in Figure 3.11.

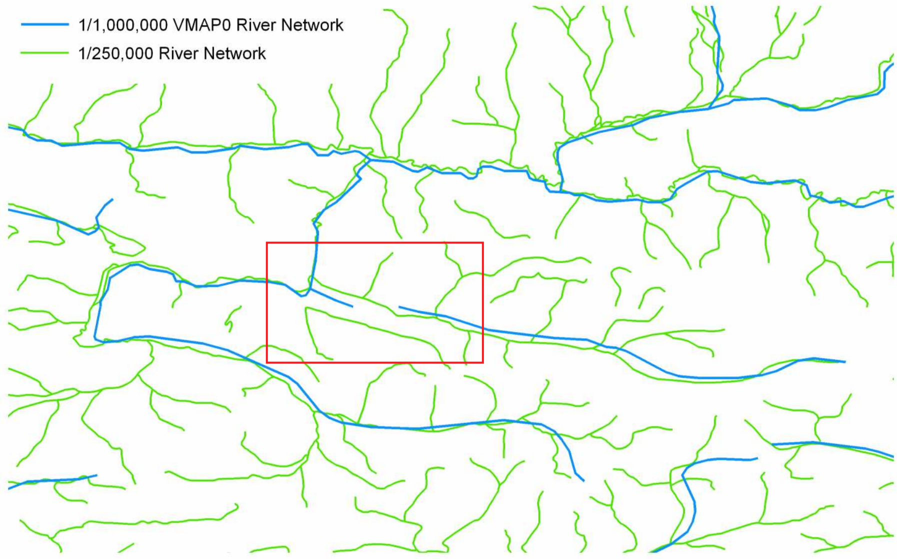


Figure 3.11. Quality control of VMAP 0 dataset with 1:250,000 river network

If present, such a situation will hinder navigation through the streams, which is one of the most important applications of a hydrography dataset. Although this problem is similar to separate stream lines case of discontinuity at intersection points problem mentioned above, it is in macro scale and hence can be determined by manual inspection. Therefore, in order to determine this kind of missing stream lines, all features in VMAP-0 water courses sub-layer are visually checked and compared with reference maps. Found missing lines are added to VMAP-0 by manual digitizing.

3.3.5. Excess stream lines

Like missing stream lines pointed out above, there also exist excess stream lines in VMAP-0 water courses sub-layer when compared with reference maps. Although presence of most of the excess stream lines is acceptable within the accuracy limits of the dataset, some of them disturb the connectivity relations in the stream network; hence they should be removed. Such stream lines can be divided into two groups. The ones that can be classified in the first group are small stream lines, which are causing tiny loops on the stream network. The others are long stream reaches that incorrectly connect two points on the stream network to each other. Samples from both types of stream lines are given in Figure 3.12.

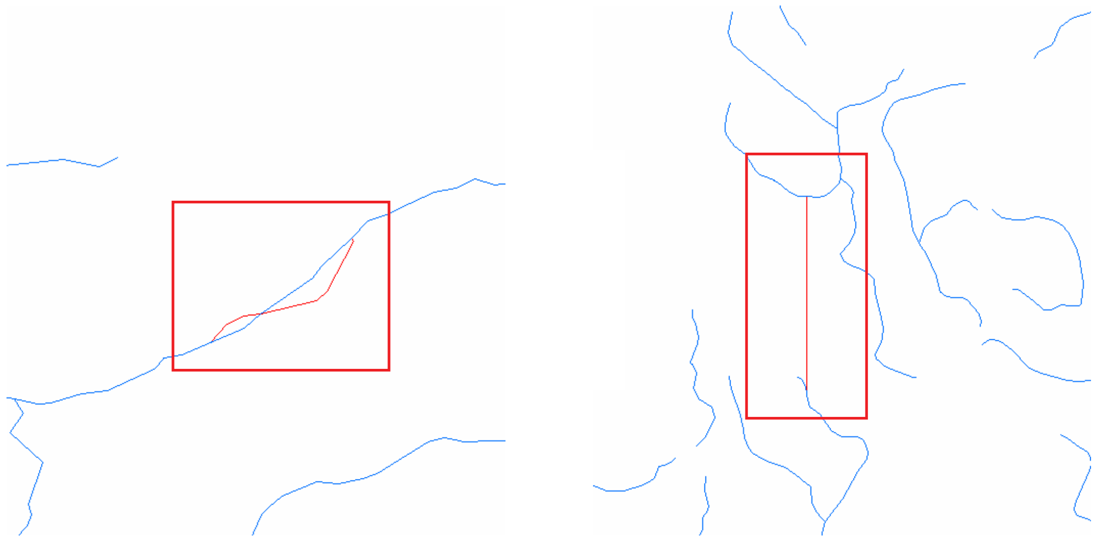


Figure 3.12. Excess stream lines causing a) loops, b) incorrect connections

Excess stream lines causing tiny loops are encountered especially on stream lines, which are highly meandering. Also at locations, where irrigation is taking place excessively, such stream lines are present more. VMAP-0 water courses sub-layer is compared with reference maps for such loops and stream lines that result in loops are deleted from VMAP-0 if they do not exist in the reference maps, especially having the same scale like the administrative units map of GCM. Getting rid of loops also facilitates navigation through the stream network, since the network becomes simplified.

Excess stream lines causing incorrect connections in stream network are also examined by comparing VMAP-0 water courses layer with reference maps. Just a few of such excessive stream lines are found to be present in VMAP-0. Several of them are encountered at locations where ONC tiles are coming together. Most probably such stream lines are artifacts of digitization and merging process. All these lines are removed from VMAP-0 dataset.

3.3.6. Shift in location of stream lines

While working with VMAP-0 sub-layers, positional accuracy of the dataset should always be kept in mind. When stream lines of VMAP-0 water courses sub-layer is compared with reference maps, especially with 1:250,000 scale dataset, geographic locations of some streams are found to be shifted. Amount of positional shift is not uniform through the study area and differs from location to location. At some locations (in western parts of Turkey) perfect match with reference map is observed, while at some locations (in central parts of Turkey) significant amount of difference is noticed. Both cases are illustrated in Figure 3.13a and Figure 3.13b respectively. Actually, the reason for these shifts is the ultimate accuracy of VMAP-0 dataset. As indicated in its metadata document, vertical and horizontal accuracies of VMAP-0 at a specific location depend on the source map used at that location. Vertical accuracies up to 2000 meters on average are indicated to be expectable (DOD, 1995).

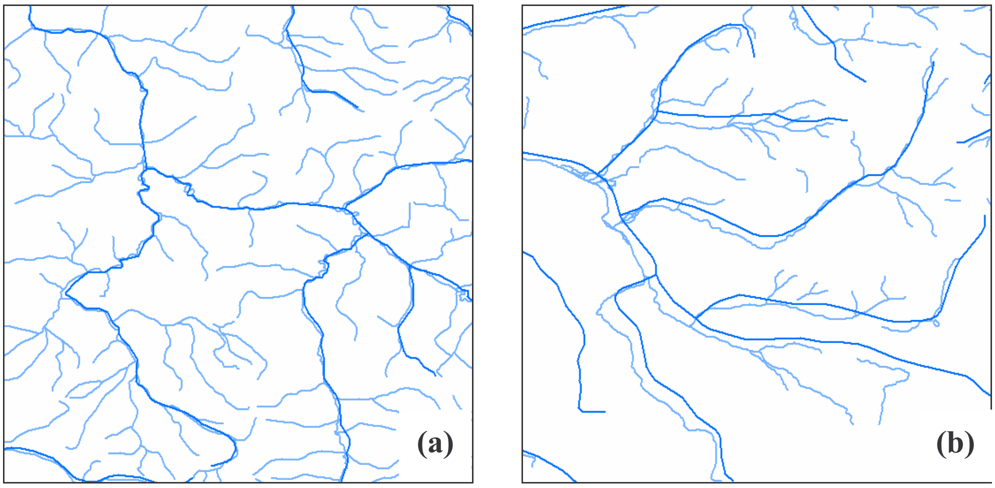
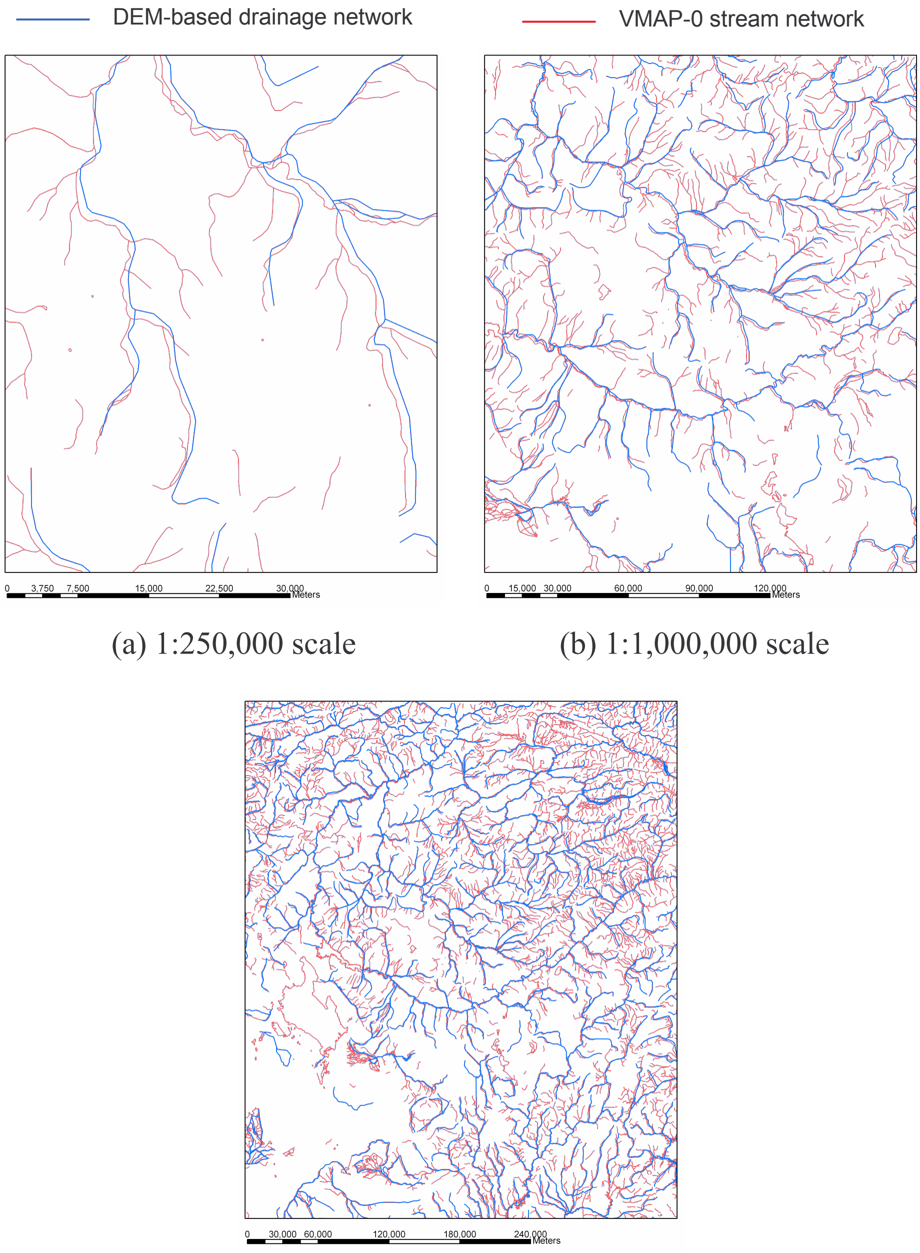


Figure 3.13. Variable positional accuracy of VMAP-0 hydrography layer

Therefore, presence of positional shifts similar to the one given in Figure 3.13b is a characteristic of VMAP-0 and should be accepted by the user at the beginning. If such an accuracy is not enough for the aimed application, a different and more accurate dataset should be used. Since the accuracy is fine enough for the development of a prototype national hydrography dataset, VMAP-0 is used in this study without any hesitation. However, one should pay attention to the scale at which the dataset is displayed. Unlike traditional paper maps, for which the scale is constant, digital maps can be visualized at any scale in GIS. But if the display scale is larger than the source scale of the digital map, problems related with the accuracy of the map may be more easily revealed. This situation is illustrated in Figure 3.14 for VMAP-0 hydrography layer with reference to 1:250,000 scale dataset.



(a) 1:250,000 scale (b) 1:1,000,000 scale

(c) 1:2,000,000 scale

Figure 3.14. Comparison of VMAP-0 with 1:250,000 scale reference map

Since the source scale of VMAP-0 is 1:1,000,000, at a display scale that is larger than this scale the positional shifts get easily observable (Figure 3.14a). However, as the display scale gets smaller, positional shifts lose their importance and resolving the differences becomes much more difficult (Figure 3.14b), even impossible (Figure 3.14c). Use of a scale smaller than or equal to 1:1,000,000 can be recommended for VMAP-0 and also for the hydrography dataset produced in the study, which is a derivative of that.

3.3.7. Lack of attribute data

VMAP-0 water courses sub-layer has a built-in attribute table that includes textual information on features. However, as given in Appendix C the only attributes are the name of the feature and its hydrological category, which show whether the feature is permanent or intermittent. No other information is made available that is related with hydrologic or physical characteristics of stream reaches. Also the names of very few streams (approximately 15% for Turkey) are available in the attribute table. Figure 3.15 shows distribution of originally named and unnamed streams in Turkey.

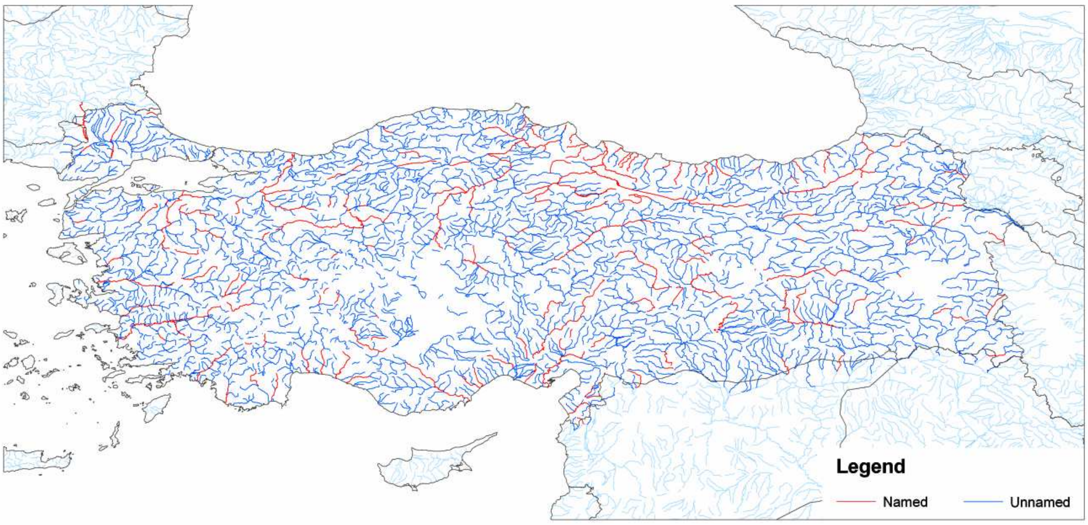


Figure 3.15. Named and unnamed streams in VMAP-0 (original state)

All available map sources and reference documents (like discharge yearbooks) are examined and widely used names of unnamed streams are determined in a similar way to unnamed inland water bodies that was explained before. At the end of the naming process, proportion of identified streams increased to 65%, which is quite high compared with the initial percentage. Final geographical distributions of named and unnamed streams are given in Figure 3.16.

Figure 3.16. Named and unnamed streams in VMAP-0 (final state)

3.4. Extensions to Feature Attribute Tables

Once inland water bodies and water courses sub-layers of VMAP-0 are corrected to establish the continuity of features and to reflect the actual shapes of water bodies and courses, a set of topologic and hydrologic data fields are calculated and added to their attribute tables. These data fields are especially useful for:

- In-depth evaluation of hydrologic relationships,
- Navigation through the stream network without spatial analysis,
- Classification of features,
- Production of thematic maps,
- Quality assessment, and
- Further hydrologic and environmental modeling studies (as basic data)

3.4.1. Extensions to Inland Water Features Attribute Table

The following attributes are calculated and/or manually entered for all features in inland waters sub-layer:

- Surface area: In order to calculate surface areas of inland water bodies, inland waters sub-layer, which is in geographic coordinates, is first projected into Albers Equal Area projection. Then surface areas are calculated by using area calculation feature of the GIS.

- Circumference: Similar to surface area, circumference of each inland water body is calculated using perimeter calculation feature of the GIS.

- Elevation: Average elevation of the inland water bodies are calculated from SRTM30 DEM. For this purpose, elevation grid cells that are completely within and intersecting with inland water bodies are extracted from the DEM, and for each water body their arithmetic mean is taken.

- Data source: In order to indicate the source of manually added and/or updated inland water features, a source field is added to the attribute table. Values used in this field and corresponding sources are given in Table 3.3.

Table 3.3. Attribute codes used in data source field

Value	Description
VMAP0	Vector Map Level 0 (1:1,000,000 scale)
HGK98	"Administrative Units of Turkey" map of GCM (1:1,000,000 scale)
SHW92	"Dams, Power Stations, and Irrigation Establishments" map of SHW (1:800,000 scale)
SHW94	Watershed maps from 1994 Discharge Yearbook of SHW (~1:800,000 scale)

- Basin number: The number of the major national basin, in which the inland water body resides, is stored in this attribute.

- Type of inland water body: This attribute is added to indicate the types of inland water bodies, i.e. whether they are natural or man-made in origin. Valid values are ‘Natural Lake’, ‘Saltpan’, ‘Wetland’, ‘Reservoir’, and ‘Constructed Dam’.

- Type of water: Water type of the inland water body is stated in this field. ‘Fresh’, ‘Salty’, and ‘Soda’ are available attribute values.

- Position in stream network: Information regarding to position of the inland water body in the stream network is specified in this attribute. If the water body is an end point in the stream network, like the water bodies located in closed basins, then this attribute is set as ‘Sink’. If water flow is continuous in the water body through influent and effluent points, then this water body is indicated as ‘On-stream’.

- Turkish name: The ‘Name’ field found in the attribute table, which originates from VMAP-0, actually contains the Turkish names of the inland water bodies. However, the names are based on English alphabet and letter specific to Turkish alphabet (e.g. ç, ş, ö) are not used. Also all letters are in upper case. For example, in this field Van Lake is named as ‘VAN GOLU’. To facilitate labeling of inland water bodies in Turkish, their names are made available in a separate field, in which Turkish characters are used.

Extended feature attribute table of inland water bodies sub-layer, including the original attribute fields, is summarized in Table 3.4.

Table 3.4. Extended inland water feature attribute table

Attribute	Description	Value
id	Unique feature ID	Number
f_code	FACC feature code	*
f_code_des	FACC feature code description	*
hyc	Hydrological category	*
hyc_descri	Hydrological category description	*
nam	Feature name	*
nam_descri	Feature name description	*
area	Surface area (km^2)	Number
perimeter	Circumference (km)	Number
elev	Average elevation (m)	Number
source	Data source	VMAP0
		HGK98
		SHW92
		SHW94
basin_no	Major basin number	Number (1 – 26)
type	Inland water type	Natural lake
		Saltpan
		Reservoir
		Wetland
		Constructed dam
wat_type	Water type of the body	Fresh
		Salty
		Soda
position	Position in the stream network	On-stream
		Sink
nam_tr	Turkish feature name	Text

* These values are given in Appendix C

3.4.2. Extensions to Water Course Features Attribute Table

Similar to inland waters, a set of attributes are also calculated and/or manually entered for all features in water courses sub-layer. Since data source, basin number, and Turkish name fields among the added attributes are the same with the ones described in inland waters part, they will not be described again in detail. Attributes special to water courses are as follows:

- Starting/ending nodes: In order to determine starting and ending points (nodes) of stream lines, first all nodes of stream lines are extracted from water course coverage in ArcView 3.2 GIS using Node Information Generating Tools (NIGT) extension developed by Horby (2002a). Extracted nodes are uniquely identified and used to generate a point coverage, which can be used as supplementary dataset to the existing water courses coverage. Using the same extension mentioned above, types of nodes related with their positions in the stream network are determined. For headwater nodes 'Head' is assigned as position attribute, whereas for nodes located at the mouths of streams 'Mouth' and for intersection nodes 'Connection' values are assigned. A stream network with node classifications is illustrated in Figure 3.17.

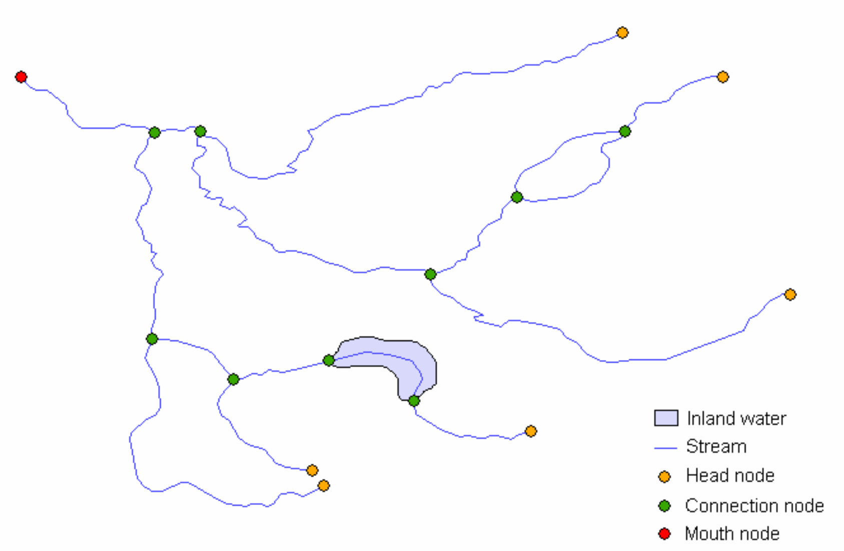


Figure 3.17. A sample stream network with nodes

Using Grid Analyst v1.1 extension developed by Saraf (2000), elevation values at the nodes are extracted from SRTM30 DEM and added to the attribute table the coverage. Finally, numbers of stream lines that are intersecting at the nodes are calculated for each node feature, which is a measure of stream line divergence. Complete feature attribute table description of stream line nodes coverage is given below in Table 3.5.

Table 3.5. Stream line node features attribute table

Attribute	Description	Value
Id	Unique feature identifier	Sequential number
Type	Node type	Head
		Mouth
		Connection
elev	Elevation at the node (m)	Number
diverge	Number of streams intersecting at the node	Number

In order to provide connectivity information explicitly in the attribute table of water courses coverage, starting and ending nodes of stream lines are determined using NIGT extension. Unique identifiers that were assigned to these nodes previously during the production of nodes coverage are extracted and stored in separate fields in the water courses feature table. 'FNode' field is used for starting node ids, whereas 'TNode' field is used for ending node ids.

- <u>Stream length:</u> Lengths of streams are determined using distance calculation feature of GIS, and added to the attribute table. Before the calculation of the lengths, water course sub-layer is projected from geographic coordinates into a metric equidistant projection system in order to maintain the accuracy.

- <u>Slope:</u> Average slopes of the stream lines are calculated by dividing the elevation difference between starting and ending nodes into calculated stream length. Although for majority of the stream lines calculated slopes are found to be positive as expected, for some stream reaches negative results are obtained. This problem arises due to vertical accuracy of SRTM30 DEM and positional accuracy of VMAP-0 hydrography layer, which are used as base datasets and could not be corrected unless more accurate data sources are used. Hence, they are left as they are.

- Type of stream reach: A type field is added to the feature attribute table to indicate the type of stream reaches with respect to their positions in the stream network. By using spatial query features of the GIS package, stream lines that intersect with headwater nodes calculated in previous steps are determined and specified as 'Headwater' reaches. Likewise, stream lines that intersect with mouth nodes are termed as 'Mouth' reaches. All other stream lines, except artificial stream lines that are drawn manually through the inland water bodies, are termed as 'Ordinary' streams. Artificial stream lines are specified specially as 'Artificial'. A sample stream network classified according to stream types is illustrated in Figure 3.18.

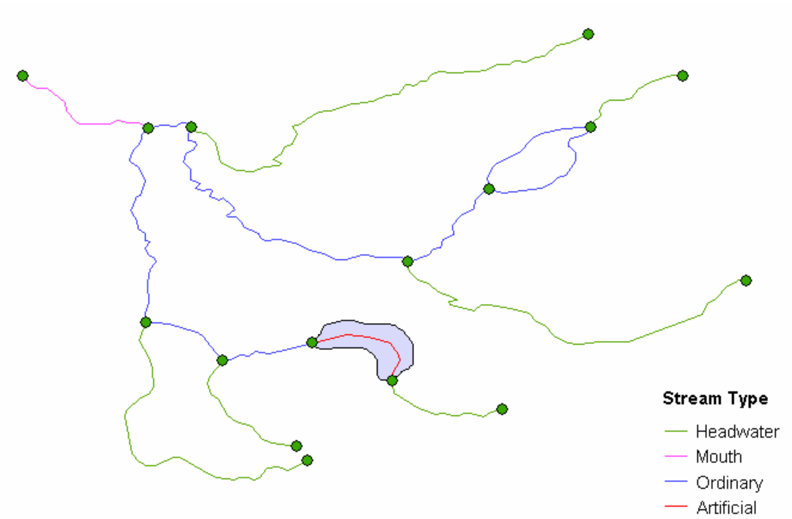


Figure 3.18. A sample stream network with stream types indicated

- Number of down-stream reaches: For each stream line, the number of neighbor stream lines that are located at the down-stream end of the stream line, are calculated and this information is added to the feature attribute table. In order to determine the number of down-stream segments, each stream line in the stream network is selected separately and streams that have starting node ID equal to the ending node of the selected stream line are counted by simple attribute query methods of GIS. Number of down-stream reaches is illustrated in Figure 3.19.

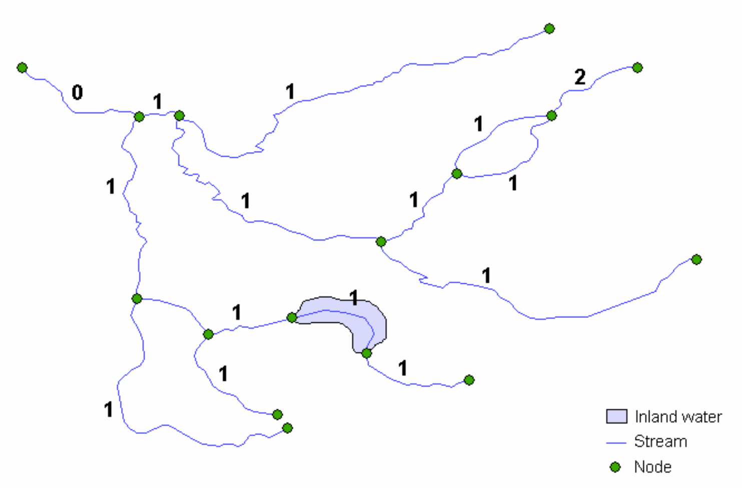


Figure 3.19. A sample stream network with number of down-stream reaches

- Number of up-stream reaches: Similar to number of down-stream reaches, number of up-stream reaches is also calculated for each stream line. For this purpose, stream lines that have ending node ID equal to starting node is of the selected stream are counted. Number of up-stream reaches is illustrated in Figure 3.20.

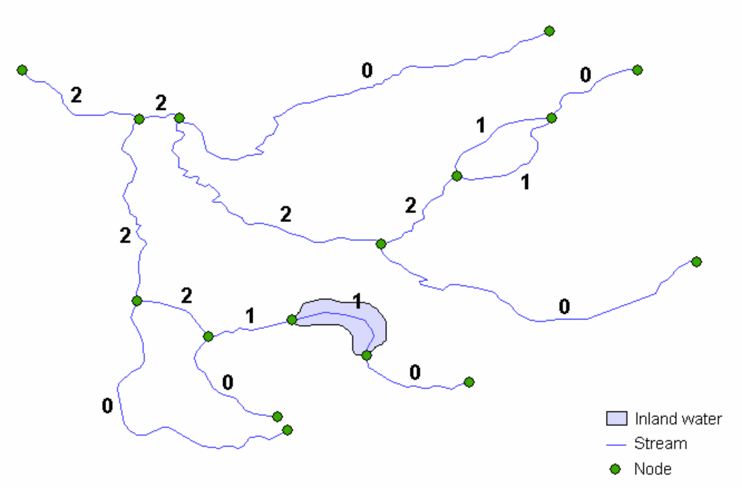


Figure 3.20. A sample stream network with number of up-stream reaches

* Divergence: In order to differentiate major stream line from minor ones, where the stream network branches into two or more downstream segments, a divergence attribute is defined for water courses sub-layer. A divergence value of zero is assigned for single downstream reaches. Multiple downstream reaches are numbered sequentially starting from one in the order of decreasing majority. For example if two alternative downstream segments are present, the major segment takes a divergence value of 1 and the minor segment takes a value of 2. In order to assign divergence values to stream lines, whole stream network is inspected visually and divergence values are assigned to branched stream lines manually by personal judgment on major/minor segments. Divergence values of the remaining stream lines are set to zero. Sample stream network with divergence values is illustrated in Figure 3.21.

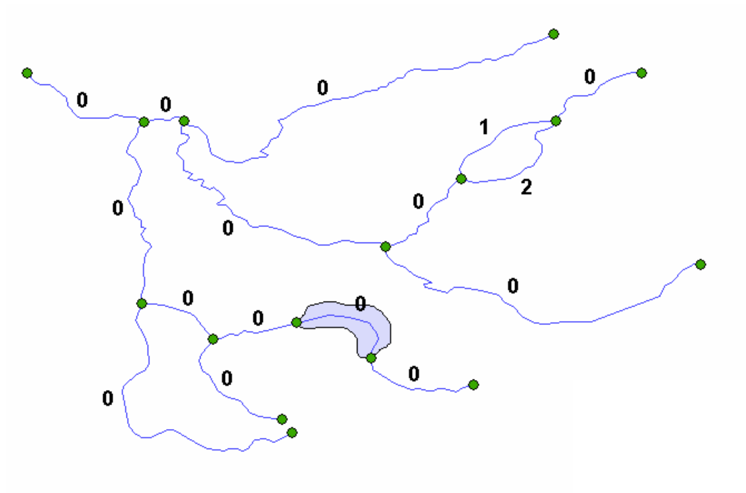


Figure 3.21. A sample stream network with divergence values

* Strahler order: Hydrologic orders of stream lines with respect to Strahler ordering are calculated using Strahler ArcView 3.2 extension developed by Horby (2002b) and made available as a separate field in feature attribute table. In Strahler ordering, all stream lines with no tributaries are assigned an order of 1. Stream order only increases when streams of the same order intersect. For example, the intersection of a first order and second order

stream line results in again a second order stream. But when two second order streams intersect, the down-stream reach is assigned an order of three. Strahler ordering of a sample stream network is illustrated in Figure 3.22. Strahler order is an important hydrological parameter and can be used for classification of water courses. Classification of Turkey’s surface waters according to their Strahler orders is shown in Figure 3.23, which is produced by using thematic mapping tools of ArcView GIS.

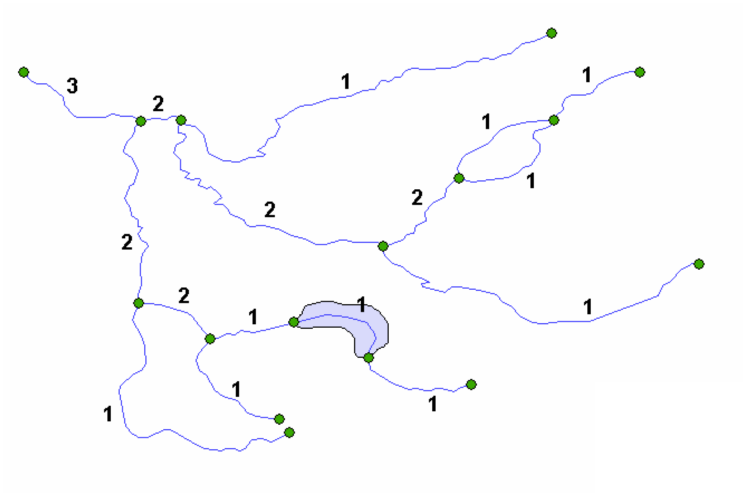


Figure 3.22. A sample stream network with Strahler orders

- <u>Shreve order:</u> Similar to Strahler orders, Shreve orders of the stream lines are also calculated and made available in feature attribute table. In Shreve ordering, magnitudes of intersecting streams are added and assigned to the down-stream. In order to assign Shreve orders to the stream lines, a custom AVENUE script has been developed, which takes braiding stream lines into account. Normally, Shreve stream order can not be calculated if a stream network branches into two or more down stream reaches. To cope with such situations, the algorithm chooses the stream line having the smallest divergence value calculated previously. The orders of remaining streams are set to zero. Shreve ordering of a sample network is illustrated in Figure 3.24.

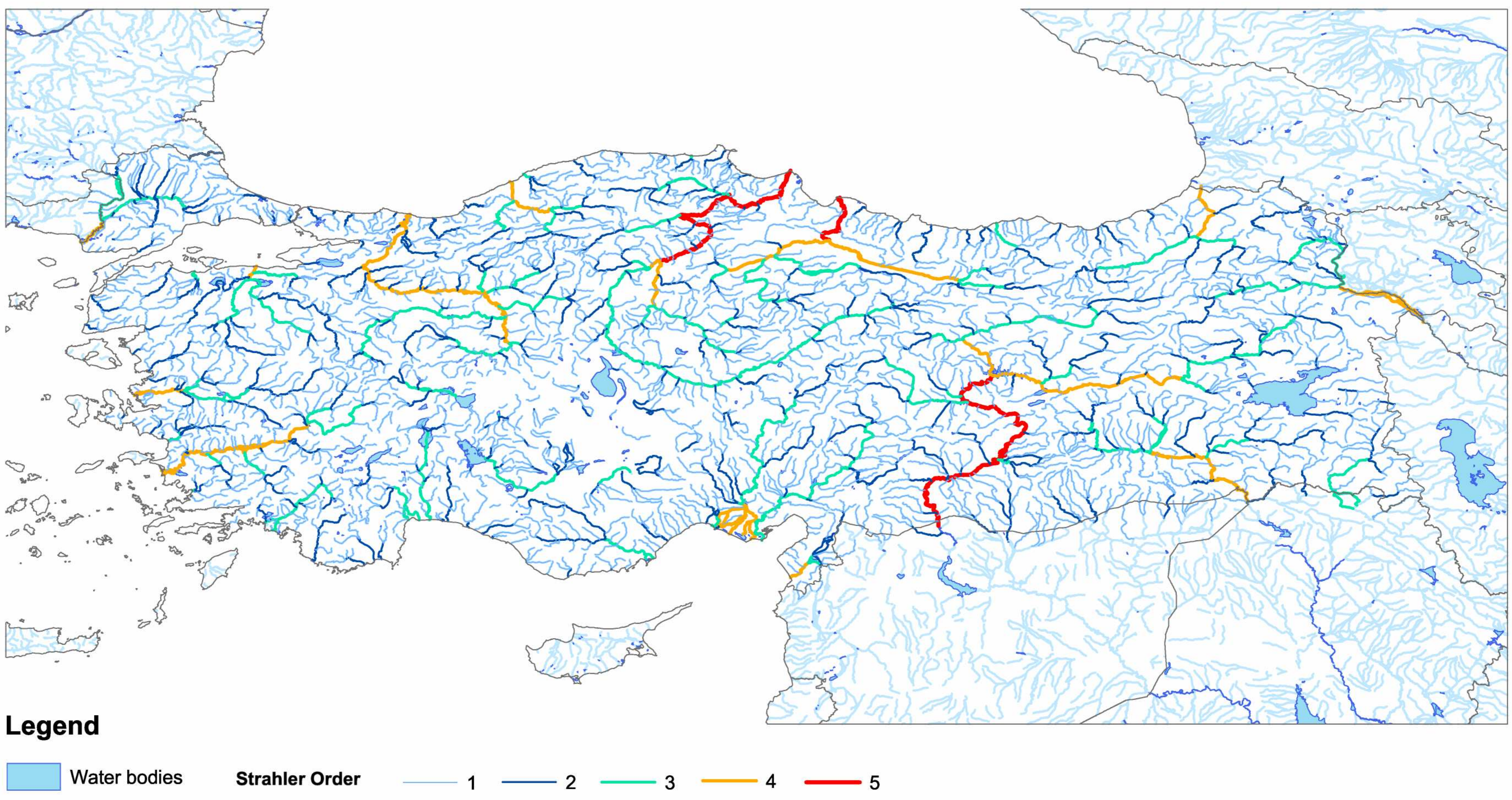


Figure 3.23. Strahler orders of water courses in Turkey

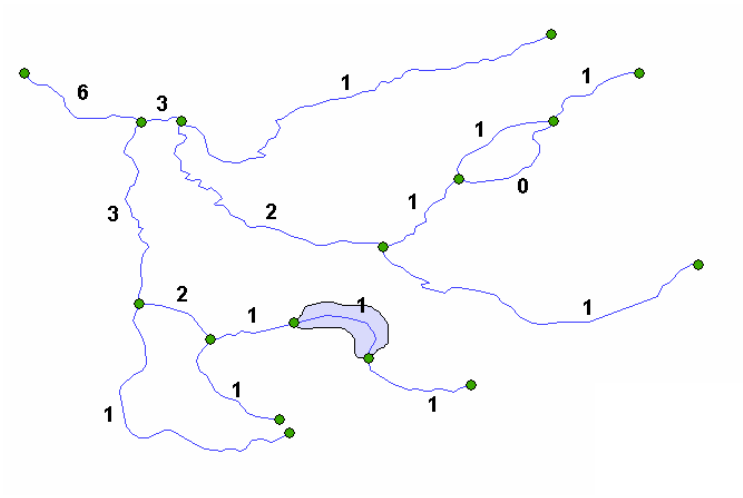


Figure 3.24. A sample stream network with Shreve orders

- Arbolate sum: In order to calculate the arbolate sum for each stream segment, all stream lines that are located up-stream of the stream segment are selected by navigating through the stream network following from-node/to-node attribute values. Stream lengths of selected stream line segments are summed together and added to the stream length of the initial stream line. Found value is recorded as the arbolate sum. This attribute is actually the sum of all stream lengths that flow to the downstream end of a stream. A sample stream network with calculated arbolate sums is given in Figure 3.25.

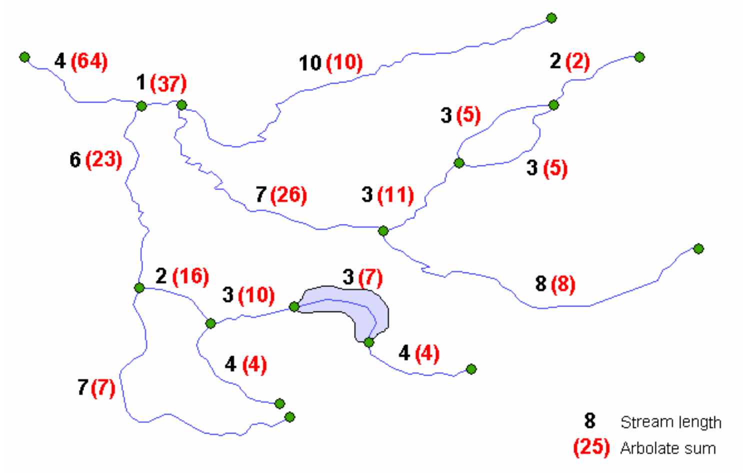


Figure 3.25. A sample stream network with arbolate sums

- Path length: The distance from the down-stream end of a stream line to the end point of the stream network is calculated for each stream line and added to the feature attribute tables as path length. Path length is a measure of how far a stream is located from the outlet of the stream network, and can be used in travel-time calculations. In order to calculate path length, a custom AVENUE script is written in ArcView 3.2. This script navigates for each stream line down-stream in the stream network and sums the stream lengths till the end point is reached. If a braiding segment is found during the navigation, then the stream line having the smallest divergence value is selected and navigation is continued in the down-stream direction. A sample stream network with calculated path lengths is illustrated in Figure 3.26.

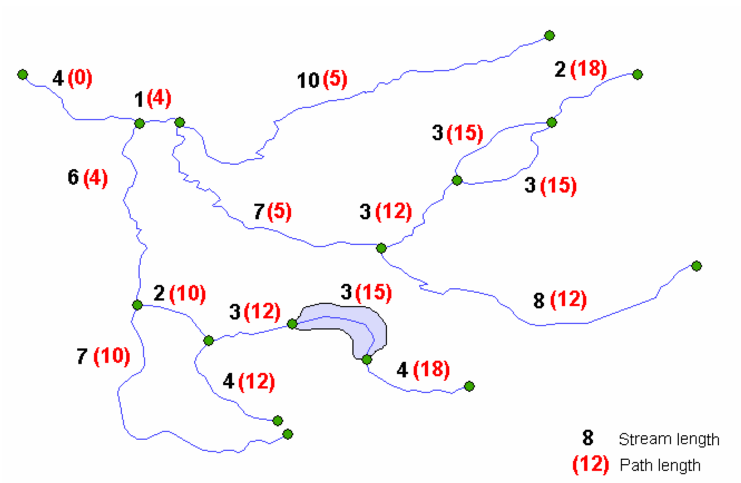


Figure 3.26. A sample stream network with path lengths

Extended feature attribute table of water courses sub-layer, including the original attribute fields, is summarized in Table 3.6.

Table 3.6. Extended water course feature attribute table

Attribute	Description	Value
id	Unique feature id	Number
f_code	FACC feature code	*
f_code_des	FACC feature code description	*
hyc	Hydrological category	*
hyc_descri	Hydrological category description	*
nam	Feature name	*
nam_descri	Feature name description	*
source	Data source	VMAP0
		HGK98
		SHW92
		SHW94
basin_no	Major basin number	Number (1 – 26)
nam_tr	Turkish feature name	Text
fnode	Starting node ID	Number
tnode	Ending node ID	Number
length	Stream length (km)	Number
slope	Average stream slope (km/km)	Number
type	Water course type	Headwater
		Mouth
		Ordinary
		Artificial
num_down	Number of down-stream reaches	Number
num_up	Number of up-stream reaches	Number
diverge	Stream divergence	Number
strahler	Strahler order	Number
shreve	Shreve order	Number
arb_sum	Arbolute sum of stream lengths	Number
path_len	Path length	Number

[*] These values are given in Appendix C

CHAPTER 4

DEVELOPMENT OF WATERSHED BOUNDARIES

In this chapter studies conducted to determine watershed boundaries from the DEM of the study area are explained in detail, in which automated methods are utilized that are based on flow direction/flow accumulation calculations.

In order to determine the watershed boundaries, first the selected DEM (SRTM30) is pre-processed and made suitable for hydrologic modeling. In this step, sinks found in the DEM are removed and inaccurate elevation values are corrected. Then using Deterministic-8 (D8) method developed by O'Callaghan and Mark (1984), and Jenson and Domingue (1988) flow direction and flow accumulation grids are calculated, from which the drainage network and watershed boundaries of the study area are derived. Since obtained results were not satisfactory enough, a modification of the D8 algorithm proposed by Garbrecht and Martz (1997) is also applied to the DEM and it is found to be superior to the original algorithm yielding more realistic drainage lines. Final drainage network and watershed boundaries are delineated using this method. For this purpose, a set of watershed boundaries are generated using different area thresholds. Obtained watershed boundaries are evaluated according to the study criteria and the one that fits best to the study criteria is selected as the final watershed boundaries dataset. At the last step, the watersheds in the selected dataset are named according to ERICA-CS watershed coding system of EU. Tools are also developed for navigation through the watersheds in GIS.

4.1. Determination of the Study Area and Preparation of DEM

In order to obtain realistic drainage networks and watershed delineations from automated DEM-based algorithms, the integrity of study area reflects a great importance. A DEM that has an extent smaller than the estimated size of the target watersheds will result in inaccurate delineations, especially at locations closer to the DEM boundaries. For Turkey, which has major cross-boundary rivers having watersheds extending to neighbor countries, the study area should not be limited to country boundaries. In this respect, a rectangular area extending between 25° - 46° East longitudes and 34° – 44° North latitudes is selected for the study, which provides an additional frame of one degree in East/West and two degrees in North/South directions on either side of the country. The extent of the study area is illustrated in Figure 4.1.

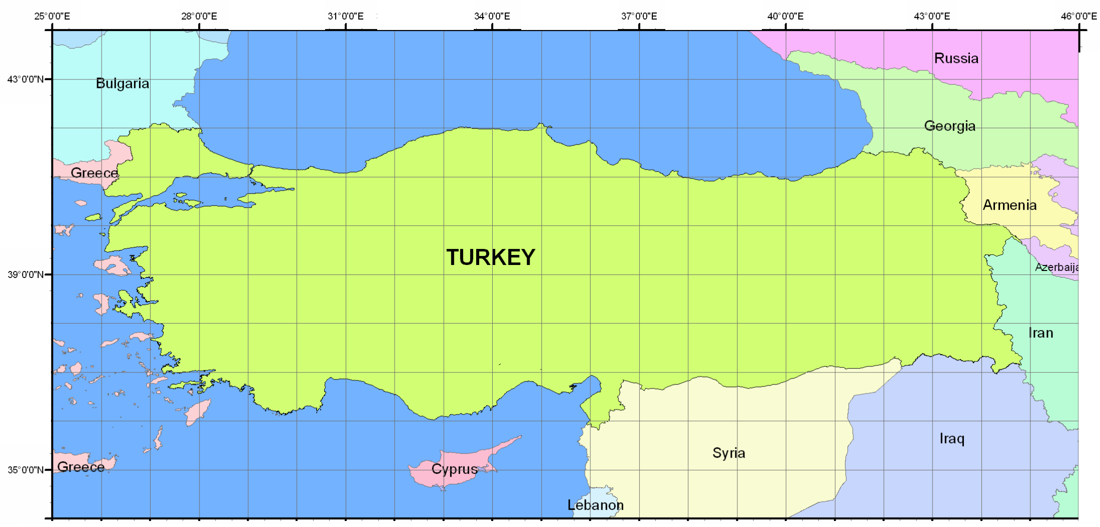


Figure 4.1. Extents of the study area

Using Grid Analyst Extension v1.1 developed by Saraf (2000), SRTM30 global elevation dataset is cropped to boundaries of the study area. Shaded relief image of the resulting elevation model and its histogram showing the distribution of elevation values with respect to count of grid cells are given in Figure 4.2 and Figure 4.3 respectively.

