Development of GIS-based Stream Flow Data Analysis System for Turkey

Serkan Girgin, Zuhal Akyurek, Nurunnisa Usul

Data visualization and analysis tools constitute an important part of today's water resources protection, development, and management studies. Especially, GIS is very widely used in the last decades. U.S. EPA's BASINS and European Union's GREAT-ER systems are sound examples of latest developments in GIS-based systems. Although located at water critical geo-political location and has many on-going and planned water resources related projects, Turkey still has neither national hydrography datasets nor local water quality/quantity data analysis tools. In this study, a GIS-based data visualization and analysis system has been developed for stream flow data collected in Turkey. The system developed using AVENUE scripting language of ArcView 3.2 features a graphical user interface that utilizes dialogs, tables and charts to interact with the user and visualize stored data. A number of spatial and statistical analysis tools are also made available to reveal trends in data, calculate summaries and create thematic maps.

Introduction

Turkey is a country which forms a bridge between 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, the Middle East. Turkey has a yearly average precipitation of 642 mm, which results in a total water potential of 501 km^3 per year. 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 per year, 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 [1]. Therefore, development and protection of water resources reflects great importance.

Stream flow 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 their forms are appropriate for data analysis methods and tools [2]. Large amounts of stream flow gauging data are available for surface water resources of Turkey. However, majority of these data are on paper in the form of yearbooks, reports, and print-outs. This is especially the case for the data that are collected before the second half of 1990's. In addition to that, available data are distributed among several institutions and a single national database does not exist. This results in a lot of additional work to be done to collect required data for water resources related studies. Data analysis and visualization tools to support local studies are also lacking. In the current state, it is very difficult to evaluate trends in stream flow data even for a single water year. The task gets much more complicated if one should work on data of several years. 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. Computerized data visualization and analysis tools, especially Geographic Information Systems (GIS) can be very useful in solving these problems. Actually, GIS is being widely used in today's water resources development and management studies throughout the World.

U.S. EPA's Better Assessment Science Integrating Point and Non-point Sources (BASINS) [3] and European Union's Geography-referenced Regional Exposure Assessment Tool for European Rivers (GREAT-ER) [4] are sound examples of latest developments in GIS-based water resources management systems. However, so far such tools did not found any application in Turkey.

In order to lessen the problems mentioned above, a GIS-based stream flow data visualization and analysis system applicable to local conditions of Turkey has been developed as a part of a more detailed study, which includes development of a national hydrography dataset, delineation of national sub-basins, and development of a water quantity/quality data analysis system [5]. Stream flow data analysis system is built on a database structure, which is designed according to the format of stream flow data collected by the national institutions. A graphical user interface is developed on top of the GIS, which utilizes dialogs, tables, and charts to interact with the user and visualize data stored in the database. A number of tools are made available to easily enter new data, to reveal trends in data, and to calculate statistical summaries. In this paper, first a summary of stream flow data sources in Turkey is given. After that, the structure of the database is described and developed data visualization and analysis system is explained in detail. Discussions of the results and conclusions are given at the end.

Stream Flow Data Sources

In Turkey there exists no single institution that is responsible for monitoring of water resources. Instead, several institutions are collecting hydrological data for their own needs. Leading institutions in this area can be listed as follows:

- General Directorate of State Hydraulic Works
- General Directorate of Electrical Power Resources Survey and Development Admin.
- General Directorate of Rural Services

Different types of monitoring studies are being conducted by these institutions. Collected data include stream flows, water levels in lakes, water quality and sediment measurements, some meteorological parameters, and snow depths. General Directorate of State Meteorological Works can also be added to the list in terms of meteorological data. Within the scope of this study, attention is given to the stream flow monitoring studies.

General Directorate of State Hydraulic Works (SHW), which is founded in 1953, is one of the primary managerial water agencies of Turkey. The directorate that is bound to the Ministry of Energy and Natural Resources (MoENR) 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. In order to supply data needed for these duties, SHW collects hydrometeorological data all over the country. Stream flows of the water courses are monitored by gauging stations. By the end of 2002, there were 1139 stream flow gauging stations operated by SHW [6].

General Directorate of Electrical Power Resources Survey and Development Administration (EPRSDA) operates the second largest stream flow monitoring network of Turkey. EPRSDA is an investor governmental institution that is founded in 1935. The directorate, which is also bound to the MoENR, carries out engineering services related to electrical energy production.

Since 1935, EPRSDA has been collecting stream flow data along the nation's large surface water courses. As of 2003, there are 284 stream flow monitoring stations that are being operated by the regional hydrometric directorates of EPRSDA [7].

General Directorate of Rural Services (GDRS) is another institution, which collects data on 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 to 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. Unlike SHW and EPRSDA, which collect nation-wide data, data collected by GDRS are limited to small sized watersheds that are located within the service boundaries of the directorate's research institutes. Currently, there are 21 watersheds monitored by 10 research institutes [8]. Typically there exists only one stream flow gauging station in each GDRS watershed, which is located at the outlet of the watershed. However in large watersheds there may be more than one gauging station. Total number of gauging stations operated by GDRS is less than 30.

