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Separation of Hydrograph Components Using Stable Isotopes Case Study: The Güvenç Basin, Ankara

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Abstract

In this research, a stable environmental isotope study was carried out from an analysis of water samples collected from rainfall, runoff (total discharge), springs (subsurface flows) and wells (groundwater) between 1996 and 2000. The research site was the Güvenç Basin located near Yenimahalle-Ankara with a drainage area of about 16.125 km^2. The aim of the study was to investigate the rainfall-runoff relationship for the Güvenç Basin using the stable isotope method in the separation of hydrographs. Recorded total discharge hydrographs are separated into their components using isotopes (oxygen-18, deuterium) contents. Among these samples, unit hydrographs from 2 single-peaked storm hydrographs were derived using both isotope and graphical (Barnes semi-log) methods and the derived unit hydrographs' peaks were compared. It was found that the contribution of subsurface flow originating from various sublayers of the basin is important in hydrograph separation when using the isotope method of approach.

Key words: Hydrograph separations, Stable isotopes, Graphical method, Unit hydrograph.

Introduction

Spatial and temporal distributions of precipitation vary significantly in different regions of Turkey. In general, the amount of precipitation is low in the central part of the country. It is necessary to store water to prevent drought when the precipitation is lower than expected. Should excess precipitation occur in the short term, catchment management and flood control structures must be considered to prevent floods. In this situation it is necessary to know the hydrologic properties (such as precipitation, runoff and evaporation) to obtain long-term economic water storage structures. For these reasons, there are many representative hydrologic basins established in Turkey by the General Directorate of Rural Services (GDRS). In these basins, precipitation and runoff values are recorded continously and the relationships between these values have been investigated for the last 20 years. Güvenç Basin, the study area, is one of these representative basins. In this basin, a streamgauging station and 5 raingauges have been installed to collect runoff and rainfall data. A small dam was constructed at the outlet of the basin to store and provide water for agricultural areas.

The aim of this study was to investigate the proportion of storm water during distinct hydrologic events and also to analyze hydrograph separation. In addition, we sought to better understand the behaviour of individual precipitation events using the isotope method and then compared the results using a semi-log graphical method. Water balance can be used by the isotope composition of the hydrologic cycle to identify the important processes of flow patterns that cause the generation of streamflow in a basin.

Basin Description

The Güvenç Basin is located about 44 km north of Ankara. The altitude of the 16.125 km^2 basin is between 1053 m at the river sampling site and 1458 m (Figure 1). A 90° V-notch weir (W-17), located at the outlet of the basin, continuously records stream discharge. The main channel (Kayaönü River) is a fourth order, perennial stream at the outlet. Five standard rain gauges (R24-R28) are located within the basin and these are used to continuously record the amount of precipitation (Figure 1). The data are then collated by the Ankara Research Institute of the GDRS.

The mean annual precipitation depth is 441.5 mm (1984-1996), and 33% of the precipitation falls during spring. Spring runoff is the dominant hydrologic event in this region. The mean annual runoff is 94.53 mm with 26.85 mm surface, 17.50 mm subsurface and 50.18 mm groundwater runoff.