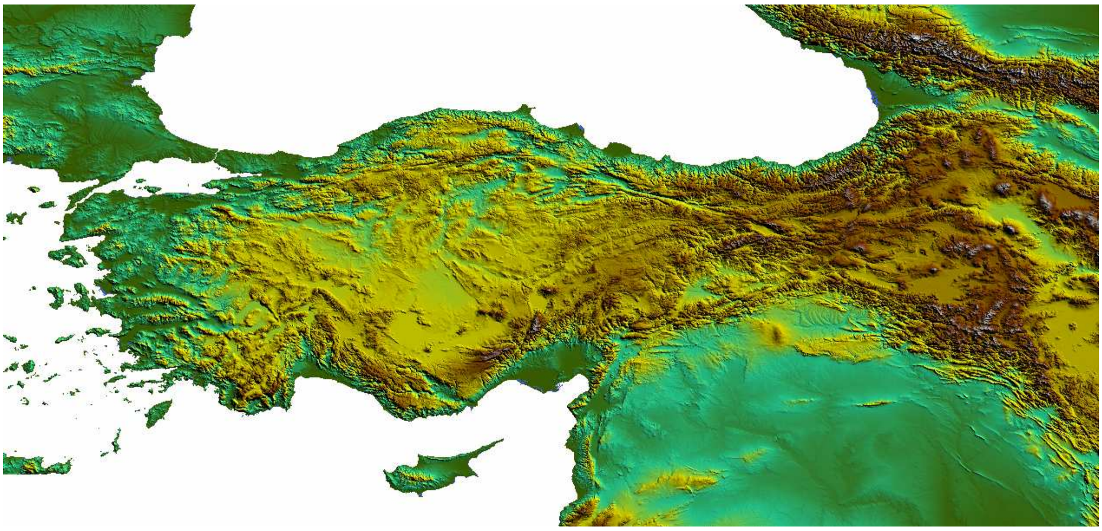


Figure 4.2. SRTM30 DEM of the study area

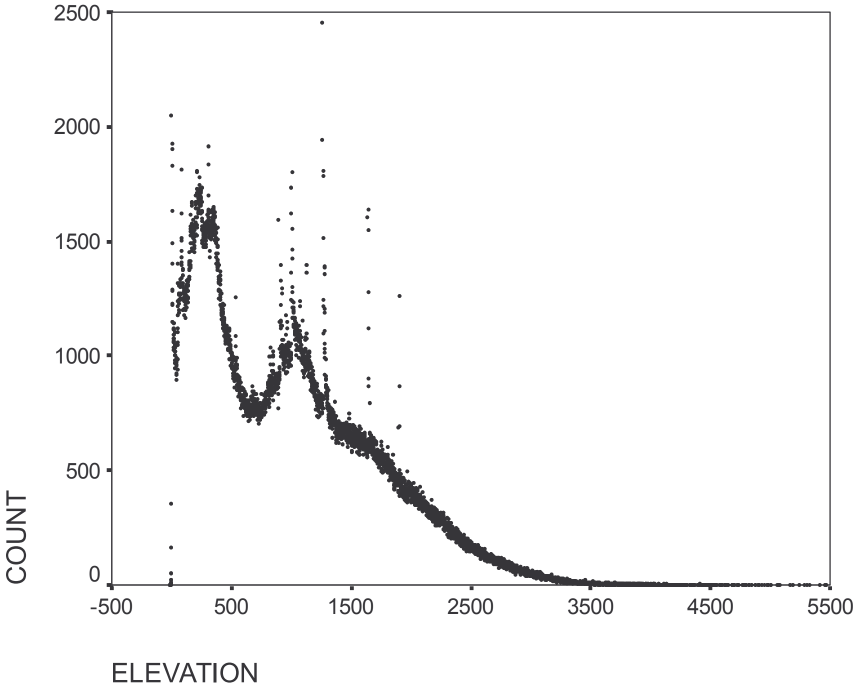


Figure 4.3. Histogram of SRTM30 DEM for the study area

Characteristics of the DEM used for the study, including its dimensions, grid spacing, and elevation statistics are summarized in Table 4.1.

Table 4.1. Characteristics of DEM used for the study

Number of columns	2520
Number of rows	1200
Total number of grid cells	3,024,000
X cell size (degree)	0.0083333333
Y cell size (degree)	0.0083333333
Minimum elevation (m)	-14
Maximum elevation (m)	5472
Standard deviation (m)	713.7530

30-arc seconds ($0.008\overline{3}$ decimal degrees) grid spacing of SRTM30 equates to approximately one kilometer at the equator. But this dimension is not constant, and decreases in the longitudinal direction as latitude increases. Approximate dimensions of a 30 arc-second grid cell at different latitudes are listed in Table 4.2.

Table 4.2. Dimensions of a 30-arc second grid cell at different latitudes (USGS, 1997b)

Latitude (degrees)	**Ground Distance (meters)**	
	East/West	**North/South**
0 (Equator)	928	921
10	914	922
20	872	923
30	804	924
40	712	925
50	598	927
60	465	929
70	318	930
74	256	930
78	193	930
82	133	931
86	64	931
89	16	931
90	0	931

Since the study area boundaries are 34 – 44 North latitudes and 25 – 46 East longitudes, ground distance of a grid cell in North/South direction is nearly constant and can be taken as 924 meters. However, the distance in East/West direction changes approximately between 770 to 670 meters, with an average of 720 meter at 39^o North latitude. This variation in the grid cell dimensions should always be taken into consideration during cell based area or distance calculations. As stated explicitly in GTOPO30 documentation, "derivative products, such as slope maps, drainage basin areas, and stream channel length, will be more reliable if they are calculated from a DEM that has been first projected from geographic coordinates to an equal area projection, so that each cell, regardless of latitude, represents the same ground dimensions and area as every other cell." (USGS, 1997b). Since through the study such DEM derivatives will be produced extensively, DEM of the study area, which is in geographic coordinates, is projected into an equal area projection based on this recommendation. For this purpose, several projection alternatives are evaluated, and Albers Equal Area (AEA) projection, which is a conical equal area projection recommended for regions that are predominantly East-West in extent (Richardus and Adler, 1972), is selected for the study.

In order to project the DEM into AEA projection, first several projection parameters should be determined. These are actually typical parameters of a conical projection, which can be listed as first and second standard parallels, central meridian, origin of latitude, and false easting and northing. Although conical projection (i.e. shape preserving Lambert Conformal Conic projection) is extensively used for nation-wide maps of Turkey, there does not exist a single set of parameters that are officially accepted. Even GCM has two different conical projection parameter sets for Turkey, one for northern latitudes and another one for southern latitudes. These two parameter sets and also an additional widely-used parameter set that is developed by Eren (1999) are given in Table 4.3. Projections obtained by using these parameter sets are illustrated in Figure 4.4 with a map of country boundaries.

Table 4.3. Common parameter values used in Turkey for conical projections

Parameter	GCM North	GCM South	Eren
1. Standard Parallel (degrees)	40.66667	36.66667	37.5
2. Standard Parallel (degrees)	43.33333	39.33333	40.5
Central Meridian (degrees)	34	34	35
Origin of Latitude (degrees)	*	*	25
False Easting (meters)	*	*	0
False Northing (meters)	*	*	0

* Not stated

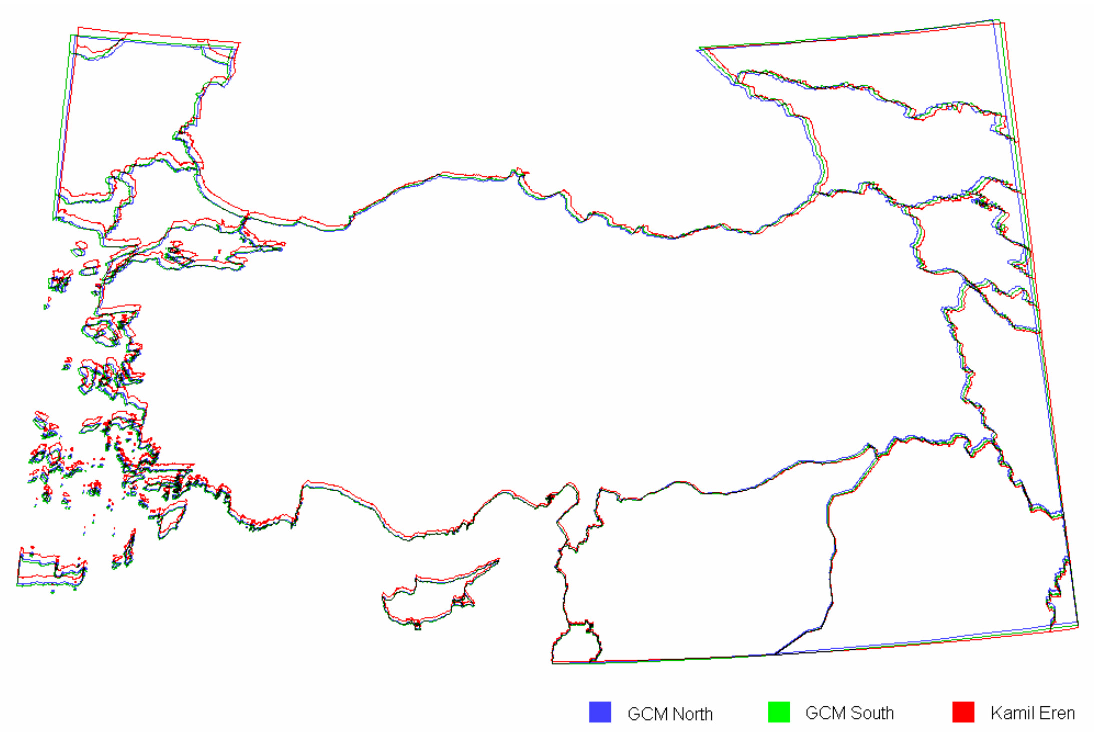


Figure 4.4. Comparison of different conical projection parameter sets

Critical parameters of AEA projection are first and second standard parallels. Various methods of determining optimum standard parallel have been proposed by different cartographers (Synder, 1987). As a rule of thumb, the standard parallels should be selected such that the area between the parallels will be equal to 4/6 of the total study area. Half of the remaining area (1/6 of the total) should be in the south of the first parallel and the other half should be in the north of the second parallel (Richardus and Adler, 1972). According to this guiding rule, none of the parameter sets given in Table 4.3 are "optimum" for the study area. However, for all three parameter sets, the surface area of Turkey is calculated as 781,161 km^2 based on VMAP-0 country boundaries. Although there are small differences in decimal places, the maximum difference is found to be not larger than 4,000 m^2, which is quite insignificant for a study having a country-wide extent. Therefore, it can be concluded that any of the parameter sets can be used for projection purposes. Because it is one of the standards of the national mapping agency, GCM North parameter set is selected for the study. Resulting DEM is given in Figure 4.5. Here it should be noted that AEA is not the ultimate projection of the datasets derived in the study. Once the required analyses are completed, obtained datasets are projected back to the geographic coordinates for final storage.

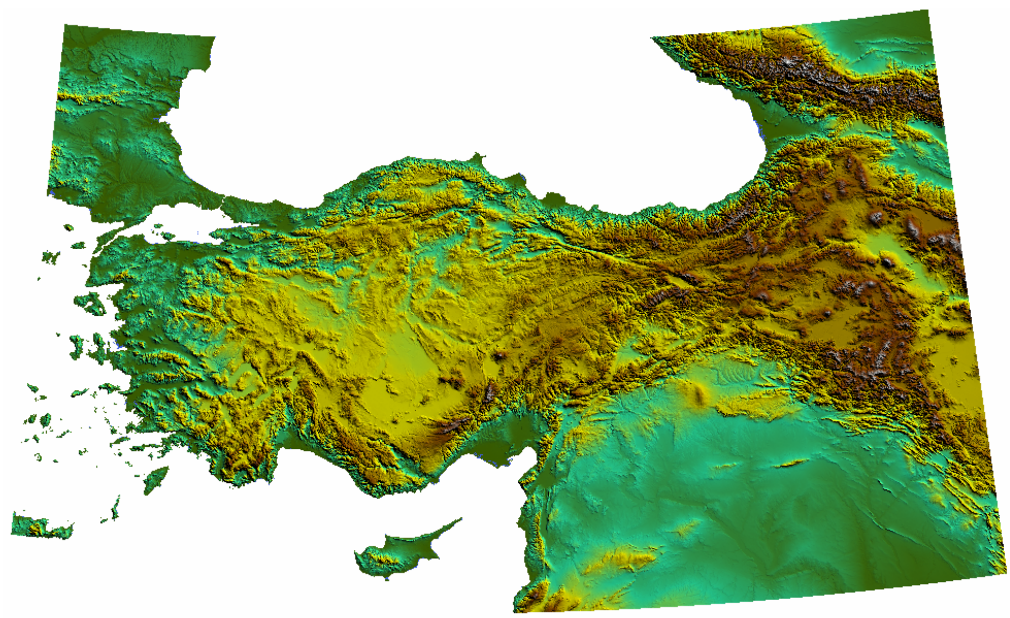


Figure 4.5. SRTM30 DEM in Albers Equal Area projection

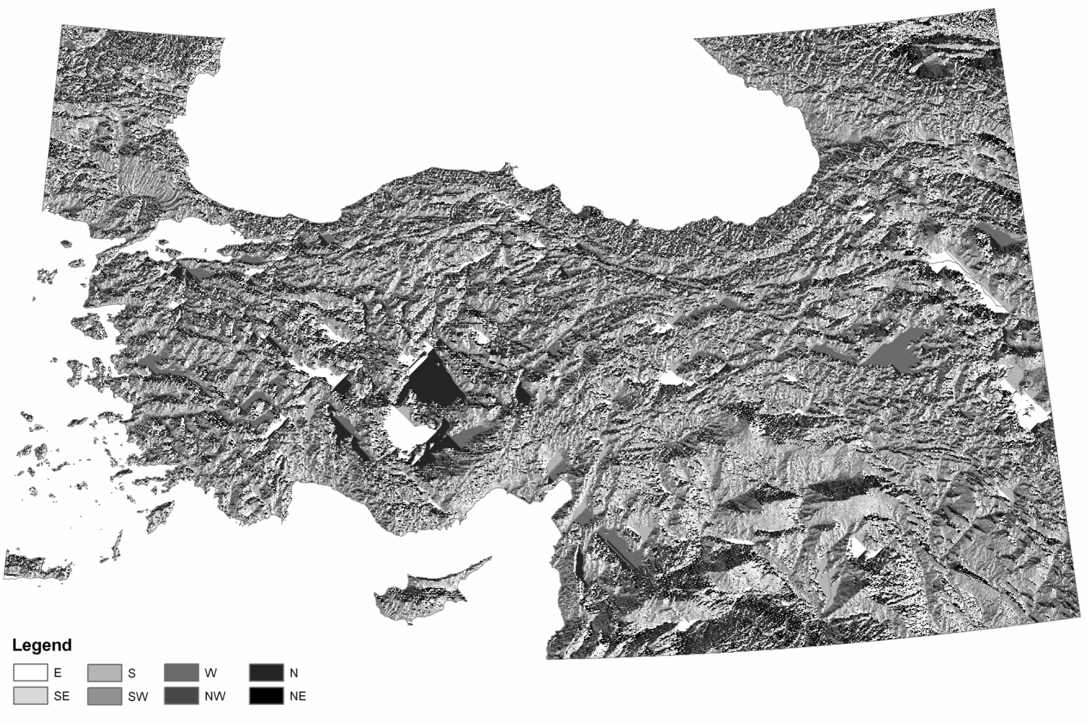
4.2. Delineation of Watershed Boundaries

There are many methods available to determine the flow directions from DEMs (Jenson and Domingue, 1988; Fairfield and Leymarie, 1991; Quinn et al., 1991; Lea, 1992; Costa-Cabral and Burges, 1994; Tarboton, 1997). These methods differ from each other mainly by the number of possible flow directions that can be assigned to each grid cell, input data used to assign flow directions, and flow direction determination criteria. Some of them are very complex algorithms that require in depth analysis and data preparation to yield satisfactory results. Since primary aim of the study is to see whether DEM-based automated watershed extraction method can be used to determine sub-basins of Turkey, but not to assess the accuracy of various methods, simple and proven techniques yielding reasonable and acceptable results are preferred for the study. In this respect, Deterministic-8 (D8) algorithm that is based on the principles set by O'Callaghan and Mark (1984), and Jenson and Domingue (1988) is used. D8 algorithm is the most widely used method for drainage network and watershed extraction from DEMs, and several implementations of the method are readily available in many GIS packages, which makes the application of the method much more easier compared with other methods that require custom written scripts or programs. In this algorithm, a single downstream cell among its eight neighbors is defined for each grid cell, so that the descent slope is the steepest. Once the flow directions are determined, the number of cells located upstream of each cell is calculated as a measure of flow accumulation. Applying a threshold value to these flow accumulation values and selecting the cells with higher accumulation values than the threshold yields a uniquely spanning drainage network. This network represents the paths of the DEM-based watershed flow system, the drainage density of which can be controlled by changing the threshold value. In order to determine the boundaries of the watersheds, the intersection points of the drainage reaches can be used as the outlets of watersheds, above which the contributing area are determined. By choosing a contributing area threshold, watershed boundaries can be delineated starting from the most up-stream ones.

D8 algorithm requires a DEM that is free of sinks, i.e. grid cells that are lower than all their neighbor cells. Hence a pre-processing step is required at the beginning. As the first step in watershed delineation process, the sinks in the SRTM30 DEM are determined using Hydrology Modeling extension of ArcGIS 8.1 (ESRI, 2002). As shown in Figure 4.6, sinks are generally very small in size and they are distributed uniformly through the study area. However, large sink groups are also observed, especially at the locations of inland water bodies. In total, 0.35% of the study area is found to be covered with sinks.

Figure 4.6. Sinks in the SRTM30 DEM

Using Hydrology Modeling extension the sinks in the DEM are filled and using sink-free DEM, flow direction and flow accumulation grids are calculated, which are given in Figure 4.7a and 4.7b respectively. In order to assess the achievement of direct application of D8 method to the DEM, vector stream network is generated from flow direction and accumulation grids with an area threshold value of 1,000 km^2. The threshold value is determined by a trial-and-error procedure, in which a simple drainage network is targeted that can be easily compared with the actual stream network and basin boundaries. Obtained drainage network for 1000 km^2 threshold value is illustrated in Figure 4.8.



(a)

(b)

Figure 4.7. DEM based a) flow direction, b) flow accumulation grids

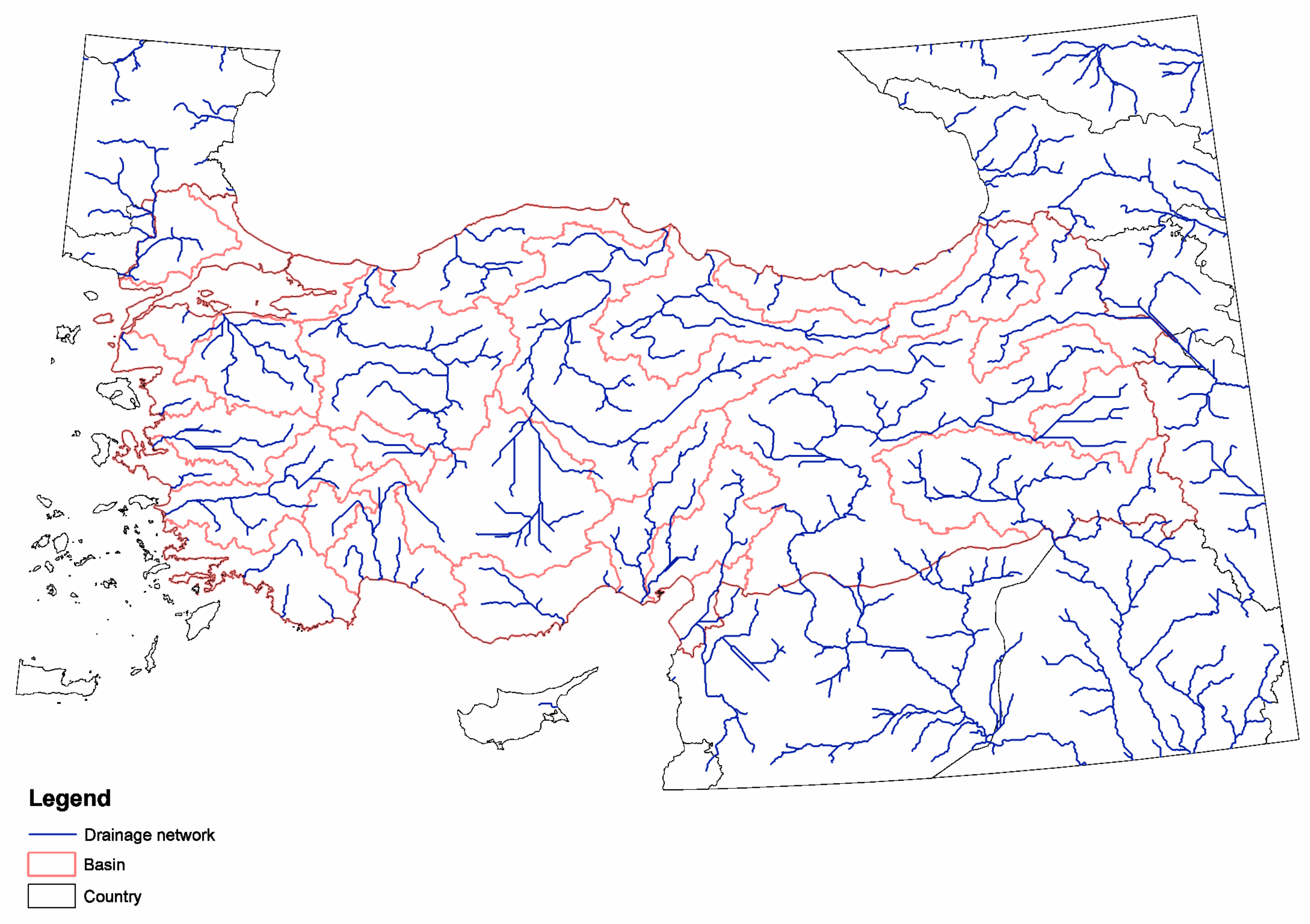


Figure 4.8. Drainage network generated by D8 method (initial condition)

As shown in Figure 4.8, 1,000 km^2 threshold resulted in a sparse drainage network which includes drainage lines of major rivers only. However, it was very useful for quick evaluation purposes. Majority of the generated drainage network is found to be consistent with the actual stream network and basin boundaries. However, drainage lines in all of the closed basins are found to be incorrectly extending outside the basin boundaries. Detailed views of the basins, which are given in Figure 4.9a – 4.9c, are more clearly illustrating this situation. Problematic locations are marked with rectangles in the figure.

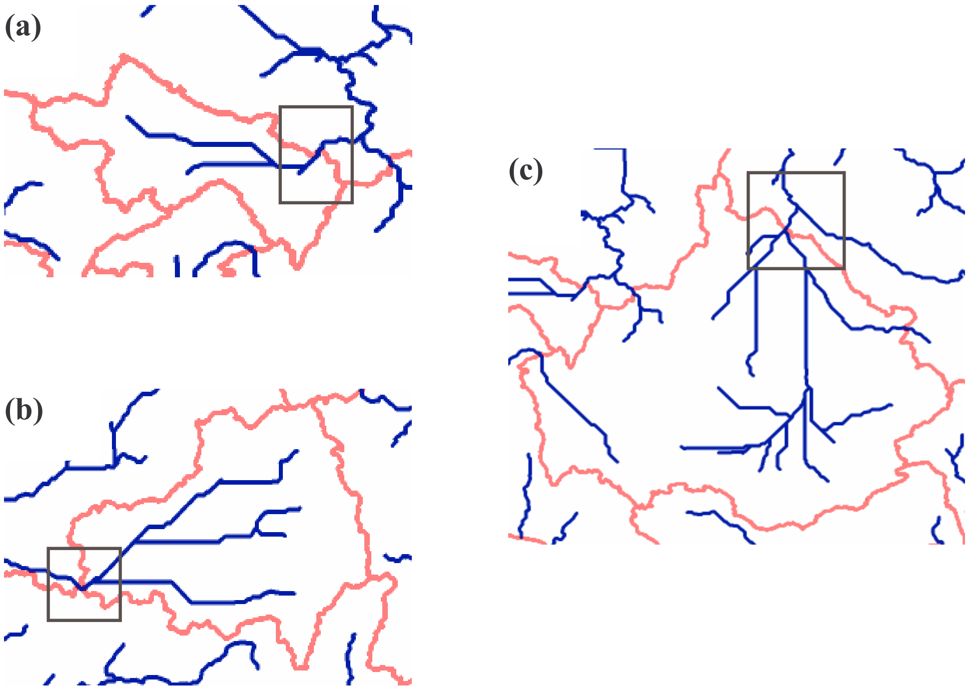


Figure 4.9. Drainage lines extending beyond the closed basins, a) Burdur Lakes Basin, b) Van Lake Basin, c) Salt Lake Basin

A close inspection of flow direction grid and filled-DEM at problematic locations revealed that the reason for extending drainage lines was flood-filling of lakes located at the centers of the closed basins. D8 algorithm could not differentiate small sized sinks due to imperfections in the DEM from these lakes. Actually, this result is not surprising, because the lakes behave like "sinks" that draw streams to themselves. In D8 method point of view, which does not consider the sizes of the sinks explicitly, both lakes and sinks are similar features that should be removed from the DEM according to process steps. The only way to prevent flood-filing of closed basin lakes is to mark the locations of these features on the DEM and to force the algorithm not the fill the DEM when it reaches to the marked grid cells. According to the implementation of the D8 algorithm in ArcMap GIS, this can be done by setting the values of grid cells belonging to the lakes to 'No Data' value. Hence, the only requirement to fix the problem is information on location and extent of lakes in closed basins.

Although inland water bodies sub-layer of the hydrography dataset includes lakes as vector features, a grid data source with the same grid spacing of SRTM30 DEM that includes the lakes is preferred as the data source in the study to prevent possible discordance between vector and raster datasets. Selected dataset is Global Land Cover Characteristics Database (GLCC), which is generated by U.S. Geological Survey's (USGS) Earth Resources Observation System (EROS) Data Center, the University of Nebraska-Lincoln (UNL) and the Joint Research Center of the European Commission (Loveland et al., 2000). The dataset is derived from Advanced Very High Resolution Radiometer (AVHRR) data spanning a 12-month period (April 1992-March 1993) and is based on a flexible database structure and seasonal land cover regions concepts. As a part of the dataset, there are a common set of derived thematic maps produced through the aggregation of seasonal land cover regions according to several classification model and schema. As an example, International Geosphere Biosphere Programme (IGBP) Land Cover Classification (Belward, 1996) thematic map is illustrated in Figure 4.10 for Turkey. From IGBP thematic map, water bodies class is extracted as a separate layer and by manual editing the water bodies are further classified into sinks and on-stream water bodies. Obtained water bodies map is given in Figure 4.11.

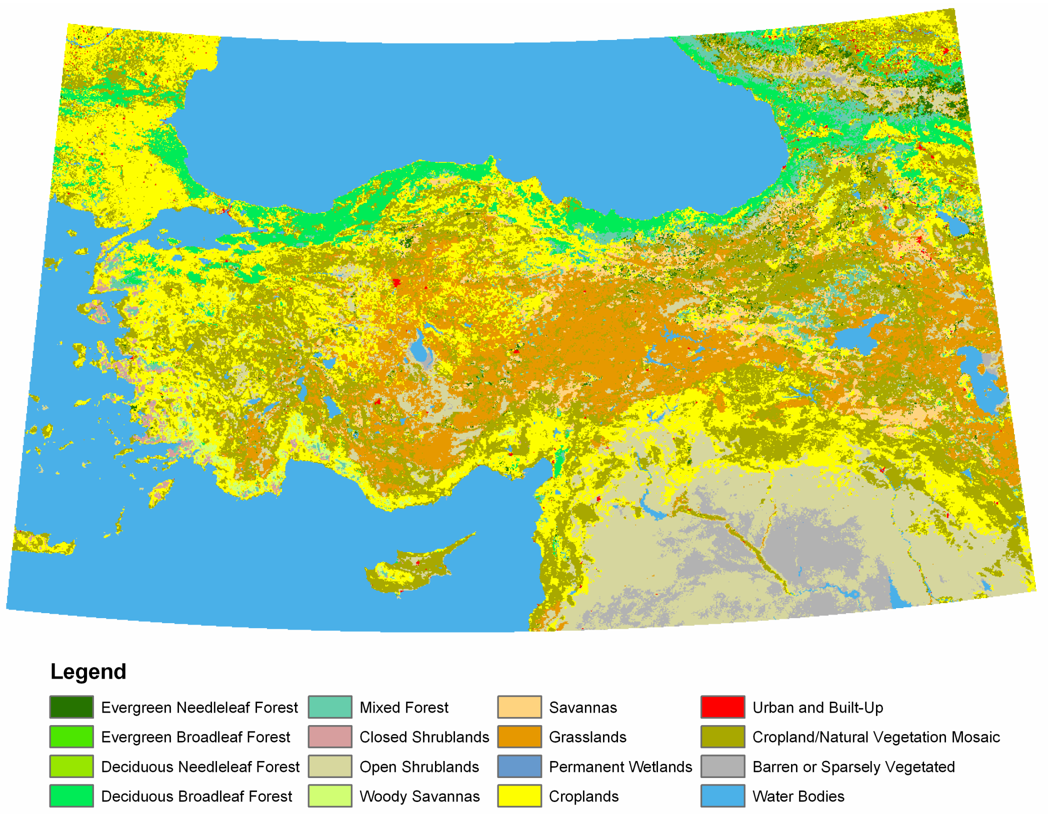


Figure 4.10. IGBP Land Cover Classification for Turkey

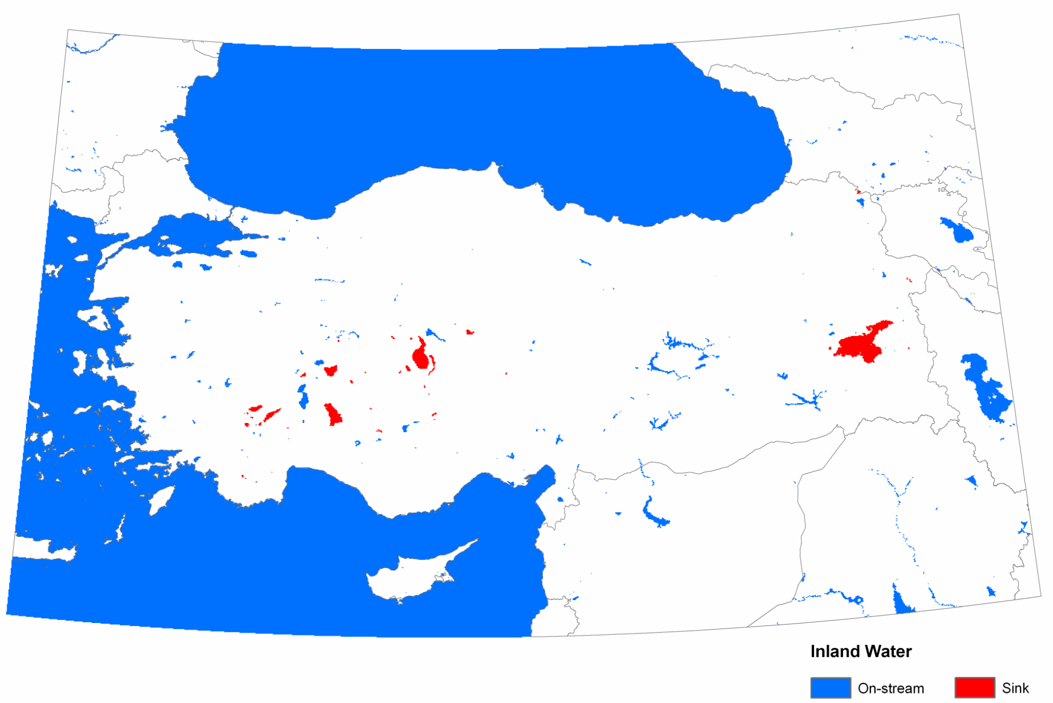


Figure 4.11. Sink and on-stream inland water bodies

Using Map Calculator tool of ArcMap 8.2, grid cells belonging to sink inland water bodies are incorporated into the study area DEM as 'No Data' values. Again, D8 method is applied to the obtained lake-aware DEM, and flow direction/flow accumulation grids are calculated. In order to assess the progress, drainage network is generated with the same area threshold value (1,000 km^2) used initially. Resulting drainage network is illustrated in Figure 4.12.

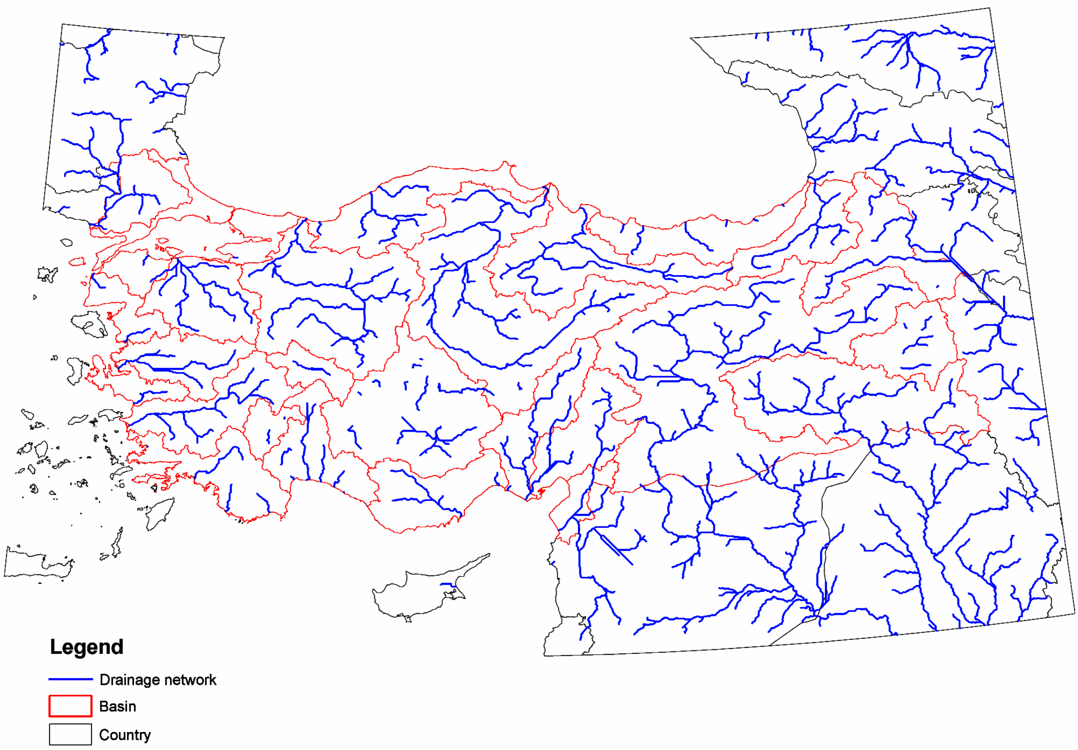


Figure 4.12. Drainage network after incorporation of sink lakes

As it can be seen from the figure, incorporation of lakes that behave like sinks in to DEM significantly corrects the drainage network. The problems observed in closed basins are completely solved and drainage lines are directed to the lakes instead of neighboring basins. However, there are still some remaining problems. For example, Ceyhan river joins to Seyhan river, a part of the Ceyhan river joins to Asi river, and Gönen Creek in Marmara Basin drains to Manyas Lake, all of which are incorrect. These problems are illustrated in Figure 4.13 in detail.

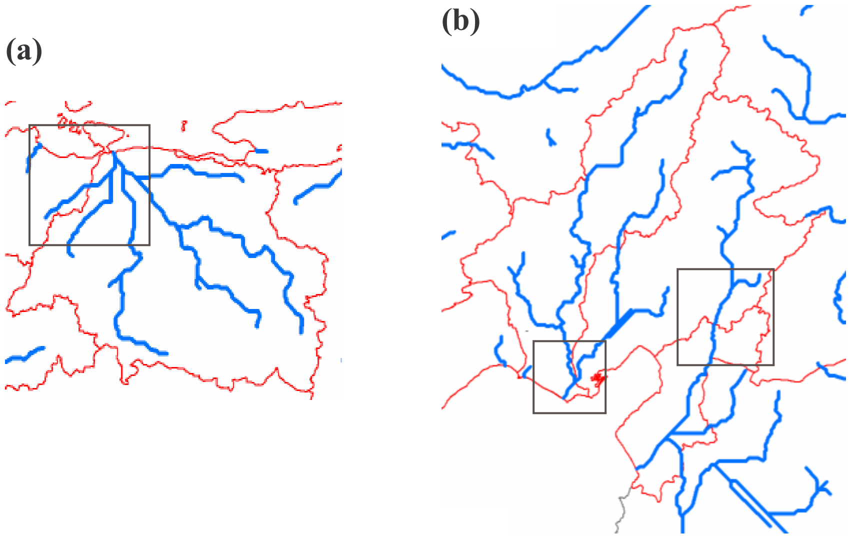


Figure 4.13. Incorrect joins in lake-burned drainage network,
a) Gönen Creek, b) Ceyhan River

Inspection of the DEM showed that the reasons for incorrect joins are grid cells having high elevation values that are located on the ways of the rivers. Either the vertical accuracy or the averaging process that is applied during the production of the original DEM may result such high elevation cells. Whatever the reason is, the solution is manually editing the DEM and altering the elevations such that drainage lines will follow actual stream line directions. Since the number of problematic locations is very low, this process can be easily done without significant labor requirement. Raster Editor extension of ArcMap is used in the study to change the elevations of approximately 10 grid cells to correct the flow directions. This number is very low compared with over 4 million cells existing in the DEM.

D8 method is applied to lake incorporated and manually edited DEM. Resulting drainage network is found to be consistent with major national basin boundaries and its shape is found to be very similar to the actual stream network. In order to further assess the accuracy of the drainage network, several additional drainage networks are generated with smaller threshold values, which are 50, 100, 250, and 500 km^2. Drainage networks corresponding to these thresholds are illustrated in Figure 4.14.

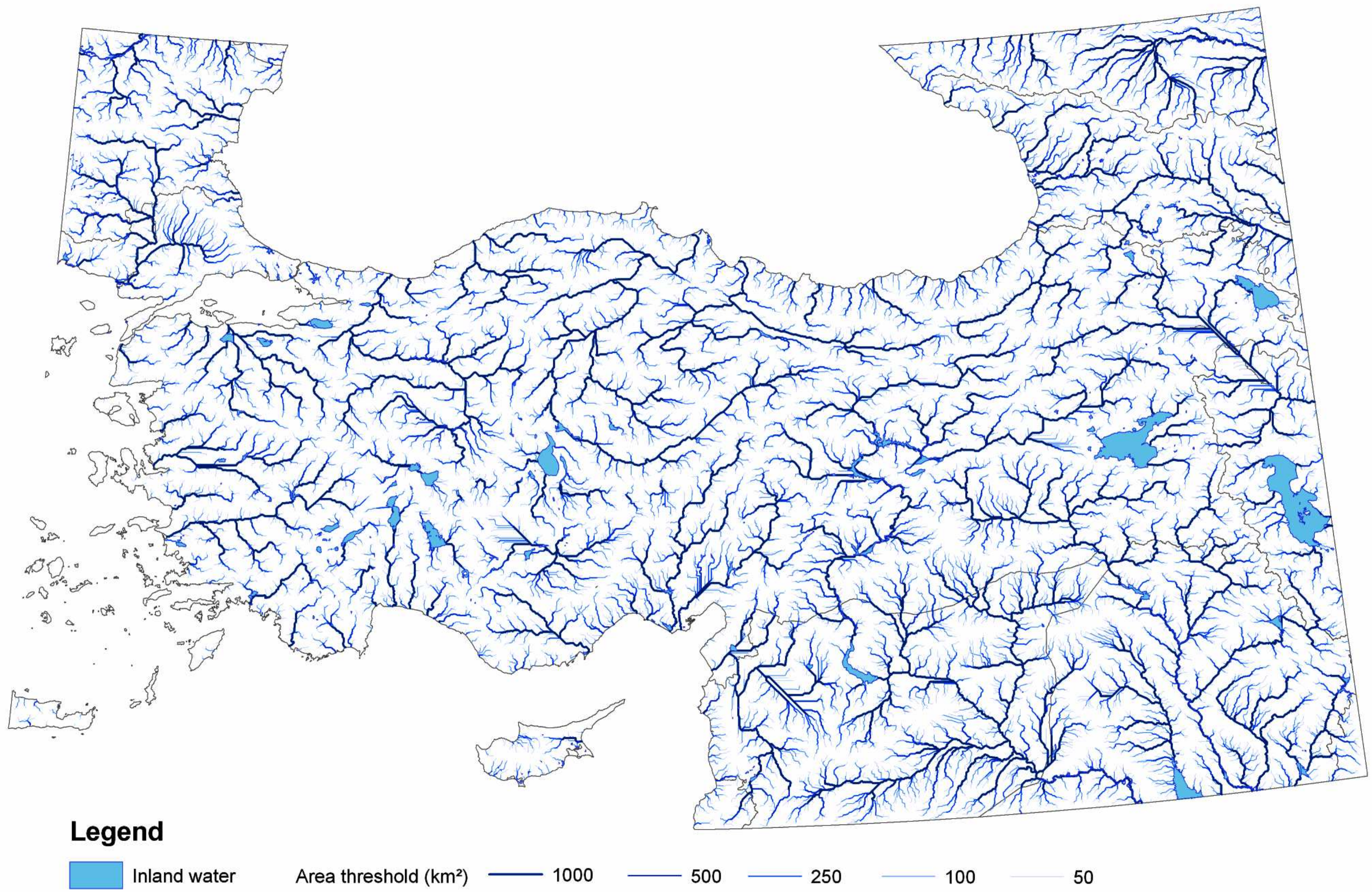


Figure 4.14. Drainage networks obtained from lake-burned and manually edited DEM at different threshold values

In the form given in Figure 4.14, drainage network obtained from the DEM very much resembles actual stream network. However, detailed comparison is required to assess possible differences and determine the variance in between. In Figures 4.15a - 4.15f, DEM-based drainage network is compared at different locations in the country with VMAP-0 based hydrography dataset developed previously in the study. Maps are screen-shots taken from ArcMap GIS while the display scale was 1:1,000,000, which is the scale of VMAP-0. As it can be seen from Figure 4.15a, 4.15b, and 4.15c, for the majority of the country the drainage network is very consistent with vector hydrography dataset. Although several differences exist for first order stream lines, second and higher order streams and drainage lines mostly coincide to each other. At some locations there are small positional shifts, but this should be acceptable if the horizontal accuracy of the datasets, especially approximately 2 km accuracy range of VMAP-0 based hydrography set, is taken into consideration. In addition to these positive results, there are also some negative cases. As given in Figure 4.15d and 4.15e, some drainage lines are found to be unnaturally linear compared with actual stream lines. Such situations are observed in areas where flow should follow a flat terrain. Actually linear drainage lines in flat zones are a characteristic of D8 method and could not be solved unless other methods or modifications are used. Another problem related with drainage lines is presence of excess amount of drainage lines. At locations, where the form of the stream network is determined by the relief of the land surface, calculated drainage lines are found to be very similar to actual stream lines. However, if other factors, like geology in carstic areas, are also significantly affecting the form of the stream lines, than obtained drainage lines may not represent the actual condition on the land. In Figure 4.15f such an example is given from Salt Lake region. Since there are many points, at which the flow accumulation value exceeds the designated threshold value, D8 method generates drainage lines. However, due to the geology of the region, no such stream lines do exist in reality. For such locations additional information should be incorporated to the drainage line extraction algorithms to obtain realistic results. Although this problem is not an easy one to solve, and requires in depth research, the former problem related with linear drainage lines could be solved by using modified methods as stated above.

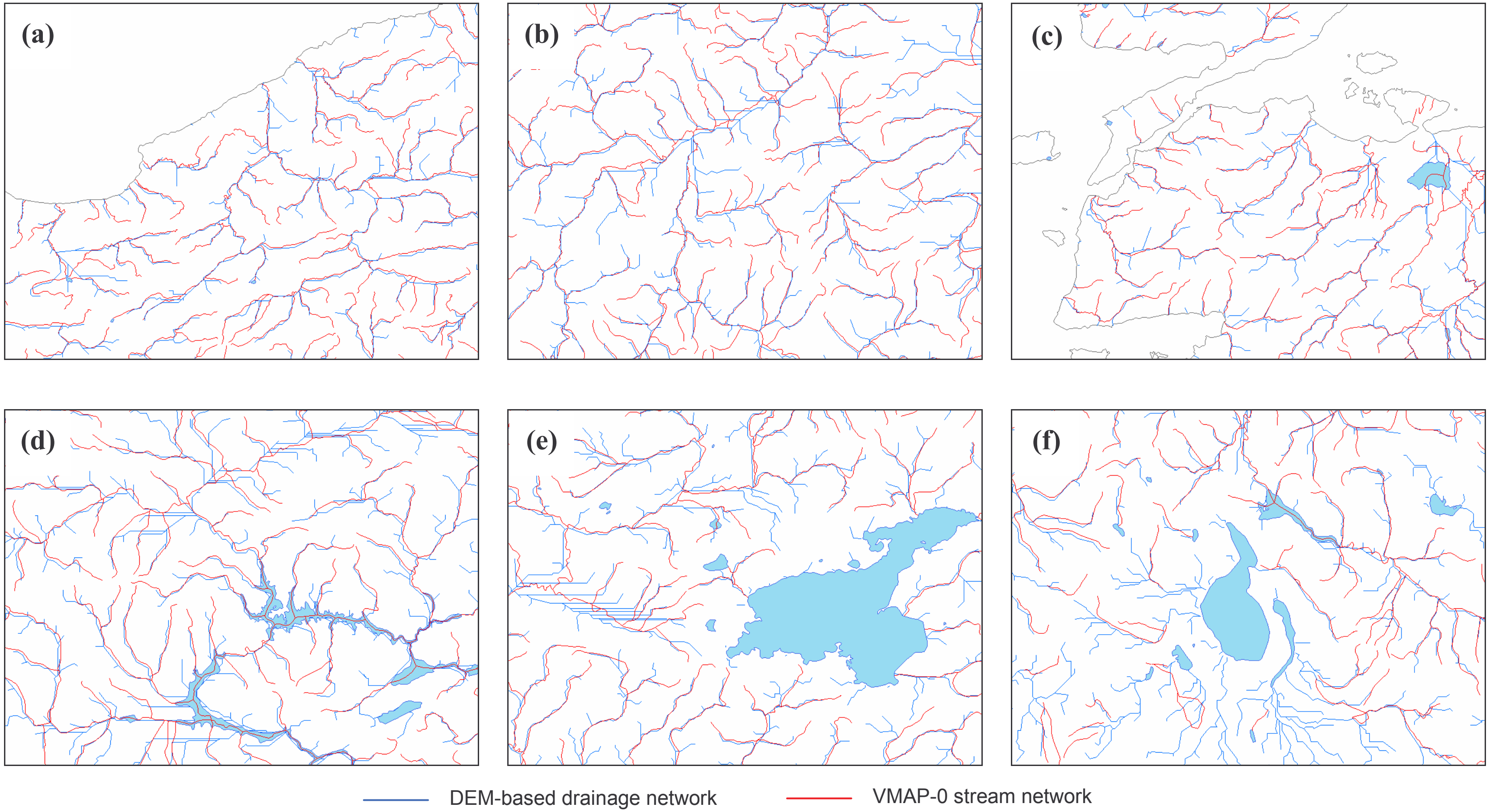


Figure 4.15. Comparison of DEM-based drainage network with 1:1,000,000 scale hydrography dataset

In this study the modification proposed by Garbrecht and Martz (1997) is used to solve linear drainage lines problem. In this method, the shape of the drainage line across the flat zones is determined according to the topography of the neighboring cells, which are located around the flat zone. This makes flat areas drain away from high topography and towards low topography. Outside the flat zones, original D8 method is applied. The details of the modification can be found in Garbrecht and Martz (1997). An implementation of the modification is also readily available in TARDEM program package developed by Tarboton (2000). TARDEM is a publicly available suit of programs for the analysis of digital elevation data, and includes implementation of D8 and D∞ (Tarboton, 1997) flow direction methods and several channel network definition methods like area-slope of length-area thresholds. Using the sink-filled DEM that is previously lake-burned and manually modified, flow directions are calculated using this program package. Comparison of the obtained results with the previous drainage network delineation is given in Figure 4.16 with an example.

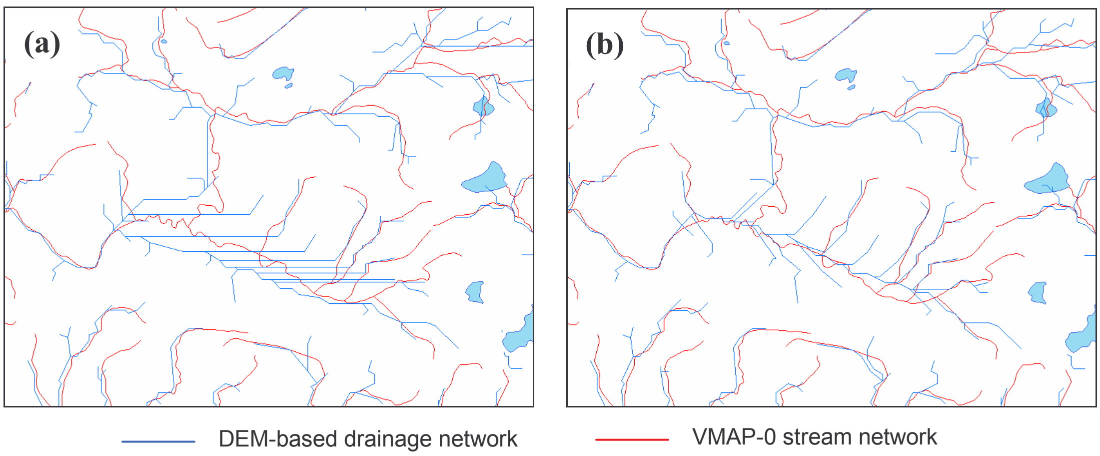


Figure 4.16. Comparison of direction methods a) D8, b) Garbrecht and Martz

As illustrated in Figure 4.16a and 4.16b, method proposed by Garbrecht and Martz yield very satisfactory results and linear drainage lines are almost completely removed. The situation is also the same for other locations, where similar problems are observed. At this point, studies on flow direction/flow accumulation are no further continued and obtained datasets are included to the database for further use.