Stream flow data collected by SHW, EPRSDA, and GDRS are published by these institutions as yearbooks. Each institution publishes its own yearbook, but the formats of the yearbooks are quite similar to each other. In these yearbooks, stream flow gauging stations that are operational in that water year are listed with respect to the national basins and detailed daily stream flow data are provided for each gauging station. All information on a gauging station is given on a single page in the yearbook under the following subheadings: general information, water year summary, daily stream flows, and monthly stream flow summaries. A sample page from SHW yearbook is given in Figure 1. General information includes geographic location (latitude/longitude and description), drainage area, approximate elevation, and recording period (starting and ending dates). As a summary of the stream flow conditions at the gauging station, minimum, maximum and average stream flows are given both the for the water year and for the whole recording period. Occurrence dates of the minimum and maximum flows are also stated. Critical data points of the rating curve are tabulated. Daily stream flow records are also given in tabular form. Columns in daily stream flow table are representing months in the water year, whereas rows are representing the days in the months. A water year starts on October, 1st of the previous year and ends on September, 30th of the stated year. Daily stream flow table for a water year is complete and there exists no missing data. Daily stream flow values given in the table are average values that are calculated from a set of values measured in a day. At the bottom of the yearbook page, summaries of the daily stream flows are given for each month. Six different monthly summaries are available, which are maximum stream flow (m^3/s), minimum stream flow (m^3/s), average stream flow (m^3/s), average yield of the basin ($l/s/km^2$), total runoff (mm), and total volume of flow (million m^3). Locations of gauging stations are indicated on separate maps that are prepared for each basin. Although yearbooks include information only on gauging stations that are operational, locations of non-operational gauging stations are indicated on these maps as well.

One significant problem related to the published yearbooks is the presence of a long time lag between the data collection and publication. For example, SHW yearbook of 1994 water year could be published just 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 (e.g. United States [9]).

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 Km^2 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
$LT/SN/KM^2$	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 $LT/SN/KM^2$

Figure 1. Sample page from SHW Stream Flow Monitoring Yearbook [10]

Structure of the Stream Flow Database

A file based database structure has been utilized to store stream flow data and general information on monitoring stations. Database tables are stored as separate Dbase IV files, which is the native database format of ArcView GIS 3.2. A directory hierarchy is created to organize the database tables. Shape files and raster grids are also organized in the same directory hierarchy. Employed directory structure is given in Table 1.

Table 1. Descriptions of directories used to store files

Directory name	Description
discharge	Daily stream flows are stored in this folder. Naming convention: Dobbnnnyyyy.dbf *
dsummary	Water year summaries are stored in this folder Naming convention: DSyyyy.dbf *
lutable	Look-up tables that are used internally by the analysis system are stored in this folder (e.g. lookup tables for basins, institutions, settings, etc.)
mdsummary	Monthly discharge summaries are stored in this folder Naming convention: MDobbnnnyyyy.dbf *
rcurve	Rating curves are stored in this folder Naming convention: RCobbnnncc.dbf *
shape	Supplementary shape files are stored in this folder (e.g. water courses, inland wated bodies, settlements, etc.)
stations	Information on stream flow gauging stations are stored in this folder.
template	Database table templates are stored in this folder.

* o = operator institution id, bb = national basin id, nnn = gauging station id, yyyy = water year, cc = rating curve id

Database tables are used for two different purposes: to store stream flow data and related summaries; and to store supplementary data that are required by the analysis system. Daily stream flows, monthly stream flow summaries, water year summaries, and rating curves can be classified in the former type, while look-up tables and database table templates can be classified in the latter. Although the number of supplementary database tables is pretty constant, the number of stream flow related database tables solely depends on the amount of data that is entered to the database. Special naming conventions, which are indicated in Table 1, are used to organize these unknown number of database tables.

In order to differentiate organizations that operate gauging stations from each other a single digit organization ID is defined. 26 national basins are indicated with two-digit basins IDs. Numbers given to stations by the operator institutions are stored as three-digit station IDs. By combining institution, basin and station IDs, unique numbers are obtained that define gauging stations and distinguish them from each other. For example a gauging station having a station number of 13 that is located in the first national basin (Meric Basin) and operated by SHW will have an identifier of 101013. These unique identifiers are used to name stream flow data tables. ‘obbnnn’ terms found in table names, as given in Table 1, represent these IDs. ‘yyyy’ terms designate water years and ‘cc’ terms designate rating curve numbers. For example daily stream flows are named according to ‘Dowwnnnyyyy.dbf’ convention, so 1999 water year daily stream flow data of the station that was given as an example above will be stored in ‘D1010131999.dbf’ file.

Stream Flow Gauging Station Maps

Similar to stream flow data availability problem, access to gauging station coverage maps is also a trouble in Turkey. None of the governmental institutions responsible from stream flow gauging supplies publicly available digital gauging station coverage maps that can be used in GIS. Commercial datasets are also not available. Hence, such datasets should have to be created by the end-user. Two data sources are available for this purpose: paper maps showing the locations of stream flow gauging stations and latitude/longitude values that are given in the stream flow yearbooks. Studies showed that the coordinates given in EPRSDA yearbooks are highly accurate and can be used to create the required coverage map. However, the accuracies of gauging station coordinates are poor in SHW yearbooks. Hence manual digitizing of SHW gauging station maps is the only way to obtain an accurate station coverage map.

For EPRSDA stream flow gauging stations, Excel sheets having the same information as general information section of the yearbooks 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. By visual inspection, locations of gauging stations are compared with the ones given in stream flow yearbook maps for validation purposes. Locations of only two gauging stations are found to be incorrect, and they are corrected by manual editing. For SHW stream flow gauging stations, maps available in the stream flow yearbooks are scanned, combined and geo-rectified to obtain a single raster map. Neither a grid nor geographic coordinates were available in the original maps, which made the rectification difficult. Watershed boundaries and settlements are used as control points in rectification and after an intensive work reasonable results could be obtained. Stream flow gauging stations are manually digitized from the resulting raster map and a point coverage is obtained for SHW gauging stations.

Since the number of stream flow gauging stations operated by GDRS is low and these stations are distributed in a limited geographical extend, they are not included to the database of the analysis system. However, the analysis system is fully compatible to the data collected by GDRS and these data can be used directly without any modifications to the system.

A map showing the EPRSDA and SHW stream flow gauging station coverages and national basins of Turkey is given in Figure 2.

General Information on the Analysis System

Based on the database structure and datasets explained above, an analysis system has been developed that combines database, mapping, data visualization and data 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 ArcView GIS 3.2 were limited, custom scripts were written using AVENUE scripting language that are working together with custom designed dialogs to perform the tasks that are needed by the analysis system. A typical session of the developed stream flow analysis system is illustrated in Figure 3.