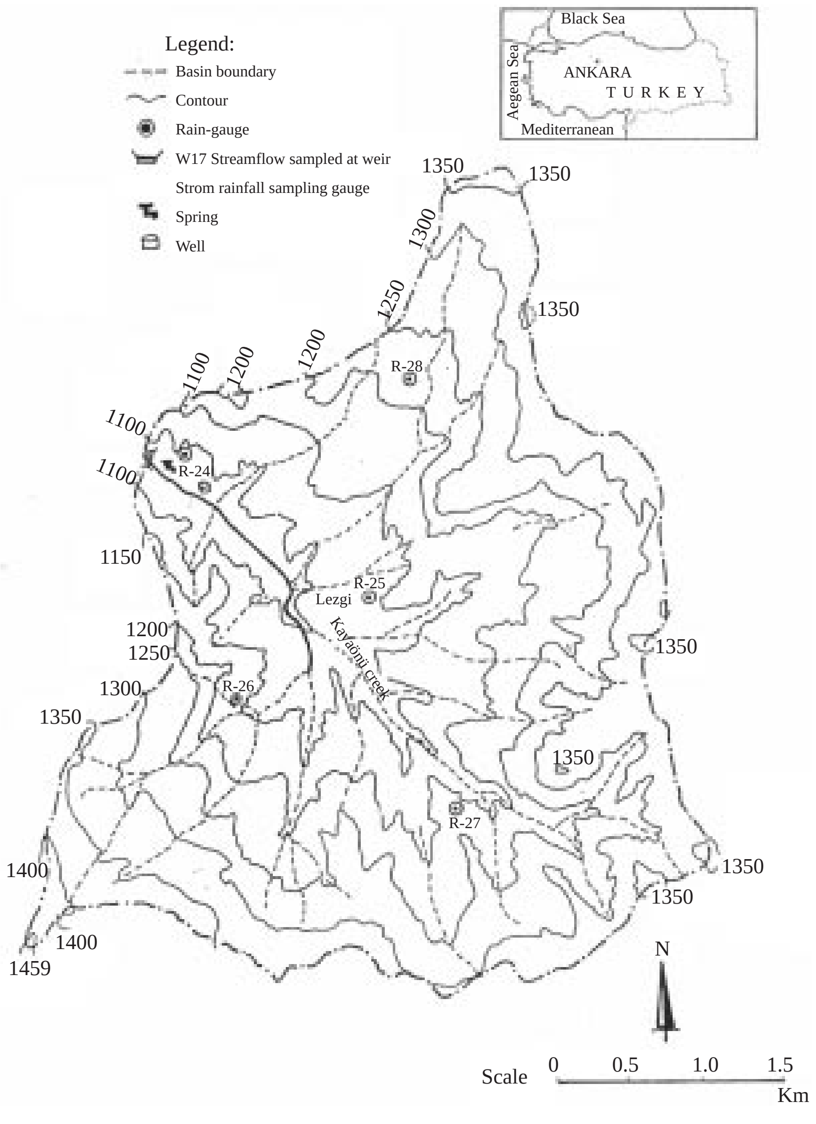


Figure 1. Topography and location of sampling points in the Güvenç Basin.

The topography is mature with the 21% average slope of the basin characterized mainly by rounded hilltops. The soil texture of basin ranges from sandy–clay to clay–loam. Soil depth varies from 15 to 80 cm. Along the stream side, the soil characteristics consist only of abundant clay with 3% organic matter (Cebel *et al.*, 2001). The vegetation consists of 4% forest, and 46% meadow shrubs and trees, which are located along some drainage lines. The remaining part of the basin is covered by dry agricultural areas (40%). The center of the basin is covered in limestone of the Sarıbeyli formation and loam sandy stone of the Dikmendere formation in the southeast part of the basin.

Literature Review

Dinçer and Payne (1970) determined the water budget of 3 lakes and also investigated the origin of the waters that emerge from the large karstic resources in the Mediterranean region using stable isotopic concentrations.

Sklash and Farvolden (1979) outlined the following conditions for the use of environmental tracers: (1) the isotope content of the new water is distinguishable from the old water content (2) the groundwater and vadose water (which together compose the old water) are isotopically equievalent; and (3) surface storage contributes minimally to the runoff.

Fontes (1980) stated that research on the use of hydrogen isotopes to estimate the sources of water during storm runoff began with Hubert *et al.* (1969), who used tritium content as a label for rainfall and prestorm stream flow.

According to Kennedy *et al.* (1986), rainfall intensity and isotopic composition were quite variable within an individual storm. Gentle to moderate intensity rain may infiltrate into the soil, whereas intense rainfall with a very different isotopic composition may flow over hillslopes quite rapidly. As a result, the isotopic composition of surface stormflow may not match that of the average isotopic composition of the rain.