Comparison of DEM-based drainage network with 1:250,000 scale reference map also gives interesting results. Although the source of calculated drainage network is a 30-arc second grid spacing DEM, which has an approximate scale of 1:1,000,000, the accuracy is found to be very high when compared with 1:250,000 scale map. In Figure 4.17, 1:250,000 (reference) and 1:1,000,000 (hydrography) scale maps are compared with drainage network for the same area. Detailed views are also given.

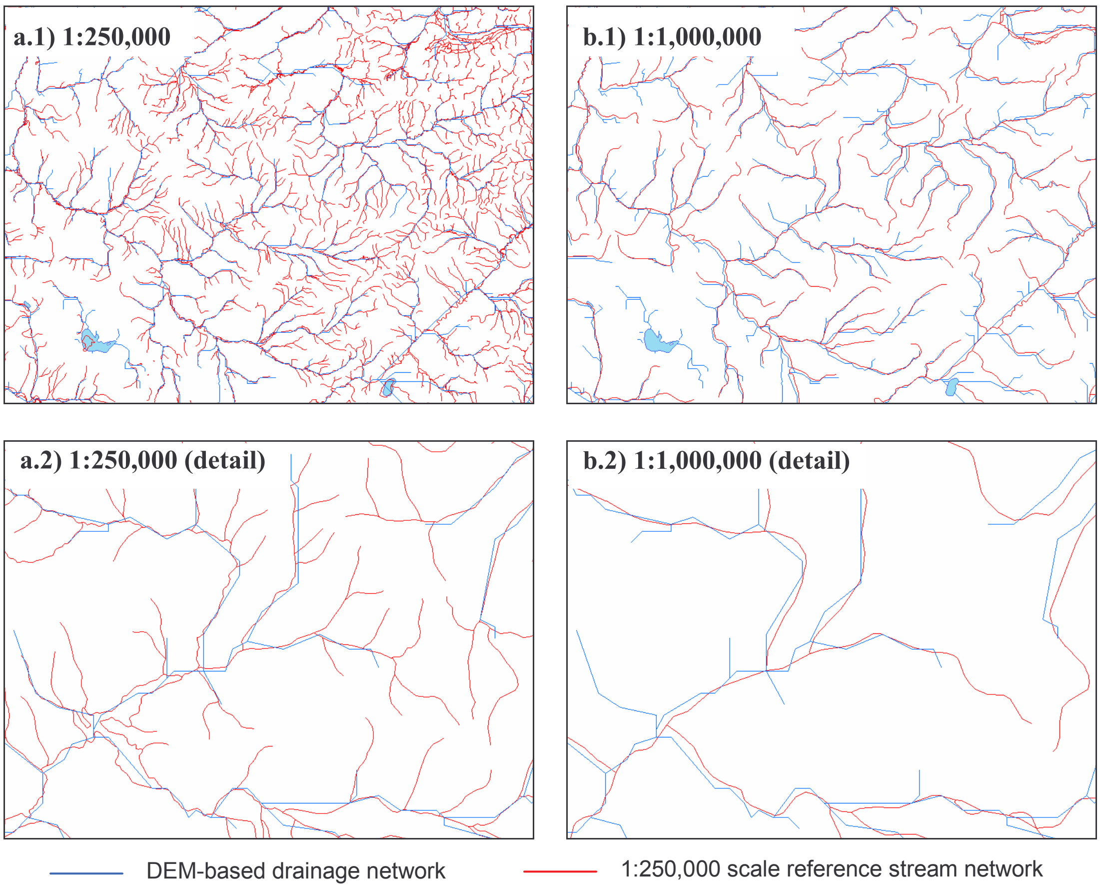


Figure 4.17. Comparison of 1:250,000 and 1:1,000,000 maps with drainage network

As it can be seen from detailed views in Figure 4.17, calculated drainage network gives a very good fit with 1:250,000 scale reference map. Even, the position shifts are less in 1:250,000 scale map compared with 1:1,000,000 scale hydrography dataset. Actually, SRTM30 DEM used for the study has a very high vertical accuracy due satellite interferometic production methods, which results in high positional accuracy of drainage lines.

In order to determine watershed boundaries for Turkey, flow direction and flow accumulation grids calculated in the previous step are utilized. Once these grids are at hand, the only requirement to determine the watershed boundaries is selection of area threshold, like that case for drainage network determination. However, this time larger threshold values compared to drainage network part should be used to obtain reasonable number of watersheds. Low threshold values result in enormous number of small watersheds that do not have hydrologic meaning. In contrary, very high threshold values result in very large watersheds that are not very useful to create a nested-level hierarchy. Therefore a trial-and-error approach is required to determine an optimum threshold value. But before determining the boundaries of sub-basins, it is wiser to determine the accuracy of DEM-based watershed extraction method. Similar to drainage network case explained above, this could be done by comparing already existing national major basin boundaries with the ones that will be determined automatically from DEM.

For this purpose first, small sized watersheds are generated by using a very small (50 km^2) area threshold. Then, obtained watersheds are merged together based on the stream networks of major basins to obtain their DEM-based delineations. Location based selection commands of ArcMap GIS are used to select small watersheds for merging. Obtained DEM-based national basins with comparison to actual basins are given in Figure 4.18. As it can be seen from the figure, the accuracy of DEM-based watershed delineation is quite high. Almost all of the basin boundaries coincide to each other. Only small differences are observed in South-West Anatolia, around the closed basins. Surface areas of the basins are good measures for comparison, since they can be computed precisely both for actual and DEM-based basins. Table 4.4 lists surface area values calculated for each basin. These values are also drawn as scatter plot in Figure 4.19, where the axes are the surface area of the features. A nearly perfect straight line is obtained in the figure, which shows that the surface areas are pretty much the same. As it can be clearly seem from maps, tabular values and charts, DEM-based watershed delineation method is accurate and hence, it can be used to determine sub-basin boundaries.

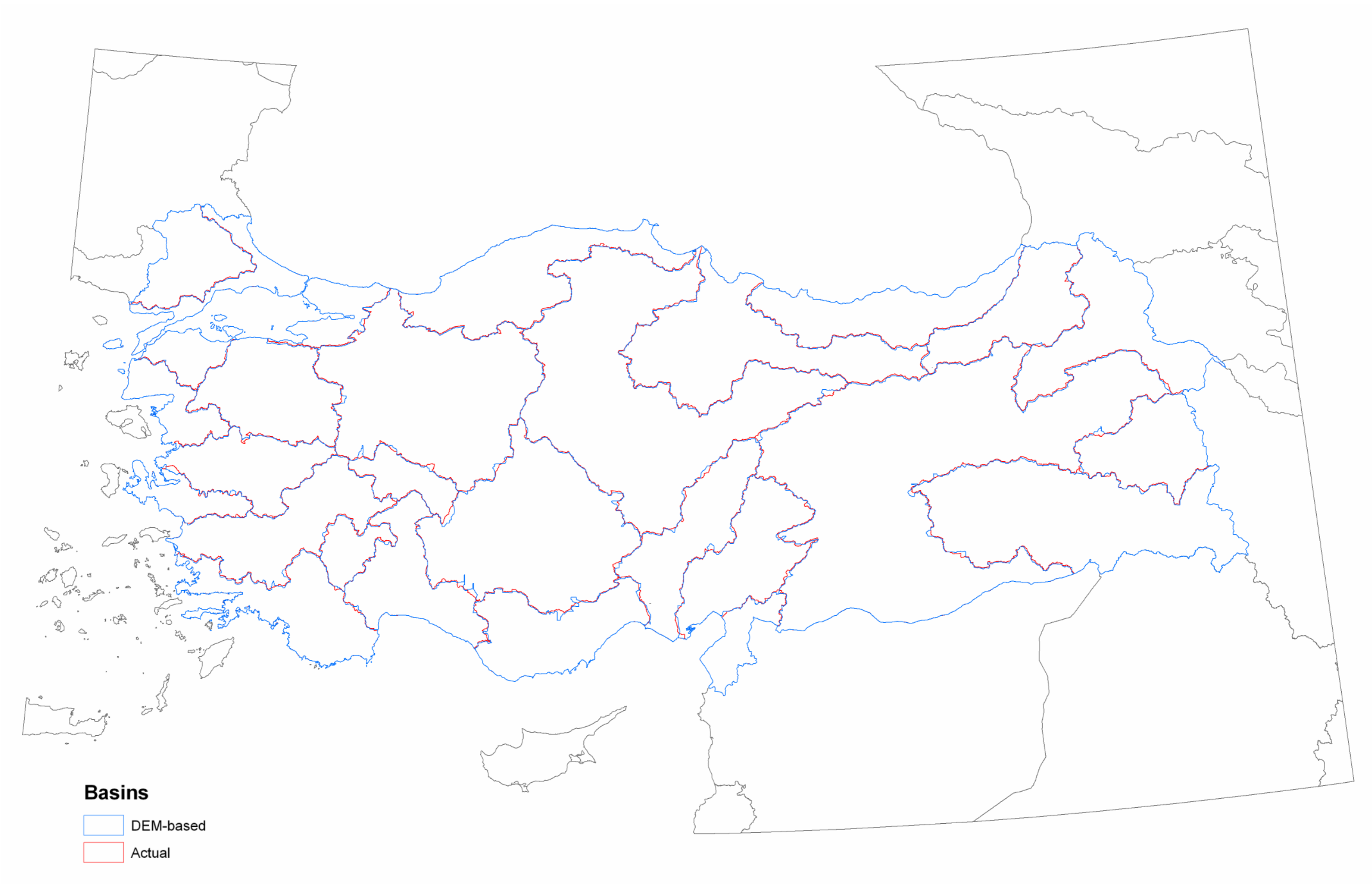


Figure 4.18. Comparison of actual basins with DEM-derived basins

Table 4.4. Comparison of surface areas of actual and DEM-based basins

Watershed	Surface Area (km^2)		Difference (%)
	DEM-based	Actual	
Meriç	14,452	14,278	1.22
Marmara	24,757	24,695	0.25
Susurluk	23,834	23,865	-0.13
North Aegean	9,170	9,130	0.44
Gediz	175,744	176,075	-0.19
Küçük Menderes	7,148	7,117	0.44
Büyük Menderes	25,738	25,798	-0.23
West Mediterranean	22,012	22,077	-0.29
Antalya	20,254	20,249	0.02
Burdur Lakes	6,371	6,401	-0.47
Akarçay	8,098	7,893	2.60
Sakarya	57,919	58,022	-0.18
West Black Sea	29,822	29,427	1.34
Yeşilırmak	39,719	39,550	0.43
Kızılırmak	82,613	82,726	-0.14
Konya Closed	52,214	52,394	-0.34
East Mediterranean	21,702	22,077	-1.70
Seyhan	21,823	21,893	-0.32
Asi	7,242	7,270	-0.39
Ceyhan	22,577	22,346	1.03
Fırat	122,050	123,076	-0.83
East Black Sea	23,401	23,070	1.43
Çoruh	20,202	20,070	0.66
Aras	27,972	27,647	1.18
Van Closed	18,293	18,123	0.94
Dicle	54,184	54,398	-0.39
		Range	4.30
		Average (unsigned)	0.68

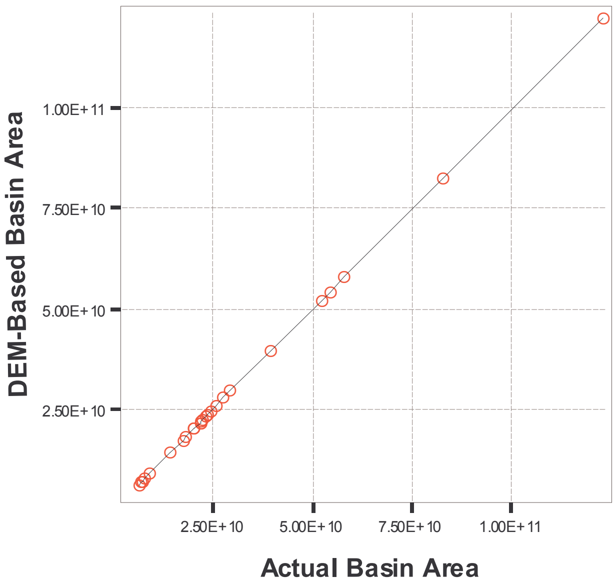
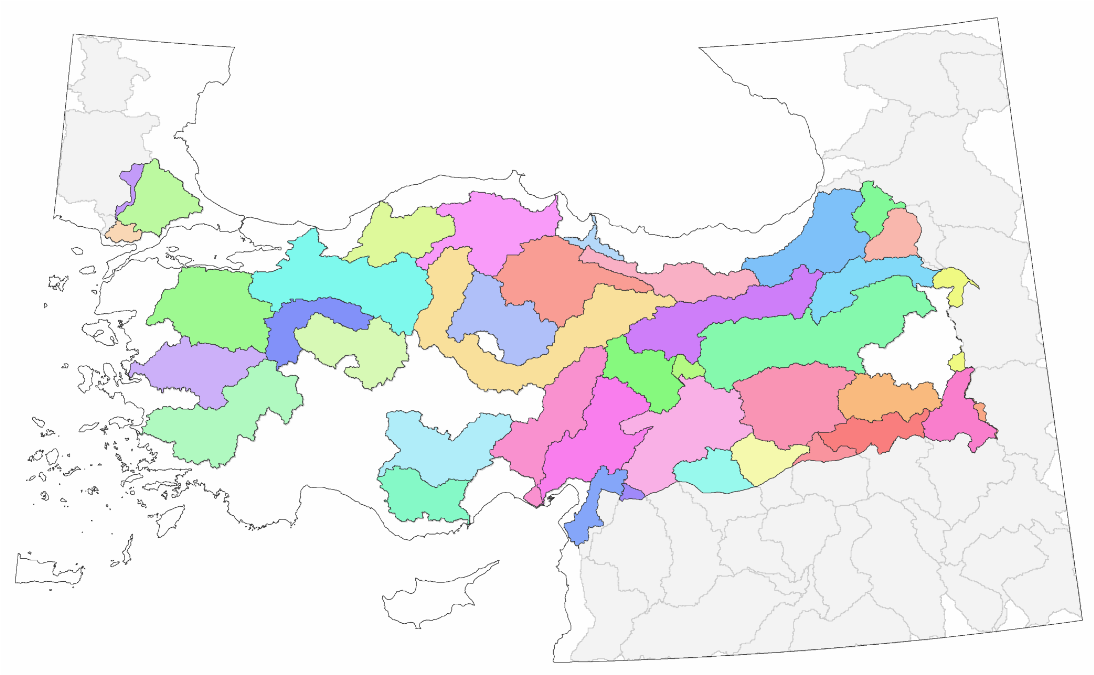


Figure 4.19. Actual basin area vs DEM-based basin area plot

In order to determine sub-basins of major national basins, a set of DEM-based drainage basins are generated by applying different area thresholds. Starting from 250 km^2, 8 different thresholds are tried up to 50,000 km^2. At each level, generated basins are first cropped to the country boundaries. To get rid of very small basins that are artifacts of raster to vector conversion, such basins are either deleted or combined with neighboring larger basins. For the remaining basins, several statistical measures are calculated, which are used as supplementary data to judge on the area threshold value that will be used to generate the final sub-basin boundaries for the study. To illustrate obtained results, sub-basins belonging to three representative thresholds (10,000, 1,000 and 250) are given in Figures 4.20 – 4.22. Results from other thresholds are given in Appendix E. These figures consist of three different parts: a map showing geographical distribution of DEM-based drainage basins, a table that includes calculated statistics, and a histogram that show the overall distribution of drainage basins with respect to their surface area. Basins that are located outside the country boundaries of Turkey, including the parts of cross-boundary basins, are shown in the maps as gray-out. Number of classes in each histogram depends on the number of basins at that threshold value.

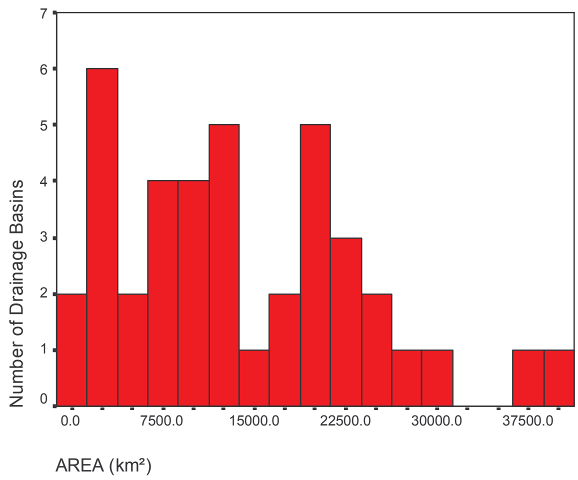


a. Geographic distribution

AREA

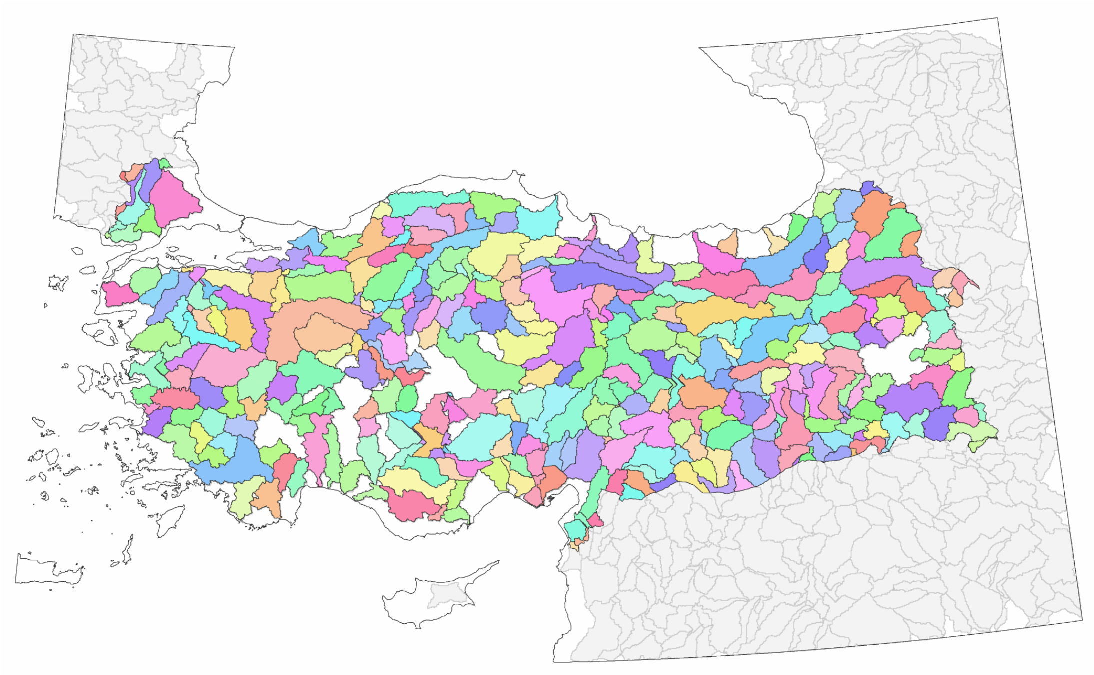
N		40
Mean		14140.16
Median		11665.07
Std. Deviation		10169.76
Variance		103423987.76
Skewness		.726
Kurtosis		.198
Range		40548.74
Minimum		606.01
Maximum		41154.75
Percentiles	25	5969.19
	50	11665.07
	75	21021.47

b. Statistics



c. Histogram

Figure 4.20. DEM-based drainage basins for 10,000 km^2 area threshold

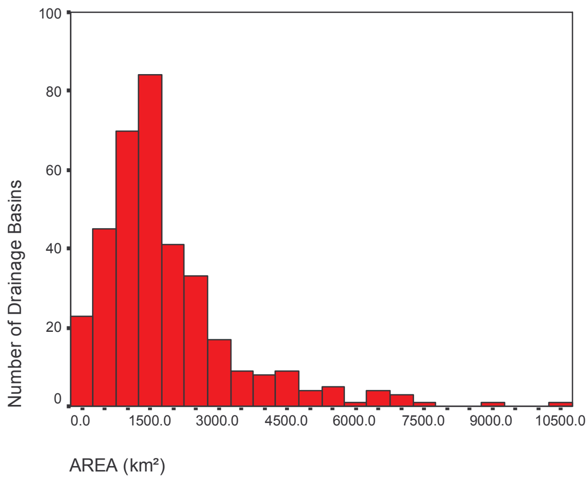


a. Geographic distribution

AREA

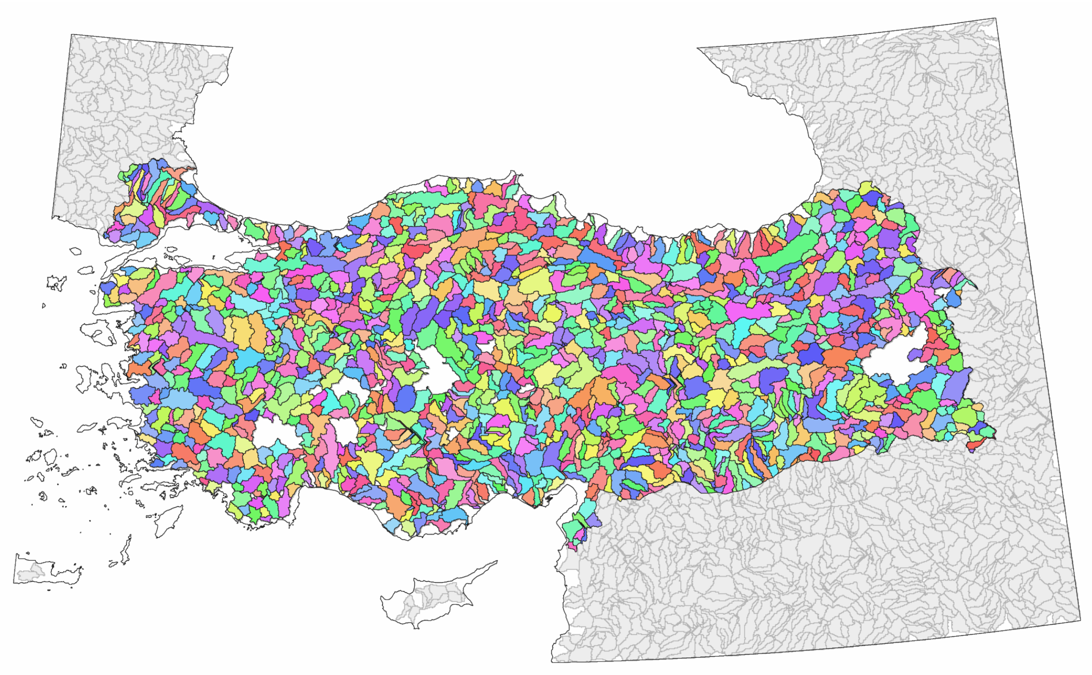
N		359
Mean		1857.89
Median		1488.94
Std. Deviation		1527.91
Variance		2334509.63
Skewness		1.987
Kurtosis		5.488
Range		10653.75
Minimum		39.94
Maximum		10693.69
Percentiles	25	1017.56
	50	1488.94
	75	2293.63

b. Statistics



c. Histogram

Figure 4.21. DEM-based drainage basins for 1,000 km^2 area threshold

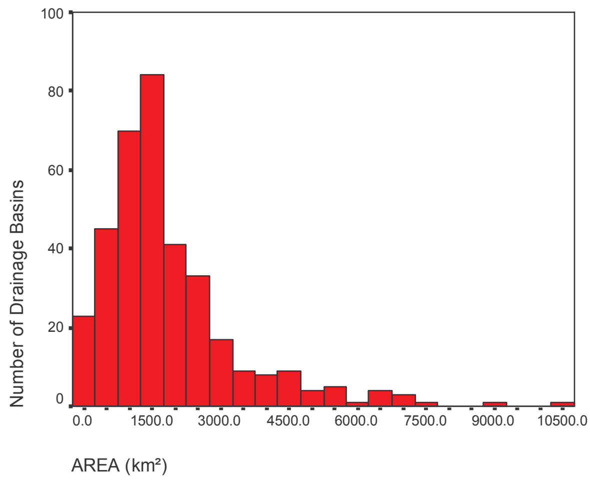


a. Geographic distribution

AREA

N		1458
Mean		490.03
Median		397.97
Std. Deviation		365.15
Variance		133331.50
Skewness		2.147
Kurtosis		8.464
Range		3776.06
Minimum		32.06
Maximum		3808.12
Percentiles	25	273.94
	50	397.97
	75	620.44

b. Statistics



c. Histogram

Figure 4.22. DEM-based drainage basins for 250 km^2 area threshold

As expected, the number of DEM-based drainage basins increases as the threshold value decreases. On the contrary, sizes of the basins get smaller. Number of basins and their average, minimum and maximum surface areas are summarized in Table 4.5. Change in number of basins and average area with area threshold is also illustrated in Figure 4.23. It should be noted that basins smaller than 30 km^2 in size are taken as artifacts of raster to vector conversion and exempted from calculations.

Table 4.5. Comparison of DEM-based drainage basins

Area Threshold (km^2)	Number of Basins	Average Area (km^2)	Minimum Area (km^2)	Maximum Area (km^2)
50,000	5	66,465.91	22,050.16	121,654.78
25,000	12	35,092.20	4,959.69	111,536.50
10,000	40	14,140.16	606.01	41,154.75
5,000	69	8,551.99	158.01	38,221.88
2,500	140	4,423.39	118.49	34,128.56
1,000	359	1,857.89	39.94	10,693.69
500	708	981.45	32.06	6,444.56
250	1458	490.03	32.06	3,808.12

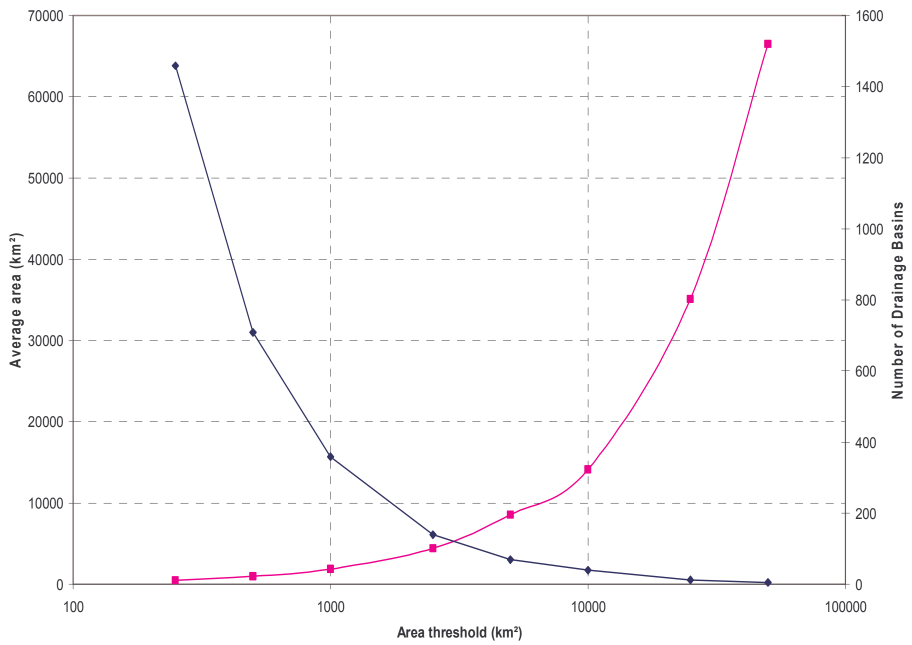


Figure 4.23. Change in number of basins and average basin area with threshold

Although sizes of the basins get smaller as their number increases, the total area covered by them increases. This can easily be seen in the Figures 4.20 – 4.22. At a threshold value of 10,000 km^2, a very large part of the country could not be covered with basins. This part includes some major national basins as well. As threshold value decreases, large basins are divided into smaller sub-basins and also basins get started to be formed in the areas that are not covered by the basins previously. At a threshold value of 250 km^2, almost all of the country is covered with basins. However, there are still uncovered parts remaining, especially around the sea and lake coasts. In order to cover these locations, much smaller threshold values should be used. Theoretically, threshold values can go down to the grid cell size of the DEM used for calculations. However, such low threshold values result in basin boundaries that do not have any hydrological meaning and that are nonsense. Also as the threshold value decreases, additional area covered at each step also gets smaller compared with the previous step. Therefore additional area that is covered may not be noteworthy compared with increase in the number of basins, which make the management of basins difficult. This situation is illustrated in Figure 4.24 for the values used in the study. It may be concluded that one should stop at a threshold value that satisfies the needs, and if required remaining uncovered parts should be either manually delineated or left as they are.

Based on this principle, obtained DEM-based basins at each threshold value are evaluated to determine the optimum threshold value for the study. Since the primary aim of this part of the study is delineation of sub-basins of major national basins, an additional criteria also appears naturally, which is to have at least 26 basins. This condition could not be proven by 50,000 and 25,000 km^2 threshold values; hence they are directly eliminated. Although at 10,000 and 5,000 km^2 threshold values there exist more than 26 basins, some major national basins could not be delineated at those levels. For example North Black Sea, North Mediterranean, and Marmara basins could not be generated at these thresholds, as shown in Figure 4.25 for 5,000 km^2 threshold. Therefore these thresholds are also removed from the list.

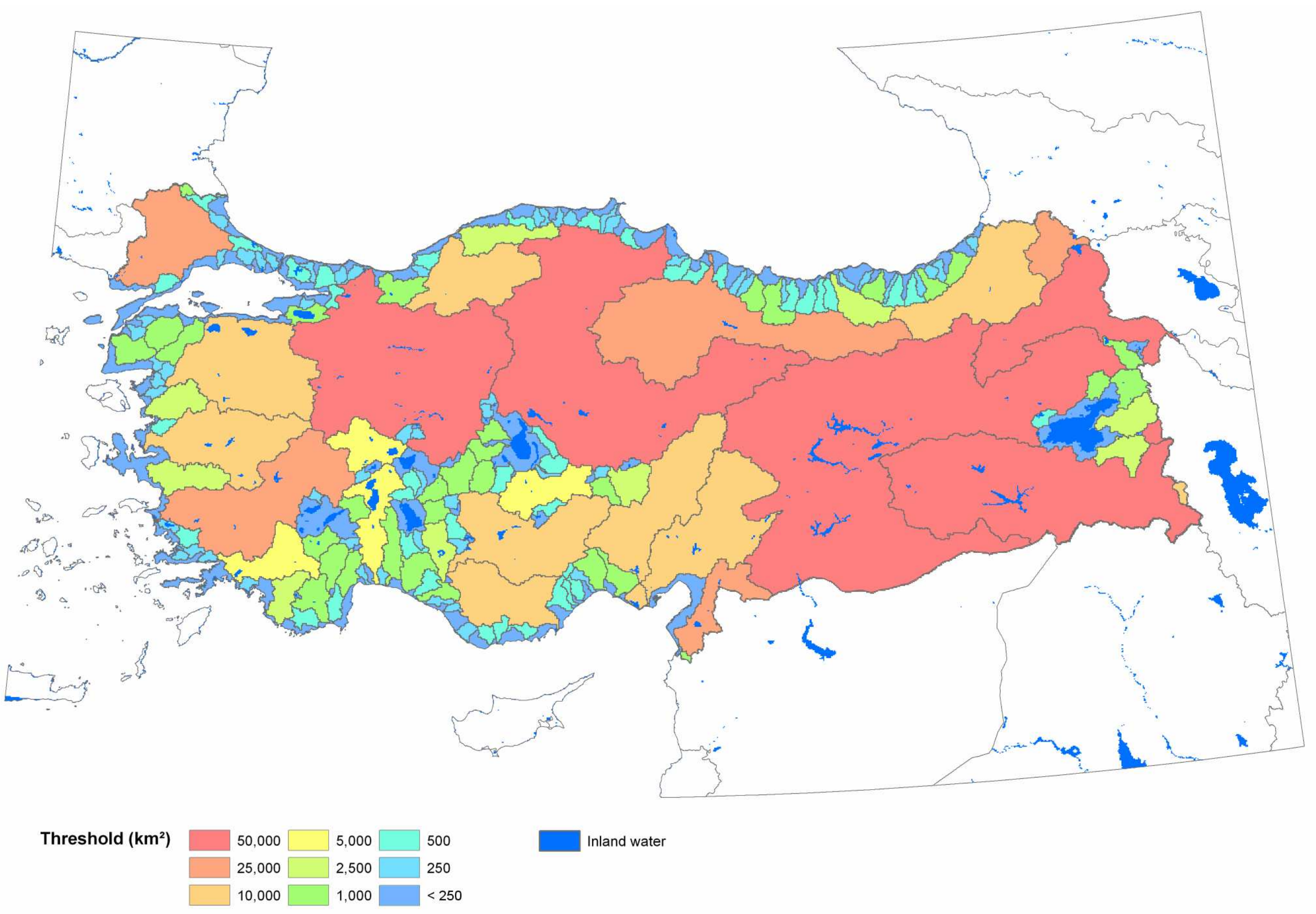


Figure 4.24. Additional area covered by DEM-based drainage basins at each threshold value

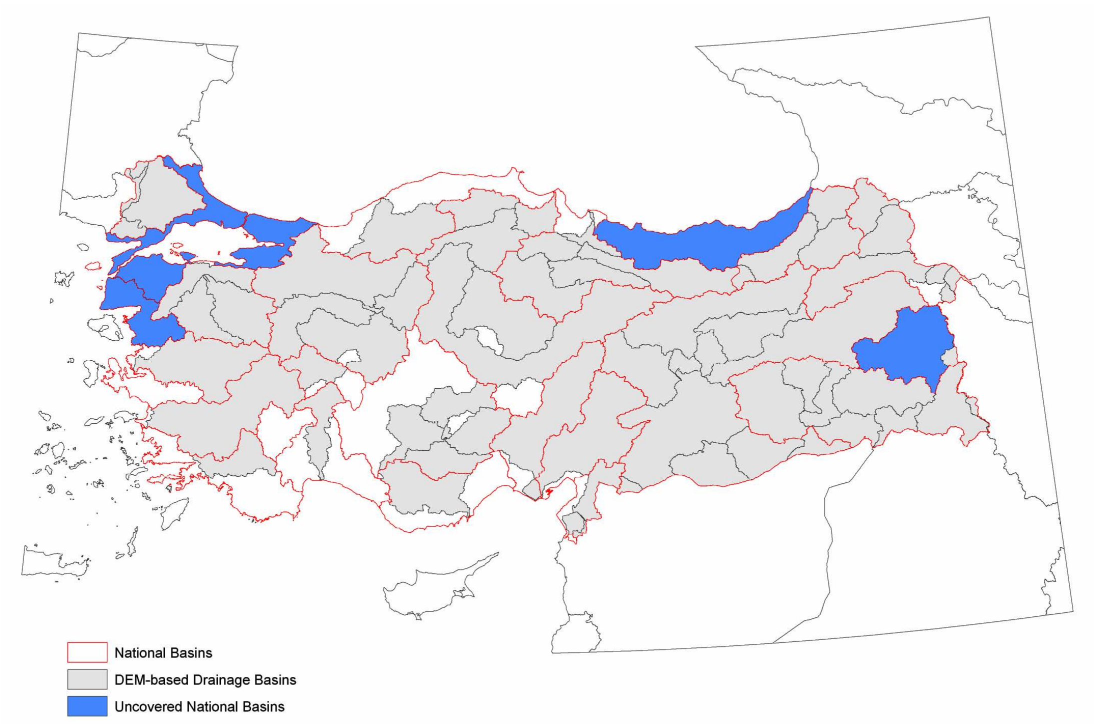


Figure 4.25. National major basins not covered by 5000 km^2 threshold value

While 2,500 km^2 threshold is better than 5,000 and 10,000 in terms of delineation of national major basins, Marmara basin still could not be delineated to its sub-basins at this threshold value. Therefore only three thresholds are left, one of which could be used as the final value: 250 km^2, 500 km^2, and 1,000 km^2. There exist approximately 1500 DEM-based drainage basins in the dataset generated with 250 km^2 threshold. Compared with 26 national basins, that means more than 50 folds increase in the number of basins, which is quite high actually. Starting with such a high number of basins may complicate the management and justification of basins, especially for a pilot study like this one. With better quality and smaller grid spacing DEMs, this threshold value, even smaller ones, could be used nationally. However, for SRTM30 more than 1,000 basins will be too much and loss in accuracy will be unpreventable. Hence, 250 km^2 threshold value is not preferred for the study. Remaining two threshold values, 500 and 1,000 km^2, are found to be appropriate for the study. The former threshold has approximately two folds more basins than the latter. Number of sub-basins in each major national basin for 500 and 1,000 km^2 thresholds are given in Table 4.6.

Table 4.6. Comparison of surface areas of actual and DEM-based basins

Watershed	Number of Sub-Basins	
	1,000 km^2 Threshold	500 km^2 Threshold
Meriç	12	21
Marmara	4	12
Susurluk	14	20
North Aegean	2	7
Gediz	7	15
Küçük Menderes	3	3
Büyük Menderes	13	21
West Mediterranean	3	14
Antalya	8	15
Burdur Lakes	2	2
Akarçay	2	8
Sakarya	30	61
West Black Sea	11	19
Yeşilırmak	16	38
Kızılırmak	37	85
Konya Closed	23	48
East Mediterranean	6	18
Seyhan	12	18
Asi	5	5
Ceyhan	12	20
Fırat	67	130
East Black Sea	6	13
Çoruh	8	16
Aras	11	26
Van Closed	7	8
Dicle	38	65
TOTAL	**359**	**708**

Average sub-basin per national basin is approximately 14 for 1,000 km^2 and 27 for 500 km^2 threshold values. Although the number of sub-basins in each national basin is low in 1,000 km^2, there exists more than one sub-basin for each basin. Hence, this threshold value is a limit to delineate sub-basins of all national basins. A higher threshold may result in no sub-basin situation like the case in 2,500 km^2 threshold. The number of sub-basins, which is more than 350, is also a good starting point for future studies and applications. This many features can be processed even manually; hence data management will be easier compared with other thresholds. Although 500 km^2 has more detailed sub-basin delineations, due to these reasons 1,000 km^2 is selected as the final area threshold for the study and further data processing is done on sub-basins dataset generated by this threshold value only. It is interesting to note that the average size of DEM-based watersheds generated with selected 1,000 km^2 threshold value is very close to the average size of sub-basins in U.S. As given in Table 1.2, average size of U.S. sub-basins is 1,820 km^2, whereas the average size of 1,000 km^2 threshold value watersheds is 1,857.59 km^2. This similarity can also be used as a measure of proper selection of the threshold value. Such a similarity was also observed between national major basins of Turkey and basins of U.S previously.

4.3. Coding DEM-based Watersheds

After the generation of the sub-basin boundaries, the next step is uniquely coding these sub-basins, so that they can be easily identified and differentiated from each other. There are several coding system alternatives that are used in different countries. In U.S., watersheds are named according to a hierarchical coding system. In this system, larger watersheds are divided into smaller sub-watersheds by forming nested levels. Application of such a leveled watershed cataloging system requires generalization of watersheds from a lower level to a higher level. Starting from the smallest ones, the watersheds should be merged together to obtain higher level units at each level. A previous pilot-scale study conducted in Küçük Menderes Basin to assess the applicability of U.S. cataloging system to Turkey showed that generalization process gets complicated as the number of levels increases

(Girgin et al., 2003). Although simple criteria, such as Strahler order of streams in the watersheds, can be used to produce cataloging levels up to third order, it was found out that additional criteria and special expertise are required for more levels (Girgin et al., 2003). Therefore, additional studies are required if U.S. cataloging method would be used. Watershed classification methodology of the European Union (ERICA-CS) forms an easy to apply alternative, which does not require merging of watersheds. The coding system of ERICA-CS explicitly creates nested watershed hierarchy based on the position of watersheds along the stream network. Therefore no additional criteria are needed. Also since Turkey is a candidate for being an EU-member country, use of ERICA-CS will be more appropriate for the future. Hence, ERICA-CS is selected as the watershed classification methodology for DEM-based watersheds generated in this study.

ERICA-CS, which is a combination of German and Norwegian coding systems, provides explicit information on the sea that the watershed drains to. It allows straightforward identification of all areas above and below a given point, thus provides an indicator of position. Also it denotes the size of the watershed within predefined ranges. The system is flexible in that it can accommodate additions to the watershed or stream dataset and allow an indefinite depth of watershed coding. The system uses a combination of the following codes (Flavin et al., 1998):

- A marine code to identify the sea that the watershed drains to,
- A marine border code for the mouth or costal stretch draining to the sea of interest, or sea/ocean adjoining that sea,
- A series of nested catchment codes, and
- A catchment size indicator

The code is in the form of MM BBB N1 N2 N3 N4 A, where MM = a two digit marine code, BBB = a three digit marine border code, N1-N4 = two digit nested catchment codes (their number may be more), and A = a single character area band. As marine code, International Hydrographic Bureau coding system is used.

According to this system, Mediterranean Sea has a code of 28, Sea of Marmara has a code of 29 and Black Sea has a code of 30. Starting from 1, even marine border codes are assigned to the stream mouths and odd ones are assigned to coastal stretches in between. The direction is from north to south. Nested catchment codes are also assigned as even and odd number. For watersheds that are on the main channel of a stream odd numbers are used, whereas for subsidiary branches even numbers are assigned. This is continued in a nested manner until all watersheds are numerated. Area band code indicates the size of the watershed according to predefined classes. An example of ERICA-CS coding is given in Figure 4.26 (Flavin et al., 1998).

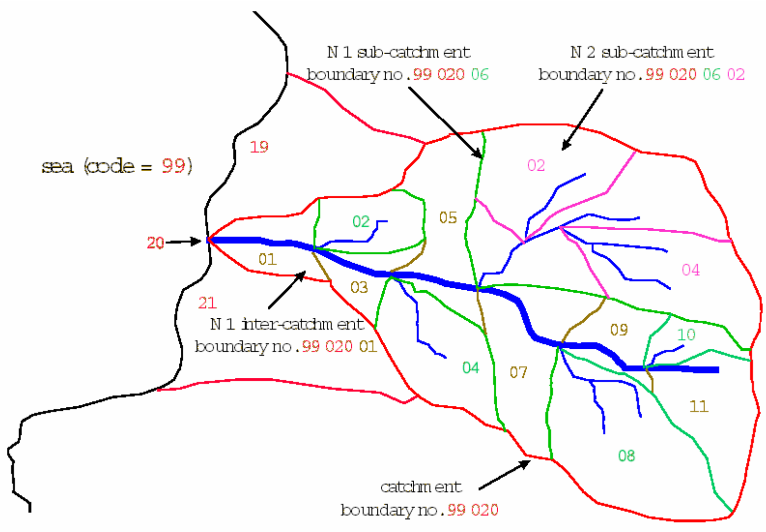


Figure 4.26. Example ERICA-CS coding

Following the ERICA-CS coding system, all sub-basins in the DEM-based sub-basin dataset generated previously are named. A sample coding is given in Figure 4.27 for North Black Sea Basin.

ERICA-CS also facilitates up-stream/down-stream navigation of catchments. Without any geographical analysis, just by following code numbers systematically one can obtain for a selected watershed (i) all up-stream watersheds, (ii) up-stream watersheds that are on the main stream, (iii) all down-stream watersheds, and (iv) down-stream watersheds that are on the main stream.

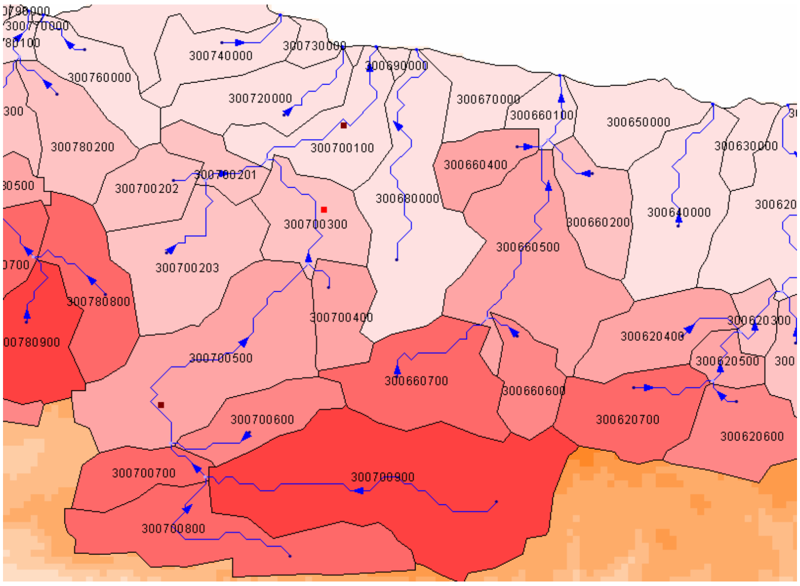


Figure 4.27. ERICA-CS coding in North Black Sea Basin

Because following the code numbers manually is not an easy task, tools are developed as a part of the study to assist watershed navigation. 4 tool buttons are added to the toolbar of View Window of ArcView 3.2 GIS. Depending on the desired watershed navigation type, corresponding tool button should be activated and a watershed should be selected from the map. Once the user chooses a watershed, appropriate watersheds among the stream network are selected automatically by the system. The algorithms developed for watershed navigation are given in Tables 4.7 - 4.10. Illustrative examples of watershed navigation are given in Figure 4.28 for different navigation types.