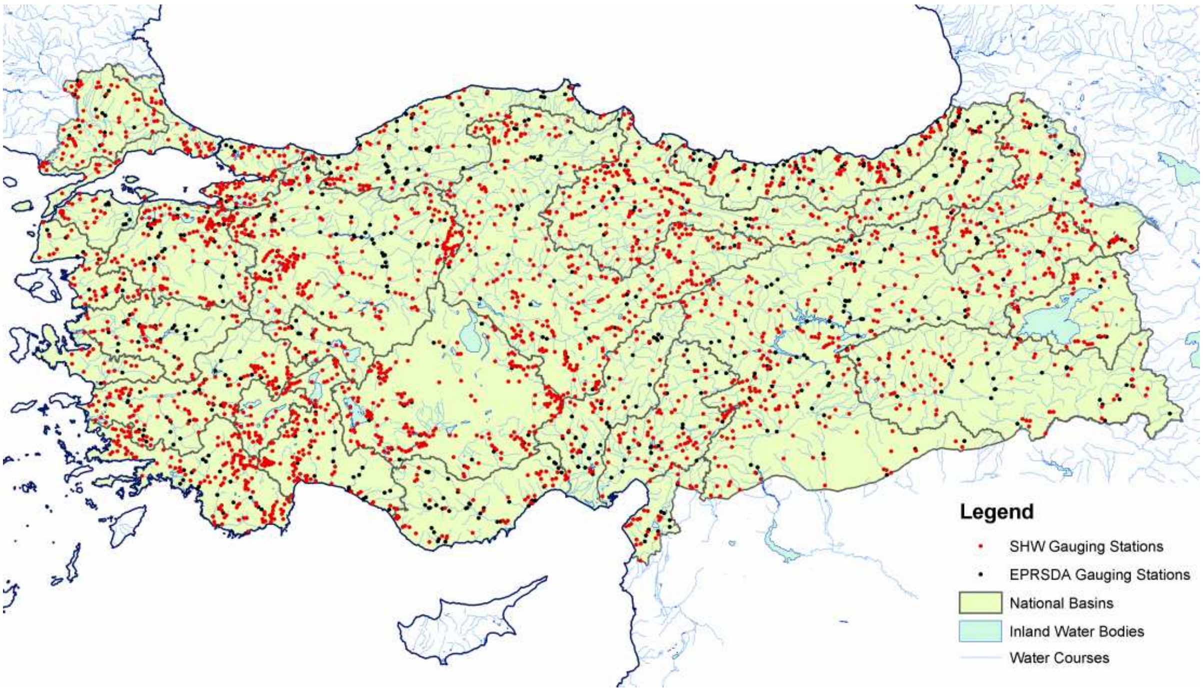

Figure 2. EPRSDA and SHW stream flow gauging stations and national basins of Turkey

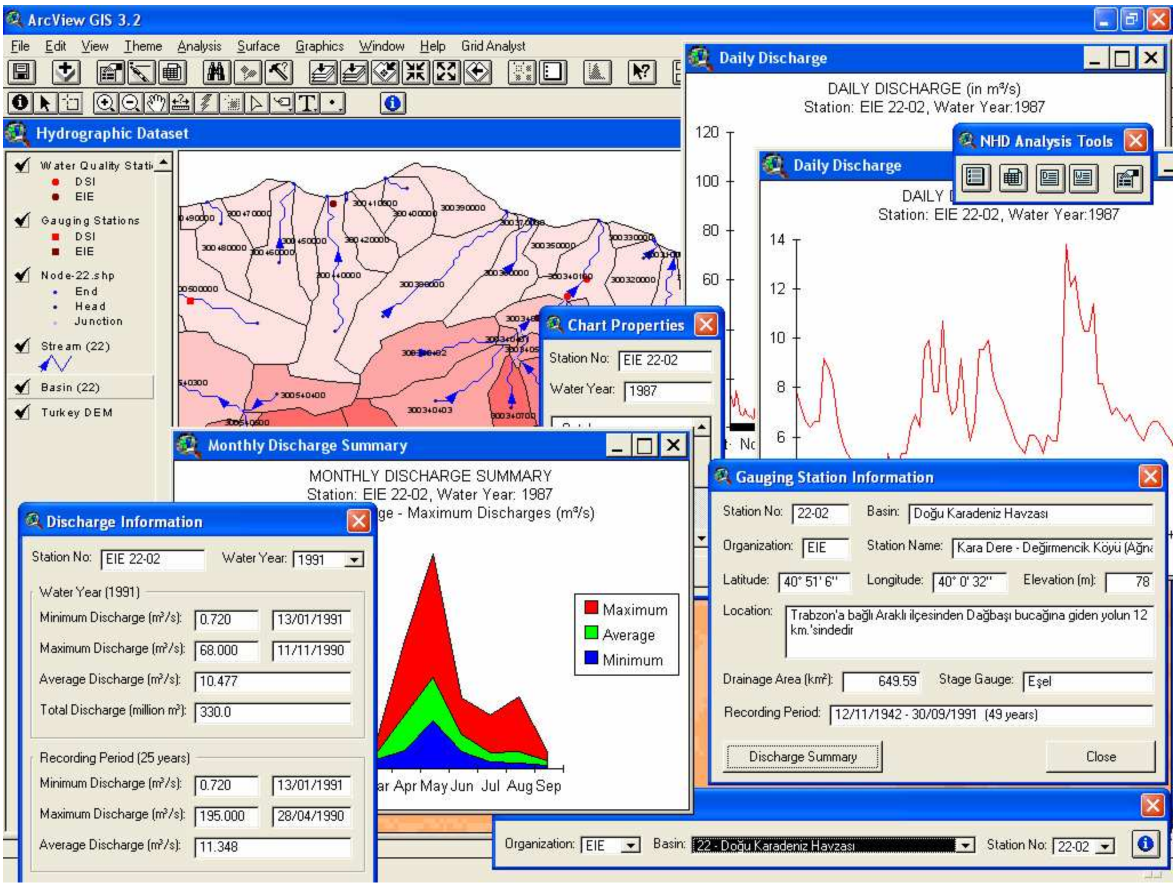

Figure 3. A typical session of the stream flow data analysis system

The key features of the developed analysis system are as follows:

- Stream flow gauging stations operated by different national institutions are made available on a single map,
- General information on monitoring stations can be accessed through an easy-to-use dialog based user interface,
- Data visualization and analysis tools are provided that are compatible with national stream flow data formats and standards,
- Water year summaries of the stream flow gauging stations can be obtained,
- Daily stream flow 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 stream flow values,
- 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,

A set of tools are made available in the system for the following purposes:

- Access to information on gauging stations and stream flow data
- Creation of new database tables for custom data entry
- Assessment of stream flow data availability
- Assistance to data calculations
- Changing analysis system settings

Above mentioned tools can be accessed through the ‘Analysis Tools’ toolbar, which includes buttons for each tool (Figure 4).

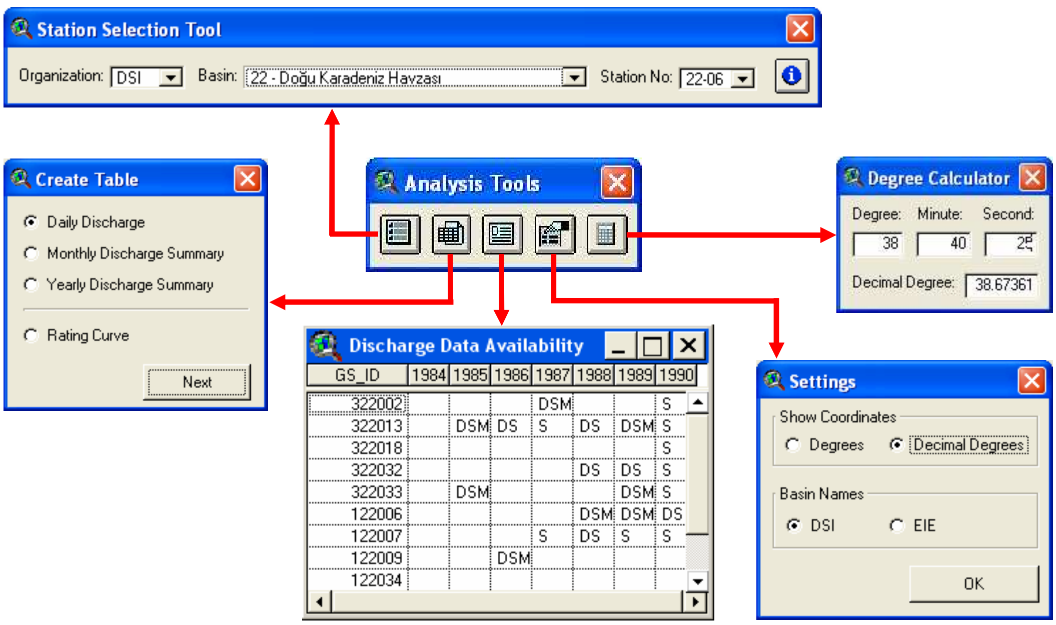

Figure 4. Stream flow data analysis tools

First button on the ‘Analysis Tools’ toolbar displays the ‘Station Selection Tool’ dialog window, which has three list boxes for the selection of operator institution, basin and gauging station. Once the user selects an institution and a watershed from the dialog, gauging station list box is updated with a list of stations that are within the selected watershed and operated by the selected institution. ‘Info’ button can be used to obtain detailed information on a selected gauging station and stream flow data recorded at that station. For this purpose the analysis system displays ‘Gauging Station Information’ dialog of the selected station (Figure 5). More details on this dialog window will be given in the ‘Stream Flow Data Analysis Tools’ section.

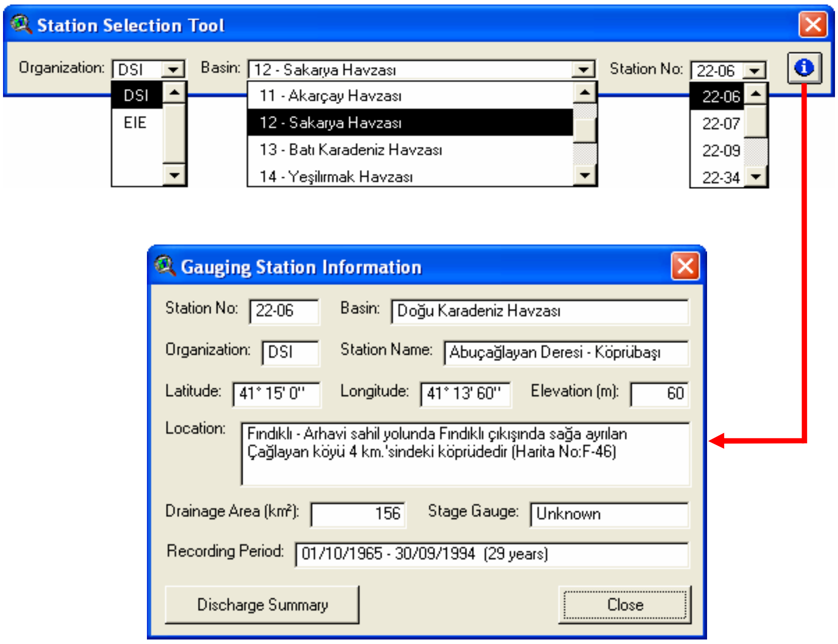

Figure 5. Selection of a gauging station from the Station Selection Tool dialog

Second button on the ‘Analysis Tools’ toolbar displays the ‘Create Table’ dialog, which can be used to create new database tables for custom data entry. Although a basic set of data is already entered to the database, new data entry is unavoidable since the sample data are limited both in time and in spatial coverage. For entering new data, several database tables should be created according to pre-defined table structures and these tables 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 by using the database table creation features of ArcView GIS. However, this may be time consuming and open to mistakes that may adversely affect the operation of the analysis system. In order to prevent such mistakes and to speed up data entry process, database table creation tools that can be used even by the most inexperienced user are developed as a part of the analysis system. The following database tables can be created by using ‘Create Table’ dialog, which is the parent window of these table creation tools:

- Daily Stream Flow
- Monthly Stream Flow Summary
- Yearly Stream Flow Summary
- Rating Curve

Once the user selects the database table that s/he wants to create and presses the 'Next' button on the 'Create Table' dialog, a second dialog is displayed. The contents of this second dialog depend on selected table type, but generally it includes basin name, operator institution, station no, and water year fields. According to the information entered to the second dialog, a blank database table of the requested type is created automatically based on the templates that are stored in the system database. All the user should have to do next is to enter data to the appropriate rows and columns of the table. Secondary dialogs and sample database tables are shown in Figure 6.

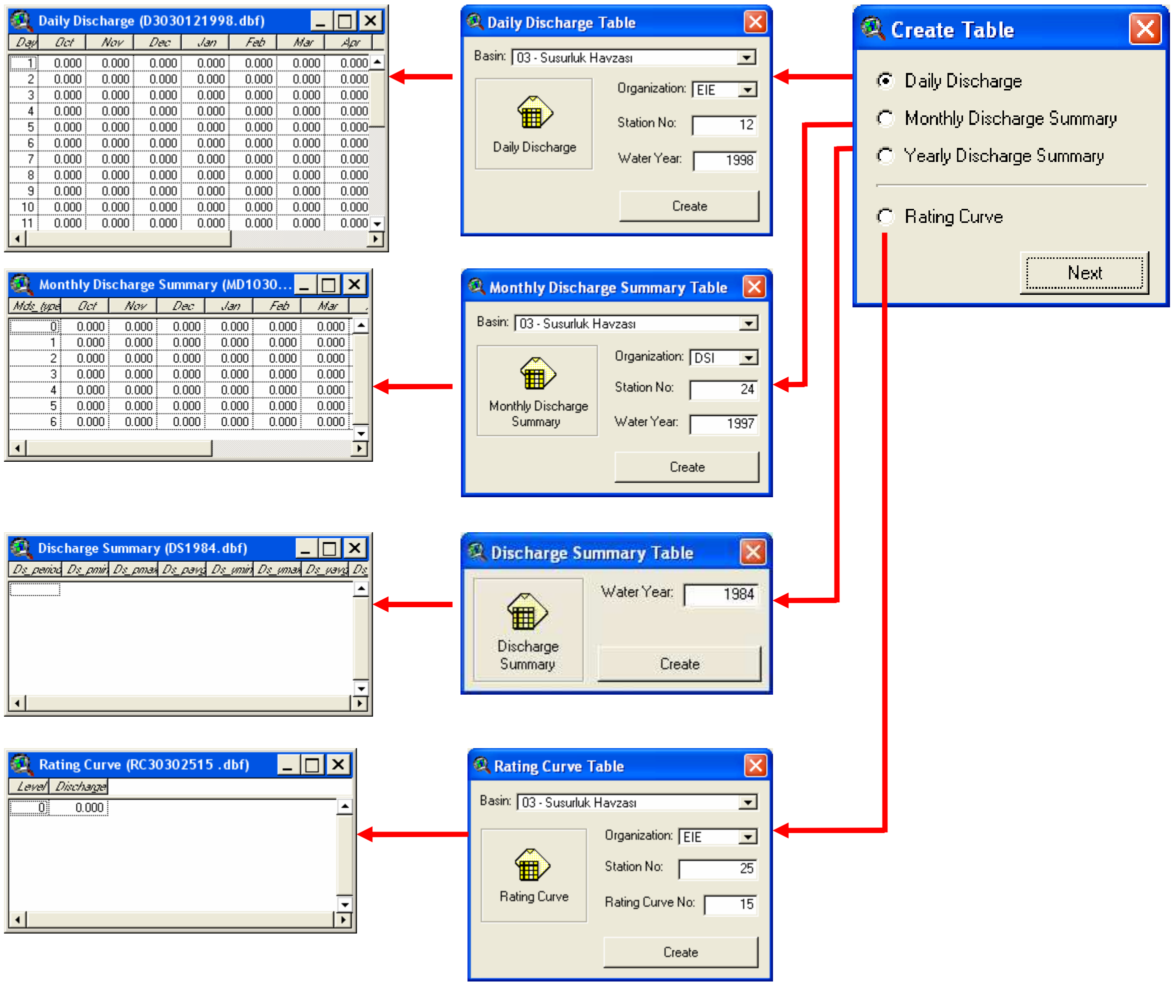

Figure 6. Create Table dialog and its sub-dialogs

Third button on the 'Analysis Tools' toolbar provides information on the distribution of available stream flow data in the database. Once this button is pressed, 'Discharge Data Availability' table will be displayed, which includes a column listing the gauging station IDs and a number of additional columns (one for each water year) showing information on stream flow data availability. Three different types of data may be available for a water year: daily stream flows, monthly stream flow summaries, and water year summaries. Presence of daily stream flow data is indicated with a 'D' in the table, whereas 'M' is used for monthly summaries and 'S' is used for yearly summaries (Figure 4). This table could be especially used to determine the stations or time periods, for which stream flow data are missing in the database.