The determination of runoff from snow melting using stable isotopes was performed first in Turkey by Ertan (1987). The water equivalent of snow was determined by using both nuclear and classical techniques on the northern slopes of Uludağ mountain near Bursa. It was discovered that the nuclear methods can be applied either separately or in combination with classical methods.

Stable isotope methods were used by Günyaktı *et al.* (1991) to predict the contributions of surface runoff, snowmelt, subsurface interflow and base flow of the Ankara-Yenimahalle Güvenç Basin. For 3 major storm events in 1989, flow separations were accomplished by means of isotope methods; a good correlation was found with the classical approach. In this study, it was also recommended that isotopic data should be collected at the same intervals on an hourly or even shorter duration, and these may be used for hydrologic analysis in order to apply the isotopic methods efficiently.

Weiler *et al.* (1999) have shown that field hydrometric measurements and hydrograph separation should be coupled to allow a meaningful description of flow components and their generation mechanisms. The 4 main runoff processes listed below are derived from their investigation results using dye tracer experimentation.

1) Saturation overland flow (SOF) in the lower part of the hillslope,

2) A combination of SOF and Hortonion overland flow in the upper part of the hill slope,

3) Rapid subsurface flow through macropores and root channels, and finally

4) Slow lateral subsurface flow within saturated areas.

The results of the experiments show that the pre-event water fraction of the surface flow is around 20% at the beginning of the experiment and levels off around 5% after 100 min once the upper soil horizon has been saturated. This pre-event water, around 20%, comes from return flow and soil water (pre-event water) in the upper soil layer.

Method

Collection of water samples

Water samples from precipitation, spring, well and streamflow were collected for deuterium (δ D) and oxygen-18 (δ 0-18) analysis during the period 1996-2000 by field observation and a technician assigned from the Ankara Research Institute.

The characteristics of precipitation data collected at rain-gauge station (R-24), installed near the runoff measuring station (W-17), are given in Table 1 with date, quantity, intensity and duration. To monitor the groundwater isotopic composition, regular samples were also collected from a well dug near a runoff station (Figure 1). Subsurface samples collected from a spring representing the contribution interflow from the unsaturated zone were collected from a natural spring located not far from the rainfall station R-24 (Figure 1). Streamflow samples were collected as well from the W-17 station, located at the outlet of the basin, during each event. The frequent water samplings were performed during the rising limb and the frequency of sampling decreased during the falling limb of hydrographs. All samples were filled to near the capacity of the container to avoid air entrapment, stoppered tightly and then labeled giving information about the source of samples such as rain, streamflow or spring. The samples were sent to the isotope laboratory for analysis at the Technical Research and Quality Control Division (TAKKD) of the State Hydraulic Works (DSİ), Ankara.

Isotope method

Deuterium and oxygen-18 analyses were performed by mass spectrometer. The results are expressed in standard notation relative to (SMOW) standard mean ocean water given by the following equation:

$$\delta = \frac{C_{sample} - C_{refence}}{C_{refence}} \tag{1}$$

where the C terms are the D/H isotope concentration ratios for deterium and the O_{18}/O_{16} isotope concentration ratios for oxygen-18. The precision of δ D values is, generally, 1.0%o, and of δ 0-18 is 0.1%o (DSİ, 1987).

A 2-component separation model is followed first using Eqs. (2) and (3).

$$Q_s = Q_t - Q_i \tag{2}$$

$$Q_i = ((C_t - C_s) / (C_i - C_s))Q_t \tag{3}$$

where Q_t, Q_i and Q_s represent total streamflow, interflow (stored subsurface water, including soil water and groundwater) and surface water (rainfall) rates, respectively, and C_t, C_i and C_s are the respective isotope concentrations.