Table 4.7. Algorithm to select all down-stream catchments

```
idWS = Selected WS_ID
idWSPrev = ADDZERO(LEFT(idWS, 5), LEN(idWS))
QUERY("WS_ID >= idWSPrev and WS_ID <= idWS", SELECT_NEW)
```

Table 4.8. Algorithm to select down-stream catchments

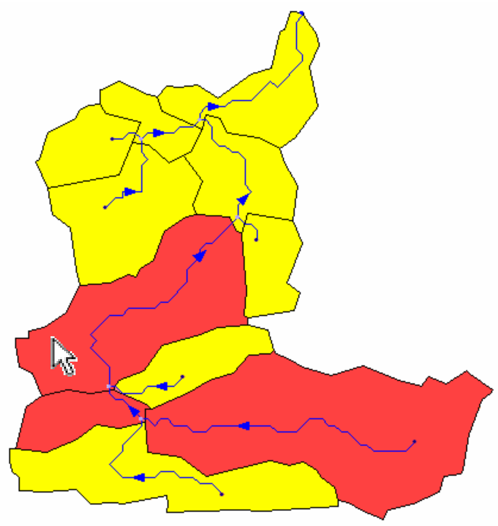
```
idWS = Selected WS_ID
idWSLen = LEN(idWS)
WHILE (TRUE)
    QUERY("WS_ID = ADDZERO(idWS, idWSLen)", SELECT_OR)
    IF (LEN(idWS) = 5) THEN BREAK
    id = MIDDLE(idWS, LEN(idWS) - 2, 2)
    IF (id < 2) THEN
        idWS = LEFT(idWS, LEN(idWS) – 2)
    ELSE
        IF (id MOD 2 = 0) THEN id = id – 1 ELSE id = id – 2 END
        idWS = CONCATENATE(LEFT(idWS, LEN(idWS) – 2),
        ADDZERO(id, 2))
    END
END
```

Table 4.9. Algorithm to select all up-stream catchments

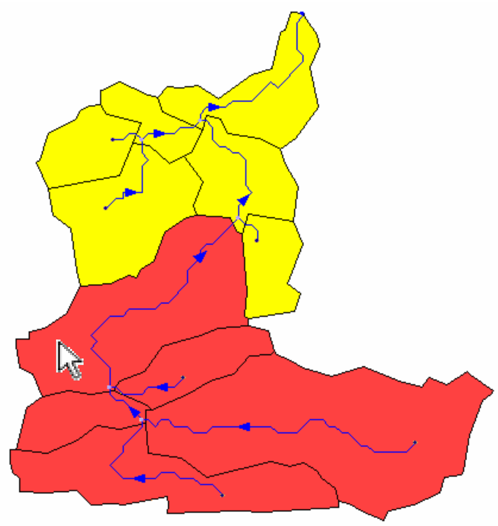
```
idWS = Selected WS_ID
idWSNext = idWS
WHILE (idWSNext MOD 100 = 0) idWSNext = idWSNext / 100
IF (idWSNext MOD 2 = 1) AND (LEN(idWSNext) > 5) THEN
    idWSNext = TRUNC(idWSNext / 100, 0) + 1
    idWSNext = ADDZERO(idWSNext, LEN(idWS))
    QUERY("WS_ID >= idWS and WS_ID < idWSNext", SELECT_NEW)
ELSE
    QUERY("WS_ID = idWS", SELECT_NEW)
END
```

Table 4.10. Algorithm to select up-stream catchments

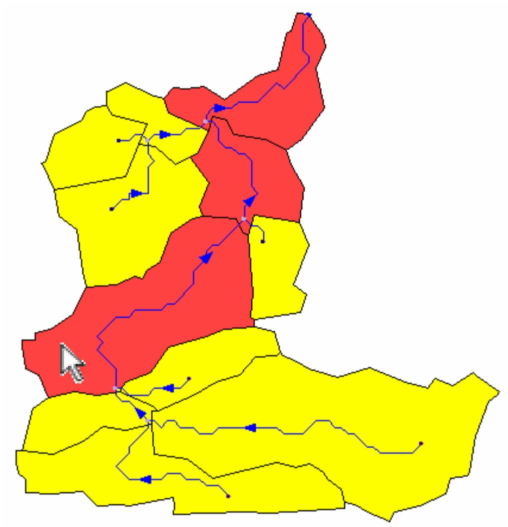
```
idWS = Selected WS_ID
idWSNext = idWS
WHILE (idWSNext MOD 100 = 0) idWSNext = idWSNext / 100
IF (idWSNext MOD 2 = 1) AND (LEN(idWSNext) > 5) THEN
    id = idWSNext MOD 100
    FOR EACH i in id .. 100 by 2
        idWS = ADDZERO(idWSNext + i - id, LEN(idWS))
        QUERY("WS_ID = idWS", SELECT_OR)
    END
ELSE
    QUERY("WS_ID = idWS", SELECT_NEW)
END
```



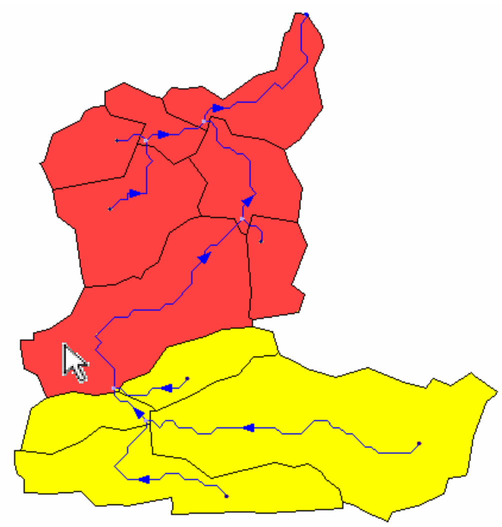
a. Upstream along main channel ( )



b. Upstream all ( )



c. Downstream along main channel ( )



d. Downstream all ( )

Figure 4.28. Watershed navigation types

CHAPTER 5

DEVELOPMENT OF WATER QUALITY/QUANTITY DATA ANALYSIS SYSTEM

As explained in Chapter 2.3, great amount of stream flow and water quality monitoring data are available for surface water bodies of Turkey. However, available data are broken up among different organizations. This causes a lot of additional work to be done to collect required data for water resources related studies. Although the formats of data collected by different organizations are the same, there exist no data analysis and visualization tools that are available for end-users. All data are provided in numerical form and media is most of the time paper, i.e. yearbooks, reports or print-outs. This is especially the case for data that are collected before the second half of 1990's. Due to today's highly computerized analysis, modeling and reporting needs, the end-user should have to convert these data into digital format and use different programs and tools for visualization and analysis. In the current tabular format of data, it is very difficult to evaluate trends in data even for a single water year. The task gets much more complicated if several years should be compared. This is also the case if different stations should be compared to each other. Although maps are present, spatial aspects of collected data should have to be evaluated manually by the user, since maps and data tables are available on different media.

In order to solve the problems mentioned above, a GIS-based data visualization and analysis system has been developed as a part of the thesis study. The analysis system is build on a database structure, which is designed according to the format of stream flow and water quality monitoring data collected by SHW, EPRSDA and GDRS. Since several organizations are taken into consideration during the design, data belonging to all these organizations can be stored in the same database and can be analyzed easily. A graphical user interface is developed on the top of GIS, which utilizes dialogs, tables, and charts to interact with the user and visualize data stored in the database. A number of analysis tools, both spatial and statistical, are made available to reveal trends in data, to calculate summaries and create thematic maps. Base map data collected from several sources, like VMAP-0 and SRTM30, are provided as separate map layers. Hydrography, watershed, and hydrologic DEM derivatives (flow direction, flow accumulation, etc.) datasets that are prepared in the first part of the study are also utilized, and tools based on these datasets are provided. The overall structure of the analysis system is illustrated in Figure 5.1.

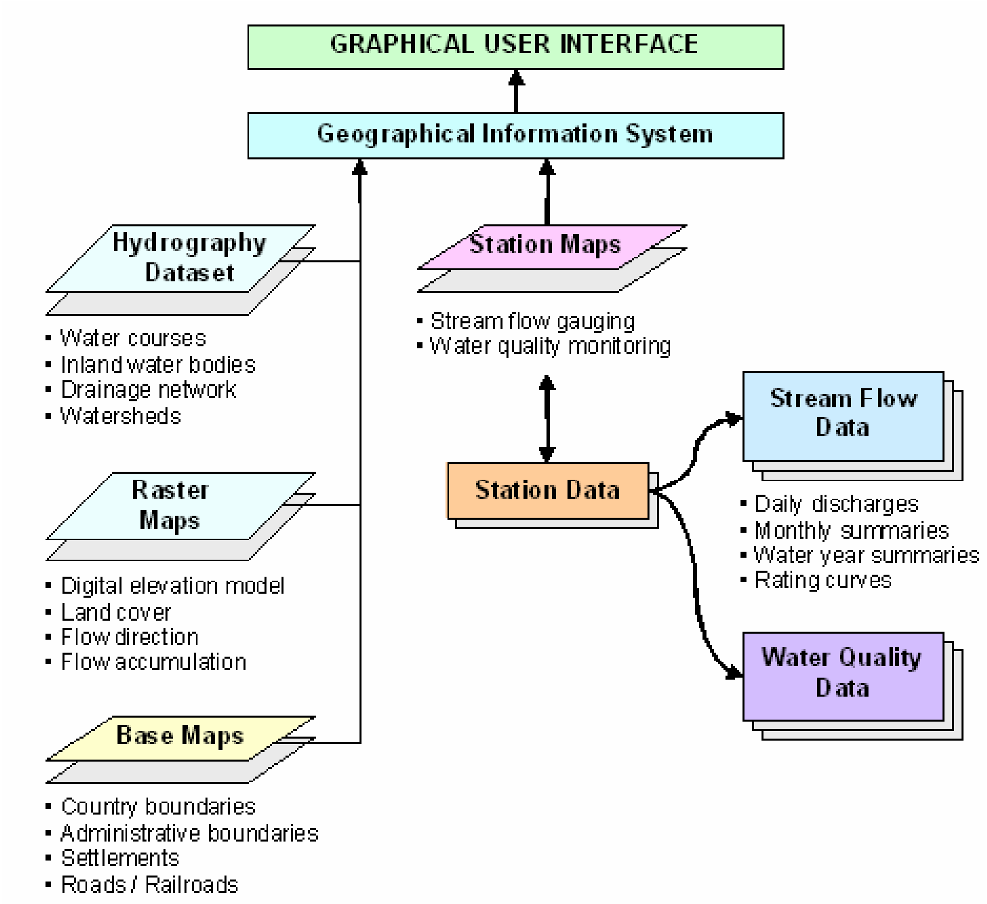


Figure 5.1. Structure of the developed analysis system

5.1. Structure of the Spatial Database System

A file based database structure is utilized to store stream flow and water quality data and also general information related with monitoring stations. Database tables are stored as Dbase IV files, which is the native database format of ArcView GIS 3.2 that is the selected GIS for the development of analysis system. A directory hierarchy is created to organize the database tables. Shape files and raster grids are also organized in two different directories in a similar way. Employed directory structure, including stored table and coverage names, is illustrated in Figure 5.2. Short description of the directories and files that are stored in these directories are also given in Table 5.1.

Table 5.1. Descriptions of directories used to store files

Directory name	Type of data stored
discharge	Daily discharges
dsummary	Water year summaries
lutable	Look-up tables
mdsummary	Monthly discharge summaries
raster	Raster grids
rcurve	Rating curves
shape	Shape files
stations	Monitoring stations (gauging and water quality)
template	Database table templates
wquality	Water quality measurements

Database tables are used for two different purposes: to store monitored data and related summaries; and to store supplementary data that are required by the analysis system, which will be explained in detail in the forthcoming sections. Daily discharges, water year summaries, monthly discharge summaries, rating curves and water quality data tables can be classified in the former type, while look-up tables and database table templates can be classified in the latter.

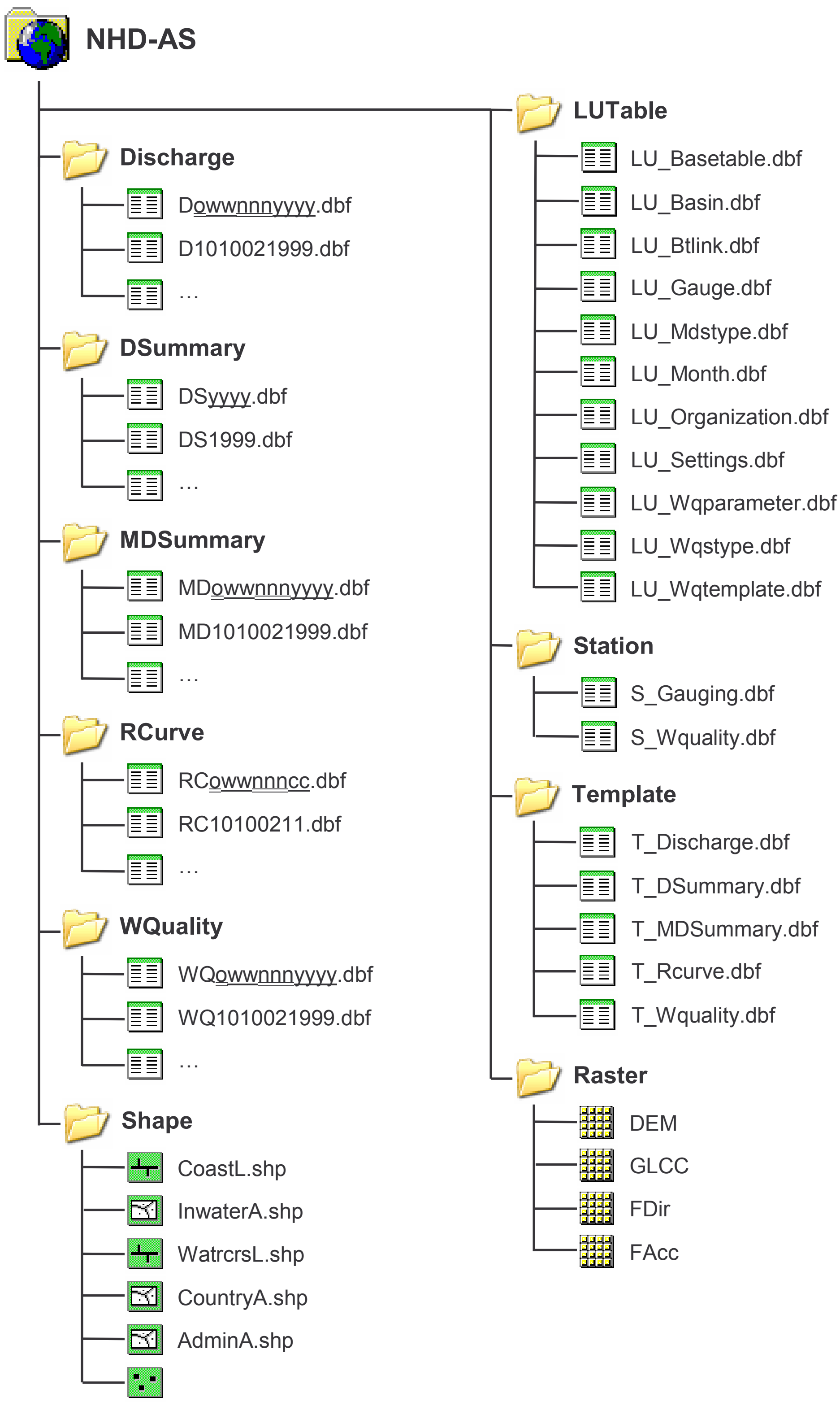


Figure 5.2. Directory structure of the spatial database system

Look-up tables are kind of dictionaries, which include detailed information organized in a column structure and indexed by a key attribute. They are used mainly to store information related with organizations, basins, gauge level recorders, or program settings. Database table templates are used internally to facilitate creation of new database tables to store additional stream flow and/or water quality data according to user needs. General information regarding stream flow gauging and water quality monitoring stations are stored separately.

As shown in Figure 5.1, internal tables are unique and they are named individually. However, this is not the case for monitored data and summaries. The number of tables in this category depends solely on the amount of data entered to the database. Daily discharge and monthly discharge summaries may exist for each gauging station-water year pair. Likewise yearly stream flow summaries may exist for each water year with changing number of stations at each year, and gauging stations may have several rating curves depending on water years. Water quality data may also exist for each monitoring station-year pair. It is impossible to start with a database that is fully loaded with all stream flow and water quality data collected in previous years by related organizations. These data could only be entered to the database step by step in time. Also each year new data will be available. Therefore, the number of monitoring data tables is not constant. In order to organize these theoretically unlimited number of database tables, special naming conventions are used.

In order to differentiate organizations that own monitoring stations from each other a single digit organization ID is defined. 26 national watersheds are indicated with two-digit watershed IDs. Numbers given to stations by owner organizations are stored as three-digit station IDs. By combining organization, watershed and station IDs, unique numbers are obtained that define monitoring stations and distinguish them from each other. For example a gauging station having a station number of 13 that is located in Meriç Basin and operated by SHW will have an identifier of 101013. These unique identifiers will be termed as ‘Gauging Station ID’ for stream flow gauging stations and ‘Water Quality Station ID’ for water quality monitoring stations throughout the text.

Gauging and water quality station IDs are used for naming monitoring data tables. ‘owwnnn’ terms found in table names, as shown in Figure 5.2, represent these IDs. ‘yyyy’ terms designate water years and ‘cc’ terms designate rating curve numbers. For example daily discharges are named according to ‘Dowwnnnyyyy.dbf’ convention, so 1999 water year daily discharge data of the station that were given as an example above will be stored in ‘D1010131999.dbf’ file.

List of important database tables and their short descriptions are given in Table 5.2. Detailed information on all database tables and their structures are available in Appendix F in tabulated format.

Table 5.2. Descriptions of important database tables

Table name	Description
Dowwnnnyyyy	Daily discharge table for station *owwnnn* and water year *yyyy*
MSowwnnnyyyy	Monthly discharge summary for station *owwnnn* and water year *yyyy*
DSyyyy	Discharge summaries of gauging stations for water year yyyy
RCowwnnncc	cc^{th} rating curve table of station owwnnn
WQowwnnnyyyy	Water quality monitoring data table for station owwnnn and year yyyy
S_Gauging	Table of gauging stations
S_Wquality	Table of water quality monitoring stations
LU_Organization	Look-up table of organizations
LU_Basin	Look-up table of basins
LU_Gauge	Look-up table of gauge recorders
LU_Wqstype	Look-up table of water quality station types
LU_Mdstype	Look-up table of water quality summary types
LU_Wqparameter	Look-up table of water quality parameters

There are also additional tables that are not listed in Table 5.2 and used internally within the analysis system. Database tables are linked to each other by primary and foreign key attributes, or by monitoring station IDs found in their filenames. Complete listing of database tables with their attributes and relations between them are given in Figure 5.3. In the figure, links are represented by arrow headed lines, each starting from a foreign key in a table and ending at corresponding primary key in another table. Attributes that are not directly connected, but associated to each other are indicated with dotted lines. Internal tables, which are not connected to any other table, are gathered together and given at the lower left corner of the figure. Attributes of database tables are listed under each table name. Names of attributes are mostly self-explanatory of their function, but complete descriptions of and sample data for each attribute are given in Appendix F. List of attributes for each table are determined according to data available on stream flow and water quality monitoring, and format of SHW, EPRSDA and GDRS publications.

There exists a previous study in the literature that is related with stream flow gauging data collected in Turkey. State Hydraulic Works Hydrometric Data Bank (DSIHVB) developed by Karagöz in 1995 (Karagöz, 1995) was aimed to store information about river and lake gauging stations operated by SHW. It consisted of two databases, HC23 for stream flow data, and GOL for lake stage data. DSIHVB was actively used in SHW for a period of time, and at that time more than 150Mb data and related information were stored in these databases (Karagöz, 1995). INFORMIX relational database management system was used by DSIHVB and all data were stored in specific database tables. Although the structures of DSIHVB tables are not exactly the same with the ones used in this study, attribute fields are mostly identical, since the data stored in both systems are coming from the same sources. Therefore, DSIHVB data can be transferred to the database of the analysis system developed in this study by simple transformations. If possible, such a transfer will solve the data entry problem for the developed system and also data can be analyzed by the user in a more advanced GIS-based system, which is superior in data visualization and geographical analysis.

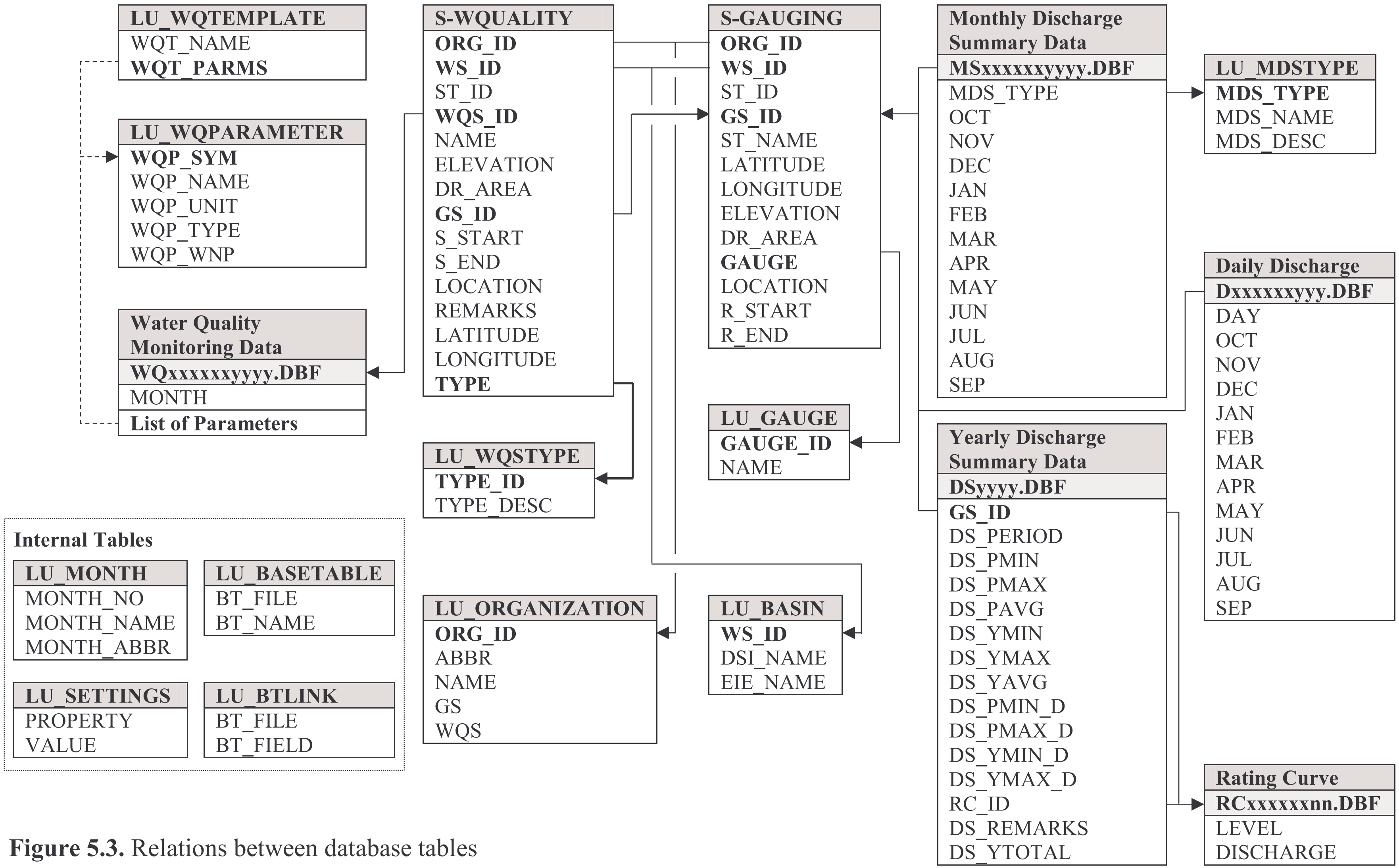


Figure 5.3. Relations between database tables

5.2. Development of Monitoring Station Coverages

In order to create stream flow gauging and water quality monitoring station coverages, which are used as base datasets in analysis system, data sources that are mentioned in Chapter 2.3 are utilized.

For EPRSDA stream flow gauging stations, related Excel sheets are downloaded from the web site of the directorate and a point coverage is created in GIS by using the geographic coordinates given in these Excel sheets. General information of the stations are transferred from Excel sheets to the attribute table of the coverage in the common format designed for the study, which is given in Appendix F. By visual inspection, locations of gauging stations are compared with the ones given in discharge yearbook maps for validation purposes. Locations of only two gauging stations are found to be incorrect, and they are corrected by manual editing. Obtained EPRSDA gauging stations coverage map is illustrated in Figure 5.4.

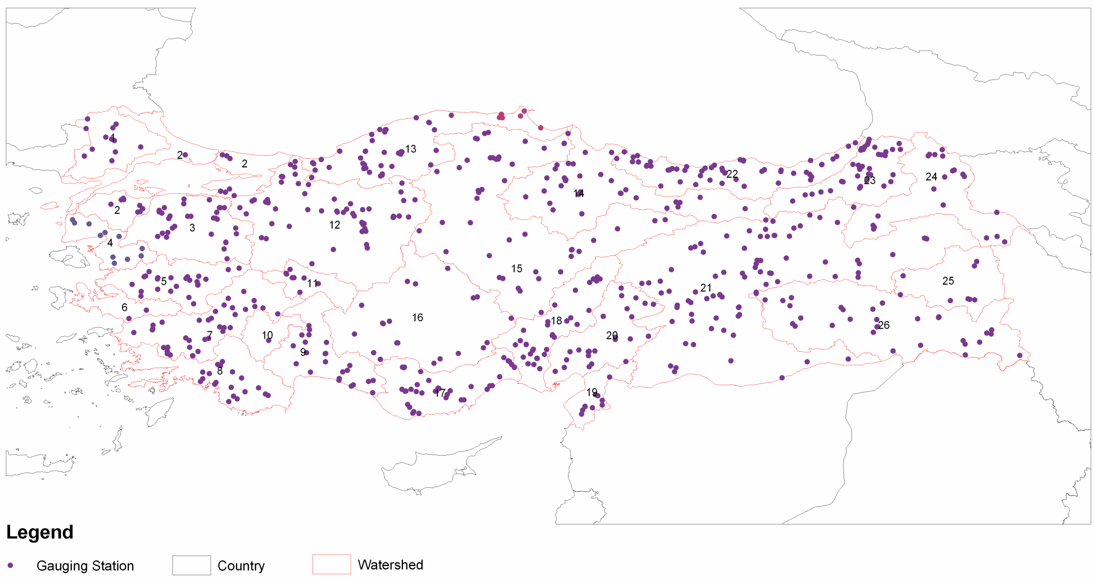


Figure 5.4. Distribution of EPRSDA stream flow gauging stations

For SHW stream flow gauging stations, a single up-to-date source similar to EPRSDA Excel sheets is not available for the coordinates of stations. "Album of Stream Flow Monitoring Network" includes information for stations that are in-operation or closed until 1988. But information on stations that are opened after 1988 should be collected from discharge yearbooks. In this manner, the coordinates of gauging stations are extracted for 1988 album and missing stations in the album are completed from 1994 discharge yearbook that is published in 1999. Like the EPRSDA data, a point coverage is created in GIS by using these extracted coordinates. However, as previously indicated in Chapter 2, the accuracies of geographic coordinates given in these sources are found to be low. Many gauging stations are observed to be scattered outside the country boundaries (Figure 6.1). Although locations of several stations are tried to be corrected manually at the beginning, since the number of stations with incorrect coordinates is quite high this task could not be completed. Instead of this, the watershed maps given in the appendix of 1994 discharge yearbook, on which the locations of gauging stations are marked, are scanned to create raster maps. These raster maps are geo-rectified using Rectification tool of ArcMap 8.2 and combined together to obtain a single raster map coverage. As indicated in Chapter 2, neither grid nor geographic coordinates were available in these maps; hence, watershed boundaries and settlement markers are used as control points in rectification and after an intensive work, reasonable results could be obtained. Using the final raster dataset as a base map, gauging stations are digitized manually to produce SHW gauging stations coverage. Obtained coverage map is illustrated in Figure 5.5. Compared with the map generated at the beginning (see Figure 6.1), a significant amount of increase in accuracy is observed. However, compared with EPRSDA gauging stations coverage obtained accuracy is still low, and the coverage should be used carefully by considering possible positional shifts due to rectification. As a last step, general information related with gauging stations are collected from 1994 discharge yearbook and 1988 album, and entered to the attribute table of the coverage like done for EPRSDA coverage before.

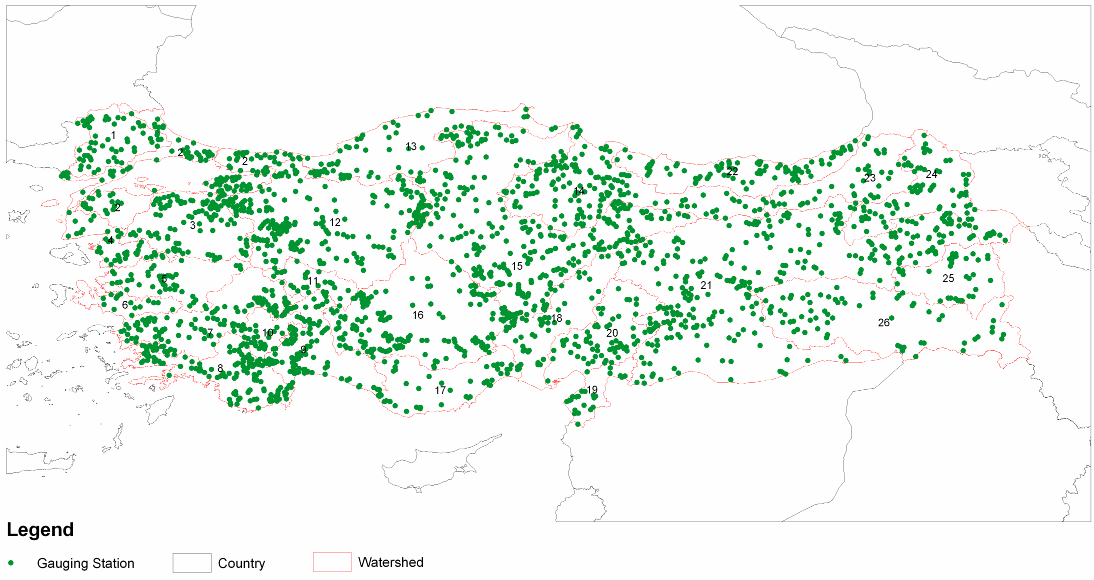


Figure 5.5. Distribution of SHW stream flow gauging stations

Since the number of stream flow gauging stations owned by GDRS is low and they are distributed in a limited geographical extend, these stations are not included explicitly to the station database of the analysis system. However, the analysis system is fully compatible with the data collected by GDRS and it can be used directly without any modification. GDRS is already defined in the system as an organization owning stream flow gauging stations. Hence, the only thing that should be done is to add station information in to G-STATIONS database table in the form mentioned in Appendix F.

5.3. Development of Water Quantity/Quality Data Analysis System

Based on the database structure and datasets explained so far, an analysis system has been developed that combines database, mapping, data visualization and analysis features within a unified graphical user interface that utilizes easy to use dialogs, tables and graphs. ArcView GIS 3.2 from Environmental Systems Research Institute (ESRI) is used as the development platform, which supplied basic GIS, database connectivity and data visualization needs. Since standard features supplied by the

GIS are very limited, custom scripts are written that are working together with custom designed dialogs to perform the tasks that are needed by the analysis system. Using AVENUE scripting language and Dialog Designer of ArcView GIS 3.2, 115 scripts and 20 dialogs are developed that are working in conjunction with 18 different types of database tables.

Key features of the developed analysis system are as follows:

- Integrates database, mapping, data visualization and analysis tools related with hydrographic and hydrologic data in a single program package,
- Uses a national hydrography dataset as the base dataset, that is hydrologically validated and suitable for up-stream/down-stream navigation,
- Gives an opportunity to use nationally derived DEM-based hydrologic cataloging units (watersheds) for area based analyses,
- Stream flow gauging and water quality monitoring stations owned by different organizations are made available in a single map,
- General information on monitoring stations can be accessed from an easy to use dialog based user interface,
- Data visualization and analysis tools are provided that are compatible with national hydrologic data formats and standards,
- Yearly summaries of stream flow gauging stations can be obtained,
- Daily discharge values recorded at gauging stations, their monthly summaries, and yearly rating curves are made available both in tabular and graphical formats,
- If needed, monthly summaries can be calculated automatically from daily discharge values,
- Statistical summaries of water quality measurements can be obtained for any water quality parameter and any time period,
- Time-wise change in a water quality parameter can be examined in detail by the time series graphs,

- Monthly averages of water quality measurements can be calculated and histograms showing overall distribution of the measurements can be produced,
- Thematic maps of water quality monitoring stations with respect to water quality statistics can be created and monitoring stations can be ranked accordingly,
- Database tables that are required for new data entry can be created automatically,
- Analysis results (maps, charts, and tables) can be inserted easily into layouts for reporting purposes,
- Includes tools for up-stream/down-stream navigation of watersheds,

A typical session of the analysis system, which will be explained in detail in the following sections, is illustrated in Figure 5.6.

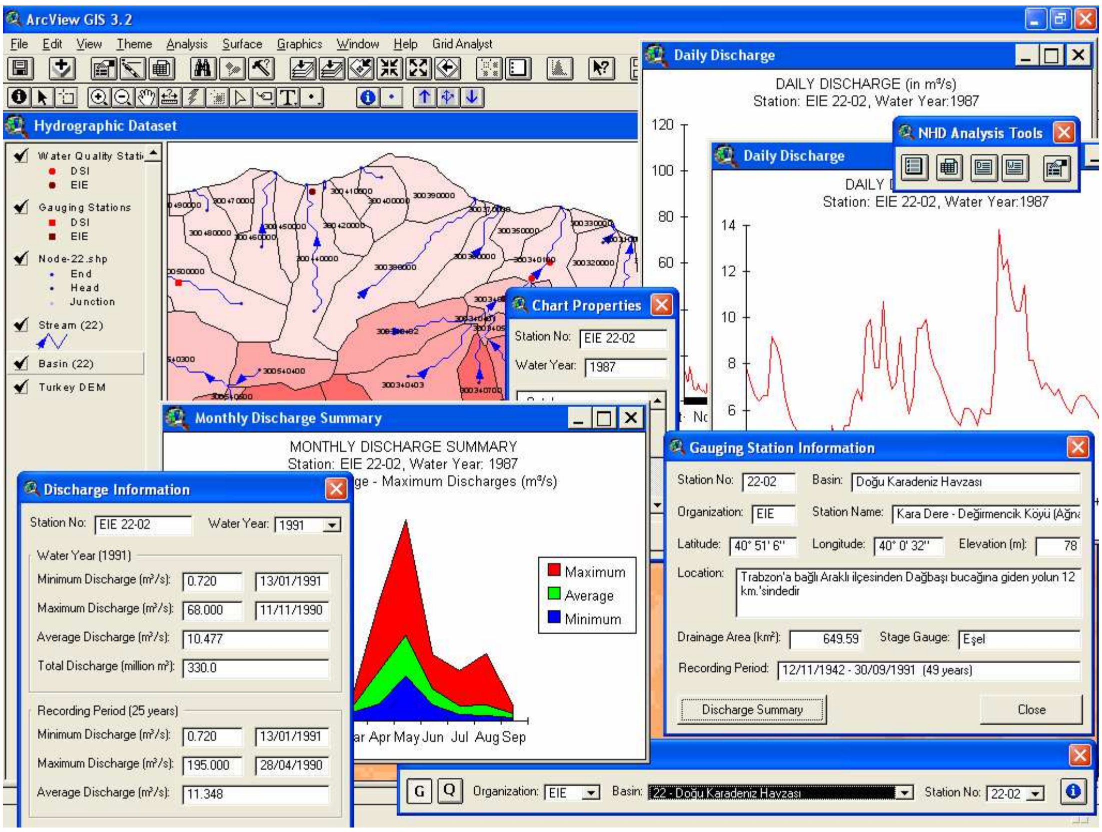


Figure 5.6. A typical session of the developed analysis system

5.3.1. General Usage of the Analysis System: Data Entry and Data Access

A set of tools are provided with the system for the following purposes:

- Access stream flow and water quality data,
- Create related database tables for new data entry,
- Assess data availability,
- Facilitate data calculations, and
- Change the system settings.

'NHD Analysis Tools' toolbar can be used to reach aforementioned features. Each button on the toolbar is linked to a dialog window with specific functionality (Figure 5.7).

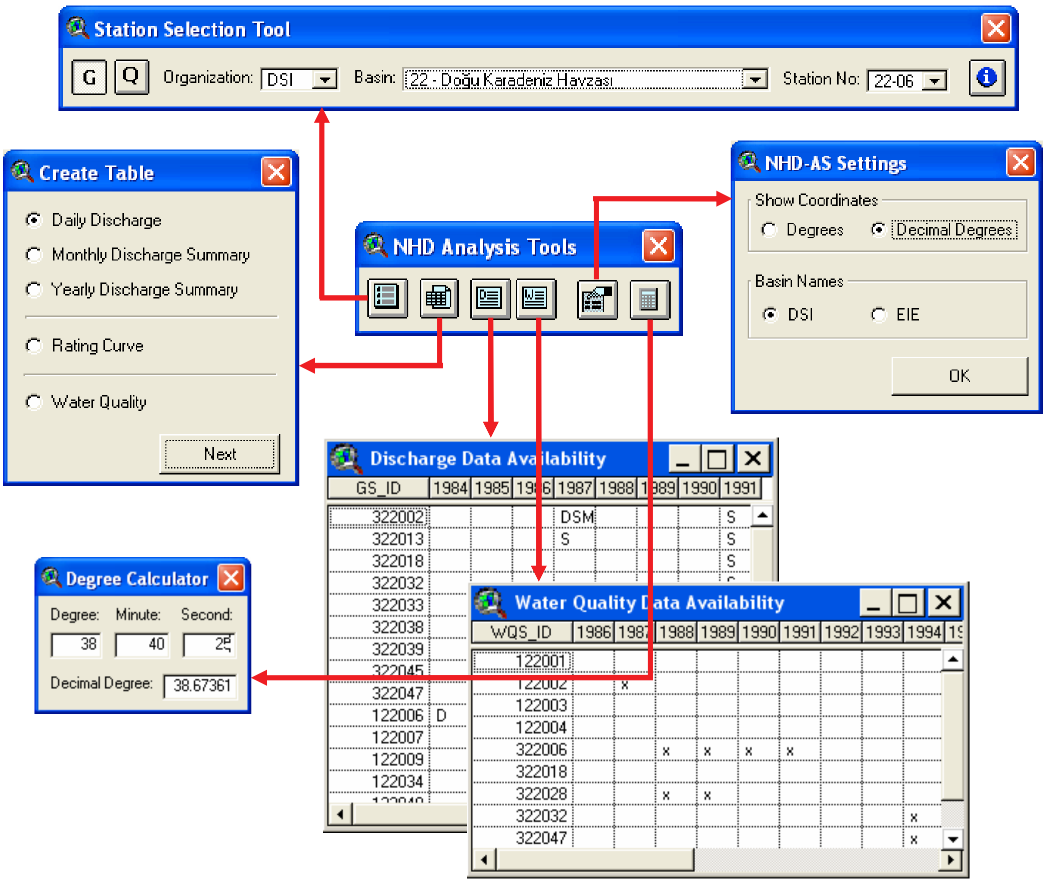


Figure 5.7. NHD analysis tools

First button on the toolbar displays ‘Station Selection Tool’ dialog. The user may find out from this dialog, which stream flow or water quality monitoring stations of different organizations are available in the database. Also detailed information on general characteristics of the station and water year based monitored records can be obtained by selecting a station from this dialog. On the ‘Station Selection Tool’ dialog there are three buttons (G, Q, and Info) and three list boxes (Organization, Basin and Station No). In order to obtain information on a station from the dialog, the user should first select the station type by pressing either ‘G’ or ‘Q’ buttons on the dialog. ‘G’ button is for flow gauging stations and ‘Q’ button is for water quality monitoring stations (Figure 5.8).

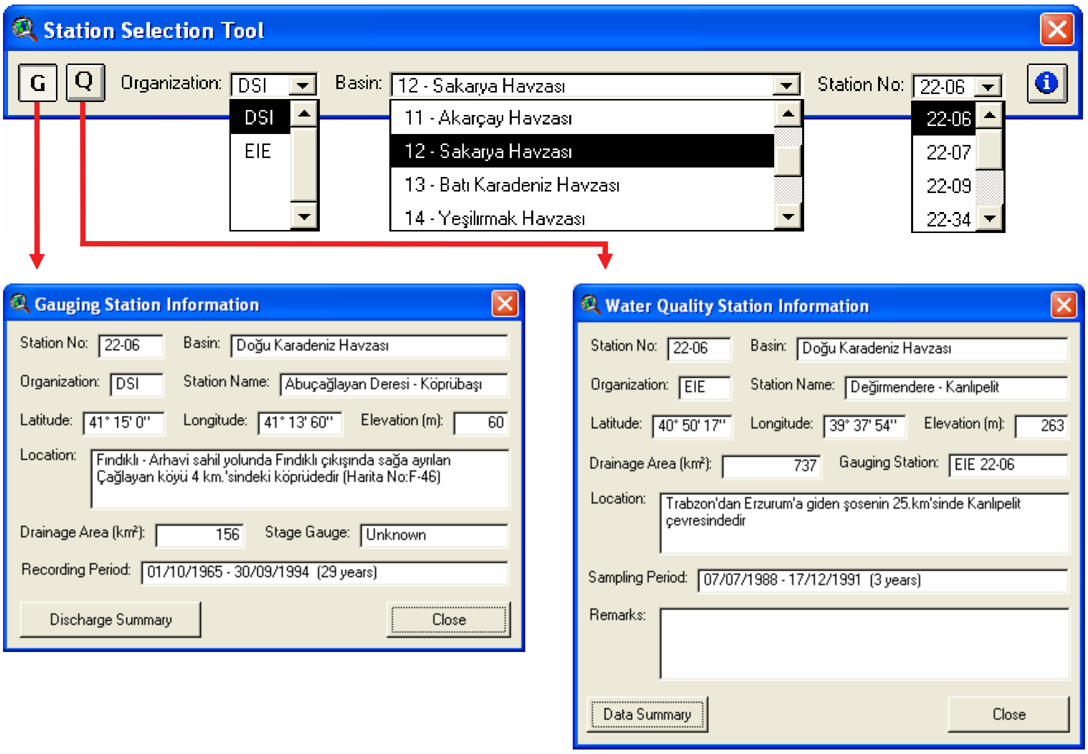


Figure 5.8. Station selection from Station Selection Tool dialog

When the user presses any of these buttons, contents of organization list box are updated so that it shows available organizations, which are operating specified type of monitoring stations, from the database. Once the user selects an organization and a watershed from the dialog, ‘Station No’ list box is also updated to reflect stations that are within the selected watershed and operated by the selected organization. Not all, but the stations that are entered to the database are listed in this list box. In order to display station information dialog, the user should select a station no and press Info button which is the left most control in the dialog. Displayed station information depends on the station type, i.e. whether the station is a stream flow gauging or a water quality monitoring. Detailed explanation on this topic will be given in the forthcoming sections.

Second button on 'NHD Analysis Tools' toolbar displays 'Create Table' dialog, which can be used to create database tables for new data entry (Figure 5.7). Developed analysis system deals with a wide range of data, like daily stream flows, water quality measurements, monthly summaries, etc. There exist many database tables, each of which is associated with different type of data and should be filled by the user or related organization for an effective operation of the analysis system. Although a basic set of data is already entered to the system, new data entry is unavoidable since the sample data is very limited both in time and spatial extent. While entering new data, several database tables should be created according to pre-defined table structures and they should be placed into correct locations in the directory hierarchy. An experienced user, who knows the internals of the analysis system well, may create these tables manually using the database table creation features of the GIS. However, this may be very time consuming and open to mistakes that may adversely affect the operation of analysis system. In order to prevent such mistakes and to speed up data entry process, database table creation tools are developed for the system, which can be used even by the most inexperienced user. 'Create Table' dialog is the starting point of database table creation process (Figure 5.9). The following database table types can be created by using 'Create Table' dialog:

- Daily Discharge
- Monthly Discharge Summary
- Yearly Discharge Summary
- Rating Curve
- Water Quality

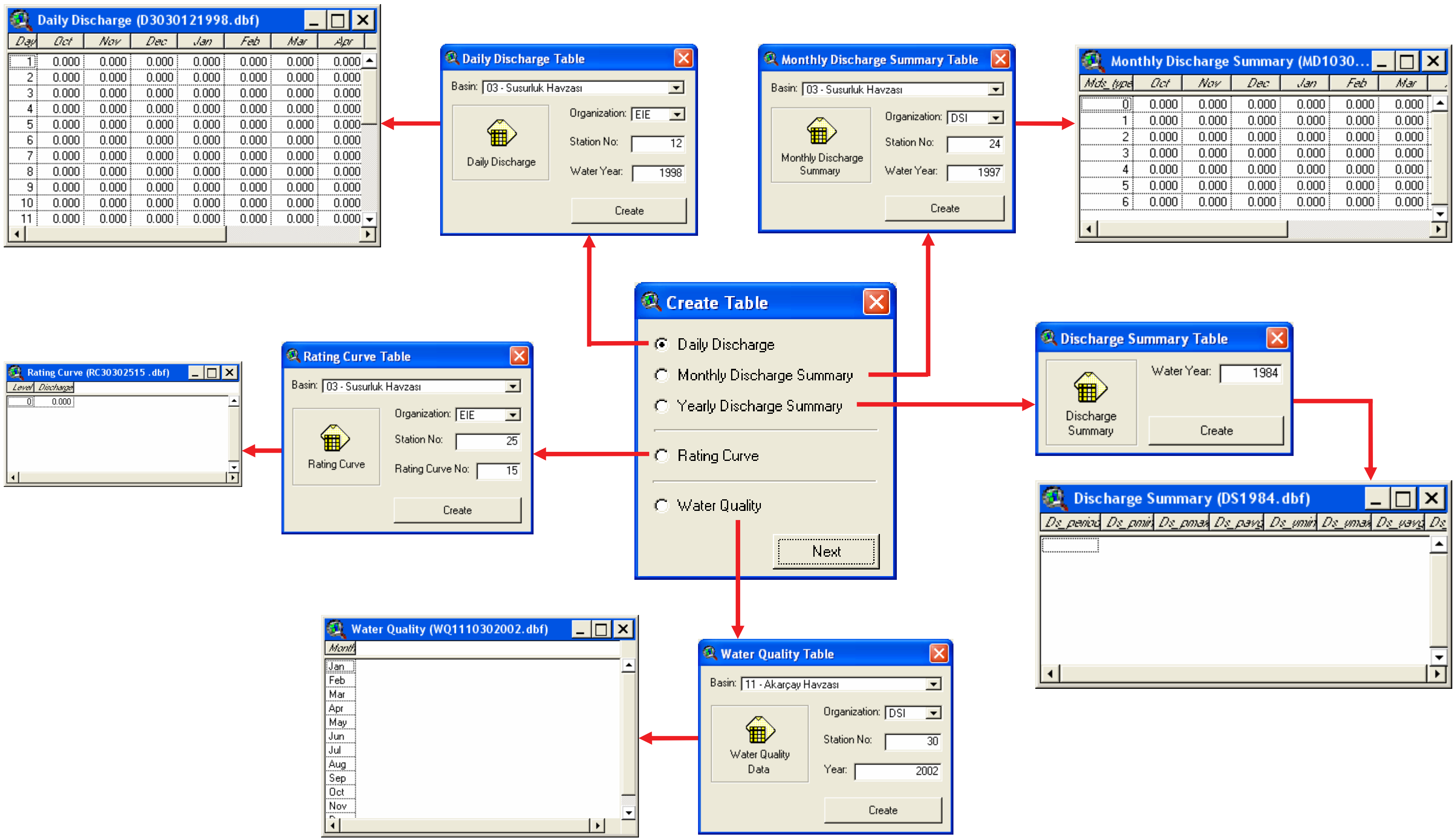


Figure 5.9. Create Table dialog and its sub-dialogs

Once the user selects database table type that he/she wants to create from 'Create Table' dialog and presses 'Next' button, a second dialog is displayed. The contents of this second dialog depend on selected table type, but generally it includes basin name, organization, station no and water year fields that should be filled or selected by the user. According to information entered to second dialog, selected type of database table is created based on the templates that are stored in the system database. Secondary dialogs and sample resulting database tables are illustrated in Figure 5.9.

Because the number of records that should be filled by the user are constant in daily discharge and monthly discharge summary tables, these tables are created with predefined number of empty records. The user should only enter data to appropriate rows and columns, and there is no need to add extra rows (i.e. records) to these tables. However this is not the case for other tables. Number of determined points on a rating curve changes from curve to curve; hence the number of records that should be entered to rating curve data is not constant. In order to enter rating curve data, the user should add enough number of rows to rating curve table using record adding feature of GIS. The case for yearly discharge summary table is also similar. In this table, each record represents yearly discharge summary of a single stream flow gauging station. Therefore the number of records depends on the total number of stream flow gauging stations that are in operation in the specified water year. This value changes from water year to water year as well. Like rating curve table, the user should add proper number of records to the yearly discharge summary table. The last table type that can be created from 'Create Table' dialog, water quality table, has a very special situation. In this table, the number of records is limited with the number of months in a year; thus the number of records is constant. However, water quality parameters, which are represented as columns in the table, are changing from station to station. The list of water quality parameters may even change for a single station from time to time. As a result, the user should add appropriate number of columns to this table. But this is not an easy task even for an experienced user, because each water quality parameter requires a specific column with predefined name, type, length and precision, all stated in LU_WQPARAMETER separately.