Forth button on the ‘Analysis Tools’ toolbar displays a dialog window that is related to the 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 could be displayed as degrees or decimal degrees. The second setting is related with the naming convention of the national basins. Unfortunately, a common naming convention on national basins does not exist between SHW and EPRSDA. Instead of supporting just a single naming convention, both naming conventions are made available for selection. By changing ‘Basin Names’ setting, the user could determine which naming convention should be used in dialogs, tables and charts.

The last button on the ‘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. Latitudes and longitudes are given in degrees in most of the yearbooks. However, decimal degrees is a better format for the storage in the database. Hence, degrees should be converted to decimal degrees. Degree Calculator is developed to facilitate this conversion.

Stream Flow Data Analysis Tools

Information on stream flow gauging stations can be accessed in two ways: by selecting a station from ‘Station Selection Tool’ dialog or by selecting a station from the station coverage map by using ‘Info’ tool. In both cases, ‘Gauging Station Information’ dialog that includes general information on the selected gauging station will be displayed on the screen (Figure 5). Detailed explanation of the location of the station in terms of latitude, longitude, elevation and narrative textual description are given in addition to basic information like basin name, operator institution, station name, and station no. 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. Detailed stream flow data can be accessed by using ‘Discharge Summary’ button, which displays ‘Discharge Information’ dialog of the selected gauging station (Figure 7).

Before displaying the ‘Discharge Information’ dialog, the analysis system searches through the database to determine water years for which yearly stream flow summaries are available for the specified gauging station. Water year list box on the dialog is updated accordingly. Once the user selects a water year from the list box, the following information is provided as the summary of the selected water year: amount and date of minimum stream flow (m^3/s), amount and date of maximum stream flow (m^3/s), average stream flow (m^3/s), and total stream flow (million m^3). Information on minimum, maximum and average stream flows are also given for the recording period of the gauging station, which starts from the establishment of the station and ends at the selected water year. Textual remarks on the stream flow conditions in the water year are indicated as well. In order to access detailed stream flow data and statistics, the user should use five buttons located at the bottom of the dialog window. These buttons display the following charts and tables:

- Rating Curve (RC)
- Daily Discharge Chart (DDC)
- Daily Discharge Table (DDT)
- Monthly Discharge Summary Chart (MDC)
- Monthly Discharge Summary Table (MDT)

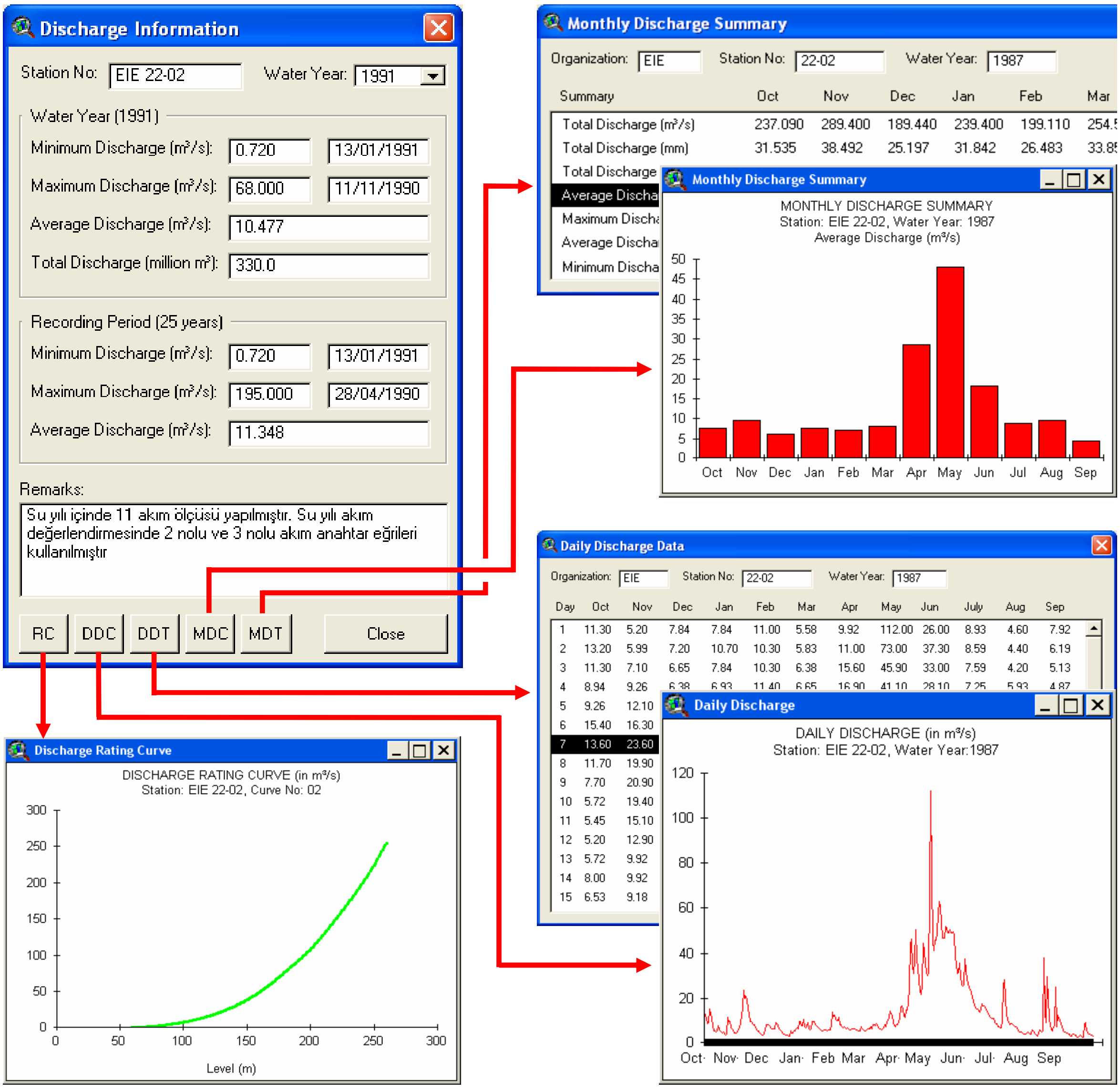

Figure 7. Information that can be accessed through Discharge Information dialog

In stream flow yearbooks, information on the rating curve used in a water year is given by a set of stream stage versus stream flow values, which consists of typically 5 to 12 data pairs. RC is drawn by the analysis system by interpolating these data points. The shape of the RC is assumed to be linear between the points of interpolation. The user can use 'Info' tool located on the toolbar to determine the stream flow at a specific stage level by clicking on the RC at that level.