A 3-component separation model is also used by applying Eqs. (4) and (5) to include soil water as a separate component

$$Q_t = Q_s + Q_{sb} + Q_{gw} \tag{4}$$

$$\begin{aligned} Q_{sb}/Q_t = & \Big((C_t - C_{gw})/(C_{sb} - C_{gw}) \\ & - Q_s/Q_t(C_s - C_{gw})/(C_{sb} - C_{gw})\Big) \end{aligned} \tag{5}$$

where subscripts *sb*, *t*, *gw* and *s* represent subsurface, total streamflow, groundwater and channel flow inputs, respectively.

The calculation of the isotopic composition of total runoff is made using the formulation proposed by the International Hydrologic Programme (IHP-V, 2001). If the isotope concentration of the components is significantly different during an individual storm event in comparison to the pre-event water, the mixing ratio of the 2 components during the event is then estimated using continuity and simple isotopic mass balance equations as follows:

Table 1. Rainfall, intensity and time values of individual events.

Date D/M/Year	Total rainfall (mm)	Intensity (mm/h)	Excess rain time (min)	Total time (min)
28.9.1996	28.5	7.7	20	410
13.10.1996	6.8	4.5	30	270
11.06.1997	17.7	22.2	10	420
19.05.1998	9.5	7.1	20	420
27.05.1998	21.0	64.8	10	50
13.05.1999	8.1	22.2	10	60
10.06.1999	13.9	13.6	10	160
13.04.2000	11.7	6.6	10	240
24.05.2000	22.3	53.9	10	235
02.06.2000	10.1	27.4	10	200

$$Q_t = Q_s + Q_0 \tag{6a}$$

and

$$\delta_t Q_t = Q_t \delta_s + Q_0 \delta_s \tag{6b}$$

where Q_t denotes the total runoff, Q_s the surface runoff and Q_0 base flow component, and derived from the individual isotope (δ_i) and runoff (Q_i) values measured during the event at an instant (i) by the relationship

$$\delta_t = \frac{\sum \delta_i Q_i}{\sum Q_i} \tag{7}$$

The relative proportion of the surface runoff $Q_s/Q_t$is derived using the above equation in order to determine $Q_s$or percentage of it.

$$Q_s/Q_t = (\delta_t - \delta_0)\,/\,(\delta_s - \delta_0) \tag{8}$$

where δ_s and δ_0 denote the isotopic compositions of the precipitation and baseflow, shortly prior to the precipitation event.

Discussion of Results

A total 159 samples collected for processing during the data collection period (1996-2000) were analyzed.

The results of δ 0-18 and δ D values of all collected samples were studied to compare the present results with the average global meteoric water line in order to visualize them graphically (Tekeli *et al.*, 2000). Among 10 observed individual event storms, only 5 are found as single-peaked storms, but the others are recorded as multi-peaked storms. Hydrograph separations using both graphical and isotope methods were accomplished, but only 3 of those events are shown in Figure 2. Components of the hydrograph determined by isotope and graphic methods are presented numerically in Tables 2a and 2b. The results of single-peaked hydrograph components are given in Table 3 in order to show the difference between the graphical and isotope methods.