In order to facilitate the addition of water quality parameters into water quality tables, ‘Water Quality Parameter Selection’ tool is developed. When a water quality table is active in GIS application, pressing ‘Add Parameter’ button on the toolbar displays parameter selection tool dialog (Figure 5.10). Two list boxes are located on two sides of the dialog. List box on the left hand side includes a list of available water quality parameters, whereas the list box on the right hand side includes a list of water quality parameters that are already added to the database table at that time. For a blank water quality table, selected parameters list box is empty and available parameters list box includes all water quality parameters that are registered to the system. The user may move any water quality parameter from one list box to the other by using two arrow buttons that are located between the list boxes. Once needed water quality parameters are selected, they can be added to the water quality table by pressing ‘Apply’ button (Figure 5.10).

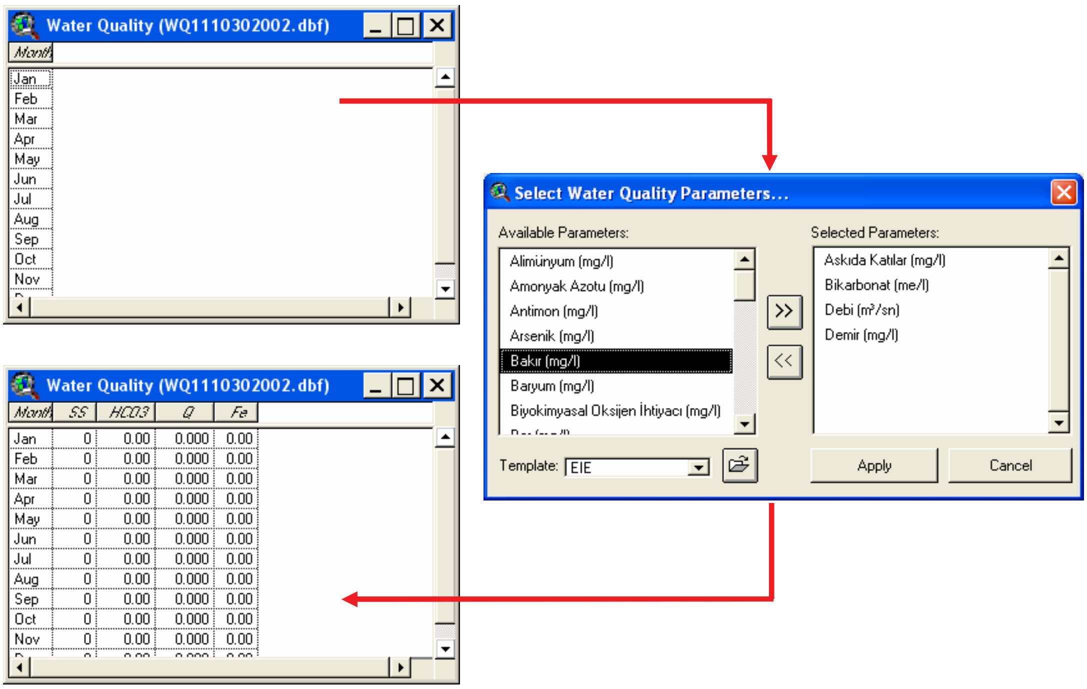


Figure 5.10. Adding water quality parameters to water quality database

All water quality parameters, which are not in the table columns before, are added to the table directly. If there are some water quality parameters in the table columns that are not listed in the selected parameters (i.e. removed by the user from selected parameters list), then for each such water quality parameter the user is warned that corresponding column will be removed from the table and all entered data will be lost. If the user approves the removal of the water quality parameter, the column is deleted from the table.

The number of water quality parameters measured at a station is typically in the range of 10 to 20. Although use of water quality parameter selection tool significantly facilitates insertion of these parameters to water quality tables, selection of appropriate parameters from a long list of available parameters may take some time, especially if the number of stations that should be entered to the database is high. Taking the fact that water quality stations operated by the same organization share a common list of water quality parameters most of the time, a template list loading feature is added to 'Water Quality Parameter Selection' dialog to speed up water quality parameter selection procedure. A set of template water quality parameter lists are available from 'Template' list box that is located at the bottom of the dialog. By selecting a template name from the list box and pressing load button located next to it, the user may directly update the selected parameters list according to the parameters that are listed in the template (Figure 5.11). The following templates are currently available for selection:

- EPRSDA Water Quality Monitoring Station Parameters
- SHW General Water Quality Monitoring Station Parameters
- SHW Drinking Water Quality Monitoring Station Parameters
- SHW Groundwater Quality Monitoring Station Parameters

Complete listings of water quality parameters for each template are given in Appendix B.2. The user may also add new templates to the database by adding new records to LU_WQTEMPLATE table according to structure given in Appendix F.

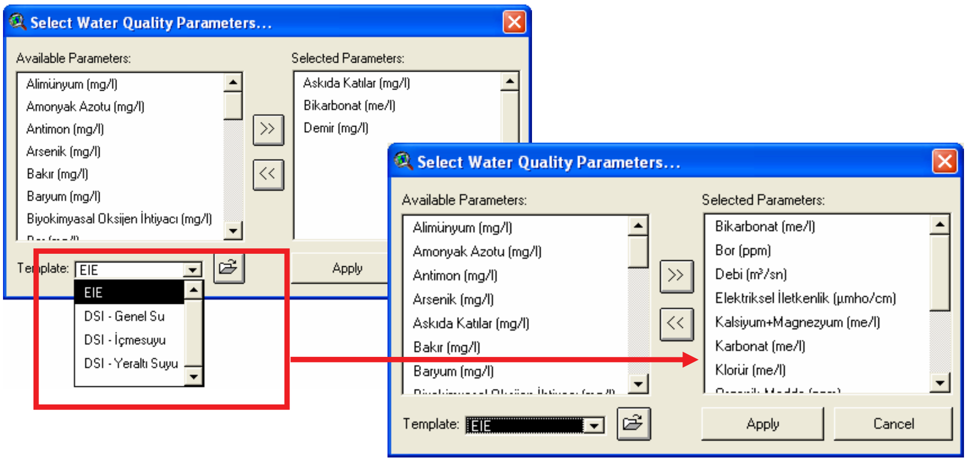


Figure 5.11. Loading water quality parameters template

Third and forth buttons on the 'NHD Analysis Tools' toolbar are related with available data in the database. By using these buttons, information on the distribution of available stream flow and water quality data in the database can be obtained on station basis. Similar tables will be displayed both for stream flow and water quality data, which have a first column that include station IDs and a number of additional columns that include data availability information for different years. For water quality monitoring stations, there is only one kind of data availability information, which is whether any data exists for a year or not. Years with available data are indicated in 'Water Quality Data Availability' window with an 'X' mark. For stream flow gauging stations, three different data may be available for a water year: daily discharges, monthly summaries of these discharges, and water year summary. Presence of daily stream flow data is indicated with a 'D' mark in the 'Discharge Data Availability' window, whereas 'M' is used for monthly summaries and 'S' is used for yearly summary. The contents of these tables are updated regularly before they are displayed to the user; hence they reflect the latest conditions of the database. 'Discharge Data Availability' and 'Water Quality Data Availability' windows can be used especially to determine the stations or time periods with missing or limited data. Based on this information, study plans for data entry may be formed and additional data needs may be determined.

Fifth button on the ‘NHD Analysis Tools’ toolbar displays a dialog that is related with analysis system settings. Currently two settings are available that can be altered by the user. The first one, ‘Show Coordinates’, is associated with display of latitude/longitude coordinates in dialogs. By changing this setting, the coordinates may be displayed as degrees or decimal degrees. The second setting is related with the naming convention of 26 national basins. As stated previously, a common naming convention does not exist between the organizations related with stream flow gauging and water quality monitoring. Instead of preferring a single naming convention through the analysis system, the decision is left to the user and both naming conventions (SHW and EPRSDA) are made available for selection. By changing ‘Basin Names’ setting, the user may determine which naming convention should be used in dialogs, tables and charts.

The last button on the ‘NHD Analysis Tools’ toolbar displays a tiny, but very useful tool: Degree Calculator. The aim of this tool is to convert degrees into decimal degrees and vice versa. Latitude/Longitude information is given as degrees (i.e. in the form of degrees^{o} minutes’ seconds”) in most of the yearbooks and data sources related with stream flow and water quality monitoring. But this type is not very suitable for storage in a database due to requirement of three separate fields. Decimal degrees can be stored just in a single field. Therefore it is the type that is used in database tables of the analysis system, and coordinates should be entered to the system in this format. In order to facilitate conversion of coordinates between the two formats, Degree Calculator could be used by the user. Entering degrees, minutes and seconds, and pressing ‘Enter’ key will calculate decimal degrees. Likewise entering decimal degree and pressing ‘Enter’ key will calculate degrees, minutes and seconds.

5.3.2. Stream Flow Data Analysis Tools

As stated previously, information related with stream flow gauging stations can be accessed in two ways: Selecting a station from ‘Station Selection Tool’ or selecting a station from the coverage map by using ‘Info’ tool.

In either case 'Gauging Station Information' dialog will be displayed on the screen, which includes general information on the selected gauging station. In addition to basic information like basin name, organization, station name, and station no, detailed explanation of location of the station in terms of latitude, longitude, elevation and narrative textual description are given. Drainage area in square kilometers; starting date, ending date, and duration of the recording period; and type of stage gauge used at the station are also indicated (Figure 5.8). The user can access to stream flow summaries of the station by pressing 'Discharge Summary' button.

As indicated before, stream flow summaries are stored in the database as water year based yearly discharge summaries. In order to display these summaries 'Discharge Information' dialog is used (Figure 5.12). On the dialog, short name of the station is indicated and for the selection of the water year a list box is made available. If the user requests to see discharge summaries of a stream flow monitoring station, the system first searches through the database and determines water years for which yearly discharge summaries are available for the specified station. Water year list box on the 'Discharge Information' is updated accordingly. The following information is provided for each water year as a summary: minimum discharge (m^3/s) and its occurrence date, maximum discharge (m^3/s) and its occurrence date, average discharge (m^3/s) and total discharge (million m^3). Minimum, maximum and average discharges that are observed not only in the specified water year, but through the whole recording period since the opening of the station till the specified water year are also indicated on the dialog. Additionally, remarks on stream flow in the water year are given if they are reported.

'Discharge Information' dialog furthermore provides means of access to detailed stream flow data, statistics and graphs. Rating curve that is used at the station during the water year, discharge values recorded day by day at the station and monthly statistics calculated from these discharges are types of information that can be reached through 'Discharge Information' dialog. All these information are made available to the user both in conventional tabular form and as interactive charts (Figure 5.12).

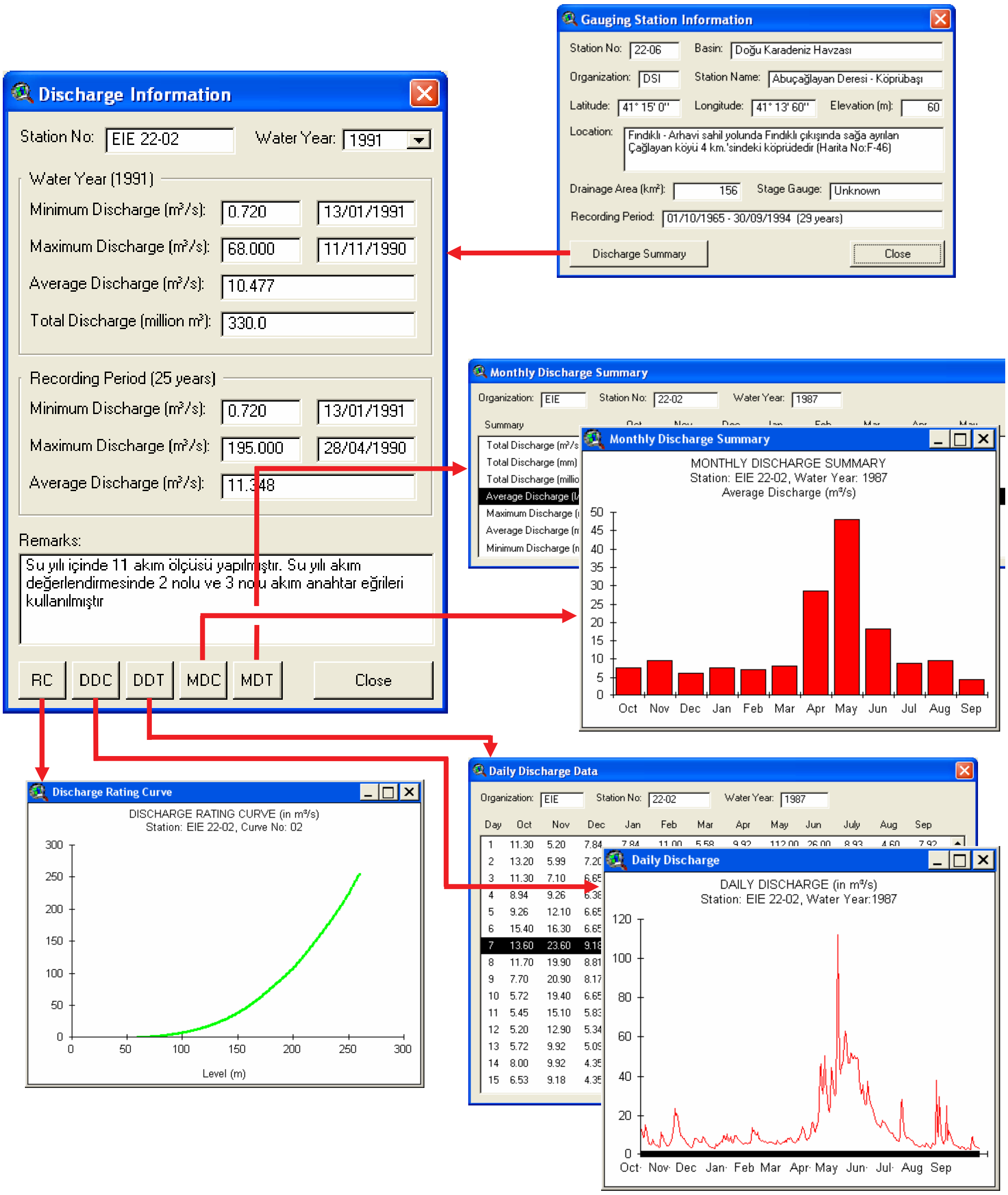


Figure 5.12. Information that can be accessed through Discharge Information dialog

In order to access detailed stream flow data and statistics, the user should use five buttons located at the bottom of the 'Discharge Information' dialog. The buttons are labeled with abbreviations of the following information representations: <u>R</u>ating <u>C</u>urve (RC), <u>D</u>aily <u>D</u>ischarge <u>C</u>hart (DDC), <u>D</u>aily <u>D</u>ischarge <u>T</u>able (DDT), <u>M</u>onthly <u>D</u>ischarge Summary <u>C</u>hart, and <u>M</u>onthly <u>D</u>ischarge Summary <u>T</u>able.

Rating curve, which is used to convert stream stage values measured at the station into stream flow values, is drawn as a chart by interpolating values of determined points on the rating curve that are given in yearbooks in tabular form (Figure 5.12). The shape of the curve is assumed to be linear between the points for the interpolation. Graphical representation of the rating curve believed to be interpreted more easily by the user compared with the tabular representation; therefore it is the preferred representation of the analysis system. If numerical values are required, the user can use 'Info' tool located on the toolbar to access discharge value at a specific stage level by clicking on the rating curve at that level.

Tabular daily stream flow data can be accessed from the 'Discharge Information' dialog by pressing the 'DDT' button. Once the user presses this button, 'Daily Discharge Data' window will be displayed (Figure 5.12). At the top of the 'Daily Discharge Data' window, organization, station no and water year are indicated separately. Daily discharges are given as a matrix, the axes being months and days in months. In discharge yearbooks, daily discharge records are complete for a station in a year and there exist no missing data. Therefore daily discharge table given in 'Daily Discharge Data' also do not include any cells with missing data. But the days that do not exist in a year (like 31^{th} of September) are indicated.

Daily discharge records could also be accessed as daily discharge graphs. By pressing 'Daily Discharge Chart' button on 'Discharge Information' dialog, the user may create a time series graph of all daily stream flows recorded at the station for the specified water year. Like the rating curve graph, individual stream flows on the graph can be determined by using 'Info' tool at the toolbar. An important feature of the daily discharge chart is its interactive behavior. While the chart window is displayed on the screen, another dialog called 'Chart Properties' is also made visible to the user. 'Chart Properties' dialog provides user interface controls to alter the range of stream flow data that is displayed on the chart window. This dialog and the chart window are linked to each other, and depending on the active data range of selected daily discharge chart (there may be more than one chart at a time), selection of months in the list box of 'Chart Properties' dialog gets updated. Likewise, if the user changes the selection in the list box to cover a different range of months, active daily discharge chart gets updated to show corresponding date range. This feature is illustrated in Figure 5.13. In order to select all months in a year, the user may use 'Select All Months' button located at the bottom of 'Chart Properties' dialog. Owing to dynamic and interactive behavior of daily discharge charts, detailed stream flow graphs for specific intervals in a water year can be prepared and trends in stream flow at the monitoring sites can be studied more easily. This is an important progress on the tabular representation of daily discharge values.

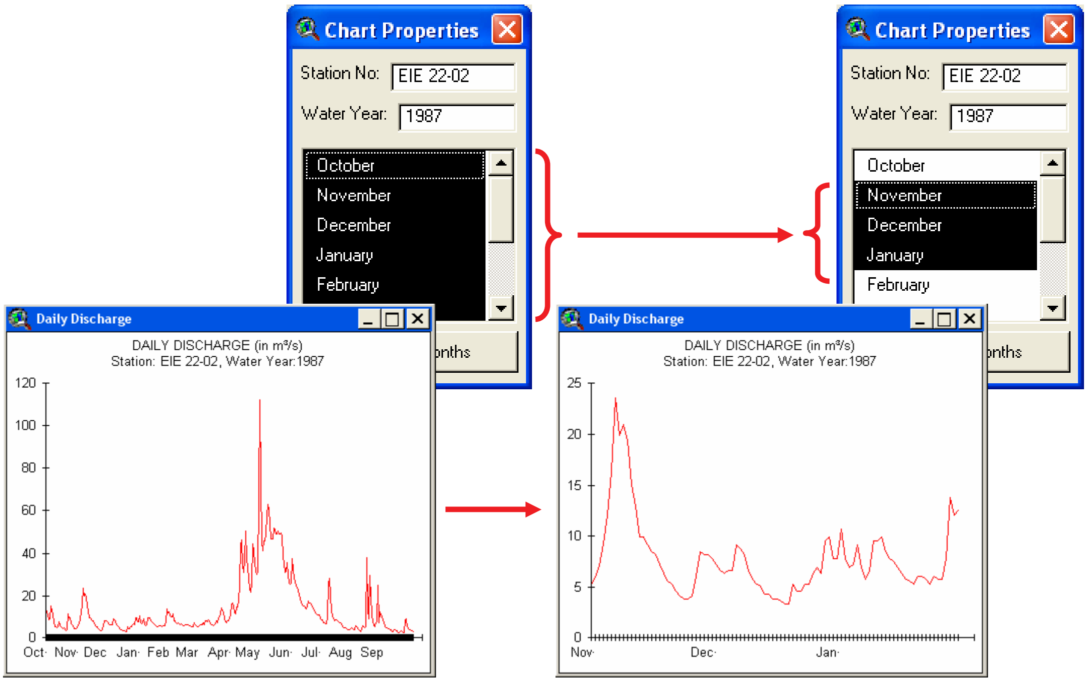


Figure 5.13. Dynamic behavior of daily discharge chart

In addition to detailed daily stream flow data, monthly stream flow summaries are also made available to the user. Like daily data, monthly summaries are provided both as numeric data in tabular format, and as charts for each monthly summary type. The following monthly summaries are stored in the database for each water year of a stream flow gauging station: total discharge (m^3/s), total runoff (mm), total volume (million m^3), maximum discharge (m^3/s), minimum discharge (m^3/s), average discharge (m^3/s), and average yield (l/s/km^2).

The user may enter monthly stream flow summaries manually to the database from yearbooks. This is the suggested method of data entry, since some of the summaries given in yearbooks, like maximum and minimum discharges, are calculated not from daily average values, but from instantaneous stream flow values which are not explicitly given in yearbooks. Therefore for accurate statistics the user should rely on reported monthly summaries. However, if monthly summaries are not available or the user does not wish to enter data into database separately, the system is capable of calculating approximate monthly summaries from daily discharge values. If daily discharges are available in the database but monthly summaries do not exist for a water year and the user requests to see monthly summaries from 'Discharge Information' dialog by pressing either monthly discharge summary chart (MDC) or monthly discharge summary table (MDT) buttons, then the system asks from the user whether monthly summaries should be calculated from daily values or not. If the user answers affirmatively, monthly discharge summaries are calculated by using the equations given in Table 5.3.

Table 5.3. Monthly stream flow summary statistics

Monthly summary	Formula
Total discharge (m^3/s)	$\sum_{i=1}^{n} F_i$
Total volume (million m^3)	$\left(\sum_{i=1}^{n} F_i\right) \cdot 86{,}400 \Big/ 1{,}000{,}000$
Average discharge (m^3/s)	$\sum_{i=1}^{n} F_i \Big/ n$
Maximum discharge (m^3/s)	$Max(F_i)$
Minimum discharge (m^3/s)	$Min(F_i)$
Total runoff depth (mm)	$\left(\sum_{i=1}^{n} F_i\right) \cdot 86{,}400 \Big/ Area \cdot 1000$
Average yield (l/s/km^2)	$\left(\sum_{i=1}^{n} F_i \Big/ n\right) \cdot 1{,}000 \Big/ Area$
where; F_i = daily stream flow, n = number of days in the month $Area$ = Catchment area of the gauging station	

Similar to daily discharge chart, monthly discharge summary chart is also dynamic and interactive. A 'Chart Properties' dialog, which has a similar working principle with daily discharge chart properties dialog, is displayed with monthly discharge summary chart. Instead of a list of available months, a list of available summary types is provided on the dialog. All summary types given in Table 5.1 can be selected from this list, and corresponding bar chart can be obtained. Additionally, an area chart showing minimum, maximum and average monthly discharges on the same graph is also made available (Figure 5.14). Especially this last chart type summarizes a significant amount of data in a single graph. Using 'Info' tool from the toolbar, the value of the summary at a given month can be found.

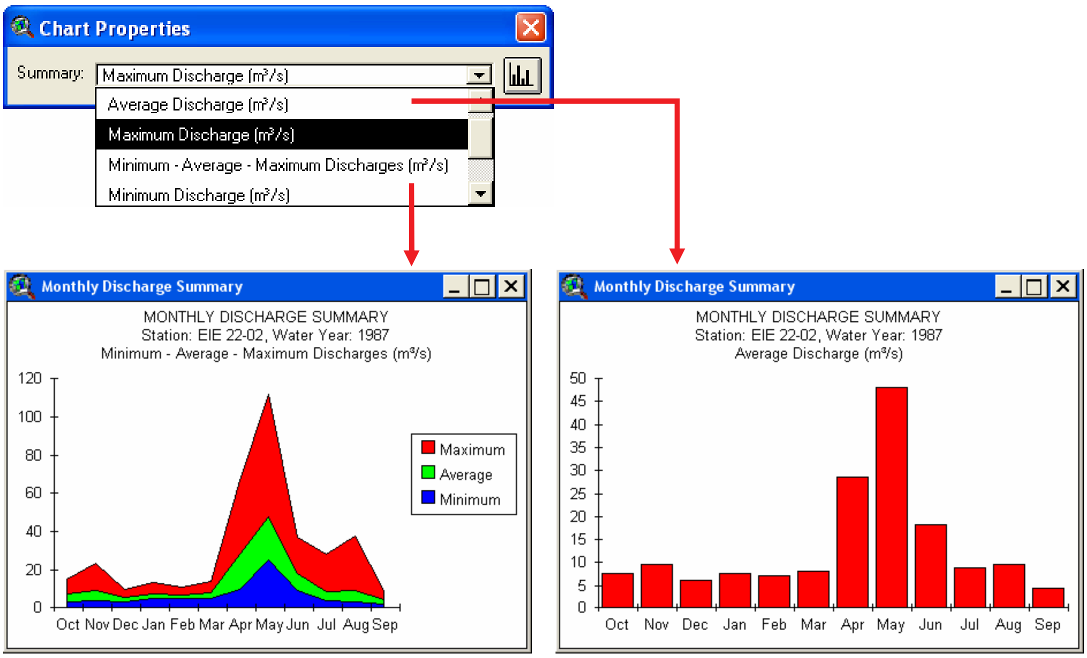


Figure 5.14. Monthly discharge summary chart examples

All charts mentioned so far are fully customizable by the user. The user may change title, line and bar colors, and ranges of axes of the charts according to his/her needs and resize them to any size. Charts can be inserted into ArcView Layouts to prepare reports together with maps and tables, and to obtain hard copy outputs whenever they are required.

5.3.3 Water Quality Data Analysis Tools

'Water Quality Station Information' dialog that can be accessed similar to 'Gauging Station Information' dialog includes general information on the selected water quality station. Besides basic information like basin name, owner organization, station name, and station no, detailed explanation of location of the station in terms of latitude, longitude, elevation and textual description are given. Drainage area in square kilometers; starting date, ending date, and duration of the monitoring period; and remarks on the water quality station are also available (Figure 5.8). If water quality station location coincides with a stream flow gauging station, gauging station number and owner organization are specified. Hence, by using 'Gauging Station Information' dialog the user may access detailed stream flow data in addition to water quality measurements. Detailed information on measured water quality parameters can be obtained through 'Data Summary' that is located at the bottom of the dialog (Figure 5.8).

When the user presses 'Data Summary' button, 'Water Quality Summary' dialog will be opened. Statistical summaries of the measurements for any time period can be obtained from this dialog for a selected water quality parameter. At the top of the dialog, name and owner of the station are indicated. The dialog includes three list boxes; one for selection of water quality parameter and two for selection of time period. Since the list of water quality parameters measured at a station may be variable with time, a single list of water quality parameters that is specific to the station is not enforced by the analysis system. Instead, a complete list of water quality parameters that are measured by all organizations is provided, from which the user may select the water quality parameter of concern. Complete list of water quality parameters currently available in the analysis system is given in Appendix B.1. If needed, the user may also add new water quality parameters to the system by adding new records to LU_WQPARAMETER database table, the structure of which is given in Appendix F. The time period, for which statistical summaries should be calculated, can be selected by 'Starting Date' and 'Ending Date' list boxes. By default, starting date it set to 1950 and ending date is set to the current year. Hence, all data that are available in the database will be used by default.

Once the user selects a water quality parameter and determines the time period, the analysis system automatically searches through the database and extracts all measurements that fall into these criteria. ‘Data Summary’ part of the dialog is used to display the summary of the results. Actually, this part of the dialog is dynamic in nature and updates itself automatically, if any change occurs in the selection of water quality parameter or specified time period. This is illustrated in Figure 5.15.

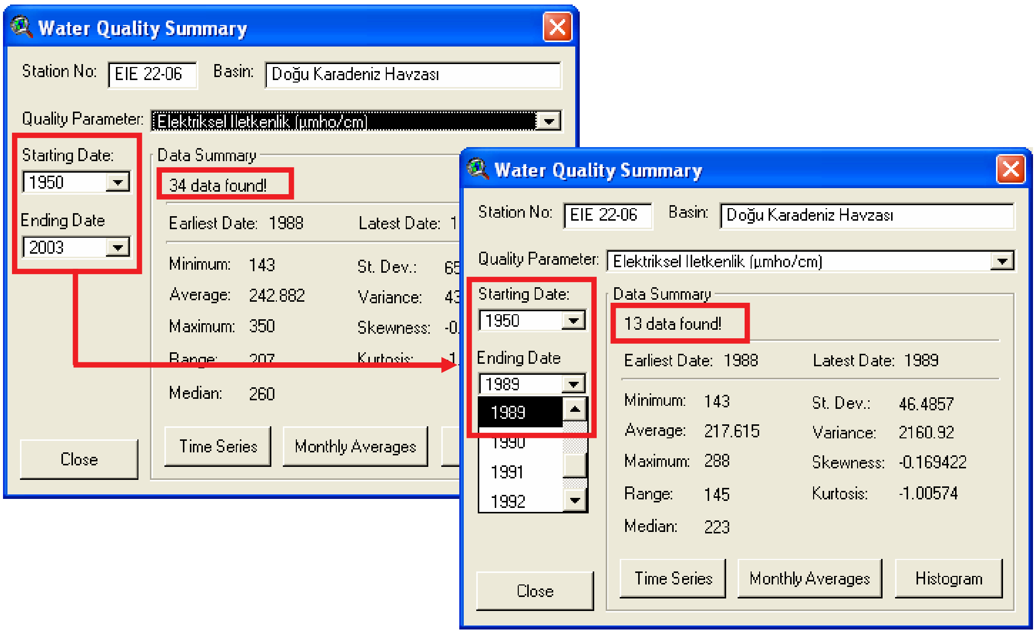


Figure 5.15. Time dependency of water quality summary calculations

In this part, first the number of records that are extracted from the database is given. If no data are found, it is specified as well. Earliest and latest monitoring dates of the found measurements are indicated separately, since they may differ from the starting and ending dates specified by the user. For a first-sight-evaluation of the data, nine different statistics (maximum, minimum, average, median, range, variance, standard deviation, skewness and kurtosis) are calculated and shown in ‘Data Summary’ frame. Equations that are used to calculate statistics are given in Table 5.4.

Table 5.4. Water quality statistics

Statistic	Formula
Maximum (C_{max})	$Max(C_i)$
Minimum (C_{min})	$Min(C_i)$
Median	$\begin{cases} n = odd & C_{[(n-1)/2]+1} \\ n = even & (C_{(n/2)+1} + C_{n/2})/2 \end{cases}$
Range	$C_{\max} - C_{\min}$
Average (C_{avg})	$\sum_{i=1}^{n} C_i \Big/ n$
Variance (σ^2)	$\sum_{i=1}^{n} (C_i - C_{avg})^2 \Big/ (n-1)$
Standard Deviation (SD)	$\sqrt{\sigma^2}$
Skewness	$n \cdot \sum_{i=1}^{n} (C_i - C_{avg})^3 \Big/ (n-1)(n-2)SD^3$
Kurtosis	$\dfrac{n(n+1)\sum_{i=1}^{n}(C_i - C_{avg})^4 - 3(n-1)\left(\sum_{i=1}^{n}(C_i - C_{avg})^2\right)^2}{(n-1)(n-2)(n-3)SD^4}$
where; C_i = measured quality parameter value, n = number of measurements	

Besides summary statistics, evaluation of the complete data is also possible in terms of graphs. Three different types of graphs can be created by the system: time series graph that shows all of the found measurements, monthly averages graph that is obtained by taking the averages of the measurements based on the months of a year, and histogram of the measurements that shows the distribution of measurements with respect to each other. These charts are accessible through the three buttons located at the bottom of 'Water Quality Summary' dialog (Figure 5.16). Time series bar chart includes all measurements of the water quality parameter between the selected starting and ending years. If starting and/or ending years are outside the measurement period limits (earliest-latest measurement years) than the limiting years are taken as minimum and/or maximum value of the time axis. Months without measurement are indicated as 'No Data' on the graph. Therefore, missing monitoring data can be easily determined from the time series graph. 'Info' tool on the toolbar can be used to obtain numerical value of the measurement at a specified time.

Figure 5.16. Charts accessible from Water Quality Summary dialog

Monthly averages bar chart is formed by calculating monthly average values of measurements that are found from the database. Time series and monthly averages graphs have similar characteristics. Like time series graph, if there do not exist any data through the selected time period for a month, than the monthly average value is indicated as 'No Data' in the monthly averages graph. Using 'Info' tool, the user may determine the numerical value at a specified month, and also he/she can learn how many data are used to calculate the monthly average. Last graph that can be reached from 'Water Quality Summary' dialog is the histogram of measurements. The range of water quality measurement values is divided into five equal intervals, and the number of measurements that fall into each interval is counted. The result is turned into a histogram, the axes being the number of measurements and mid points of the intervals. This histogram shows time independent distribution of the measurements and their grouping with respect to their magnitude. Therefore it can be used to identify the type and shape of the distribution, and also possible outliers. Like the graphs of 'Discharge Information' dialog, the graphs of 'Water Quality Summary' dialog are fully customizable by the user, and they can be inserted into ArcView Layouts for reporting purposes.

Thematic maps of water quality stations with respect to statistical summaries can be created using 'Water Quality Classification' tool. Water quality classification tool button located on the toolbar of View window can be used to display 'Water Quality Classification' dialog (Figure 5.17). In order to create a thematic map, the user should first choose a water quality parameter from the list box located at the top of the dialog. Then several classification criteria should be determined, which are organized in three different sections on the dialog. First section includes controls related with time period selection. The user may use two list boxes to choose starting and ending years, for which statistical summaries will be calculated. Alternatively, check box located at the bottom of list boxes can be used to process all available data in the database. In this case, time period limits are not taken into consideration and all available data will be used to calculate the statistics. 11 different statistics can be used for thematic mapping. Available statistics are count, average, maximum, minimum, median, range, standard deviation, skewness, kurtosis, variance and threshold. Equations for these statistics (except threshold) are given in Table 5.4. Threshold requires the user to specify a threshold value, which is used to group the stations into two classes according to greatness of their average statistics from the threshold value. Last section on the dialog is related with classification type that will be used for thematic mapping. Four different classification methods are available, each of which will result in different class limits, hence different thematic maps for the same data. Equal interval, natural breaks, quantile and standard deviation classifications can be selected by the user. For detailed description of these methods the user should refer to ArcView GIS Users Manual (ESRI, 1999). Desired number of classes can also be specified. By default, equal interval classification with 5 distinct classes is used for thematic mapping. After selection of classification criteria, the user should press 'Create Thematic Map' button to finalize thematic mapping process. A new water quality monitoring stations layer will be added to the active ArcView Project, the legend of which is set according to specified classification. Dots with different sizes are used to represent each class as illustrated in Figure 5.17. Water quality monitoring stations that do not have any measurement for the given time period are also separately indicated. Obtained thematic map is very informative, since it shows both geographic and numerical distribution of a water quality parameter over the surface water bodies and watersheds. Using this map, problematic locations with low environmental quality can easily be determined. Also change in water quality along a stream, both in up-stream and down-stream directions, can be evaluated.

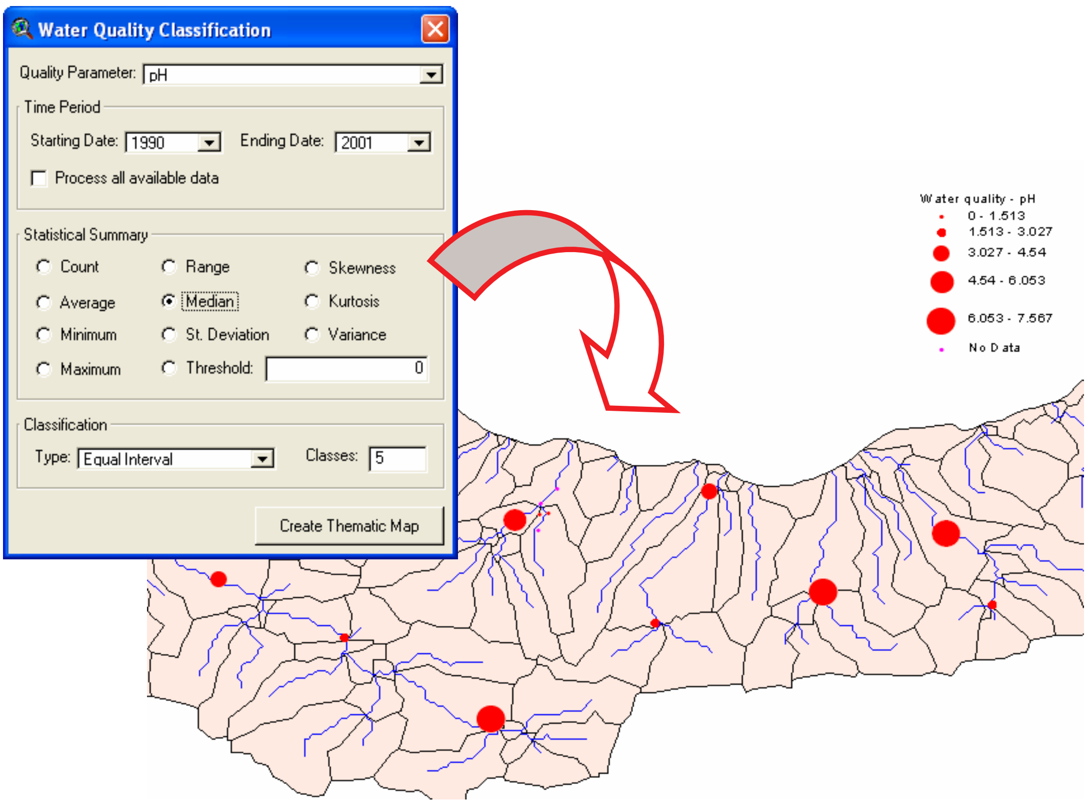


Figure 5.17. Water quality classification tool and resulting thematic map

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The primary aims of the study were development of national hydrography and watershed datasets that can be used in GIS to support water resources related studies, and development of analysis tools for local hydrometric and water quality data. The works done in the study for these purposes can be summarized step-by-step as follows:

- Determination of watershed boundaries beyond 26 large national basins, which can be used as cataloging units for hydrographic features,

- Development of a prototype national hydrography dataset that covers nation's water courses and inland water bodies,

- Development of GIS-based spatial tools that facilitate analyses on produced national watershed and hydrography datasets, and

- Development of state-of-the-art stream flow and water quality data analysis system that is based on the structure of nationally available data.

First two steps in this list can be termed as data preparation steps, in which already existing data sources are collected, evaluated and processed according to the needs of the study to create new, value-added datasets. In the third step several tools are developed to facilitate working with the produced datasets. Finally in the last step, the datasets are used as building blocks in addition to a custom designed database for the development of an analysis system that targets water quantity and quality related data

In order to determine the watershed boundaries and drainage network, first a widely-used and proven DEM-based watershed delineation method that is based on D8 algorithm of Jenson and Domingue (1988) has been utilized. The best public access DEM that is currently available for Turkey (SRTM30) is used as the base dataset for the calculations. Although obtained results were satisfactory in general, invalid drainage networks are obtained for closed basins. Also especially in flat areas, unnatural linear drainage lines are observed. In order to correct the drainage network in the closed basins and their boundaries, water bodies located at the center of such basins are extracted from satellite imagery-based land cover data and marked as “sinks” in the DEM. Application of D8 algorithm to this lake-aware DEM solved the problems related with invalid drainage networks. However, unnatural drainage lines could not be corrected until a modified version of D8 algorithm has been applied. Algorithm developed by Garbrech and Martz (1997), which takes the relief around the flat areas into account to determine the flow direction, gave very satisfactory results with lake-burned DEM and increased the accuracy in a significant amount. Hence, flow direction grid produced by this method is used for the final analysis, and drainage network and watershed boundaries are determined accordingly. Concordance of generated watershed boundaries with the boundaries of already existing 26 major basins is examined, and it is found that DEM-based watershed boundaries are quite accurate. Likewise, calculated drainage network is compared with actual stream network, and both networks are found to be very similar to each other. Obtained watersheds are used as cataloging units for the further steps of the study. Calculated DEM-derivatives (flow direction and flow accumulation grids), which are used as input to watersheds delineation step, are further utilized in the development of dynamic watershed delineation tool and they are included to the final hydrography dataset as supplementary layers. DEM-base drainage network dataset is also made available as a supplementary layer.

Catchment coding system of EU, which is termed as ERICA-CS, is applied to watersheds derived from the DEM and the watersheds are named accordingly. ERICA-CS is found to be quite satisfactory and easy-to-apply coding system, which facilitates the naming process. Also since coding systematic takes the position of catchments in the stream network into consideration and nested catchment identifiers are assigned accordingly, it provides means of up-stream/down-stream navigation through the watersheds. To utilize this property, watershed navigation tools are developed within GIS and made available to the user. This study is most probably one of the first studies that applied ERICA-CS coding system and also developed tools are the first in their kinds.

For the development of hydrography dataset, several map sources are evaluated according to cost, public availability, map format, scale, accuracy, and labor requirement criteria. Among the alternatives, VMAP-0 vector dataset has been selected as the base dataset for the study, whereas the other sources are used as reference. Water courses and inland waters sub-layers of hydrography thematic layer of VMAP-0 are processed in several ways to end up with an accurate hydrography dataset. Water bodies that are missing from inland water bodies sub-layer are added to the dataset. Also the water bodies that have different boundaries from generally accepted ones are corrected and unnamed water bodies are named. The majority of correction and validation works are done on water courses sub-layer. In this sub-layer, wrong stream lines directions are corrected, connectivity of stream network is established through inland water bodies and at stream line intersections, missing stream lines are added, excess ones are removed and textual attribute data are updated mostly by adding previously unknown names to stream reaches. Once these corrections are made, additional attribute data are calculated and entered to the related database tables. Additional data include mainly hydrologic properties such as stream length, slope, and order. Also for each stream line a unique identifier is assigned and starting/ending nodes are extracted. These nodes and unique identifiers are used for up-stream/down-stream navigation through the stream network. For this purpose custom navigation tools are developed within the GIS, which can easily be accessed through the user interface buttons.

In the last part of the study, a GIS-based data analysis and visualization system has been developed for stream flow and water quality data that are collected in Turkey. The analysis system is built on a database structure, which is designed according to format of data collected by various governmental organizations. A graphical user interface is developed on top of the GIS, which utilizes dialogs, tables, charts and maps to visualize data stored in the database and results of various data analyses. A number of spatial and statistical analysis tools are made available to the user, which can be used to determine trends in data, to calculate representative summaries and to create thematic maps. A coverage map of stream flow gauging and water quality monitoring stations is prepared, through which the user can access detailed information on stream flows and water quality measurements. Related with stream flow, daily average discharges, monthly discharge summaries, and water year summaries are made available both as textual data in dialogs and as interactive charts. Similarly, statistics of measured water quality parameters, their time-series graphs, and yearly summaries are made available. Tools for classification of water quality stations with respect to a set of water quality statistics are also developed and integrated to the analysis system. As a whole, developed system can be termed as a comprehensive GIS-based data analysis and visualization framework that can be used for local stream flow and water quality data collected in Turkey. A similar system having such wide range of features was not developed before; hence the system can be claimed to be an important progress for Turkey.

At the end of the study, it can be concluded that the targets aimed at the beginning of the study are fulfilled in a satisfactory manner. Prototype national hydrography and watershed datasets are created at a scale of 1:1,000,000. Basic quality assessments are done and the datasets are validated. GIS-based tools are developed for navigation through water courses and watersheds. Finally, a comprehensive data analysis and visualization system is developed for water quality and quantity data collected by national governmental institutions. It is hoped that the study will set an example for future works, and its products will be useful to all people working on topics related with surface water resources of Turkey.

The following recommendations are believed to be enlightening for the future studies and further development of hydrography dataset, watershed boundaries, supporting tools, and water quantity and quality data analysis system:

- Although maps, charts and tables generated by stream flow and water quality analysis tools can be easily inserted into layout documents and print-outs can be taken from GIS, presence of reporting tools with pre-defined layouts will be very useful. Especially layouts, which are similar to layouts in daily discharge and water quality yearbooks may facilitate reporting needs, and hence may increase the interest on the analysis system.

- Success of the developed analysis system definitely depends on the available data, which can be used by the system. Although tools to facilitate data entry are present in the system and for small studies the required data can be entered manually, it is still very difficult to collect and enter data for regional or national studies. Especially if the study should cover a long time period, then this task becomes very labor extensive. An institutional framework and support of related organizations, i.e. SHW and EPRDA, are required to overcome this problem. Data collected by these organizations, which are already available in digital format, could be transformed into database format used by the analysis system, or analysis system can be extended to support existing data structures (if there exist any). Cooperation with governmental organizations is required in this respect.

- In its current state, the analysis system supports only stream flow gauging and water quality monitoring stations. However, there also exist other types of monitoring stations, at which different types of hydrologic data are collected. Lake monitoring, snow monitoring and meteorological stations of different governmental organizations (e.g, SHW, EPRSDA, SMW) can be listed as example. Supporting these stations and providing analysis tools for the data collected at these stations, should be one of the first extensions to the current system. There were several studies conducted in the past, especially for meteorological stations (Şendeniz, 1999), from which ready-made data can be taken with permission and incorporated to the analysis system. This will shorten the time required for additional development.

- Water quality and quantity data are crucial for many applications related with water resources. In the current situation, there exist several governmental institutions in Turkey that collect these data independently from each other. Although the formats of collected data are quite similar, storage techniques differ from institution to institution. This results in various difficulties, especially in data access. National databases for the storage and retrieval of water quality and quantity measurements, which should be shared and operated together by related institutions, are a major requirement. Reliable and long-lasting studies and applications on water resources can be supported only in this way. There are many countries in the world that have such systems for quite a long time, so there is no reason not to have a similar one for Turkey. Developed analysis system and its database structure are not the answer for these needs. Definitely, there is a requirement for stronger tools and databases that support distributed data access and storage, variable user privileges, advance query capabilities, and better data visualization and analysis. But, this study is a good example which shows what is available at hand, what should be done, and how GIS can be used to solve encountered problems. The methods used in the study may guide the works for a national water resources database in this respect, and hence should be taken into consideration.

- As indicated several times in various chapters, there are 26 major basins in Turkey, which are used extensively for water resources related studies. SHW and EPRSDA prepare development plans based on the extents of these watersheds, hydrometric data monitoring stations are distributed and named accordingly, and also available hydrometric data are organized with respect to them. However, although they are so widely used by various organizations, there is no common agreement on the boundaries of these major watersheds. Two major institutions, SHW and EPRSDA, have determined different watershed boundaries in time and they are resisting to use a common set of watershed boundaries. The case for watershed names is also similar. Like the boundaries, these organizations have different watershed names. It is definitely nonsense to have such a situation, and it complicates referencing to watersheds in the studies. Also this situation distrusts studies that aim to develop sub-watershed boundaries, like the one mentioned so far. If there is disagreement even for the major watersheds, how can it be possible to have common sub-watersheds? This is really questionable, and should be corrected as soon as possible. Common boundaries and names should be determined for major watersheds, and studies should be conducted to decide the delineations of sub-watersheds. The methods used in this study and obtained catchment boundaries may guide such studies. Even they can be used as prototype sub-watershed boundaries.

- In order to show the applicability of produced hydrography dataset, watershed boundaries and corresponding spatial analysis tools (i.e. watershed navigator, stream line navigator, dynamic watershed delineation tool), they should be used in water resources related studies and their success should be evaluated. Due to time restrictions, such sample applications could not be conducted as a part of the thesis study. However there are many possible applications that can be realized easily. For example using dynamic watershed delineation tool, the drainage areas of stream flow gauging stations can be delineated and their surface area can be calculated. By comparing calculated values with the values indicated in yearbooks, validation of yearbook values can be done, which are highly criticized due to their low accuracies (Kulga and Dizdar, 1994). Another application may be indexing of stream flow gauging and water quality stations to stream reaches. In this way, water quality and quantity measurements at the stations can be overlaid to the stream network and by simple thematic mapping water quality and quantity distribution along the network can be visualized. Such maps will be very useful, since they will summarize significant amount of information and present it in an easy to understand format. An interesting application may be the visualization of time-wise change in water quality and quantity. Charts available from stream flow and water quality information tools, and thematic maps available from water quality analysis tools can be created for different water years and by showing them one after another an animation can be formed that will illustrate time-wise change in measured parameters. Such an animation will be a very effective presentation aid, also it will facilitate realization of time-dependence of water quality and quantity in water resources. Once having the dataset and analysis tools developed in the study at hand, many similar applications can be planned and conducted. As stated at the beginning, such applications will be very useful to show the importance of national hydrography and watershed datasets and may result in further developments, like production of better quality datasets or more featured analysis tools. Further studies are required in this respect.