DDT dialog can be used to obtain daily stream flow data. At the top of the dialog, operator institution, gauging station no, and water year are indicated. Daily stream flow data are given as a matrix, the axes being months and days in months. This is the same format as the stream flow yearbooks, which is mentioned before. By pressing DDC button on the 'Discharge Information' dialog, the user may create a time series graph of daily stream flow records for the specified water year. An important feature of the DDC is its interactive behavior. While the chart window is displayed on the screen, another dialog window called 'Chart Properties' is also made visible to the user. 'Chart Properties' dialog provides controls to alter the range of stream flow data that is displayed on the chart. This dialog and the chart window are linked to each other, and depending on the active data range of selected DDC (there may be more than one chart at a time), selection of months in the list box of the 'Chart Properties' dialog gets updated. Likewise, if the user changes the selection in the list box to cover a different range of months, active DDC gets updated to show corresponding date range. This feature is illustrated in Figure 8. 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 DDCs, 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 stream flow values. Similar to the rating curve graph, individual stream flow values on the graph can be determined by using 'Info' tool.

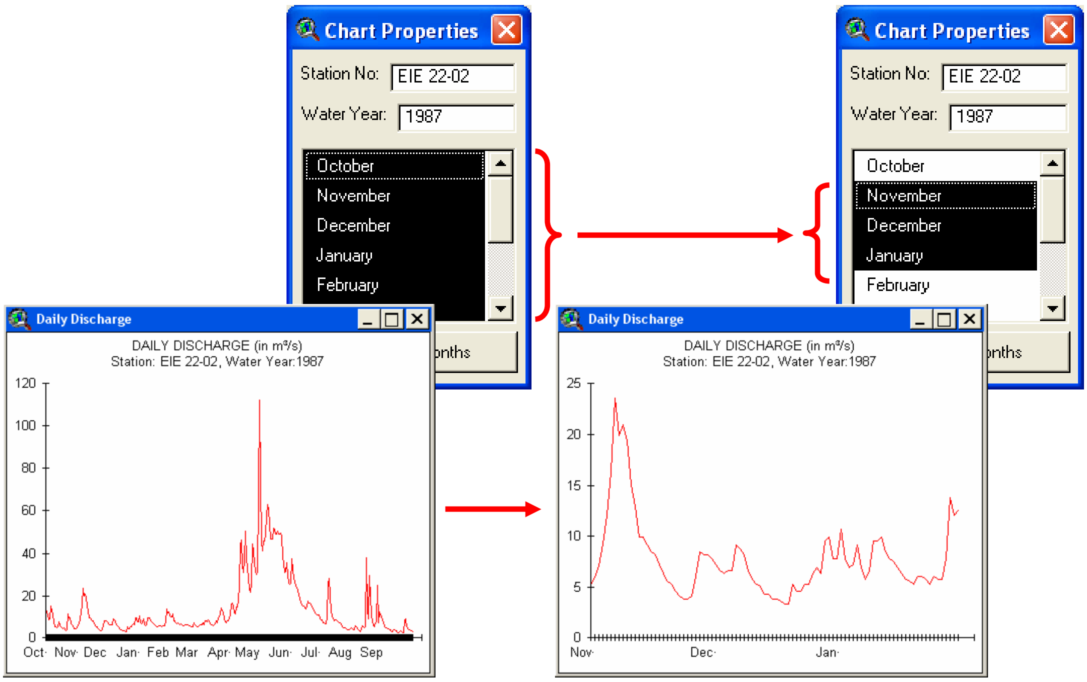

Figure 8. Dynamic behavior of the Daily Discharge Chart

In addition to daily stream flow data, monthly stream flow summaries are also made available to the user. Like the daily data, monthly summaries are also provided both in tabular form and as bar charts. Either MDT or MDC buttons on the 'Discharge Information' dialog should be used in order to access monthly stream flow summaries. The following summaries are available for each month in a water year: total discharge (m^3/s), total runoff depth (mm), total volume of flow (million m^3), maximum stream flow (m^3/s), minimum stream flow (m^3/s), average stream flow (m^3/s), and average yield of the basin (l/s/km^2). The user may enter these summaries manually to the database from the yearbooks. This is the suggested method of data entry, since some of the summaries given in yearbooks were calculated from instantaneous stream flows, which are not explicitly available. However, if monthly summaries are not available or the user does not want to enter data into the database separately, the system is capable of calculating approximate monthly summaries from daily stream flow values. If daily stream flows are available in the database but monthly summaries do not exist for a water year, then the system asks to the user whether monthly summaries should be calculated from daily values or not. If the user confirms, monthly stream flow summaries are calculated automatically by using the equations given in Table 2. Similar to DDCs, MDCs are also dynamic and interactive. Once a MDC is displayed on the screen, a 'Chart Properties' dialog that has a similar working principle with the DDC properties dialog is also displayed (Figure 9). A list of available summary types is provided on the dialog for selection. All summary types given in Table 2 can be selected from this list, and corresponding bar chart can be obtained. Additionally, an area chart showing minimum, maximum and average monthly stream flows on the same graph is also made available (Figure 9). Especially this last chart type summarizes 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 determined.