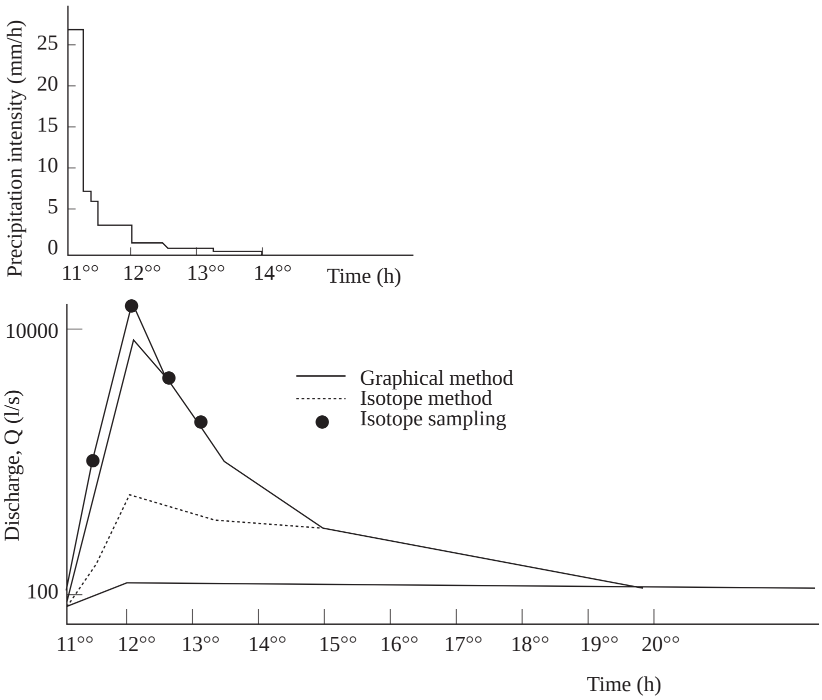


Figure 2a. Hydrograph separation with graphical and isotopic method and isotope samples (2.06.2000).

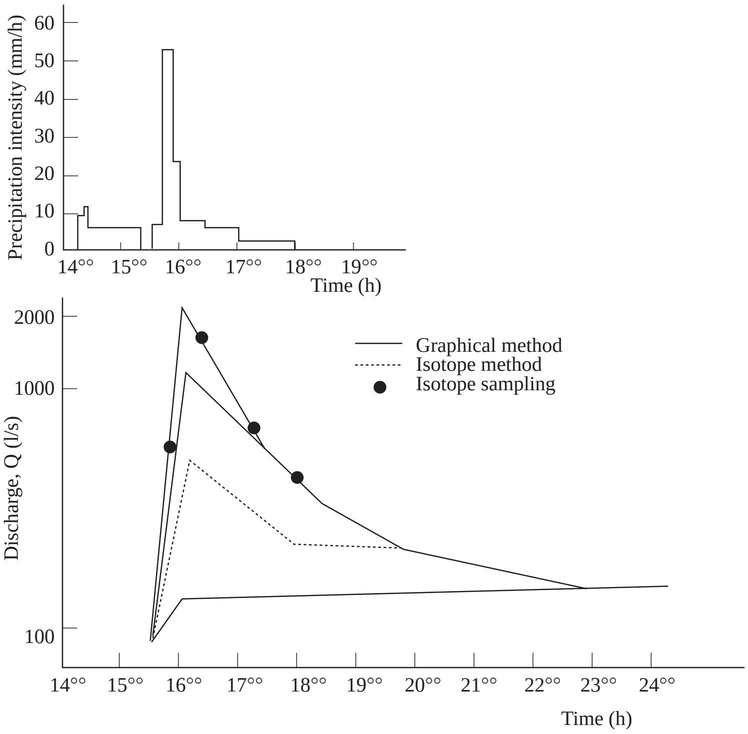


Figure 2b. Hydrograph separation with graphical and isotope method and isotope samples (24.05.2000).