- Although the scales and accuracies of the produced hydrography and watershed datasets will most probably be sufficient for initial studies, as different applications will come to existence they may not fulfill the needs. Better quality datasets, especially from national sources, should be evaluated periodically and as they become available they should be processed and incorporated into national datasets. Availability of 1:250,000 scale dataset will definitely broaden the application areas of hydrography dataset, in addition to increase in accuracy and detail. Similarly, watershed boundaries that will be determined from a DEM with finer grid spacing will be much more accurate than current boundaries, which are based on coarse, 30-arc seconds grid spacing. 3-arc seconds SRTM dataset, which will be made available before the mid of 2004, offers an important opportunity in this respect, and up to ten times increase in accuracy may be expected if this dataset will be utilized. Hence, the topic of one of the future studies may be the determination of watershed boundaries from 3-arc seconds SRTM DEM for Turkey.

- Although several attribute data are calculated and included to the hydrography and watershed datasets, additional attributes are also possible. Especially attributes related with stream flow like peak and average discharge, flow depth, width and velocity, will be very useful for hydrologic and water quality modeling purposes. Most of the data required for estimation of these attributes are made available as a result of the study. Stream network delineations given in hydrography dataset, locations of gauging stations given in stations coverage, supplementary (elevation, land use, etc.) data that are made available as separate layers, and stream flow data stored in the database can be listed for this purpose. There are several studies in the literature that utilized such data to calculate stream flow statistics at ungauged sites. For example a neural network based method, which uses drainage area and elevation as input, has been applied to U.S. Reach Files for the prediction of two-year peak stream discharges at each reach (Muttiah et al., 1997). Flow width and depth are also calculated by using empirical equations that are derived from regression analysis, in which discharge is the only independent variable (Allen et al., 1994). Flow statistics can also be calculated by using advanced software packages specially designed for this purpose, which consider additional data like precipitation and soil types. Micro LOW FLOWS developed by Institute of Hydrology in Wallingford, UK can be given as an example (Young et al., 2000). Hence, an extension to the current study can be estimation of stream flow and related parameters by incorporating appropriate methods. If it can be conducted, such a study will be definitely a major progress in the history of Turkish hydrology.

- In the study, D8 flow routing algorithm that is based on principles stated by Jenson and Domingue (1988), and one of its modifications by Garbrecht and Martz (1997) are utilized. D8 is one of the simplest methods to determine the flow directions in a DEM. There are also other methods like Rho8 (Fairfield and Leymarie, 1991), FD8 (Quinn et al., 1991), Aspect-driven single flow direction (Lea, 1992), DEMON (Costa-Cabral and Burges, 1994) and D∞ (Tarboton, 1997). Although majority of these methods are developed for more advanced hydrological modeling purposes, some of them can also be used to determine the watershed boundaries. Application of different methods will most probably result in different flow directions and hence different drainage network and watershed boundaries. Although results obtained from the modified version of D8 are found to be sufficiently accurate for the study, evaluation of other methods may also give important information related with suitability of these methods to Turkey. Especially for studies related with rainfall-runoff and non-point source pollution modeling, use of a different method may be more appropriate. This should be taken into consideration and applicability of D8 algorithm should be assessed.

REFERENCES

Allen, P. M., Arnold, J. G., and Byars, B. W., 1994, Downstream Channel Geometry for Use in Planning-Level Models, Water Resources Bulletin, Vol. 30, No. 4, August, 1994

Baltacı, F., 2003, Drinking water sector and environment in Turkey, in Proceedings of Effects of Pollution in Inland Waters of Turkey and Solution Proposals, Directorate of Drinking Water and Sewerage Department, General Directorate of State Hydraulic Works, June 2002, Ankara

Belward, A.S., ed., 1996, The IGBP-DIS global 1 km land cover data set (DISCover)-proposal and implementation plans: IGBP-DIS Working Paper No. 13, Toulouse, France

Costa-Cabral, M. C., and Burges, S. J., 1994, Digital elevation model networks (DEMON): a model of flow over hillslopes for computation of contributing and dispersal areas. Water Resources Research, Vol. 30, No. 6, pp 1681-1692

Danielson, J.J., 1996. Delineation of drainage basins from 1 km African digital elevation data. In: Pecora Thirteen, Human Interactions with the Environment - Perspectives from Space, Sioux Falls, South Dakota, August 20-22, 1996

DMA, 1987, Product specifications for Operational Navigation Charts (ONC) Scale: 1:1,000,000. First edition 1981 and changes/amendments thereto, Defense Mapping Agency, Washington, D. C.

DOD, 1992, Millitary Specification Digital Chart of the World (DCW)

DOD, 1995, Millitary Specification Vector Smart Map (VMap) Level 0

EPRSDA, 1996a, 1992 Water Year Discharges, Directorate of Hydraulic Surveys Department, General Directorate of Electrical Power Resources Survey and Developmeng Administration, Publication No. 95-25, ISBN 975-7566-49-7, Ankara

EPRSDA, 1996b, Water Quality Data for Surface Waters in Turkey, Directorate of Hydraulic Surveys, General Directorate of Electrical Power Resources Survey and Developmeng Administration, Ankara

EPRSDA, 2003, Monthly Average Discharges (1935-2000), Directorate of Hydraulic Surveys Department, General Directorate of Electrical Power Resources Survey and Developmeng Administration, Ankara

Eren, K., 1999, Lecture Notes of GGIT 707, GPS and GIS Integration, METU, Ankara

ESRI, 1993, The Digital Chart of the World for use with ARC/INFO – Data Dictionary, Environmental Systems Research Institute Inc.

ESRI, 1999, ArcView 3.2 Users Manual, Environmental Systems Research Institute Inc.

ESRI, 2002, Hydrology Modeling Extension for ArcGIS 8.x, Environmental Systems Research Inc.

Fairfield, J. and Leymarie, P., 1991, Drainage networks from digital elevation models, Water Resources Research, Vol. 27, No. 5, pp 709-717

Farr, T.G., and Kobrick, M., 2000, Shuttle Radar Topography Mission produces a wealth of data, Amer. Geophys. Union Eos, v. 81, p. 583-585

Flavin, R. W., Andrews, A. J., Kronvang, B., Müller-Wohlfeil, D., Demuth, D. and Birkenmayer, A., 1998, ERICA – European Rivers and Catchments, A report to the European Environment Agency on the compilation of a 1:1M Catchment Geographic digital database (ERICA-1M) and two 1:250K pilot studies, European Environment Agency, June 1998

Garbrecht, J. and Martz, L. W., 1997, The Assignment of Drainage Direction Over Flat Surfaces in Raster Digital Elevation Models, Journal of Hydrology, 193:204-213.

GCM, 1998, Administrative Units Map of Turkey, General Command of Mapping, Ankara

GDRS, 1993, Precipitation-Runoff Yearbook of Research Institute Watersheds (1991 Water Year), Directorate of Land and Water Resources Research Department, General Directorate of Rural Services, Publication No: 75, Ankara

Gesch, D.B., 1994, Topographic data requirements for EOS global change research, U.S. Geological Survey Open-File Report 94-626

Girgin, S., Akyürek, Z. and Usul, N., 2003, Development of Hydrographic Dataset for Turkey: Initial Studies, Proceedings of Prague 2003 – Sixth International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe and the Commonwealth of Independent States, 1-4 September 2003, Prague, Czech Republic

GLOBE Task Team and others (Hastings, D. A., Dunbar, P. K., Elphingstone, G. M., Bootz, M., Murakami, H., Maruyama, H., Masaharu, H., Holland, P., Payne, J., Bryant, N. A., Logan, T. L., Muller, J.-P., Schreier, G., and MacDonald, J. S.), eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A. Digital data base on the World Wide Web and CD-ROMs.

Haines, G., 2001, Aselect Connect AVENUE script for ArcView 3.2, Lheidli T'enneh First Nation Prince George, B. C., February 12, 2001

Hastings, D. A., and Dunbar, P. K., 1999. Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Documentation, Volume 1.0. Key to Geophysical Records Documentation (KGRD) 34. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A.

Horby, D. D., 2002a, Node information generation tools extension for ArcView 3.2, 24 December 2002

Horby, D. D., 2002b, Strahler extension v3.0 for ArcView 3.2, 20 February 2002

Horn, C. R., Hanson, S. A. and McKay, L. D., 1994, History of the U.S. EPA's River Reach File: A National Hydrographic Database Available for ARC/INFO Applications, Office of Wetlands, Oceans, and Watersheds, U.S. EPA

Jenson, S. K. and Domingue, J. O., 1988, Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, Photogrammetric Engineering and Remote Sensing, 54.11:1593-1600

Jet Propulsion Laboratory, 1997, DEM auxiliary datasets preparation plan: digital elevation mapping support to the EOS/AM1 platform - JPL D13508, Release 2. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

Karagöz, İ., 1995, State Hydraulic Works Hydrometric Data Bank, Ph. D. Thesis, Civil Engineering Department, METU, Ankara

Kulga, Z. and Dizdar, M., 1994, Frequency Analysis of Maximum Discharges in Turkish River Basins, Directorate of Survey and Planning Department, General Directorate of State Hydraulic Works, Ankara

Langaas, S., 1995, Completeness of the Digital Chart of the World (DCW) database, Project Report No. 2/1995, UNEP/GRID-Arendal, Stockholm, Sweden

Langbein, W. B. and Iseri, K. T., 1983, Manual of Hydrology: Part 1. General Surface-Water Techniques, 3rd Ed., U.S. Government Printing Office

Lea, N. J., 1992, An aspect-driven kinematic routing algorithm. In Overland Flow: Hydraulics and Erosion Mechanics, edited by A. J. Parsons and A. D. Abrahams, Chapman and Hill, Newyork

Legleiter, K. J., 2001, Interagency Development of National Watershed and Subwatershed Hydrologic Units, 33th ESRI International Users Conference, 2001

Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, J, Yang, L., and Merchant, J. W., 2000, Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data: International Journal of Remote Sensing , v. 21, no. 6/7, pp 1303-1330

Morris, D. G. and Kronvang, B., 1994, Report on a study into the state of river and catchment boundary mapping in the EC and the feasibility of producing an EC-wide river and catchment boundary database, January 1994

Muttiah, R. S., Srinivasan, R., and Allen, P. M., Prediction of Two-year Peak Stream Discharges Using Neural Networks, J. American Water Resources Association, Vol. 33, No. 3, June, 1997

NIMA, 1995, Military Specification MIL-V-89033 Vector Smart Map Level 1

NIMA, 2000, Vector Smart Map (VMap) Level 0 Meta Document

O'Callaghan, J. F. and D. M. Mark, 1984, The Extraction of Drainage Networks From Digital Elevation Data, Computer Vision, Graphics and Image Processing, 28: 328-344

Official Gazette, No.20748, Water Pollution Control Regulation Technical Aspects Bulletin, Ratified in 7 January, 1991

Quantitative Decisions, 2000, FlipLine extension for ArcView 3.2, Quantitative Decisions, Merion, PA

Quinn, P., Beven, K., Chevalier, P., and Planchon, O., 1991, The prediction of hillslope flow paths for distributed hydrological modeling using digital terrain models, Hydrological Processes, Vol 5., pp 50-79

Richardus, P., and Adler, P. K., 1972, Map projections for geodesists, cartographers, and geographers, Amsterdam

Row, L.W., and D.A. Hastings, 1994. TerrainBase Worldwide Digital Terrain Data on CD-ROM, Release 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, Colorado

Row, L. W., Hastings, D. A., and Dunbar, P. K., 1995, TerrainBase Worldwide Digital Terrain Data, Documentation Manual, CD-ROM Release 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, Colorado

Saraf, A. K., 2000, Grid Analyst Extension v1.1, Department of Earth Sciences, University of Roorkee, India, 18 May 2000

Seaber, P., Kapinos, F. P., and Knapp, G., 1987, Hydrologic Unit maps, United States Department of Interior, US Geological Survey, Water Supply Paper 2294, 63 pp.

SHW, 1987, Water Quality Monitoring Yearbook (1983-1984), Directorate of Drinking Water and Sewerage Department, General Directorate of State Hydraulic Works, Ankara

SHW, 1988, Album of Discharge Monitoring Network, Directorate of Survey and Planning Department, General Directorate of State Hydraulic Works, May 1988, Ankara

SHW, 1992, Map of Dams, Power Stations and Irrigation Establishments in Turkey, Directorate of Survey and Planning Department, General Directorate of State Hydraulic Works, Ankara

SHW, 1999, 1994 Discharge Monitoring Yearbook, Directorate of Survey and Planning Department, General Directorate of State Hydraulic Works, Ankara

SHW, 2001, 1999 Statistical Bulletin with Maps, Directorate of Research, Planning and Coordination Department, General Directorate of State Hydraulic Works, Publication No. 991, Group No. VIII, Special No. 177, Ankara

SHW, 2003, Water Quality Monitoring Work Plan of 2003, General Directorate of State Hydraulic Works, Ankara

Snyder, J. P., 1987, Map projections: a working manual, USGS Professional Paper 1395, Washington, DC., United States Government Printing Office

Şendeniz, İ., 1999, GIS Application for Monthly Precipitation Data in Turkey, M. S. Thesis, METU, Ankara

Tarboton, D. G., 1997, A New Method for the Determination of Flow Directions and Contributing Areas in Grid Data Elevation Models, Water Resources Research, 33(2):309-319

Tarboton, D. G., 2000, TARDEM: A suite of programs for the Analysis of Digital Elevation Data, Utah State University, May 5, 2000

U.S. EPA, 1994, The U.S. EPA Reach File Version 3.0 Alpha Release (RF3-Alpha) Technical Reference, First Edition, December 1994

U.S. Geological Survey, ed., 1997a. GTOPO30 Digital Elevation Model. U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota

U.S. Geological Survey, 1997b. GTOPO30 Documentation (README File). U.S. Geological Survey, EROS Data Center, Sioux Falls, South Dakota

U.S. Geological Survey, 2000, The National Hydrography Dataset Documentation – Concepts and Contents, U.S.A.

USGS, 2003, SRTM30 Documentation, http://edcsgs9.cr.usgs.gov/pub/data/srtm/SRTM30/SRTM30_Documentation/

Verdin, K.L., and Greenlee, S.K., 1996. Development of continental scale digital elevation models and extraction of hydrographic features. In: Proceedings, Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, January 21-26, 1996. National Center for Geographic Information and Analysis, Santa Barbara, California.

Young, A. R., Gustard, A., Bullock, A., Sekulin, A. E., and Croker, K. M., 2000, A river network based hydrological model for predicting natural and influenced flow statistics at ungauged sites: Micro LOW FLOWS, The Science of the Total Environment, Vol.251/252, pp 293-304

Internet Resources

URL 1.1: NHD Data Download, http://nhd.usgs.gov/data.html, Date visited: 11/5/03
URL 1.2: NHD Tools, http://nhd.usgs.gov/toos.html, Date visited: 11/7/03
URL 1.3: http://www.dsi.gov.tr/kararnam.htm, Date visited: 12/1/03
URL 1.4: SHW Land and Water Resources of Turkey, http://www.dsi.gov.tr/toprak.htm, Date visited: 12/4/03
URL 2.1: Digital Chart of the World, http://www.lib.ncsu.edu/stacks/gis/dcw.html, Date visited: 10/20/03

URL 2.2: DCW Data Description,
http://www.lib.ncsu.edu/stacks/gis/dcwdesc.html, Date visited: 8/5/03
URL 2.3: Digital Chart of the World Fact Sheet,
http://www.esri.com/data/catalog/esri/dcw_fact.html, Date visited: 7/16/03
URL 2.4: DCW Utilities Directory,
http://www.lib.ncsu.edu/stacks/gis/dcw_util.html, Date visited: 8/10/03
URL 2.5: Digital Chart of the World,
http://www.lib.ncsu.edu/stacks/gis/dcw.html, Date visited: 8/10/03
URL 2.6: Digital Chart of the World Fact Sheet,
http://www.esri.com/data/catalog/esri/dcw_fact.html, Date visited: 8/8/03
URL 2.7: DCW Naming Convention,
http://www.lib.ncsu.edu/stacks/gis/dcwname.html, Date visited: 8/10/03
URL 2.8: DCW Data Server at Pennsylvania State University Libraries,
http://www.maproom.psu.edu/dcw, Date visited: 8/9/03
URL 2.9: GIS Data Depot,
http://www.gisdatadepot.com/data/catalog, Date visited: 8/11/03
URL 2.10: Digital Chart of the World (DCW) Metadata,
http://agdc.usgs.gov/data/projects/pws/metadata/pwsmeta164.html
URL 2.11: http://www.mapability.com/info/vmap1_intro.html, Date visited: 10/9/03
URL 2.12: GCM Digital Maps, Date visited: 11/10/03
http://www.hgk.mil.tr/urunler/haritalar/yurticiuretim/sayisal/sayhar.htm
URL 2.13: Cost of GCM Products,
http://www.hgk.mil.tr/urunler/satis/satis1.htm, Date visited: 11/10/03
URL 2.14: http://dss.ucar.edu/datasets/ds759.2/data/tbase_doc, Date visited: 11/1/03
URL 2.15: U.S. Navy (FNOC) 10-minute Elevation,
http://www-cger.nies.go.jp/grid-e/gridtext/grid2.html, Date visited: 1/2/03
URL 2.16: TerrainBase Global Land Elevation and Ocean Depth,
http://dss.ucar.edu/datasets/ds759.2/data/tbase_doc, Date visited: 2/5/03
URL 2.17: SRTM Mission, Why Map the Earth,
http://www.jpl.nasa.gov/srtm/mission.htm, Date visited: 11/8/03
URL 2.18: SRTM Data Products,
http://www.jpl.nasa.gov/srtm/dataprod.htm, Date visited: 11/10/03
URL 2.19: SRTM Mission, SRTM Data Products,
http://www.jpl.nasa.gov/srtm/dataprod.htm, Date visited: 11/10/03
URL 2.20: NASA Shuttle Radar Topography Mission,
http://www.jpl.nasa.gov/srtm/index.html, Date visited: 11/8/03
URL 2.21: Shuttle Radar Topography Mission (SRTM) Historic Mission,
http://www.nima.mil/cda/article/0,2311,3104_74037_113538,00.html
URL 2.22: SHW Monitoring Works, Date visited: 10/17/03
http://www.dsi.gov.tr/baskanlik/etud/epd_gozlem.htm,
URL 2.23: Real-Time Map of U.S. Streamflow,
http://water.usgs.gov.waterwatch, Date visited: 7/4/03
URL 2.24: EPRSDA Hydrologic Works, http://www.eie.gov.tr/turkce/hidroloji
URL 2.25: Information on Hydrologic Monitoring Stations,
http://www.eie.gov.tr/turkce/hidroloji, Date visited: 11/19/03
URL 2.26: Sediment and Water Quality,
http://www.eie.gov.tr/turkce/hidroloji/sedim.html, Date visited: 9/17/03

APPENDIX A

AVAILABLE HYDROMETRIC AND WATER QUALITY DATA FOR TURKEY

22 - DOĞU KARADENİZ HAVZASI

22-06 - ABUÇAĞLAYAN D.-KÖPRÜBAŞI

YERİ :(41° 14' 0" D - 41° 15' 0" K) FINDIKLI-ARHAVİ SAHİL YOLUNDA FINDIKLI ÇIKIŞINDA SAĞA AYRILAN ÇAGLAYAN KÖYÜ 4.KM'SİNDEKİ KÖPRÜDEDİR.
HARİTA NO:F-46

YAĞIŞ ALANI : 156 Km² YAKLAŞIK KOT : 60 m.

GÖZLEM SÜRESİ :01/10/1965 - 30/09/1994

ORTALAMA AKIMLAR :Gözlem süresinde 9.160 m3/sn. (22 Yıllık) 1994 Su yılında 8.310 m3/sn.

ANLIK EN ÇOK VE EN AZ AKIMLAR:

1994 Su yılında anlık ençok akım	:	79.7	m3/sn	07/09/1994
1994 Su yılında anlık enaz akım	:	2.33	m3/sn	27/08/1994
Gözlem süresinde anlık ençok akım	:	350.	m3/sn	03/09/1974
Gözlem süresinde anlık enaz akım	:	0.724	m3/sn	23/10/1991

4 . Anahtar eğrisi (Seviyeler cm. - Akımlar m3/sn.)

Seviye	Akım	Seviye	Akım	Seviye	Akım	Seviye	Akım
86	2.15	166	34.2	246	81.5	326	137.
102	6.04	182	42.7	262	92.4	342	148.
118	11.6	198	51.8	278	104.	358	160.
134	18.4	214	61.7	294	115.	374	171.
150	25.7	230	71.6	310	126.	400	189.

AKIMLAR 1 EKİM 1993 'DEN 30 EYLÜL 1994 'A KADAR SANİYEDE METRE KÜP OLARAK

GUN/AY	EKİM	KASIM	ARALIK	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZİRAN	TEMMUZ	AĞUSTOS	EYLÜL
1	3.53	4.70	7.96	4.56	4.56	6.04	7.96	14.5	18.9	11.2	4.84	5.12
2	3.53	3.36	11.9	5.12	4.28	7.64	7.64	11.2	21.9	10.8	5.72	4.00
3	3.53	2.68	10.5	5.12	4.00	7.96	8.28	10.1	14.5	11.2	5.12	3.60
4	3.70	2.68	11.2	5.40	3.80	9.34	9.71	9.34	10.8	11.2	5.40	3.40
5	3.95	2.51	14.1	4.84	5.40	9.34	11.6	8.97	11.2	11.2	4.28	3.00
6	4.20	2.85	8.97	4.00	7.64	8.60	15.4	9.34	14.5	9.34	3.80	2.75
7	4.45	20.1	7.32	3.60	4.84	7.00	17.6	8.97	17.1	8.97	3.80	17.1
8	4.70	21.9	6.04	3.40	6.36	5.72	16.7	10.1	17.1	8.28	3.80	12.3
9	4.95	24.8	7.64	3.20	8.97	4.84	14.1	10.5	16.7	7.64	4.28	7.85
10	5.20	28.9	8.97	3.20	5.12	4.28	12.7	10.8	15.4	7.64	8.28	5.68
11	6.20	23.8	8.60	3.20	4.00	4.00	11.9	14.1	14.5	7.64	5.72	4.90
12	6.52	11.9	7.64	3.00	4.84	3.80	12.7	16.3	13.2	6.68	4.28	4.68
13	6.20	8.60	7.00	2.75	4.84	3.60	13.2	18.4	11.9	6.68	3.80	4.46
14	5.45	7.64	6.68	2.75	4.00	3.40	14.1	13.2	11.9	6.68	3.40	3.80
15	5.20	6.36	5.72	2.75	3.40	4.56	15.8	10.5	12.7	6.68	3.20	3.44
16	4.95	5.72	5.72	3.00	3.00	4.28	14.9	9.71	18.4	7.00	3.40	3.26
17	4.95	5.72	7.32	3.60	2.75	7.32	15.4	10.1	16.7	9.71	6.04	3.08
18	5.45	10.8	10.5	2.75	3.00	10.8	14.9	12.3	12.7	9.34	5.40	2.90
19	5.45	9.71	10.5	3.20	3.20	11.6	25.2	15.4	10.8	15.8	3.60	2.90
20	5.95	6.36	7.32	10.5	4.28	9.34	20.1	18.0	10.1	10.5	3.20	2.74
21	6.52	5.40	6.04	6.04	5.40	8.60	24.3	19.3	10.8	8.28	3.00	2.58
22	7.16	5.40	5.40	4.84	5.40	9.34	21.0	21.0	10.8	7.00	3.20	2.58
23	7.80	5.40	5.12	4.56	5.72	8.97	22.4	18.9	9.71	6.36	3.60	2.58
24	9.40	5.40	5.72	3.80	5.12	7.32	18.9	17.6	10.8	7.00	3.20	2.58
25	9.74	4.84	6.04	3.60	5.12	6.36	16.7	18.9	16.7	6.68	3.20	2.58
26	10.4	4.28	6.36	3.60	6.04	7.64	14.9	18.9	11.9	5.40	2.50	2.58
27	9.40	4.28	8.60	3.60	8.97	11.9	13.2	19.7	8.60	5.12	2.33	7.85
28	8.76	4.28	7.32	4.00	6.36	13.6	13.2	19.7	7.64	4.56	2.33	4.02
29	7.80	4.00	6.68	6.04	-----	14.5	13.6	18.0	7.64	4.56	8.28	3.08
30	6.84	3.60	6.04	6.04	-----	11.2	14.9	19.3	17.6	4.28	12.3	2.74
31	5.95	-----	5.40	6.36	-----	7.96	-----	19.3	-----	3.80	7.96	-----
Maks.	21.0	28.9	19.7	16.7	12.3	18.0	26.8	24.8	33.7	23.8	22.9	79.7
Min.	2.85	2.51	3.40	2.75	2.75	3.40	7.00	7.96	6.68	3.60	2.33	2.42
ORTALAMA	6.06	8.60	7.75	4.27	5.01	7.77	15.1	14.6	13.4	7.97	4.62	4.47
LT/SN/KM²	38.8	55.1	49.7	27.4	32.1	49.8	96.8	93.6	86.2	51.1	29.6	28.7
AKIM MM.	104.	143.	133.	73.3	77.8	133.	251.	251.	223.	137.	79.3	74.3
MİL. M3	16.2	22.3	20.8	11.4	12.1	20.8	39.1	39.1	34.8	21.4	12.4	11.6

SU YILI (1994) YILLIK TOPLAM AKIM 262.00 MİLYON M3 1680 MM. 53.2 LT/SN/KM²

Figure A.1. Sample page from SHW Discharge Monitoring Yearbook (SHW, 1999)

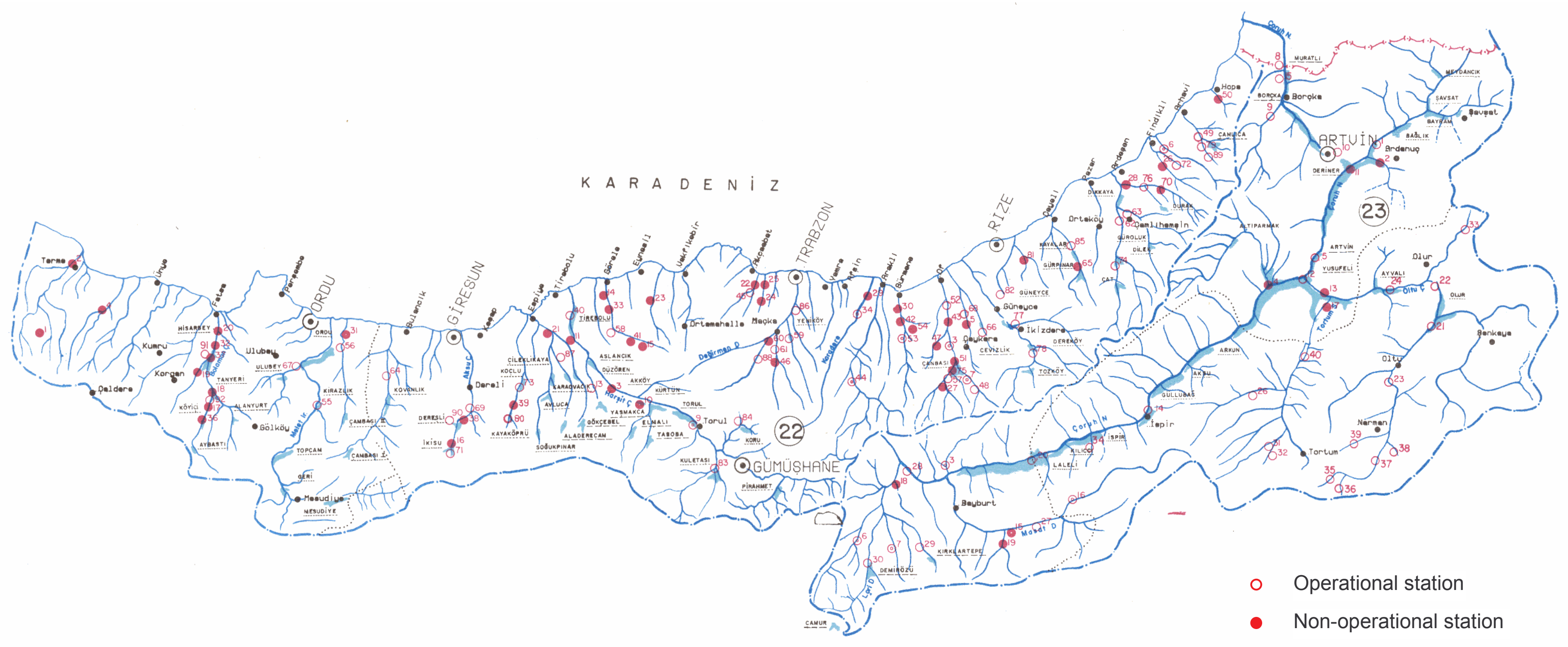


Figure A.2. Sample hydrometric monitoring network map from SHW Discharge Monitoring Yearbook (SHW, 1999)

Figure A.3. Sample map from SHW Discharge Monitoring Network Album (SHW, 1988)

DSİ GÖZLEM İSTASYONLARI TAKİP FORMU

Bölge No.	İSTASYON No	SUYUN VE İSTASYONUN ADI	AÇILIŞ TARİHİ	KAPANIŞ TARİHİ	İSTASYON DONANIMI Lim.	Eşik	Don.	Tel.	Ölçü Köp.	YAĞIŞ ALANI Km^2	RAKIM M	PAFTA No 1/100000	EK BİLGİLER KOORDİNATLAR (Derece - Dakika)	1960 Öncesi Değerlenme
11	1-1	Meriç N.- Kapıkule	1.1.1950	1.4.1967	58					20724	45	E.16	41 42 K-26 22 D	
"	1-2	Meriç N.- Meriç Köp.	1.5.1950	12.12.1969	59					26490	35	E.17	EİE 103	58-59
"	1-3	Meriç N.- Kırışhane	2.2.1950	1.7.1971						34990	34	E.17	41 39 K-26 34 D	
"	1-3	Meriç N.- Kırışhane	30.5.1985	Y.Açıldı										
"	1-4	Meriç N.-Sakıköy	25.6.1956		70					37471	29	F.17	41 24 K-26 38 D	
"	1-5	Tunca N.-Suakacağı	1.4.1950	12.12.1968	58					7855	48	E.17	EİE 104	
"	1-6	Tunca N.-Gazimihal Köp	1.1.1957	1.1.1964						8500	36	E.17	41 41 K-26 33 D	57 58 59
"	1-7	Ergene N.-Uzunhacılı	1.9.1959	1.7.1966						395.50	112	F.19		
"	1-8	Ergene N.-Lüleburgaz	5.6.1948		58 A					2794	45	F.18	41 24 K-27 21 D	
"	1-9	Ergene N.-Uzunköprü	1.5.1952	12.12.1968	52					10124	18	F.17	EİE 105	
"	1-10	Çorlu S.- Muratlı	1.9.1959	1.12.1972						601	70	F.18		
"	1-11	Anadere - Servisinanlı	3.9.1959	1.12.1972						273.5	100	F.19		
"	1-12	Lüleburgaz Ç.-Lüleburgaz	25.5.1957	31.7.1978					69	633	55	F.18	41 24 K-27 21 D	
"	1-13	Hayrabolu D.-İnecik	1.11.1952		A	71				92.18	146	G.18	40 56 K-27 17 D	
"	1-14	Şeytan D.-Kazankaya	1.11.1953	4.10.1985	S					304.3	158	E.18	41 44 K-27 17 D	
"	1-14/B	Şeytan D.-AS.Kışla	1.10.1965	1.6.1967					69	304.5	158	E.18		
"	1-15	Teke D.-Eskipolos	1.11.1957	24.6.1966						368.00	212	E.18		
"	1-16	Doğanca D.-Kadıköy	1.11.1952	1.1.1969						184.80	55	G.17	40 47 K-26 46 D	
"	1-17	Ovadere-Artezyen Köp.	1.4.1963	1.8.1966						62.30	18	E.16		
"	1-18	Hayrabolu D.-Kurtdere	18.8.1961	1.8.1964						1072	55	E.17		
"	1-19	Süloğlu D.-Süloğlu	21.8.1961	30.9.1971						222.20	141	E.17	41 46 K-26 54 D	
"	1-20	Ergene N.- İnanlı	22.8.1961		71 A				71	1415	60	F.18	41 12 K-27 28 D	
"	1-21	Çorlu S.-Velimeşe	23.8.1961	1.7.1966						718	75	F.19		
"	1-22	Hayrabolu D.-Hacılar Köp.	19.8.1961	1.1.1968						1405	45	F.18	EİE 106	
"	1-23	Teke D.- Kuştepe	1.10.1961	1.8.1963						1679	30	F.17		
"	1-24	Beşiktepe- Çeneköy	31.8.1961	31.5.1973						397.4	52	F.18		
"	1-25	Basamkalar D.Balaban	1.10.1961	1.11.1968						341.60	13	F.17		
"	1-26	Meriç N.-İpsala Köp	3.6.1962		64 A					50030	5	G.16	40 57 K-26 30 D	
"	1-27	Kaynarca D.-Yancıklar	1.11.1961	25.6.1966						117.70	136	E.18		
"	1-28	Hacala D.- Hacala	19.3.1963	25.6.1966						85.60	20	F.17		
"	1-29	Muzalı D.- Keşan	21.3.1963	28.2.1977	73 A				74	204.64	30	G.17	40 52 K-26 36 D	
"	1-30	Kömür Köyü Kozan	Açılmadı							114.0				
"	1-31	Soğucak D.-Soğucak	9.7.1964							71.3	283	E.19	41 38 K-27 39 D	
"	1-32	Poğaça D-Karaidemir	30.7.1964	1.7.1975	73				73	387.9	78	G.18		
"	1-33	Ergene N.- Güneşkaya	18.7.1964	1.7.1971						59.20	149	F.19		
"	1-34	B.Dere - Seştankaya								309.5				
"	1-35	Teke D.- Bedre	12.8.1964	1.1.1969						519.00	117	E.18	EİE 107	
"	1-36	Dobralı D.- Değirmenci Köy.	28.7.1964	1.10.1969						7660	28	F.17		
"	1-37	(Provadi) Serin D.-Taşocakları	23.7.1964	1.10.1969						241.20	44	E.17	Yeniden açıldı 1-55 oldu.21.9.1982	
"	1-38	Çimendere - Dedecik	4.9.1965	1.11.1969						107.20	95	G.18		
"	1-39	Poyralı -D. Poyralı	1.10.1965		71	71	71			86.4	249	E.19	41 38 K-27 36 D	
"	1-40	Gala G.- Göl Hasat	6.10.1966	1.8.1978	66					469.2	1.7	G.16	40 45 K-26 10 D	
"	1-41	Süloğlu D.- Kayaboğazı	20.8.1968	28.2.1975	72			72		206.9	160	E.17		
"	1-42	Döküsdere-Yerlisu	1.10.1969	28.2.1975	73	73		73		33.53	41	G.17		
"	1-43	Kaldırımdere - Sarpdere	6.11.1970	1.2.1972						48.1	100	G.16		
"	1-44	Altınyazı Brj. Giriş	1.11.1970	1.7.1970						39.70	41	F.17		
"	1-45	Altınyazı Brj - Çıkış	19.8.1970							85.4	20	F.17	41 04 K-26 34 D	
"	1-46	Hamzadere-Kocahıdır	16.11.1970		A					69.9	11	G.16	40 48 K-26 24 D	

DEĞERLENEN YILLAR (1960–1999)

Boşluklar Değerlendirilmemiştir.

Figure A.4. Sample follow-up form SHW Discharge Monitoring Network Album (SHW, 1988)

DSİ VII. BÖLGE-SAMSUN

2003 YILI SU KALİTESİ GÖZLEM ÇALIŞMALARI PROGRAMI

SIRA NO	İSTASYON NO	ÖRNEKLEME YERİ	ZAMANLAMA VE ÖRNEK SAYISI													HER İSTASYON İÇİN ÖLÇÜLEN ORTAK PARAMETRELER Q, T, pH, EC, CL, NH3-N, NO2-N, NO3-N, M-AL, DO, pV, o-PO4, TDS, SS, BOD5, SO4 (YERALTI SULARINDA DO, SS, BOD5 ÖLÇÜLMEYECEK) DİĞER PARAMETRELER
			n	1	2	3	4	5	6	7	8	9	10	11	12	
18	14-07-00-075	ÇEKEREK IRMAĞI-YEŞİLIRMAK KAR.ÖNCE	4	1			1			1			1			COD,P-Al,Na,K,Ca,Mg,TH,Fe
19	14-07-00-076	YEŞİLIRMAK-AMASYA GİRİŞİ (ÇAĞLAYAN KÖP.)	4	1			1			1			1			COD,P-Al,Na,K,Ca,Mg,TH,Fe
20	14-07-00-077	YEŞİLIRMAK-ÖZMAYA ATIKLARI KAR.SONRA	4	1			1			1			1			COD,P-Al,Na,K,Ca,Mg,TH,Fe
21	15-07-00-101	GÖKIRMAK-BOYABAT GİRİŞİ	4			1		1			1			1		COD,P-Al,Na,K,Ca,Mg,TH,Fe
22	15-07-02-155	DERBENT BARAJI DİPSAVAK ÇIKIŞI	4			1		1		1		1				Na, K, Ca, Mg, Fe, Mn, F
23	15-07-00-161	ÇARŞAK DERESİ-DODURGA BARAJI AKS YERİ	4			1		1			1			1		Na, K, Ca, Mg
24	15-07-00-164	KOLAZ DERESİ-GAZİDERE BARAJ AKS YERİ	4			1		1			1			1		Na, K, Ca, Mg, P-Al
25	15-07-00-181	KIZILIRMAK-BAFRA İLÇESİ ATIKLARI KAR.SONRA	4			1		1		1		1				COD,P-Al,Na,K,Ca,Mg,TH,Fe
		TOPLAM ÖRNEK SAYISI:	100													
		İÇMESUYU KALİTESİ GÖZLEMLERİ														
1	14-07-00-010	ABDAL IRMAĞI-ÇAKMAK BARAJ ÇIKIŞI	6	1		1		1		1		1		1		COD,P-Al,,Na,K,Ca,Mg,TH,Fe,T-Coli,E-Coli,F-Strp YILDA 2 KEZ ;Pb,Zn,Cu,Cr, Hg.
2	14-07-00-013	KÜRTÜN ÇAYI-KADIKÖY BARAJI AKS YERİ	3		1				1				1			COD,P-Al,,Na,K,Ca,Mg,TH,Fe,T-Coli,E-Coli,F-Strp
3	14-07-04-063	ENGİZ DERESİ-19 MAYIS BARJ. MEMBAI	3		1				1				1			COD,P-Al,,Na,K,Ca,Mg,TH,Fe,T-Coli,E-Coli,F-Strp
4	14-07-00-070	GÜLUT ÇAYI-YENİSU BARAJ AKS YERİ	4	1			1			1			1			COD,P-Al,,Na,K,Ca,Mg,TH,Fe,T-Coli,E-Coli,F-Strp YILDA 2 KEZ:Pb,As,Cr,Cu,Zn,Hg.
		TOPLAM ÖRNEK SAYISI:	16													

GENEL TOPLAM ÖRNEK SAYISI: 116

Figure A.5. Sample page from yearly water quality monitoring works program (SHW, 2003)

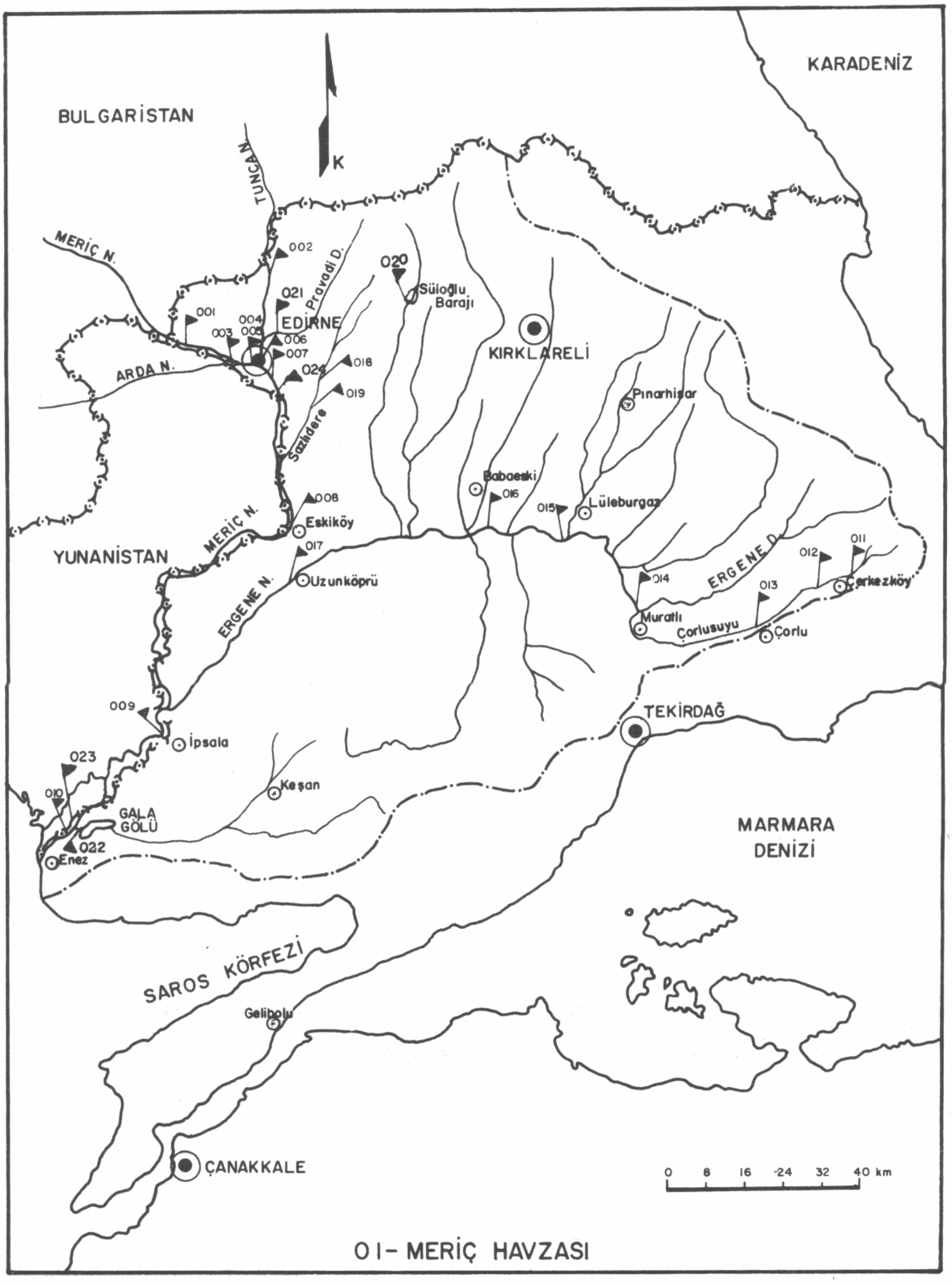


Figure A.6. Sample map from SHW Water Quality Yearbook (SHW, 1987)

22-DOĞU KARADENIZ HAVZASI

BÖLGESİ : XXII. Bölge-TRABZON

İSTASYON ADI VE YERİ : Değirmendere-Esiroğlu Regülatörü

İSTASYON NO : 22-22-00-003

AKIM GÖZLEM İSTASYONU : -

1984 YILI KALİTE GÖZLEMLERİ

PARAMETRE	n	MİNİMUM	ORTALAMA	MAKSİMUM	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZİRAN	TEMMUZ	AĞUSTOS	EYLÜL	EKİM	KASIM	ARALIK
Q																
T	11	14	18,7	23,5		18,0				23,5		23,5				14,0
pH	15	7,4	8,0	8,6		8,5		7,7		7,8		8,6		8,1		8,0
EC	20	99	202	286		253		99		150		218		212		286
TDS	14	100	164	300		100		100		100		100		300		100
SS	14	0	89	300		0		100		0		0		100		0
TS	8	100	319	500												
Turb++						2		32		3		3		8		1
Col	19	0	16	20		10		15		10		10		15		5
M-Al	16	42,5	81,3	130		105,0		50,0		70,0		100,0		100,0		130,0
P-Al	15	0,0	12,3	20		20,0										
Cl	16	3,1	5,7	7,8		6,7		3,1		7,0		5,3		7,0		7,1
NH_3-N	16	0,00	0,24	0,34		0,30		0,00		0,18		0,00		0,00		0,00
NO_2-N	20	0,000	0,000	0,000		0,000		0,000		0,000		0,000		0,000		0,000
NO_3-N																
DO	13	8,8	9,6	12,0		9,8				9,6		8,8				12,0
pV	20	0,48	1,16	2,30		0,80		1,60		1,20		1,40		1,40		0,80
BOD_5	5	0,4	0,4	0,5												
TH	20	50	104	140		132		50		78		105		108		140
o-PO_4	14	0,00	0,02	0,10		0,00		0,10		0,00		0,00		0,00		0,00
SO_4	20	0,5	13,46	27,8		9,0		0,5		3,0		7,7		6,2		15,4
CO_2	3	0	3,5	5												
Fe	15	0,00	0,79	2,20		0,70		2,00		0,00		0,70		0,60		0,20
Mn	6	0,00	0,00	0,00												
Na	16	1,80	4,32	7,00				2,00		2,30		4,60		4,60		7,00
K	16	0,00	0,58	0,80				0,40		0,40		0,40		0,80		0,60
Ca	15	14,0	30,9	44,0				14,0		24,0		36,0		33,0		44,0
Mg	15	2,4	5,7	9,1				3,6		4,0		3,6		6,1		7,3
** T-Coli	9	240	240	240												
T-Germ																
Çöz Sil	14	5,6	8,3	11,6		8,6				8,4		9,0		5,6		6,6

Figure A.7. Sample page from SHW Water Quality Monitoring Yearbook (SHW, 1987)

22 - MÜTEFERRİK DOĞU KARADENİZ SULARI

2213 - AKSU-DERELİ

YERİ :(38° 27' 1" D - 40° 44' 24" K) Giresun un Dereli ilçesindeki kemer köprününün 1 km. mansa-
:bındadır.

YAĞIŞ ALANI : 710.1 Km^2 YAKLAŞIK KOT : 248 m.

GÖZLEM SÜRESİ :15/09/1954 - 30/09/1991

ORTALAMA AKIMLAR :Gözlem süresinde 13.885 m3/sn. (30 Yıllık) 1991 Su yılında 12.832 m3/sn.

ANLIK EN ÇOK VE EN AZ AKIMLAR:

1991 Su yılında anlık ençok akım	:	130.	m3/sn	02/05/1991
1991 Su yılında anlık enaz akım	:	1.30	m3/sn	17/09/1991
Gözlem süresinde anlık ençok akım	:	400.	m3/sn	24/06/1965
Gözlem süresinde anlık enaz akım	:	0.600	m3/sn	30/07/1979

SEVİYE ÖLÇEĞİ :Eşel-Limnigraf

DÜŞÜNCELER :Su yılı içinde 17 akım ölçüsü yapılmış ve tek akım anahtar eğrisi (01 nolu)
:kullanılmıştır. 28.10.1990 da istasyon 800 m. mansaba taşınarak eşel kesitine
:teleferik inşaa edilmiştir.

1 . Anahtar eğrisi (Seviyeler cm. - Akımlar m3/sn.)

Seviye	Akım	Seviye	Akım	Seviye	Akım	Seviye	Akım	Seviye	Akım
80	1.30	120	10.9	170	59.5	220	133.	270	213.
85	1.75	130	17.4	180	72.5	230	149.	280	229.
90	2.32	140	25.5	190	86.0	240	165.	290	245.
100	3.95	150	35.5	200	101.	250	181.	300	261.
110	6.70	160	47.0	210	117.	260	197.		