Table 2. 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 stream flow (m^3/s)	$\sum_{i=1}^{n} F_i \big/ n$
Maximum stream flow (m^3/s)	$Max(F_i)$
Minimum stream flow (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	

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.

Discussions and Conclusions

In this study, a GIS-based data analysis and visualization system has been developed for stream flow data collected in Turkey. The analysis system is built on a database structure which is designed according to the format of stream flow data collected by several governmental institutions. 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 and to calculate representative

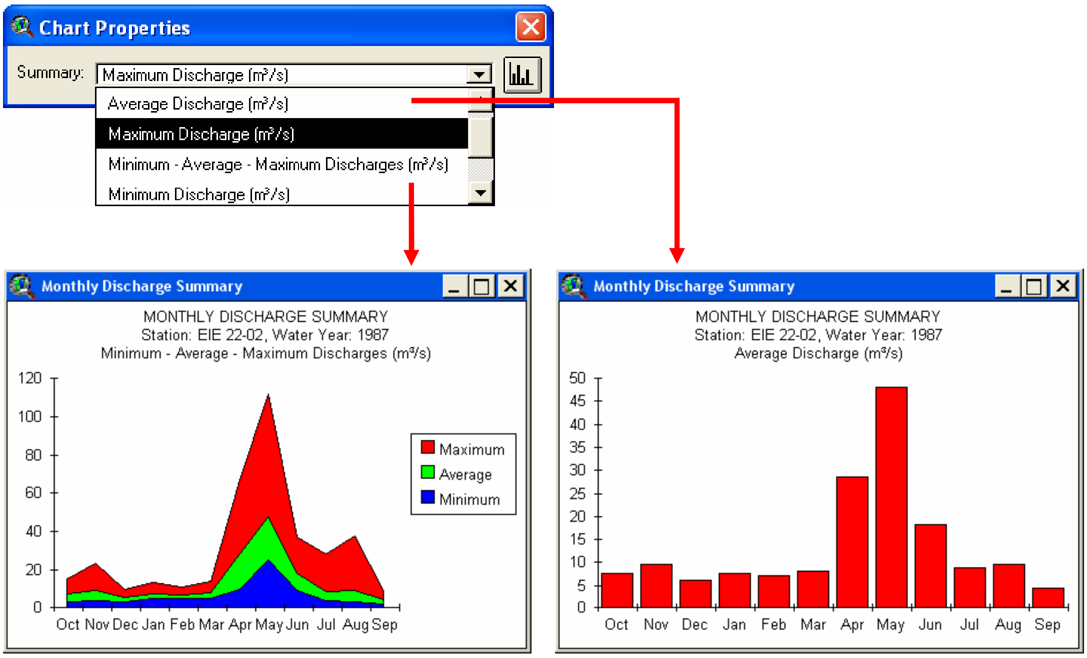

Figure 9. Monthly Discharge Summary charts

summaries. A unified map of national stream flow gauging stations is prepared, through which the user can access detailed information on stream flow measurements. Daily average stream flows, monthly discharge summaries, and water year summaries are made available both as textual data in dialogs and as interactive charts.

In the current state, the analysis system supports stream flow gauging data only. However, other types of monitoring stations, at which principal and supplementary data for hydrological studies are being collected, also exist in Turkey. Water quality and sediment monitoring stations of SHW and EPRSDA can be given as examples of such stations. Supporting these station types and providing analysis tools for the collected data could be one of the possible extensions to the developed analysis system.

Although maps, charts and tables generated by the stream flow analysis tools can easily be inserted into layout documents and print-outs can be taken from the GIS, existence of reporting tools capable of producing reports with pre-defined layouts would be very practical. Especially, reports in the format of stream flow yearbooks may facilitate reporting needs of national institutions and hence may increase the interest to the analysis system.

An interesting application of the analysis system could be visualization of change in stream flows in time. Charts of daily stream flows and monthly stream flow summaries could be created for different water years and by showing them one after another an animation could be formed, which will illustrate change in stream flow in time. Such an animation could be a very effective presentation aid.

An important factor, which will affect successful usage of the analysis system, is data availability. Although tools to facilitate data entry are present in the system and for small-sized studies the required data can easily be entered manually, it is still difficult to collect and enter data for regional or national studies. Especially if the study should cover a long time period, this task will become very labor-intensive. An institutional framework and support of national institutions (SHW and EPRDA) are required to overcome this problem. Data collected by these institutions that are available in obsolete databases could be imported by third-party tools, or the analysis system could be extended to support these database formats. In this way already existing data could be made available to the end users. Also past records that are existing on paper could be entered systematically to the database. Cooperation of governmental institutions is required in the aspect.

In the current situation, there exist several governmental institutions in Turkey that collect stream flow 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 means of data access. A national database for the storage and retrieval of stream flow data, which should be shared and operated together by related institutions, is a major requirement. Definitely, such a database would require highly developed tools to support distributed data access and storage, variable user privileges, advanced queries and better data visualization and analysis. Developed analysis system and its database structure could not support these needs. 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. A similar system was not developed before; hence the analysis system can be claimed to be an important progress for Turkey. It is hoped that the study will set an example for future works, and it will be useful for all people working on development and protection of surface water resources of Turkey.

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Author Information

Serkan Girgin
Middle East Technical University
Department of Environmental Engineering
Inonu Bulvari, 06531, Ankara/TURKEY
Phone: +90 (312) 210 58 62
E-mail: girgin@metu.edu.tr

Zuhal Akyurek
Middle East Technical University
Department of Geodetic and Geographic Information Technologies
Inonu Bulvari, 06531, Ankara/TURKEY
Phone: +90 (312) 210 24 81
E-mail: zakyurek@metu.edu.tr

Nurunnisa Usul
Middle East Technical University
Department of Civil Engineering
Inonu Bulvari, 06531, Ankara/TURKEY
Phone: +90 (312) 210 54 48
E-mail: nurusul@metu.edu.tr