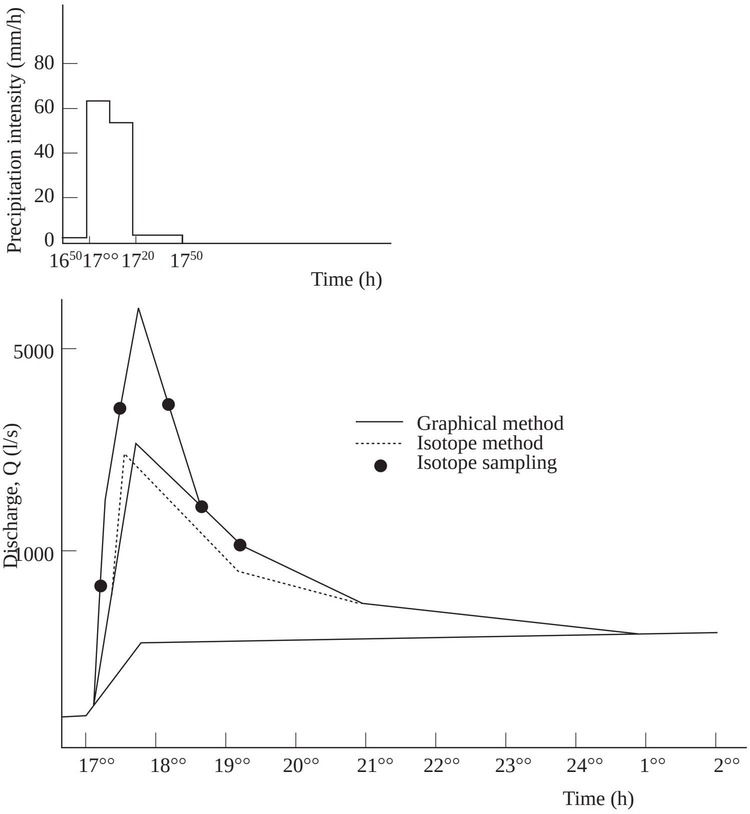


Figure 2c. Hydrograph separation with graphical and isotope method and isotope samples (27.05.1998).

During the determination of the hydrograph components using isotope method, it can be assumed that fast subsurface flow, especially rapid subsurface flow coming from daily rainfall (event water) has contributed to the hydrograph total together with direct channel runoff. This fast event response is due to preferential flow through macropores. Groundwater (O_{gw}) and lateral subsurface flow (Q_{sa}) coming from pre-event water are the second part of the total runoff contributing to the hydrograph.

In this study, the recession curves of the single peak events have also been analyzed to determine the contribution of the subsurface flow to the total flow. The storage values of the basin during the research period were calculated from the slope of the recession line (m) and initial discharge (q) of each zone and the results are shown in Table 4.

The unit hydrographs for 10 min effective rain are derived from 2 events (19.5.1998 and 13.4.2000). These unit hydrographs have been also compared with unit hydrographs derived from the graphical method for the events (Tables 5 and 6).

Using Eq. (7), the total isotopic composition (δ_t 0-18) values are calculated for 5 events given in Table 7. They vary between –7.45 and – 9.58‰. Similarly, the precipitation (δ_s) and base flow (δ_o) isotopic compositions are also recorded in order to show the contribution of surface flow as a fraction of total runoff. When the percentages are compared with the findings of Table 3, some discrepancies are noticed as a result of the measurement of individual isotope contents at discrete time intervals, which may not be sufficient to obtain the temporal average δ_t. Monthly measured isotope concentrations are used to represent δ_s and δ_o. More discussion will be presented in the following part of the study.

A sample of hydrograph separation using δ 0-18 is shown graphically in Figure 3 for the 13.04.2000 event. Figure 3a shows the intensities of precipitation and runoff over time. Figure 3b presents the δ 0-18 concentrations and, finally, the last one indicates the amount of δ 0-18 in the precipitation and runoff using the respective formulas given in Figure 3c. For runoff peak, the percentage of direct flow was 13.2%.

Table 2a. Total hydrograph components using the isotope method in multi peak events.