AKIMLAR 1 EKİM 1990 'DEN 30 EYLÜL 1991 'A KADAR SANİYEDE METRE KÜP OLARAK

GUN/AY	EKİM	KASIM	ARALIK	OCAK	ŞUBAT	MART	NİSAN	MAYIS	HAZİRAN	TEMMUZ	AĞUSTOS	EYLÜL
1	12.9	7.96	6.43	5.88	4.23	10.9	30.5	47.0	16.8	7.96	4.23	3.95
2	10.9	7.54	5.88	5.33	3.95	13.5	32.5	103.	14.8	7.54	4.23	4.23
3	7.96	6.70	6.70	5.60	4.23	12.2	54.5	57.0	12.9	7.12	3.95	4.78
4	7.96	6.43	7.54	7.12	4.50	9.64	45.9	37.8	10.9	6.70	3.95	5.33
5	7.12	6.15	8.38	7.54	4.78	8.38	34.5	32.5	12.2	6.43	3.95	5.33
6	7.54	6.43	10.1	6.70	5.05	7.12	29.5	27.5	19.8	8.80	3.95	4.50
7	6.43	10.9	10.1	6.70	5.33	6.70	28.5	32.5	19.8	19.8	3.95	4.23
8	5.60	11.6	7.96	6.43	5.60	6.43	25.5	30.5	17.4	30.5	3.95	4.23
9	5.33	34.5	8.80	6.43	5.05	7.12	28.5	31.5	16.8	23.9	3.95	3.95
10	5.60	32.5	7.96	5.88	5.60	8.80	27.5	26.5	18.2	12.2	3.95	3.95
11	7.54	22.3	6.70	4.78	5.33	8.80	26.5	23.1	24.7	10.1	4.78	3.77
12	7.12	14.2	5.88	4.50	5.88	9.64	25.5	22.3	24.7	8.80	11.6	3.77
13	7.12	10.5	5.60	4.23	6.43	14.2	22.3	21.5	21.5	7.96	4.50	3.77
14	8.80	9.22	5.88	4.23	5.88	14.2	19.0	20.6	17.4	7.12	3.95	3.77
15	7.96	10.5	5.33	4.50	7.54	10.5	22.3	20.6	16.1	6.70	4.23	2.76
16	7.54	10.1	5.88	4.50	14.8	12.2	26.5	30.5	14.2	6.43	3.95	1.66
17	5.88	10.5	6.70	4.23	15.5	16.8	25.5	32.5	10.5	6.43	4.23	1.39
18	5.33	13.5	6.15	4.23	12.9	35.5	18.2	29.5	11.6	6.15	3.95	1.30
19	5.88	16.1	5.88	4.23	12.2	31.5	14.8	25.5	10.5	6.15	3.95	1.30
20	10.5	15.5	5.60	4.50	14.8	30.5	12.9	21.5	9.22	5.88	3.77	3.23
21	8.80	22.3	5.60	4.23	8.80	39.0	14.8	28.5	8.38	5.60	3.95	12.2
22	6.43	16.8	6.15	4.23	7.96	37.8	19.8	42.4	8.80	5.33	5.60	10.1
23	7.54	15.5	6.43	4.23	9.22	40.1	26.5	34.5	10.5	5.88	6.15	5.33
24	8.80	13.5	6.15	3.95	10.5	30.5	29.5	25.5	12.9	5.88	7.12	4.50
25	12.9	10.9	5.88	4.23	11.6	25.5	31.5	23.1	12.9	6.70	6.43	3.95
26	10.9	9.64	5.05	5.05	13.5	39.0	26.5	21.5	13.5	5.88	5.88	3.41
27	8.80	9.22	4.78	5.60	10.9	50.8	29.5	23.9	11.6	5.33	5.33	3.05
28	7.54	8.80	5.05	6.43	11.6	52.0	27.5	19.8	10.1	4.78	4.78	2.90
29	6.15	8.38	7.54	5.88	-----	53.3	22.3	20.6	9.64	4.23	4.50	2.76
30	5.60	7.54	7.12	5.05	-----	59.5	26.5	19.8	8.80	4.23	3.95	2.61
31	5.60	-----	6.15	4.50	-----	44.7	-----	16.1	-----	4.23	3.77	-----
TOPLAM	240.	386.	205.	161.	234.	747.	805.	949.	427.	261.	146.	122.
ORTALAMA	7.74	12.9	6.62	5.19	8.35	24.1	26.8	30.6	14.2	8.41	4.72	4.07
LT/SN/KM^2	10.9	18.1	9.33	7.31	11.8	33.9	37.8	43.1	20.1	11.8	6.65	5.73
AKIM MM.	29.2	46.9	25.0	19.6	28.4	90.9	98.0	115.	52.0	31.7	17.8	14.8
MİL. M3	20.7	33.3	17.7	13.9	20.2	64.5	69.6	82.0	36.9	22.5	12.7	10.5

SU YILI (1991) YILLIK TOPLAM AKIM 4683. M3/SN. 405. MİLYON M3 570. MM. 18.1 LT/SN/KM^2

2213 - AKSU-DERELİ

Figure A.8. Sample page from EPRSDA Discharge Monitoring Yearbook (EPRSDA, 1996a)

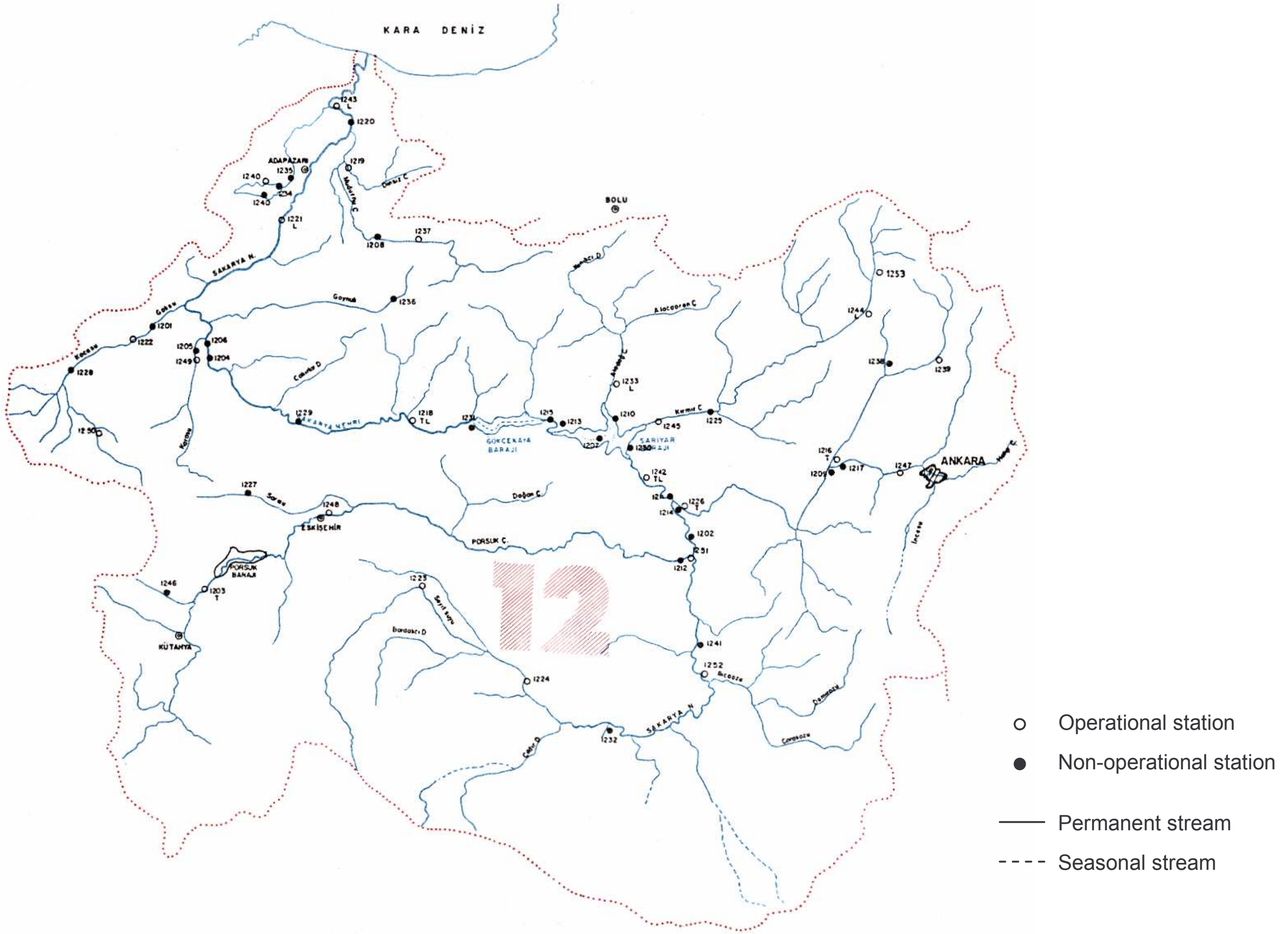


Figure A.9. Sample hydrometric monitoring network map from EPRSDA Discharge Yearbook (EPRSDA, 1996a)

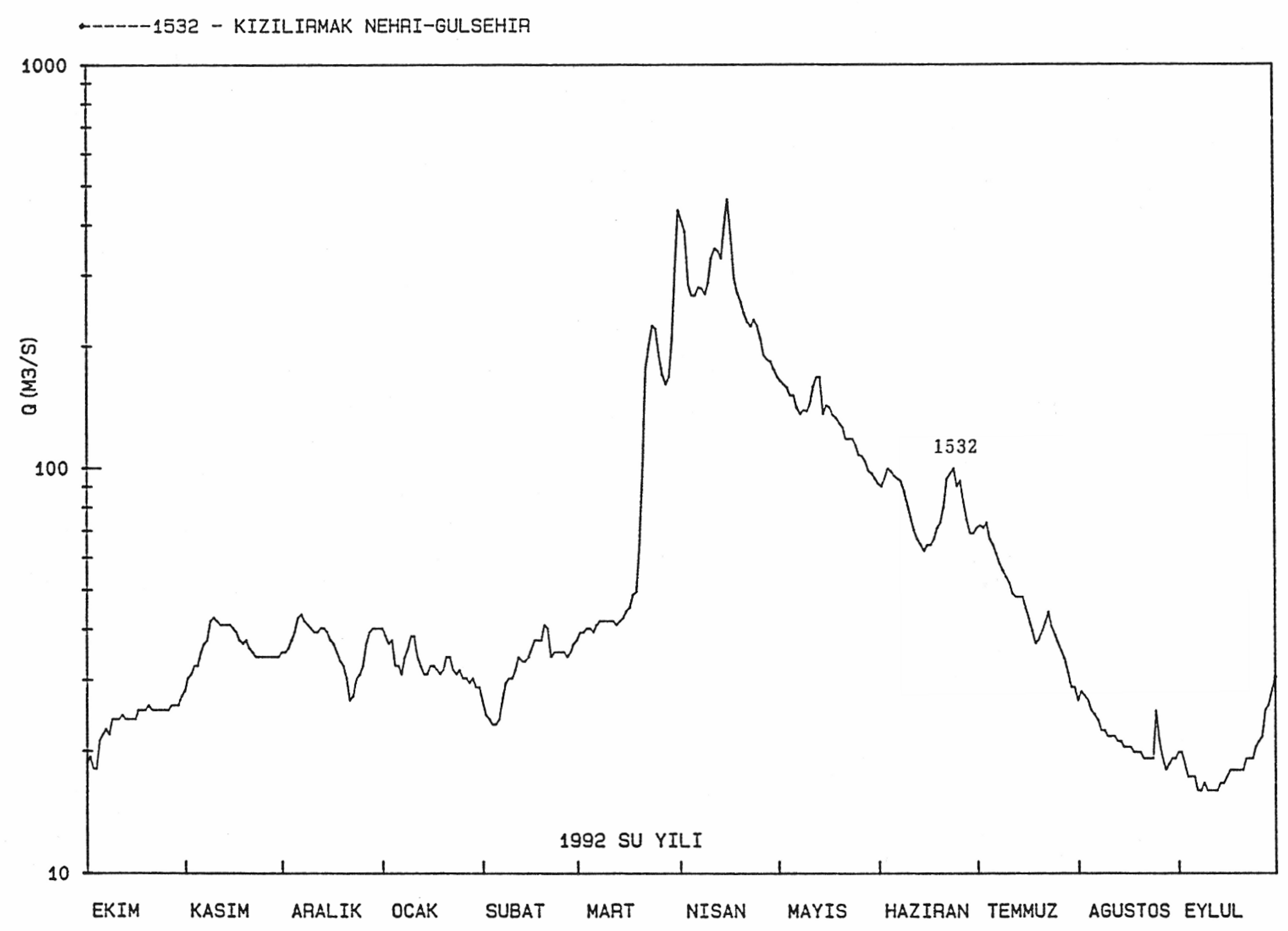


Figure A.10. Sample hydrograph from EPRSDA Discharge Yearbook (EPRSDA, 1996a)

22 - MÜTEFERRİK DOĞU KARADENİZ SULARI

AKARSU GÖZLEM İSTASYONLARI GENEL BİLGİLERİ (01 Ocak 2003)

BÖL NO	AGİ NO	SU VE İSTASYON ADI	AÇ.TAR.	KAP.TAR.	ALAN (Km²)	KOT (m)	LIM	TEL	EŞEL	SED.	SUK.	PAFTA1 1/250.000	PAFTA2 1/25.000	COĞ. KOORDİNAT	AÇIKLAMA
0	2226	TERME Ç.-TERME KÖP.	07/12/57	12/13/63	409.6	6						NK37-9	F37-c2	36 58 21D-41 12 33K	
0	2227	DUTHA S.-AŞAĞIDURAK	12/07/58	04/13/70	167.7	240						NK37-12	F46-d4	41 04 55D-41 07 24K	
9	2228	FOL D.-BAHADIRLI	12/06/60		191.4	17	B-ST			S	KL	NK37-11	F42-c4	39 16 44D-41 02 06K	Eşel 18.8.1967 tarihinde 27 cm 17.10.1968' de 27 cm indirildi.
0	2229	YAĞLIDERE-TEPEKÖY	12/03/60	06/30/66	507.6	99						NK37-14	G41-d1	38 37 43D-40 39 41K	
0	2230	ZİGAM S.-AŞAĞIDURAK	12/13/60	10/01/68	131.5	245						NK37-12	F46-d4	41 04 52D-41 07 04K	
0	2231	MELET Ç.-ÇATALKAYA	08/06/62	02/10/67	1823.2	94						NK37-14	G39-b4	37 50 53D-40 51 53K	10 km mansaba alındı (10.2.1967). 2247 Melet Çayı - Gocallı olarak çalıştırılmaktadır.
9	2232	FIRTINA D.-TOPLUCA	10/01/62		763.2	233	B-ST			S	KL	NK37-12	F46-d4	41 00 45D-41 04 19K	14.12.1992 tarihinde 500 m membaya alındı.
9	2233	TOZKÖY D.-TOZKÖY	12/01/63		223.1	1296						NK37-16	G45-d1	40 34 45D-40 40 00K	
0	2234	KARADERE-ERİKLİ	09/01/64	12/01/74	227.2	1362						NK37-15	G43-c3	39 57 10D-40 36 15K	
0	2235	GELEVERA D.-GELEVERA	09/01/64	12/01/74	136.4	1630						NK37-14	G41-c4	38 51 48D-40 36 04K	
0	2236	AKSU D.-İKİSU	09/04/64	12/01/74	317.2	1037						NK37-14	G40-c4	38 21 10D-40 34 45K	S: 2/2 1.12.1967' de 200 m mansaba alındı. 1.12.1974 tarihinde kapatıldı.Akım projesi için müteferrik olarak çalıştırılıyor.
0	2237	PAZAR S.-YÜKALAN	09/04/64	10/01/70	176.8	1450						NK37-14	G40-d2	38 03 02D-40 37 41K	26.10.1967' de 20 m mansaba alındı. 1.10.1970 tarihinde kapatıldı.
3	2238	MELET Ç.-ARICILAR	09/06/64		1024.4	949	B-E	T		S		NK37-14	G39-d3	37 40 32D-40 32 58K	09.08.1994' de eşel sıfırı 1 m aşağı indirildi.
0	2239	ELEKÇİ D.-BADALLI	09/07/64	09/30/96	271.6	124						NK37-13	G38-b2	37 24 25D-40 56 55K	
0	2240	KARADERE-PERVANE KÖP.	09/08/64	09/01/66	580.0	110						NK37-15	G43-b3	39 59 59D-40 49 45K	2202 nolu AGİ 9.12.1962' de kapatılmış. 8.9.1964' de yaklaşık 5 km membasında Pervane Köprüsünde 2240 olarak açılmış ve 1.9.1966' de kapatılmıştır. 2202 nolu AGİ 1.8.1966'da tekrar eski yerinde Ağnas'da taş köprünün 300 m membasında açılmıştır.
0	2242	CURİ D.-YAĞ.TEPEKÖY	03/01/66	05/01/72	173.6	153						NK37-9	F38-d3	37 07 38D-41 01 18K	
0	2243	CEVİZ D.-BALLIK BOĞ.	11/01/64	10/19/72	313.6	142						NK37-9	G38-d3	37 14 43D-41 00 57K	
0	2244	ARHAVİ Ç.-KAVAKKÖY	04/13/65	11/01/68	261.6	40						NK37-12	G46-b4	41 18 33D-41 19 04K	
3	2245	TERME Ç.-GÖKÇELİ	12/27/68		232.8	66	B-E			S		NK37-9	F37-c2	36 49 35D-41 05 00K	D.S.İ' den devir. 24.06.1987 tarihinde boru limnigraf kuruldu.01.08.1992 ve 09.08.1994' de eşel sıfırı 1 m aşağı indirildi.
0	2246	KAPTANPAŞA D.-KAPTANPAŞA	12/07/68	10/13/74	217.3	415		T				NK37-16	G45-b1	40 47 27D-40 57 54K	1970 su yılından itibaren istasyon No' su değişti. (Eski No:2211)
3	2247	MELET Ç.-GOCALLI KÖP.	02/10/67		1859.2	41	B-E	T			KL	NK37-14	G39-b2	37 53 48D-40 53 11K	23.10.1975' de istasyon 30 m membaya alındı. 2.10.1990' da eşel 80 m mansaba alındı.
0	2248	DEĞİRMEN DERE - ÖĞÜTLÜ	10/01/91	10/01/95	728.5	162				S	KL	NK37-15	G43-a2	39 40 58D-40 51 54K	İstasyon 1.10.1995 tarihinde 500 m mansaba taşınmış. Yeni İstasyon No: 2251 oldu.
9	2249	HARŞİT Ç.-EYMÜR	10/18/94		3175.6	111	B-					NK37-14	G41-b3	38 52 27D-40 51 01K	8 km menbasında Doğankent Santrali vardır. Lim. ve eşel DSİ' ye ait olup AGİ' nu DSİ ile ortak çalıştırılıyor.
0	2250	HOPA ÇAYI - HOPA	10/01/95	06/07/99	68.6	17						NK37-12	F46-b2	41 26 42D-41 23 20K	7.6.1999' de kapatıldı. Sağlıklı seviye değeri alınamadığından akım değerlendirmesi yapılamadı. Yıllık Akarsu Gözlem İstasyonu olarak çalıştırılacaktır.
9	2251	DEĞİRMEN DERE - ESİROĞLU	10/01/95		729.6	155	B-ST	T		S	KL	NK37-15	G43-a3	39 41 00D-40 52 10K	Eski 2248 Nolu AGİ' nin yaklaşık 500 m mansabına açılmıştır.
3	2252	ELEKÇİ DERESİ-SALİHLİ	10/01/95		278.5	180						NK37-13	G38-b2	37 24 03D-40 56 01K	2239 nolu AGİ' nin yerine 2 km membaada açılmıştır.
3	2253	PAZARSUYU D.-EMECAN	10/01/96		770.7	8	B-E	T				NK37-11	G40-a2	38 10 32D-40 55 37K	1.10.1997' den itibaren limnigraflı çalıştırılıyor.
3	2254	AKÇAY D.-DURAKLI	07/14/97		222.2	35	B-ST	T				NK37-9	F38-d2	37 08 29D-41 06 32K	[illegible] Müdürlük Oluru ile baz AGİ' na dönüştürülmüştür. 08.08.2002' de boru limnigraf ve 01.10.2002' de teleferik kuruldu.
9	2255	ÇİT D.-TORUL	11/26/97		203.8	980							G42-	39 17 32D-40 32 31K	22-25 Çit D-Torul Yıllık Akarsu Gözlem İstasyonu (YAGİ) 1.6.1997 tarihinde Genel Müdürlük Oluru ile baz AGİ' na dönüştürüldü.

NOT: ALAN=0-Kaynak, B-Boru, K-Kule, KY-Kuyu, ST-Stevens, E-Elektronik Stevens, AT-Aott, G-Gürmak, T-Teleferik, YE-Yekpare Eşel, KE-Kademeli Eşel, AE-Ağırlıklı Eşel, S-Sediment, KL-Su Kalitesi, Y-Yağış

Figure A.11. Sample page from EPRSDA gauging station information Excel sheets (EPRSDA, 2003)

22 - MÜTEFERRİK DOĞU KARADENİZ SULARI HAVZASI

SU AKIMLARI YILLIĞI KİTABINDA SU AKIM DEĞERLERİ YAYINLANAN AKARSU GÖZLEM İSTASYONLARI

AGİ NO	SU VE İSTASYON ADI	AÇ. TAR.	KAP. TAR.	YILLAR (1935-1999)																																																													
				35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
2201	HARŞİT SUYU KÜRTÜN	09/01/42	02/28/89									x	x	x	x	x	x	x4	x	x	x	x	x	x	x	x	x							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x											
2202	KARADERE AĞNAS	11/12/42										12x	x	x	x	x	x	x	x	x6	1x	x	x	x	x	x	x.									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2203	OF DERESİ DERNEKPAZAR	11/14/42	12/09/60									12x	x	x	x	x	x	x																																																		
2204	TAŞLIDERE RİZE	12/16/49	08/11/73																1x	x	x	x	x															12x	x	x	x	x6																										
2205	MERT IRMAĞI MEŞELİDÜZ	12/15/50	04/12/54																																																																	
2206	DEĞİRMENDERE KANLIPELİT	04/07/50	09/10/91																	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x										
2207	İYİDERE İKİZDERE	09/01/53	12/10/60																				x	x	x	x	x																																									
2208	AKSU DÜRO KÖPRÜSÜ	09/06/53	11/01/68																												x	x		x	x		x																															
2209	MELET ÇAYI KARAAĞAÇKÖYÜ	09/11/53	08/01/62																																																																	
2210	TURNA SUYU ÇOM	09/13/53	07/09/58																																																																	
2211	KAPTANPAŞA DERE YEŞİLTEPE	10/18/53	12/07/68																													x	x	x			x	x11																														
2212	PAZAR SUYU MAĞDALA	09/13/54	10/24/72																													x	x			x	x	x	x	x	x	x	x																									
2213	AKSU DERELİ	09/15/54																													x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

x: Kitapta yayınlanan su yılı, Rakam x: Su yılı içinde değerlendirmenin başladığı ay, x Rakam: Su yılı içinde değerlendirmenin bittiği ay, Ex: Su yılı içinde değerlendirmesi yapılmamış aylar var.

Figure A.12. Sample page from EPRSDA gauging station data history Excel sheets (EPRSDA, 2003)

HAVZA NO : 22
(Number of Drainage Area)

HAVZA ADI : MÜTEFERRİK DOĞU KARADENİZ SULARI
(Name of Drainage Area)

İSTASYON NO : 2248
(Number of Sampling Station)

İSTASYON ADI : DEĞİRMEN DERE-OĞÜTLÜ
(Name of Sampling Station)

YERİ : Trabzon-Maçka karayolunun 16. Km'sinde Esiroğlu Nahiyesi'ndeki kemer köprünün 10 m akış aşağısındadır.
(Location)

DRENAJ ALANI : 733.0 Km2
(Drainage Area)

GÖZLEM SÜRESİ : 14.01.1992-23.12.1994
(Period of Sampling)

ORTALAMA AKIM : 13.901 m3/sn (1 yıllık)
(Mean Discharge)

ELEKTRİKİ KONDAKTİVİTE : MAX : 310 MİN : 75
(Elektricity Conducktivity)

DÜŞÜNCELER :
(Remarks)

TARİH	DEBİ (M3/SN)	SU SICAKLIĞI C	SED. KONS. (PPM)	pH	ECX E6 25 C	KATYONLAR Me/Lt Na+	K+	Ca++ + Mg++	ANYONLAR Me/Lt CO3=	HCO3-	Cl-	SO4=	ORGANİK MADDE (PPM)	BOR (PPM)
14. 1.1992	2.406	3.0	106	8.1	309	0.40	0.06	2.60	0.36	2.27	0.23	0.20		0.00
14. 2.1992	2.581	5.0	74	7.7	267	0.21	0.03	2.90	0.00	2.03	0.18	0.93		0.00
17. 3.1992	12.006	8.0	418	7.7	260	0.29	0.02	2.30	0.00	2.16	0.18	0.27		0.25
8. 7.1992	9.837	11.0		7.7	225	0.20	0.03	2.00	0.00	1.90	0.13	0.20		0.00
9. 9.1992	8.584	18.0		7.8	271	0.21	0.03	2.50	0.00	2.34	0.14	0.26		0.00
14.10.1992	15.210	10.0	182	8.5	161	0.07	0.02	1.50	0.42	0.90	0.19	0.08		0.00
20.11.1992	13.842	10.0	53	8.4	125	0.13	0.03	1.00	0.70	0.30	0.12	0.04		0.10
18.12.1992	7.642	6.0	28	8.3	122	0.17	0.02	1.00	0.24	0.65	0.13	0.17		0.20
7. 1.1993	4.711	6.0	6	8.1	284	0.23	0.02	2.60	0.26	2.22	0.23	0.14		0.10
15. 2.1993	4.588	6.0	10	8.1	304	0.26	0.02	2.90	0.24	2.41	0.22	0.31		0.05
11. 3.1993	6.523	5.0	138	8.0	282	0.21	0.02	2.70	0.06	2.37	0.21	0.29		0.00
5. 4.1993	19.473	6.0	79	8.1	164	0.12	0.02	1.60	0.22	1.18	0.16	0.18		0.00
4. 5.1993	41.860	8.0	318	8.0	154	0.08	0.01	1.50	0.08	1.33	0.09	0.09		0.40
10. 6.1993	34.209	13.0	71	8.0	125	0.08	0.01	1.20	0.06	1.12	0.07	0.04		0.15
21. 7.1993	8.529	11.0	25	7.9	215	0.15	0.01	2.00	0.06	1.88	0.14	0.08		0.35
17. 8.1993	4.641	19.0	13	8.1	111	0.10	0.02	1.10	0.24	0.75	0.18	0.05		0.00
6. 9.1993	2.920	12.0	14	7.8	310	0.26	0.03	3.00	0.00	2.79	0.26	0.24		0.15
9.10.1993	2.364	11.0	29	8.1	305	0.26	0.03	2.90	0.20	2.57	0.27	0.15		0.10
14.10.1993	1.987	12.0	10	8.2	301	0.27	0.03	2.80	0.38	2.29	0.28	0.15		0.00
2.11.1993	2.181	9.0	48	8.1	261	0.27	0.03	2.40	0.22	1.96	0.32	0.20		0.60
9.12.1993	3.136	9.0	15	8.2	291	0.23	0.03	2.80	0.44	2.16	0.26	0.20		1.10
6. 1.1994	3.236	4.0	19	8.2	294	0.21	0.03	2.90	0.42	2.33	0.28	0.11		0.55
18. 2.1994	2.758	5.0	27	7.4	90	0.08	0.02	0.80	0.00	0.74	0.12	0.04		0.13

Figure A.13. Sample page from EPRSDA Water Quality Monitoring Yearbook (EPRSDA, 1996b)

A Y L I K O R T A L A M A S U K A L i T E S i D E Ğ E R L E R i

GÖZLEM iSTASYONUNUN NUMARASI VE ADI : 2248 DEĞiRMENDERE-OĞÜTLÜ
DRENAJ ALANI (KM*2) : 733.000
KOTU (M) : 140
GÖZLEM SÜRESi : 14.01.1992-23.12.1994

AYLAR	DEBi (M³/SN)	SU SICAKLIĞI C	SED. KONS. (PPM)	pH	ECX E6 25 C	KATYONLAR Me/Lt Na+	K+	Ca++ + Mg++	ANYONLAR Me/Lt CO3=	HCO3-	Cl-	SO4=	ANYON VEYA KATYON TOPLAMI	%Na	SAR	SU SERTLiĞi FS	TOTAL TUZ (PPM)	ORGANiK MADDE (PPM)	BOR (PPM) ORT.	MAX	GÖZLEM SAYISI
OCAK	3.451	4.3	33.	8.1	293.	0.26	0.03	2.69	0.33	2.27	0.25	0.14	2.99	8.90	0.23	13.47	187.	0.00	0.22	0.55	3
ŞUBAT	3.309	5.3	31.	7.8	235.	0.20	0.02	2.32	0.11	1.85	0.18	0.40	2.54	7.84	0.18	11.58	150.	0.00	0.06	0.13	3
MART	7.304	6.7	275.	7.7	238.	0.23	0.02	2.17	0.02	1.99	0.18	0.24	2.42	9.66	0.22	10.86	152.	0.00	0.16	0.25	3
NiSAN	17.145	9.0	58.	7.8	158.	0.10	0.02	1.51	0.12	1.26	0.14	0.12	1.64	6.36	0.12	7.57	101.	0.00	0.13	0.30	2
MAYIS	27.262	10.5	250.	7.9	152.	0.08	0.01	1.50	0.06	1.33	0.09	0.11	1.60	5.34	0.10	7.50	97.	0.00	0.38	0.40	2
HAZiRAN	18.620	17.5	66.	8.0	133.	0.09	0.01	1.28	0.08	1.17	0.08	0.05	1.38	6.55	0.11	6.41	85.	0.00	0.15	0.15	2
TEMMUZ	6.698	14.0	23.	7.8	226.	0.18	0.02	2.07	0.05	1.93	0.14	0.16	2.27	8.17	0.18	10.34	145.	0.00	0.15	0.35	3
AĞUSTOS	3.655	20.0	12.	8.1	166.	0.14	0.02	1.61	0.23	1.26	0.18	0.10	1.78	8.00	0.16	8.06	106.	0.00	0.04	0.10	2
EYLÜL	4.311	17.3	12.	7.8	278.	0.23	0.03	2.61	0.00	2.42	0.18	0.28	2.87	8.06	0.20	13.06	178.	0.00	0.03	0.15	3
EKiM	5.201	13.3	138.	8.4	200.	0.13	0.02	1.87	0.38	1.32	0.21	0.11	2.02	6.31	0.13	9.36	128.	0.00	0.01	0.10	4
KASIM	6.407	9.0	47.	8.3	167.	0.16	0.03	1.46	0.58	0.82	0.16	0.10	1.65	10.12	0.19	7.29	107.	0.00	0.14	0.60	3
ARALIK	5.230	7.7	21.	8.2	204.	0.19	0.03	1.92	0.26	1.43	0.18	0.27	2.14	9.18	0.20	9.62	131.	0.00	0.32	1.10	3

*** NOT : 1-SÜLFAT iYONLARI HESAP YOLUYLA BULUNMAKTADIR.
2-YAKLAŞIK SERTLiK HESABINDA (Ca+Mg) DEĞERi (Me/L) OLARAK (5) iLE ÇARPILMAKTADIR.
3-TOTAL TUZ HESABINDA (ECXE6) DEĞERi 0.64 iLE ÇARPILMAKTADIR.
4-DEBi,SU SICAKLIĞI DEĞERLERi ÖLÇÜM ANINDAKi DEĞERLERiN ORTALAMASI OLUP,DiĞER PARAMETRELER DEBi AĞIRLIKLI ORTALAMA DEĞERLERDiR.

Figure A.14. Sample page from EPRSDA Water Quality Monitoring Yearbook – Monthly Averages (EPRSDA, 1996b)

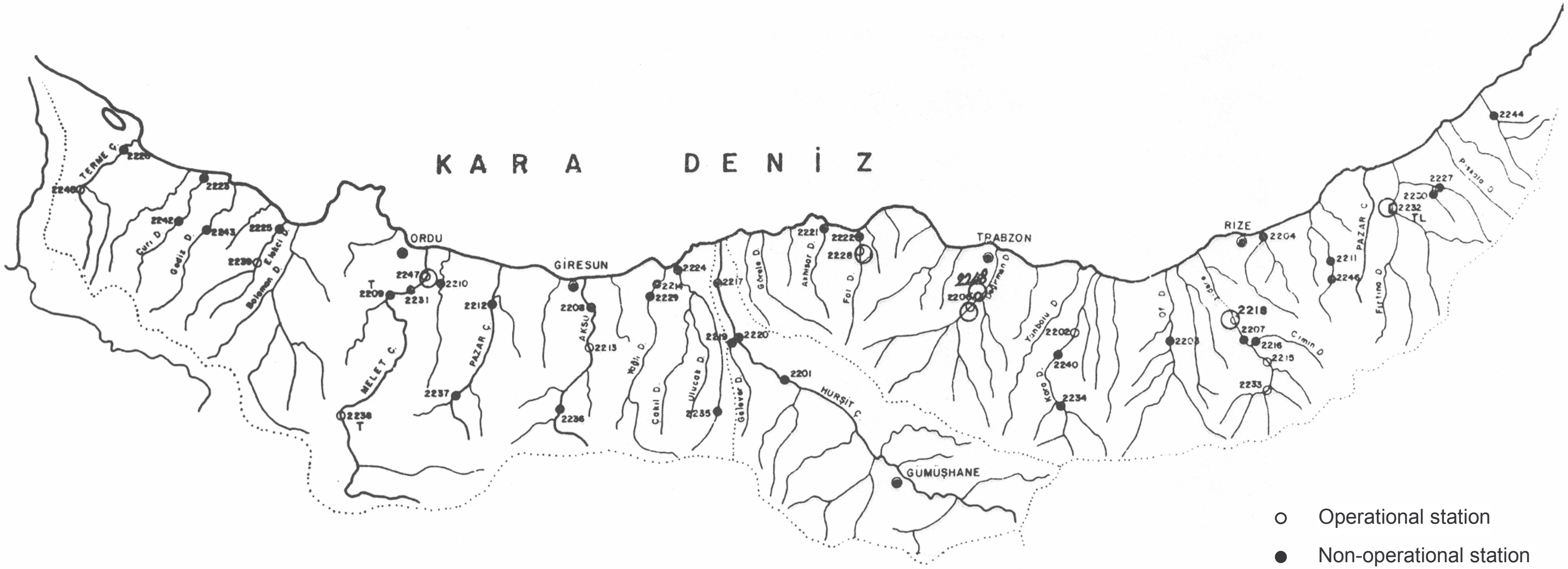


Figure A.15. Sample map from EPRSDA Water Quality Monitoring Yearbook (EPRSDA, 1996b)

AYVALI DERESİ HAVZASI 1991 SU YILI AKIM DEĞERLERİ

İstasyon Coğrafi Koordinatı : 41° 07' 30" N enlemi ve 35° 37' 30" E Boylamıdır.

Araştırma Süresi : 1980 - 2004

Ortalama Debi : 3.2 L/s

Maksimum ve Minimum Debiler : 1991 Su yılında max. debi : 58.01 L/s (6.7.1991)

1991 Su yılında min. debi : 0.69 L/s (20.8.1991)

Araştırma süresince max. debi : 4600.00 L/s(10.5.1981)

Araştırma süresince min. debi : 0.03 L/s (24.8.1986)

Seviye Ölçeği :Eşel - Limnigraf

Akımlar 1 Ekim 1990 dan 30 Eylül 1991'e kadar ve sanayide litre olarak

Günler	AYLAR											
	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX
1	5.00	3.70	3.30	3.40	1.60	2.30	2.70	5.22	5.90	2.30	1.50	1.60
2	4.70	4.00	4.18	3.40	1.60	2.30	3.55	8.14	4.60	2.00	1.50	1.60
3	5.00	4.40	3.40	3.30	1.60	2.30	6.25	4.50	3.30	2.00	1.30	1.60
4	5.70	4.40	5.01	3.20	1.60	3.40	3.71	4.00	3.20	2.30	1.40	1.60
5	5.00	4.40	3.71	3.20	1.60	4.40	3.20	4.20	6.46	2.30	1.40	1.60
6	4.40	4.50	3.54	3.30	1.60	4.18	2.80	4.67	5.00	4.40	1.40	1.60
7	4.40	4.20	3.20	3.40	1.60	3.28	2.30	5.00	3.40	2.90	1.60	1.60
8	4.40	3.21	3.30	3.40	1.60	3.20	3.63	4.85	2.90	2.61	1.70	1.60
9	4.40	4.48	3.40	3.40	1.70	2.90	9.39	4.50	4.59	2.30	1.80	1.60
10	5.06	3.30	3.30	4.12	1.70	2.70	4.70	3.80	7.78	2.40	1.80	1.60
11	5.00	3.30	3.30	4.00	1.50	2.70	4.70	4.00	9.07	2.40	1.80	1.60
12	5.00	3.20	3.30	3.40	1.50	2.70	4.95	4.40	5.20	2.30	1.70	1.60
13	4.10	3.00	3.30	3.40	1.50	2.86	4.10	4.00	4.40	2.30	1.60	1.70
14	3.30	2.80	3.40	3.40	2.00	3.74	3.30	3.40	4.50	2.30	1.50	1.80
15	3.40	3.00	3.00	3.30	4.61	2.70	4.53	4.30	4.50	2.30	1.20	1.80
16	3.40	3.40	2.81	3.85	7.10	2.60	13.78	6.33	3.90	2.30	0.80	1.70
17	3.40	3.40	3.00	3.90	3.60	2.60	8.90	4.00	2.90	2.30	0.90	1.70
18	3.40	3.40	3.30	2.90	5.00	2.70	5.70	3.40	2.60	2.30	1.20	1.70
19	3.60	3.40	3.20	2.30	3.57	3.50	5.70	3.14	2.60	2.30	1.00	1.40
20	3.60	3.40	3.20	2.30	3.00	2.70	5.70	5.48	2.40	2.30	0.70	3.44
21	3.40	3.40	3.20	2.40	2.70	2.90	5.50	15.70	2.60	2.30	0.80	2.30
22	3.40	3.40	3.20	2.30	2.30	3.20	5.30	8.99	2.70	2.30	0.80	1.93
23	3.60	3.40	3.20	2.30	2.30	2.70	5.20	6.70	2.90	2.30	0.80	1.50
24	5.36	3.40	3.20	2.20	2.30	2.60	7.27	5.40	2.80	1.90	1.00	1.60
25	3.80	3.40	3.00	1.80	2.30	2.40	7.70	5.60	2.40	1.90	1.00	1.60
26	3.70	3.30	3.00	1.60	2.30	2.60	5.40	6.90	2.40	2.30	1.10	1.60
27	3.70	3.20	2.90	1.60	2.50	2.70	4.70	6.10	2.21	1.90	1.50	1.40
28	3.70	3.30	2.70	1.60	2.60	2.70	4.40	5.50	3.20	1.50	1.60	1.30
29	3.70	3.40	3.00	1.60	-	2.70	4.40	5.50	2.50	1.80	1.83	1.50
30	3.60	3.30	3.40	1.60	-	2.70	4.00	5.70	2.00	1.80	1.60	1.20
31	3.60	-	3.40	1.60	-	2.70	-	5.90	-	1.50	1.60	-
Ortalama	4.12	3.55	3.30	2.82	2.46	2.89	5.25	5.46	3.83	2.26	1.34	1.68
L/s/km²	4.141	0.983	0.914	0.781	0.681	0.800	1.454	1.512	1.060	0.626	0.371	0.465
Akım (mm)	3.065	2.549	2.448	2.092	1.648	2.144	3.769	4.051	2.750	1.676	0.994	1.206
Ort.Yağ.(mm)	35.2	24.9	27.9	58.2	42.1	35.0	108.7	114.7	59.9	37.5	18.9	33.9

Figure A.16. Sample page from GDRS Rainfall-Discharge Yearbook (GDRS, 1993)

Havza Adı	SAMSUN-AYVALI DERESİ
Havzanın Yeri	Samsun'a bağlı Vezirköprü ilçesinin doğusunda Vezirköprü ve Havza ilçelerini birbirine bağlıyan karayolunun kuzeydoğusunda yeralmaktadır.
Havza Alanı	3.61 km^2
Havza Çevre Uzunluğu	8.875 km.
Havza Uzunluğu	3.383 km.
Havzanın Maksimum Yükseltisi	733 m.
Havzanın Minimum Yükseltisi	535 m.
Havzanın Ortalama Yükseltisi	$hort_1$ = 634 m $hort_2$ = 638.3 m
Havzanın Ortalama Eğimi	% 8
Toplam Su Yolları Uzunluğu	6.325 km.
Ana Su Yolları Uzunluğu	2.3 km.
Ana Su Yolu Profil Eğimi	% 7.7
Havza Yöneyi	Güney - Kuzey
Eğim İndisi (I_p)	% 23
Havza Şekil İndisi	SI_1 = 3.17, SI_2 = 1.47, SI_3 = 0.58
Havza Ağırlık Merkezinin Ana Su Yolu İzdüşümünden Havza Çıkışına Olan Mesafe (L_c)	1.75 km.
Su Yolları Mertebesi	Üçüncü Dereceden
Su Yolları Yoğunluğu (D_d)	1752.1 m/km^2
Havzanın Toprak Örtü Numarası (C_N)	81

Figure A.17. Watershed information from GDRS Rainfall-Discharge Yearbook (GDRS, 1993)

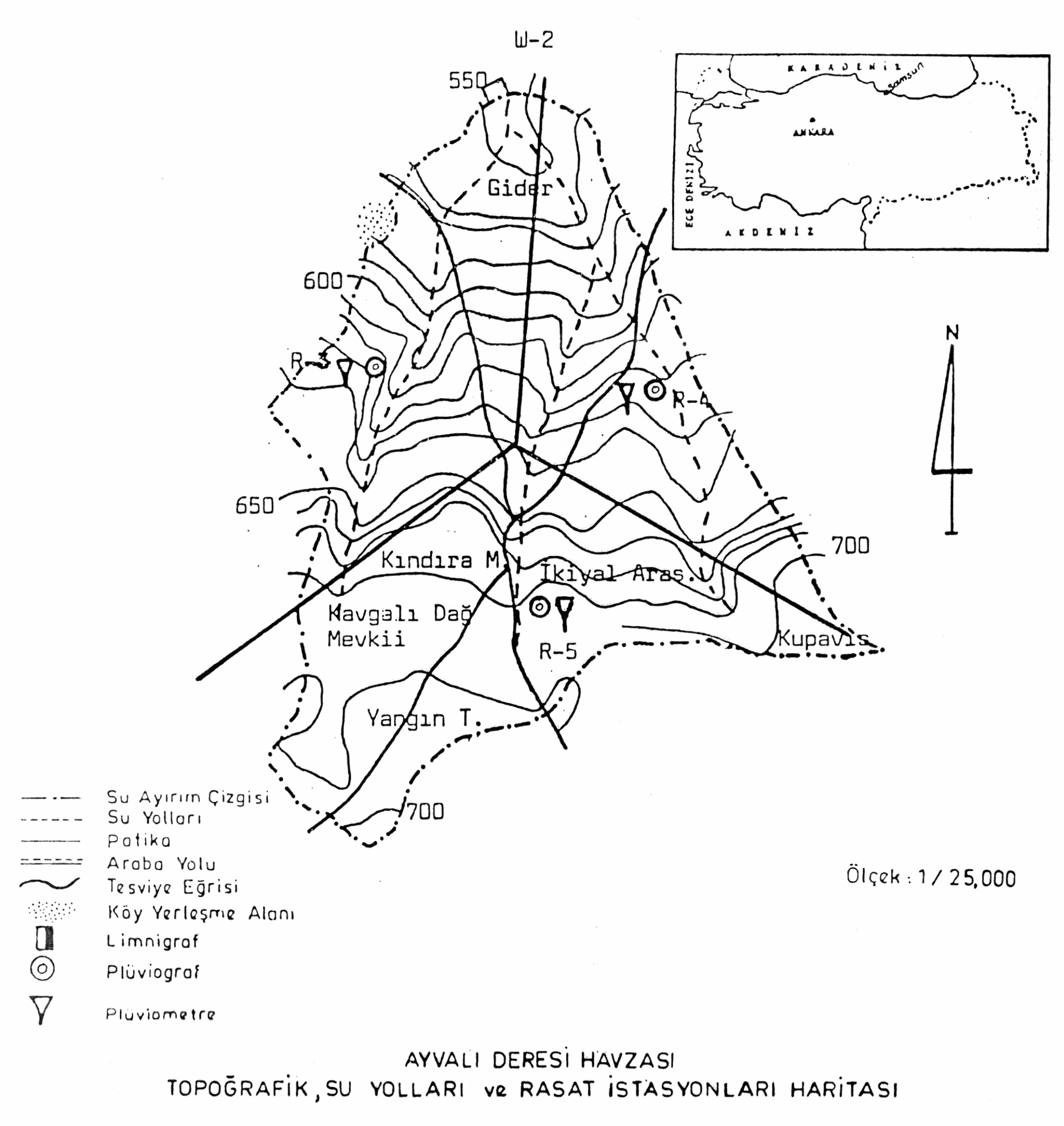


Figure A.18. Sample map from GDRS Rainfall-Discharge Yearbook (GDRS, 1993)

APPENDIX B

WATER QUALITY PARAMETERS

B.1. List of Water Quality Parameters

List of water quality parameters that are available in the database for analysis of water quality are listed in Table B.1. Symbol that is used to identify water quality parameter, its common name and units are given in the table. Data type and precision that is used to represent measured value of a water quality parameter in database tables are also indicated.