Date D/M/Year D/M/Year	Time h-min	Q_s %	Q_s l/s	Q_{sb} %	Q_{sb} l/s	Q_{gw} %	Q_{gw} l/s	Q_{sb+gw} %	Q_{sb+gw} l/s
28.09.96	08^{30}	15	12.74	85	72.08	-	-	-	-
	09^{oo}	45	42.40	55	174.05	-	-	-	-
	09^{30}	70	290.6	30	124.55	-	-	-	-
13.10.96	5^{40}	80	97.6	-	-	-	-	20	19.57
	6^{10}	77	34.82	-	-	-	-	23	8.0
	6^{40}	25	55.20	-	-	-	-	75	41.41
11.06.97	15^{30}	45	76.5	15	25.5	40	68	-	-
	16^{oo}	85	935	5	55	10	110	-	-
	16^{30}	65	650	20	200	15	158	-	-
	17^{00}	40	240	20	120	40	240	-	-
	17^{30}	5	20	60	240	35	140	-	-
11.06.99	11^{30}	30	60	-	-	-	-	70	140
	12^{oo}	35	111	-	-	-	-	65	205
	12^{30}	20	88	-	-	-	-	80	352
13.05.99	19^{oo}	10	21	10	21	80	168	-	-
	19^{30}	20	66	40	32	40	132	-	-
	20^{oo}	15	35	10	23	75	171	-	-

Table 2b. Total hydrograph components using the isotope method in single peak events.

Date D/M/Year	Time hr-min	Q_s %	Q_s l/s	Q_{sb} %	Q_{sb} l/s	Q_{gw} %	Q_{gw} l/s	Q_{sb+gw} %	Q_{sb+gw} l/s
19.05.98	16^{oo}	5	22	50	220	45	198	-	-
	16^{40}	10	50	30	150	60	350	-	-
	17^{10}	10	55	25	137	65	357	-	-
	18^{oo}	5	27	25	132	70	371	-	-
	19^{oo}	5	25	35	172	60	254	-	-
27.05.98	17^{15}	35	245	-	-	-	-	65	455
	17^{45}	35	1050	-	-	-	-	65	1950
	18^{15}	45	1350	-	-	-	-	55	165
	18^{45}	10	135	-	-	-	-	90	1215
	19^{15}	20	280	-	-	-	-	80	800
13.04.2000	16^{30}	20	54	-	-	-	-	80	216
	17^{oo}	15	45	-	-	-	-	85	255
	17^{30}	10	33	-	-	-	-	90	297
	18^{oo}	15	56	-	-	-	-	85	316
	18^{30}	25	115	-	-	-	-	75	345
	19^{30}	15	106	-	-	-	-	85	602
	20^{30}	10	61	-	-	-	-	90	549
24.05.2000	15^{30}	85	493	-	-	-	-	28	448
	16^{20}	72	1152	-	-	-	-	35	361
	16^{50}	65	670	-	-	-	-	48	298
	17^{20}	52	322	-	-	-	-	53	220
	18^{oo}	42	195	-	-	-	-	35	112
2.06.2000	11^{25}	65	208	-	-	-	-	35	112
	12^{oo}	80	993	-	-	-	-	20	248
	12^{30}	60	475	-	-	-	-	40	237
	13^{oo}	55	252	-	-	-	-	45	207

Table 3. Comparison of hydrograph components of the isotope method with graphical method in single peak events.

Date	19.05.1998		27.05.1998		13.04.2000		24.05.2000		02.06.2000	
Hydrog. comp.	g.*	i.**	g.	i.	g.	i.	g.	i.	g.	i.
Q_s(mm)	0.112	0.098	0.654	1.055	0.122	0.096	0.238	0.547	0.066	0.184
Q_{sb}+ Q_{gw} (mm)	1.076	1.09	1.338	0.918	1.577	1.603	0.599	0.290	0.510	0.392
Q_t(mm)	1.188	1.188	1.992	1.992	1.699	1.699	0.837	0.837	0.576	0.576
Q_s/ Q_t (%)	9.4	8.2	32	53	7.2	5.7	28	65	11	32

*graphical method **isotope method

Table 4. Recession curve analysis of single peak events.