Table B.1. Water quality parameters

Symbol	Quality Parameter	Units	Type	Precision
Ag	Silver	mg/l	Decimal	7.2
Al	Aluminium	mg/l	Decimal	7.2
As	Arsenic	mg/l	Decimal	7.2
B	Boron	mg/l	Decimal	7.2
B_ppm	Boron	ppm	Decimal	6.2
Ba	Barium	mg/l	Decimal	7.2
BOD5	Biological oxygen demand	mg/l	Decimal	7.2
Ca	Calcium	mg/l	Decimal	5.1
Ca_Mg_me	Calcium + Magnesium	me/l	Decimal	6.2
Cd	Cadmium	mg/l	Decimal	7.2
Cl	Chlorine	mg/l	Decimal	4.1
Cl_me	Chlorine	me/l	Decimal	6.2
CN	Cyanide	mg/l	Decimal	7.2
Co	Cobalt	mg/l	Decimal	7.2
CO2	Carbon dioxide	mg/l	Integer	5
CO3	Carbonate	me/l	Decimal	7.2

Table B.1. Water quality parameters (continued)

Symbol	Quality Parameter	Units	Type	Precision
COD	Chemical oxygen demand	mg/l	Decimal	7.2
Col	Color	Pt-Co	Integer	5
Cr	Chrome	mg/l	Decimal	7.2
Cu	Copper	mg/l	Decimal	7.2
Date	Date	-	Date	-
Det	Detergent	mg/l	Decimal	7.2
Dis_Si	Dissolved silicate	mg/l SiO_2	Decimal	5.1
DO	Dissolved oxygen	mg/l	Decimal	3.1
E_Coli	E. Coli	EMS/100 ml	Integer	5
EC	Electrical conductivity	µmho/cm	Integer	5
F	Fluoride	mg/l	Decimal	7.2
F_Coli	Fecal Coliform	EMS/100 ml	Integer	5
F_Strp	Fecal Streptococcus	EMS/100 ml	Integer	5
Fe	Iron	mg/l	Decimal	5.2
Fen	Phenol	mg/l	Decimal	7.2
H2S	Hydrogen sulfate	mg/l	Decimal	7.2
HCO3	Bicarbonate	me/l	Decimal	7.2
Hg	Mercury	mg/l	Decimal	7.2
K	Potassium	mg/l	Decimal	5.2
K_me	Potassium	me/l	Decimal	6.2
M_Al	Total alkalinity	mg/l $CaCO_3$	Decimal	5.1
Mg	Magnesium	mg/l	Decimal	5.1
Mn	Manganese	mg/l	Decimal	5.2
Mo	Molybdenum	mg/l	Decimal	7.2
Na	Sodium	mg/l	Decimal	5.2
Na_me	Sodium	me/l	Decimal	6.2
NH3_N	Ammonia	mg/l	Decimal	5.2
Ni	Nickel	mg/l	Decimal	7.2
NO2_N	Nitrite	mg/l	Decimal	7.3
NO3_N	Nitrate	mg/l	Decimal	7.2
O_PO4	Ortho-phosphate	mg/l	Decimal	5.2
Oil	Oil	mg/l	Decimal	7.2
Org	Organic material	ppm	Decimal	6.2
Org_N	Organic nitrogen	mg/l	Decimal	7.2
P_Al	Phenolphthalein alkalinity	mg/l $CaCO_3$	Decimal	4.1
Pb	Lead	mg/l	Decimal	7.2
pH	pH		Decimal	3.1
PmV	Permanganate value	mg/l O_2	Decimal	7.2
pV	Organic material	mg/l	Decimal	5.2
Q	Stream flow	m^3/sn	Decimal	7.3

Table B.1. Water quality parameters (continued)

Symbol	Quality Parameter	Units	Type	Precision
Sal	Salinity	%	Decimal	7.2
Sb	Antimony	mg/l	Decimal	7.2
Se	Selenium	mg/l	Decimal	7.2
Sec_D	Seci disc depth	cm	Decimal	7.2
Sed	Sediment	ppm	Integer	5
Set_S	Settlable solids	mg/l	Decimal	7.2
SO4	Sulfate	mg/l	Decimal	5.1
SO4_me	Sulfate	me/l	Decimal	6.2
SS	Suspended solids	mg/l	Integer	5
T	Temperature	^oC	Decimal	5.1
T_Coli	Total coliform	EMS/100 ml	Integer	5
T_Germ	Total germicide	EMS/100 ml	Integer	5
T_PO4	Total phosphate	mg/l	Decimal	7.2
TDS	Total dissolved solids	mg/l	Integer	5
TH	Total hardness	mg/l $CaCO_3$	Integer	5
TKN	Total Kjeldahl nitrogen	mg/l	Decimal	7.2
Tot_N	Total nitrogen	mg/l	Decimal	7.2
Tot_P	Total phosphorus	mg/l	Decimal	7.2
TS	Total solids	mg/l	Integer	5
Turb	Turbidity	NTU	Integer	5
Turb_JTU	Turbidity	JTU	Integer	5
Turb_SiO2	Turbidity	SiO_2	Integer	5
Zn	Zinc	mg/l	Decimal	7.2

B.2. List of Water Quality Parameter Templates

Contents of water quality parameter templates that are available in 'Water Quality Parameter Selection' dialog are given below:

a) EPRSDA Water Quality Monitoring Station Template

Date, Stream Flow, Temperature, Sediment, pH, Electrical conductivity, Sodium (me), Potassium (me), Calcium + Magnesium (me), Carbonate, Bicarbonate, Chlorine (me), Sulfate (me), Organic material (ppm), Boron (ppm).

b) SHW General Water Quality Monitoring Station Template

Stream flow, Temperature, pH, Electrical conductivity, Chlorine, Ammonia nitrogen, Nitrite nitrogen, Nitrate nitrogen, Total alkalinity, Dissolved oxygen, Organic material (mg/l), Ortho-phosphate, Total Dissolved Solids, Suspended Solids, Biological oxygen demand, Sulfate.

c) SHW Drinking Water Quality Monitoring Station Template

Stream flow, Temperature, pH, Electrical conductivity, Chlorine, Ammonia nitrogen, Nitrite nitrogen, Nitrate nitrogen, Total alkalinity, Dissolved oxygen, Organic material (mg/l), Ortho-phosphate, Total Dissolved Solids, Suspended Solids, Biological oxygen demand, Sulfate, Chemical oxygen demand, Phenolphthalein alkalinity, Sodium, Potassium, Calcium, Magnesium, Total hardness, Iron, Total coliform, E. coli, Fecal streptococcus.

d) SHW Groundwater Quality Monitoring Station Template

Stream flow, Temperature, pH, Electrical conductivity, Chlorine, Ammonia nitrogen, Nitrite nitrogen, Nitrate nitrogen, Total alkalinity, Organic material (mg/l), Ortho-phosphate, Total Dissolved Solids, Sulfate, Sodium, Potassium, Calcium, Magnesium, Turbidity, Phenolphthalein alkalinity.

APPENDIX C

VMAP-0 HYDROGRAPHY COVERAGE ATTRIBUTE TABLES

National hydrography dataset developed in this study is based on VMAP-0 hydrography coverage. Therefore it has some common feature types and attributes with VMAP-0. Structure of VMAP-0 hydrography coverage tables are extracted from MIL-V-89039 document and summarized here for information.

Table C.1. Danger Point Feature Attribute Table

Attribute	Description	Value	Value Meaning
id	Row Identifier	Sequential beginning with 1	
f_code	FACC Feature Code	BD130	Rock
		BD180	Wreck
f_code_des	FACC Feature Code Description		

Table C.2. Miscellaneous Point Feature Attribute Table

Attribute	Description	Value	Value Meaning
id	Row Identifier	Sequential beginning with 1	
f_code	FACC Feature Code	BA030	Island
		BH120	Rapids
		BH170	Spring/ Water-Hole
		BH180	Waterfall
		BI020	Dam/Weir
		BI030	Lock
		BI040	Sluice Gate
f_code_des	FACC Feature Code Description		

Table C.3. Aqueduct/Canal/Flume/Penstock Line Feature Attribute Table

Attribute	Description	Value	Value Meaning
id	Row Identifier	Sequential beginning with 1	
f_code	FACC Feature Code	BH000	Inland Water
f_code_des	FACC Feature Code Description		
exs	Existence Category	1	Definite
		5	Under Construction
		6	Abandoned/ Disused
exs_descri	Existence Category Description		
loc	Location Category	0	Unknown
		4	Below Surface/ Submerged Underground
		8	On Ground Surface
		25	Suspended or Elevated Above Ground or Water Surface
loc_descri	Location Category Description		
nam	Feature Name	Text (= UNK for unknown names)	
nam_descri	Feature Name Description	Text	

Table C.4. Miscellaneous Line Feature Attribute Table

Attribute	Description	Value	Value Meaning
id	Row Identifier	Sequential beginning with 1	
f_code	FACC Feature Code	BB040	Breakwater/ Groyne
		BB230	Seawall
		BI020	Dam/Weir
f_code_des	FACC Feature Code Description		

Table C.5. Water Course Line Feature Attribute Table

Attribute	Description	Value	Value Meaning
id	Row Identifier	Sequential beginning with 1	
f_code	FACC Feature Code	BH140	River/Stream
f_code_des	FACC Feature Code Description		
hyc	Hydrological Category	6	Non-Perennial/ Intermittent/ Fluctuating
		8	Perennial/ Permanent
hyc_descri	Hydrological Category Description		
nam	Feature Name	Text (= UNK for unknown names)	
nam_descri	Feature Name Description	Text	

Table C.6. Inland Water Area Feature Attribute Table

Attribute	Description	Value	Value Meaning
id	Row Identifier	Sequential beginning with 1	
f_code	FACC Feature Code	BH090	Land Subject to Inundation
		BH000	Inland Water
f_code_des	FACC Feature Code Description		
hyc	Hydrological Category	6	Non-Perennial/ Intermittent/ Fluctuating
		8	Perennial/ Permanent
hyc_descri	Hydrological Category Description		
nam	Feature Name	Text (= UNK for unknown names)	
nam_descri	Feature Name Description	Text	

APPENDIX D

HYDROGRAPHY LAYERS OF REFERENCE MAPS

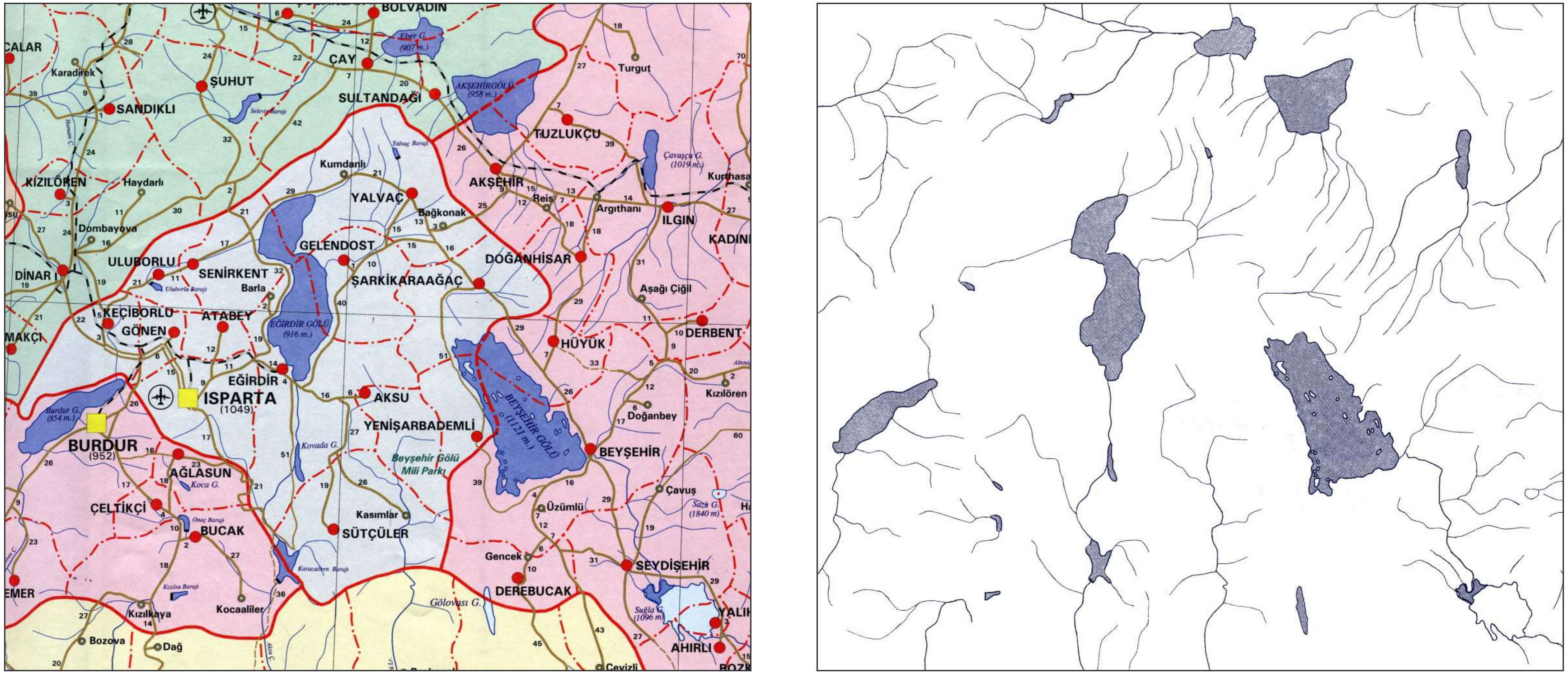


Figure D.1. 1:1,000,000 scale Administrative Units of Turkey map of GCM (GCM, 1998)

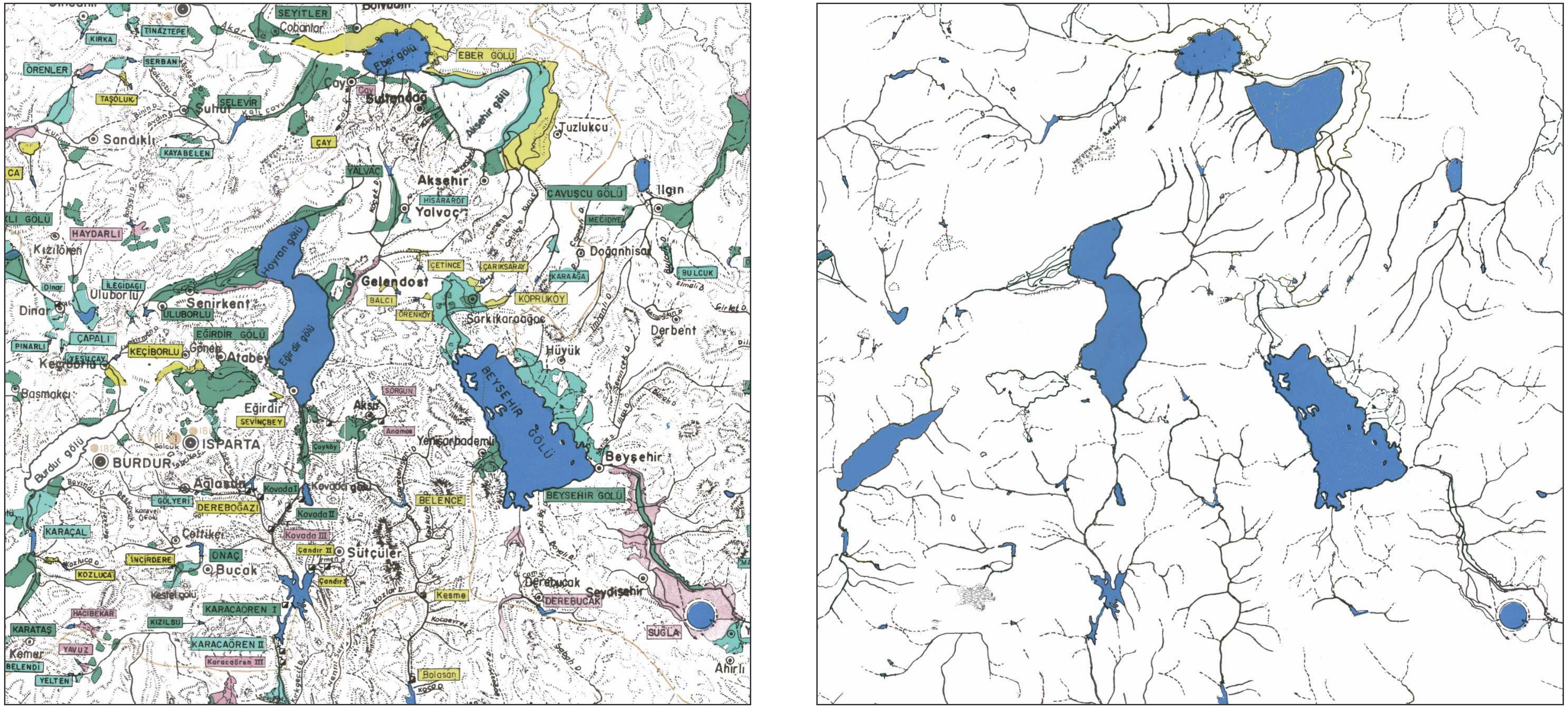


Figure D.2. 1:800,000 scale Dams, Power Stations and Irrigation Establishments map of SHW (SHW, 1992)

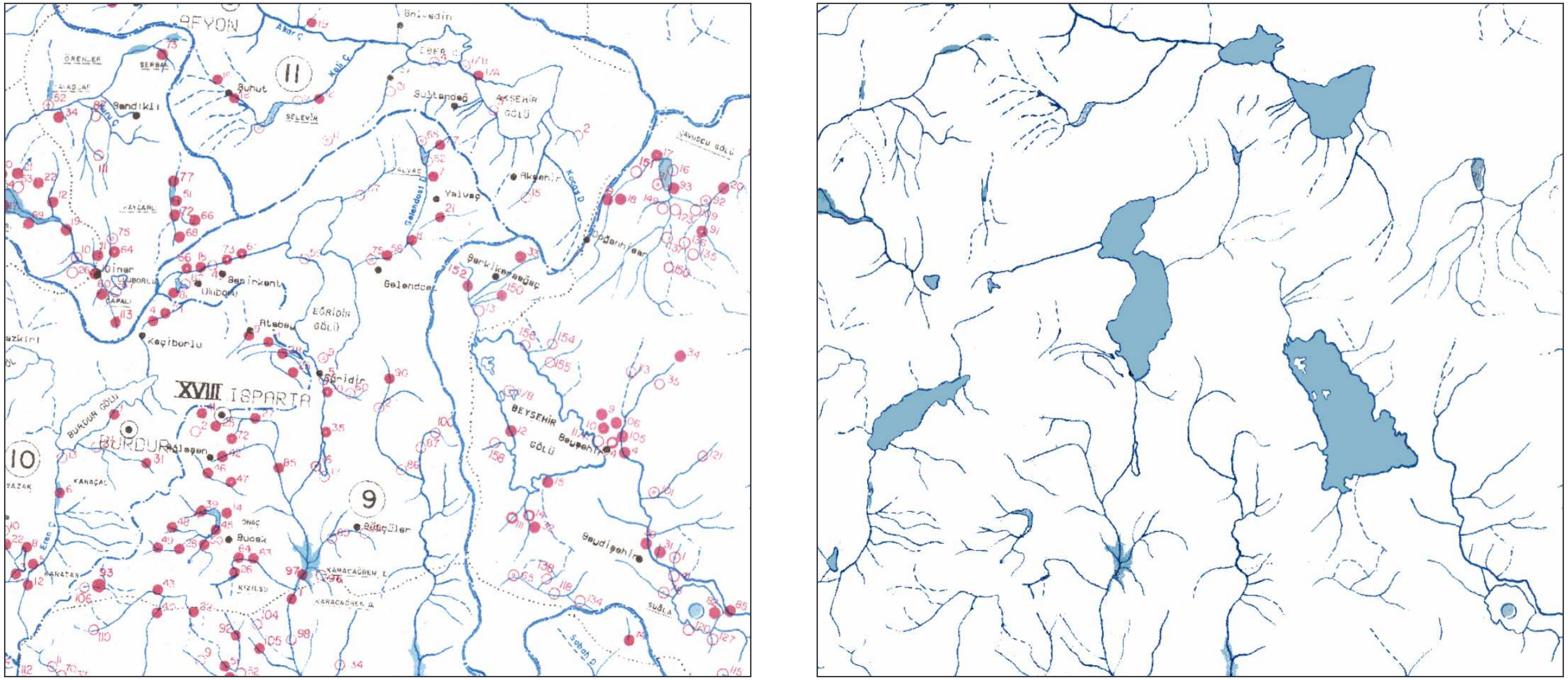
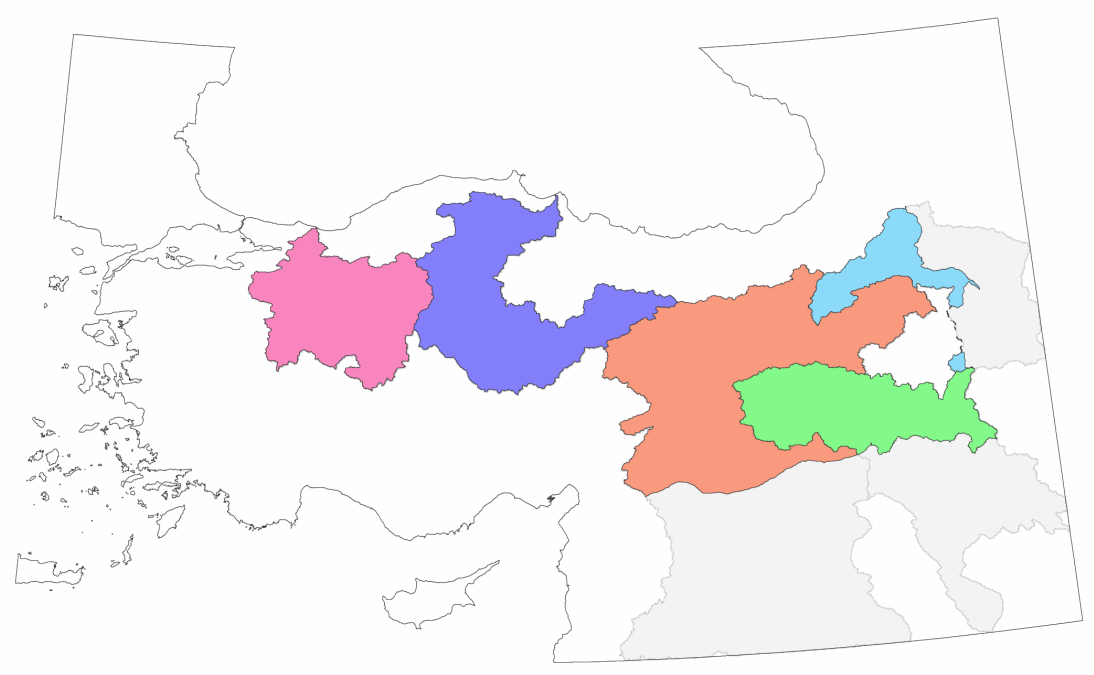


Figure D.3. Combined map of watersheds from SHW discharge yearsbook (SHW, 1999) (approximate scale: 1:800,000)

APPENDIX E

DEM-BASED DRAINAGE BASINS

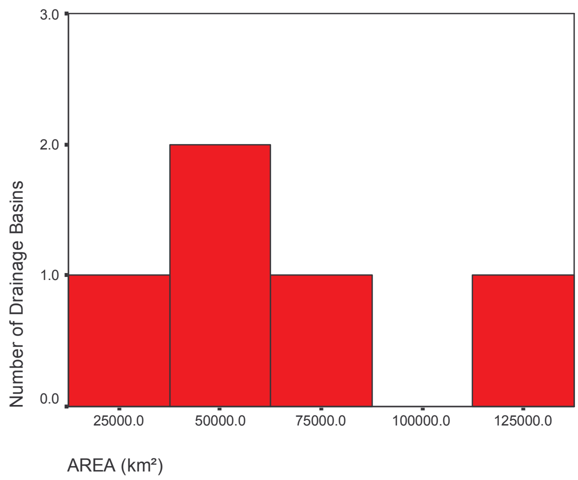


a. Geographic distribution

AREA

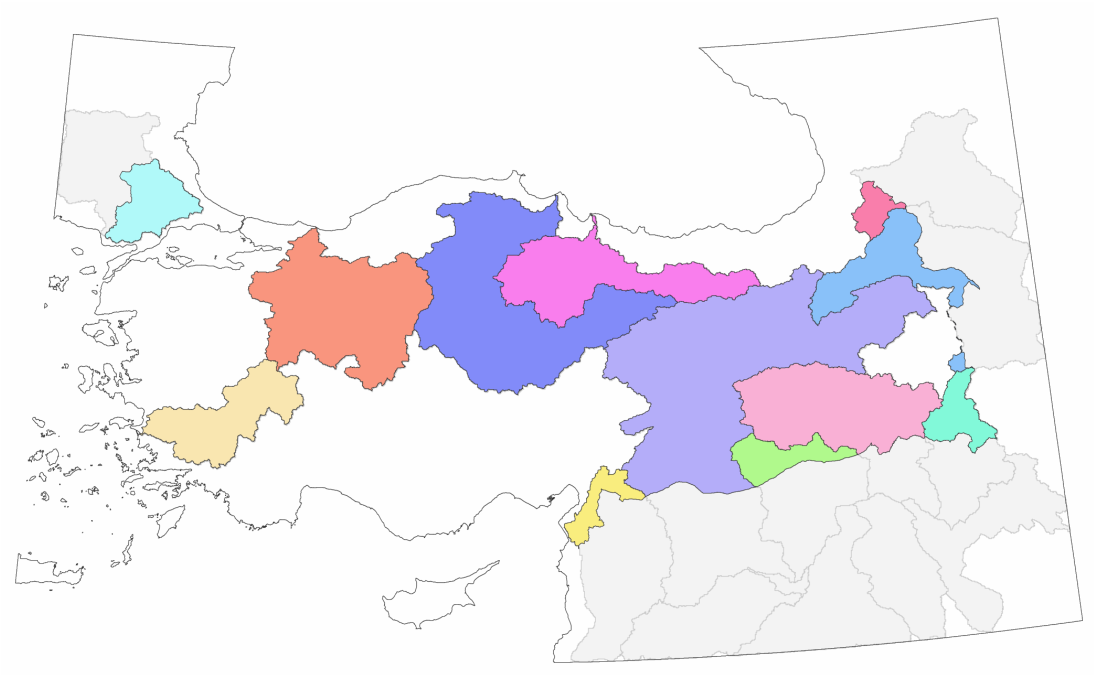
N		5
Mean		66465.91
Median		57516.75
Std. Deviation		36704.74
Variance		1347238085.48
Skewness		.665
Kurtosis		1.103
Range		99604.62
Minimum		22050.16
Maximum		121654.78
Percentiles	25	37795.47
	50	57516.75
	75	99610.92

b. Statistics



c. Histogram

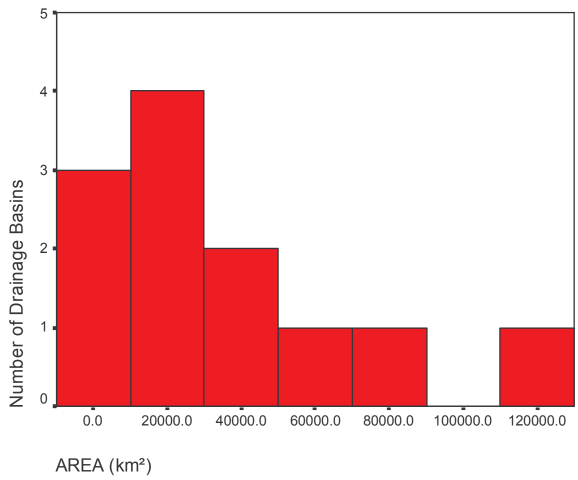
Figure E.1. DEM-based drainage basins for 50,000 km^2 area threshold



a. Geographic distribution

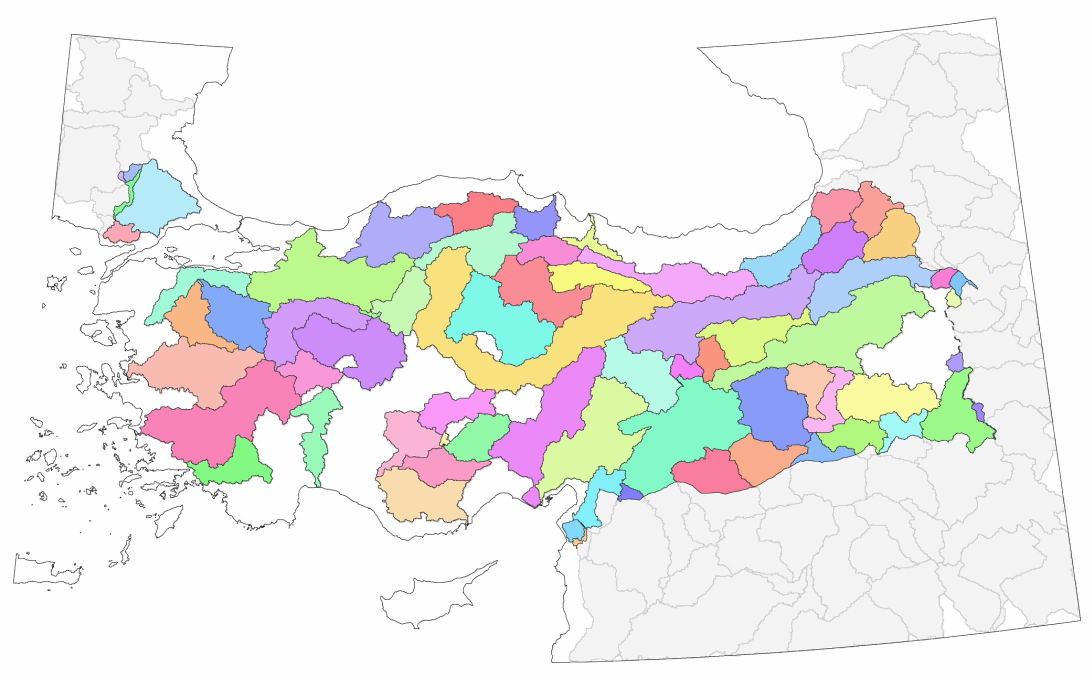
AREA		
N		12
Mean		35092.20
Median		23718.74
Std. Deviation		32936.03
Variance		1084782126.77
Skewness		1.345
Kurtosis		1.349
Range		106576.80
Minimum		4959.69
Maximum		111536.50
Percentiles	25	9580.50
	50	23718.74
	75	54172.45

b. Statistics



c. Histogram

Figure E.2. DEM-based drainage basins for 25,000 km^2 area threshold

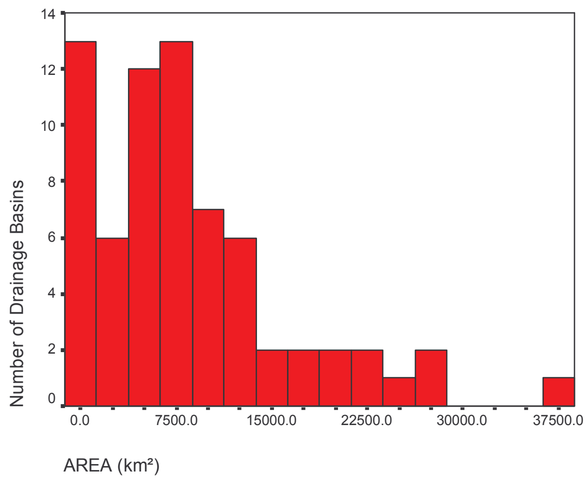


a. Geographic distribution

AREA

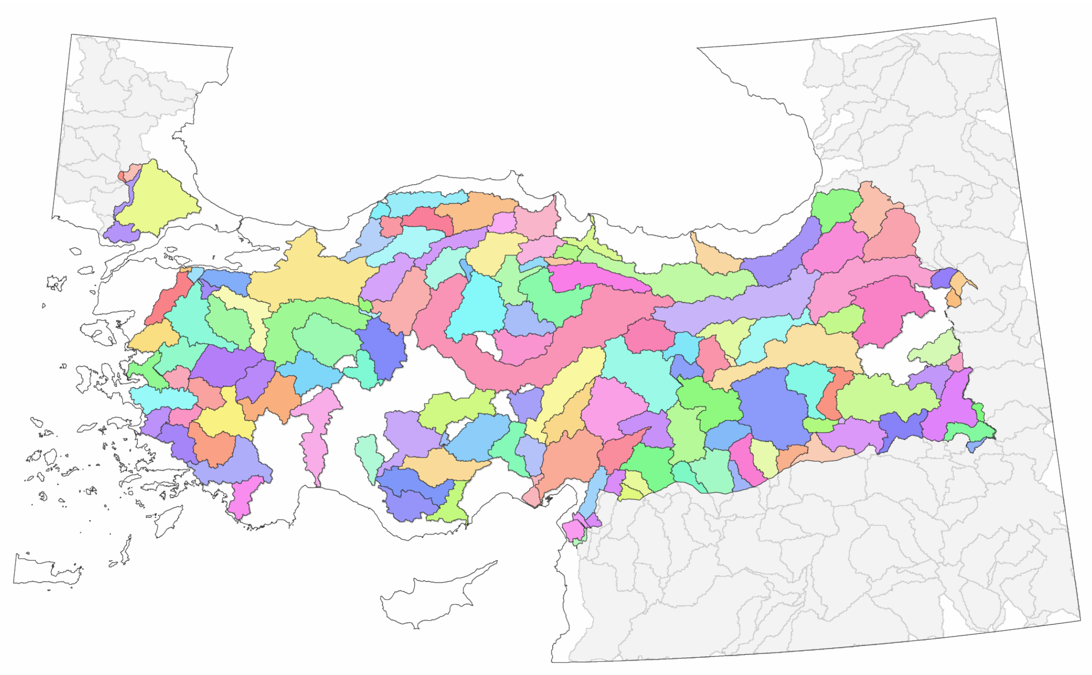
N		69
Mean		8551.99
Median		6541.87
Std. Deviation		7836.37
Variance		61408663.21
Skewness		1.524
Kurtosis		2.547
Range		38063.87
Minimum		158.01
Maximum		38221.88
Percentiles	25	2886.19
	50	6541.87
	75	11396.35

b. Statistics



c. Histogram

Figure E.3. DEM-based drainage basins for 5,000 km^2 area threshold

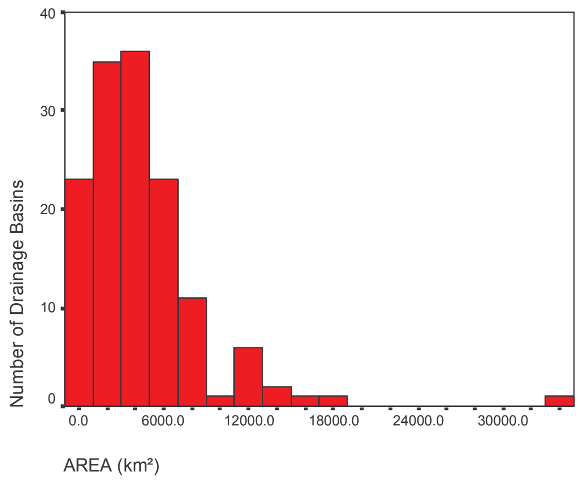


a. Geographic distribution

AREA

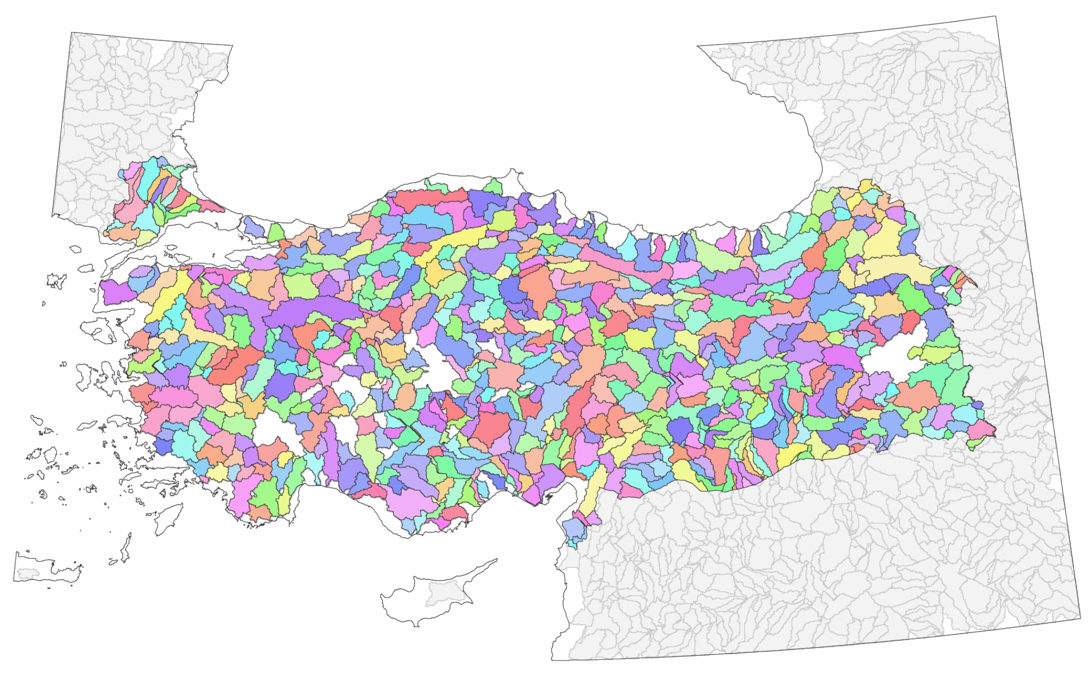
N		140
Mean		4423.39
Median		3446.85
Std. Deviation		4253.73
Variance		18094201.04
Skewness		3.149
Kurtosis		17.030
Range		34010.08
Minimum		118.49
Maximum		34128.56
Percentiles	25	1626.78
	50	3446.85
	75	6028.31

b. Statistics



c. Histogram

Figure E.4. DEM-based drainage basins for 2,500 km^2 area threshold

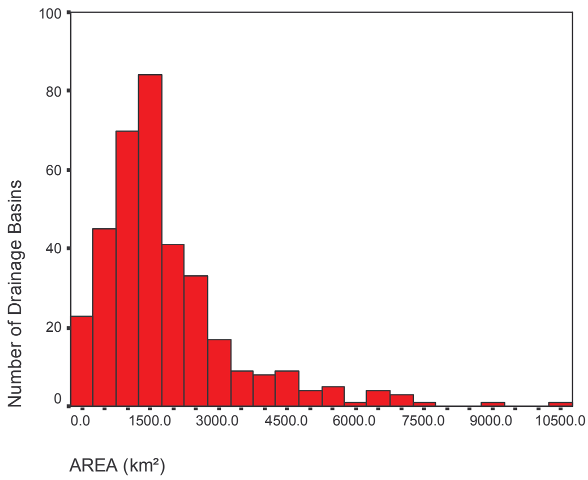


a. Geographic distribution

AREA

N		708
Mean		981.45
Median		781.87
Std. Deviation		775.32
Variance		601114.80
Skewness		2.038
Kurtosis		6.659
Range		6412.50
Minimum		32.06
Maximum		6444.56
Percentiles	25	536.92
	50	781.87
	75	1264.78

b. Statistics



c. Histogram

Figure E.5. DEM-based drainage basins for 500 km^2 area threshold

APPENDIX F

STRUCTURE OF DATABASE TABLES

Detailed information on the structure of the database tables used by the discharge and water quality data analysis system is given in this section. Field name, data type, size/precision and description of attributes are tabulated for each database table. All field names are in capital and consist of alphanumeric characters and underscore only. Description of data types used in the database tables are given in Table F.1.

Table F.1. Description of data types

Type	Description
Short	Integer stored as two binary bytes
Long	Integer stored as four binary bytes
Float	Real number stored as binary coded decimal
Text	String stored in a fixed length format
Date	Date stored as character string with format 'yyyymmdd'

Size information given in the tables has different meaning depending on the data type. For short, long and text data types, sizes are indicated by an integer that shows the length of the attribute value. For float data type, size is indicated by a decimal number. Integer part of this number indicates the scale (length) of the attribute value, whereas the decimal part indicated the precision (number of decimal places). Date data type has a predefined size; therefore its size is not explicitly given in the tables.

A set of sample data is also provided for each database table to illustrate the format of actual data that are (and will be) entered to the database.

Table F.2. Structure of LU_BASIN.DBF database table

Field Name	Type	Size	Description
WS_ID	Short	2	Watershed ID
DSI_NAME	Text	32	Watershed name used by SHW
EIE_NAME	Text	42	Watershed name used by EIE

<u>Sample Data:</u>

WS_ID	2
DSI_NAME	Marmara Havzası
EIE_NAME	Müteferrik Marmara Suları Havzası

Table F.3. Structure of LU_GAUGE.DBF database table

Field Name	Type	Size	Description
GAUGE_ID	Short	1	Gauge type
NAME	Text	64	Gauge type description

<u>Sample Data:</u>

GAUGE_ID	1
NAME	Eşel

Table F.4. Structure of LU_MDSTYPE.DBF database table

Field Name	Type	Size	Description
MDS_TYPE	Short	2	Monthly discharge summary type
MDS_NAME	Text	32	Monthly discharge summary name
MDS_DESC	Text	128	Monthly discharge summary description

<u>Sample Data:</u>

MDS_TYPE	2
MDS_NAME	Total (million m^3)
MDS_DESC	Total Discharge (million m^3)

Table F.5. Structure of LU_MONTH.DBF database table

Field Name	Type	Size	Description
MONTH_NO	Short	2	Month number
MONTH_NAME	Text	16	Month name
MONTH_ABBR	Text	3	Month abbreviation

Sample Data:
MONTH_NO 10
MONTH_NAME October
MONTH_ABBR Oct

Table F.6. Structure of LU_ORGANIZATION.DBF database table

Field Name	Type	Size	Description
ORG_ID	Short	1	Organization ID
ABBR	Text	12	Organization abbreviation
NAME	Text	64	Organization name
GS	Short	1	Has gauging stations? (0 = NO, 1 = YES)
WQS	Short	1	Has water quality monitoring stations? (0 = NO, 1 = YES)

Sample Data:
ORG_ID 1
ABBR DSI
NAME Devlet Su İşleri Genel Müdürlüğü
GS 1
WQS 1

Table F.7. Structure of LU_WQSTYPE.DBF database table

Field Name	Type	Size	Description
TYPE_ID	Short	2	Water quality monitoring station type
TYPE_DESC	Text	64	Water quality monitoring station description

Sample Data:
TYPE_ID 4
TYPE_DESC Drenaj Kanalı

Table F.8. Structure of LU_WQPARAMETER.DBF database table

Field Name	Type	Size	Description
WQP_SYM	Text	12	Water quality parameter symbol
WQP_NAME	Text	32	Water quality parameter name
WQP_UNIT	Text	16	Water quality parameter unit
WQP_TYPE	Text	8	Water quality parameter unit type (Decimal, Integer, Date)
WQP_WNP	Float	3.1	Water quality parameter unit precision

Sample Data:

WQP_SYM	T
WQP_NAME	Temperature
WQP_UNIT	^{o}C
WQP_TYPE	Decimal
WQP_WNP	7.3

Table F.9. Structure of LU_WQTEMPLATE.DBF database table

Field Name	Type	Size	Description
WQT_NAME	Text	32	Water quality parameters template name
WQT_PARMS	Text	254	List of water quality parameter symbols (comma separated)

Sample Data:

WQT_NAME	EIE
WQT_PARMS	Date,Q,T,Sed,pH,EC,Na_me,K_me,Ca_Mg_me,CO3,HCO3

Figure F.10. Structure of G-STATIONS.DBF database table

Field Name	Type	Size	Description
WS_ID	Short	2	Watershed ID
ORG_ID	Short	1	Organization ID
ST_ID	Short	3	Station ID
GS_ID	Long	6	Gauging station ID
ST_NAME	Text	64	Station name
LATITUDE	Float	6.4	Latitude (decimal degrees)
LONGITUDE	Float	6.4	Longitude (decimal degrees)
ELEVATION	Short	4	Elevation (m)
DR_AREA	Float	7.2	Drainage area (km^2)
GAUGE	Short	1	Gauge type
LOCATION	Text	128	Description of station location
R_START	Date	-	Start of recoding period
R_END	Date	-	End of recording period

<u>Sample Data:</u>

WS_ID	22
ORG_ID	3
ST_ID	2
GS_ID	2203002
ST_NAME	Kara Dere – Değirmencik Köyü (Ağnas)
LATITUDE	40.8517
LONGITUDE	40.0089
ELEVATION	78
DR_AREA	649.59
GAUGE	1
LOCATION	Trabzon'a bağlı Araklı ilçesinden Dağbaşı bucağına giden yolun 12. km'sindedir
R_START	11/12/1942
R_END	09/30/1991

Figure F.11. Structure of WQ-STATIONS.DBF database table

Field Name	Type	Size	Description
ORG_ID	Short	1	Organization ID
WS_ID	Short	2	Watershed ID
ST_ID	Short	3	Station ID
WQS_ID	Long	6	Water quality monitoring station ID
NAME	Text	64	Station name
ELEVATION	Short	4	Elevation (m)
DR_AREA	Float	6.2	Drainage area (km2)
GS_ID	Long	6	Gauging station ID
S_START	Date	-	Start of sampling period
S_END	Date	-	End of sampling period
LOCATION	Text	128	Description of station location
REMARKS	Text	128	Remarks
LATITUDE	Float	6.4	Latitude (decimal degrees)
LONGITUDE	Float	6.4	Longitude (decimal degrees)

Sample Data:

ORG_ID	3
WS_ID	22
ST_ID	6
WQS_ID	322006
NAME	Değirmendere - Kanlıpelit
ELEVATION	263
DR_AREA	737
GS_ID	322006
S_START	07/07/1988
S_END	12/17/1991
LOCATION	Trabzon’dan Erzurum’a giden şosenin 25. km’sinde Kanlıpelit çevresindedir
REMARKS	İstasyon 1992 yılında kapatılmıştır
LATITUDE	40.8381
LONGITUDE	39.6317

Table F.12. Structure of Daily Discharge (Dxxxxxxyyyy.DBF) database table

Field Name	Type	Size	Description
DAY	Short	4	Day in a month
OCT	Float	6.3	Discharge for the day in October
NOV	Float	6.3	Discharge for the day in November
DEC	Float	6.3	Discharge for the day in December
JAN	Float	6.3	Discharge for the day in January
FEB	Float	6.3	Discharge for the day in February
MAR	Float	6.3	Discharge for the day in March
APR	Float	6.3	Discharge for the day in April
MAY	Float	6.3	Discharge for the day in May
JUN	Float	6.3	Discharge for the day in June
JUL	Float	6.3	Discharge for the day in July
AUG	Float	6.3	Discharge for the day in August
SEP	Float	6.3	Discharge for the day in September

xxxxxx = Gauging station ID
yyyy = Year

Sample Data:

DAY	4
OCT	9.26
NOV	12.1
DEC	6.65
JAN	7.2
FEB	8.17
MAR	6.65
APR	15.1
MAY	45.9
JUN	26.7
JUL	6.99
AUG	5.66
SEP	4.6

Table F.13. Structure of Yearly Discharge Summary (DSyyyy.DBF) database table

Field Name	Type	Size	Description
GS_ID	Long	6	Gauging station ID
DS_PERIOD	Short	2	Length of recording period (years)
DS_PMIN	Float	7.3	Minimum discharge in recording period (m3/s)
DS_PMAX	Float	7.3	Maximum discharge in recording period (m3/s)
DS_PAVG	Float	7.3	Average discharge in recording period (m3/s)
DS_YMIN	Float	7.3	Minimum discharge in water year (m3/s)
DS_YMAX	Float	7.3	Maximum discharge in water year (m3/s)
DS_YAVG	Float	7.3	Average discharge in water year (m3/s)
DS_PMIN_D	Date	-	Date of minimum discharge in recording period
DS_PMAX_D	Date	-	Date of maximum discharge in recording period
DS_YMIN_D	Date	-	Date of minimum discharge in water year
DS_YMAX_D	Date	-	Date of maximum discharge in water year
RC_ID	Short	2	Rating curve ID used in water year
DS_REMARKS	Text	254	Remarks
DS_YTOTAL	Float	6.1	Total discharge in water year (million m3)

yyyy = Year

<u>Sample Data:</u>

GS_ID	322001
DS_PERIOD	23
DS_PMIN	2.45
DS_PMAX	731
DS_PAVG	26.131
DS_YMIN	3.35
DS_YMAX	351
DS_YAVG	31.403
DS_PMIN_D	08/06/1972
DS_PMAX_D	04/09/1978
DS_YMIN_D	07/24/1987
DS_YMAX_D	05/02/1987
RC_ID	25
DS_REMARKS	Akım durumu iyi. Yıl içinde 2 ayrı anahtar eğrisi kullanılmış, 10 akım ölçüsü yapılmıştır.
DS_YTOTAL	990.3

Table F.14. Structure of Monthly Discharge Summary (MDxxxxxxyyyy.DBF) table

Field Name	Type	Size	Description
MDS_TYPE	Short	4	Monthly discharge summary type
OCT	Float	6.3	Value for October
NOV	Float	6.3	Value for November
DEC	Float	6.3	Value for December
JAN	Float	6.3	Value for January
FEB	Float	6.3	Value for February
MAR	Float	6.3	Value for March
APR	Float	6.3	Value for April
MAY	Float	6.3	Value for May
JUN	Float	6.3	Value for June
JUL	Float	6.3	Value for July
AUG	Float	6.3	Value for August
SEP	Float	6.3	Value for September

xxxxxx = Gauging station ID
yyyy = Year

Sample Data:

MDS_TYPE	1
OCT	31.535
NOV	38.492
DEC	25.197
JAN	31.842
FEB	26.483
MAR	33.85
APR	114.109
MAY	198.18
JUN	72.755
JUL	36.651
AUG	39.949
SEP	17.738

Table F.15. Structure of Rating Curve (RCxxxxxxnn.DBF) database table

Field Name	Type	Size	Description
LEVEL	Short	3	Water level (cm)
DISCHARGE	Float	7.3	Discharge (m3/s)

xxxxxx = Gauging station ID
nn = Rating Curve ID

Sample Data:

LEVEL	60
DISCHARGE	0.64

Table F.16. Structure of Water Quality Monitoring (WQxxxxxxyyyy.DBF) table

Field Name	Type	Size	Description
MONTH	Text	3	Month Abbreviation
A set of water quality fields: Name, type and precision depends on the parameter			

xxxxxx = Water quality monitoring station ID
yyyy = Year

Sample Data:

MONTH	Jul
HCO3	1.2
B_PPM	0.05
Q	13.474
EC	153
CA_MG_ME	1.4
CO3	0.1
CL_ME	0.16
ORG	1
PH	8
K_ME	0.03
SED	125
NA_ME	0.12
SO4_ME	0.09
T	17
DATE	07/07/1988