Date D/M/Year	q_p (l/s)	m_c (h)	q_1 (l/s)	m_1 (h)	q_2 (l/s)	m_2 (h)	q_3 (l/s)	m_3 (h)	q_4 (l/s)	m_4 (h)	q_5 (l/s)
19.05.1998	580	11.1	353	30.5*	320	-	-	-	-	-	-
27.05.1998	6337	0.6	1320	1.5	952	3.6	620	8.6	520	41.5	459
13.04.2000	707	7.2	436	32.1*	373	53.4*	334	-	-	-	-
24.05.2000	2170	1.0	530	1.9	316	3.4	204	8.0	141	-	-
02.06.2000	1241	0.8	678	1.3	316	2.7	184	10.6	115	-	-

*outliers

Table 5. Total and unit hydrograph values computed by isotope and graphical methods on 19.05.1998.

Time	Total runoff (1/s)	Groundwater (l/s)		Subsurface flow (l/s)		Surface flow (l/s)		UH_{10} (l/s)	
		g.*	i.**	g.	i.	g.	i.	g.	i.
14^{50}	320	320	320	0	0	0	0	0	0
15^{30}	365	320	340	4	4	41	21	400	320
16^{30}	480	320	360	40	16	120	104	1100	1090
17^{30}	580	320	380	120	70	140	130	1280	1300
18^{30}	520	320	365	100	65	100	90	800	880
19^{30}	460	320	350	85	55	55	55	410	430
20^{30}	415	320	340	65	45	30	30	120	180
21^{30}	380	320	332	48	37	12	11	22	35
22^{10}	360	320	328	40	32	0	0	0	0

*graphical method **isotope method

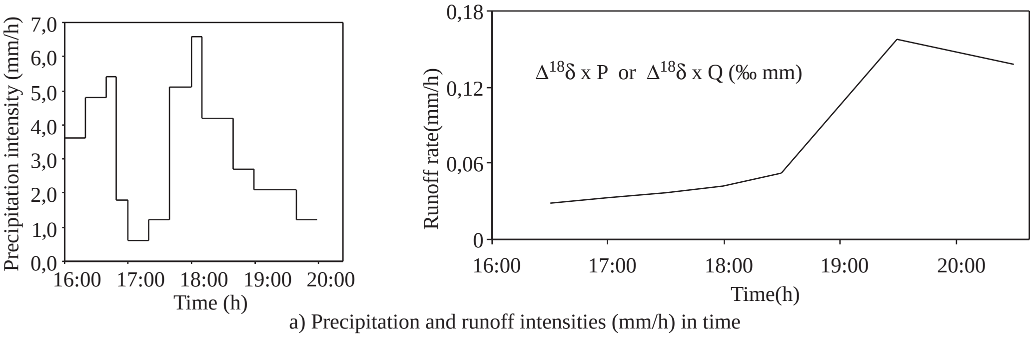
Table 6. Total and unit hydrograph values computed by isotope and graphical methods on 13.04.2000.

Time	Total Runoff (1/s)	Groundwater (l/s)	Subsurface+ Surface flow (l/s)	Surface flow (l/s)		UH_{10} (l/s)	
		g.*	g.	g.	i.**	g.	i.
16^{oo}	233	233	0	0	0	0	0
16^{30}	260	240	20	5	20	41	208
17^{00}	298	252	46	24	28	197	292
17^{30}	330	270	60	27	30	221	313
18^{oo}	374	280	94	47	44	385	458
18^{30}	460	300	160	90	40	738	1146
19^{oo}	881	320	261	151	121	1238	1260
19^{30}	707	345	362	202	127	1656	1322
20^{oo}	680	345	335	185	120	1516	1250
20^{30}	620	345	280	140	100	1148	1042
21^{oo}	581	345	241	111	81	910	844
21^{30}	520	345	180	60	40	496	416
22^{oo}	490	345	150	35	30	286	313
22^{30}	460	345	120	15	10	123	104
23^{oo}	437	345	97	0	0	0	0

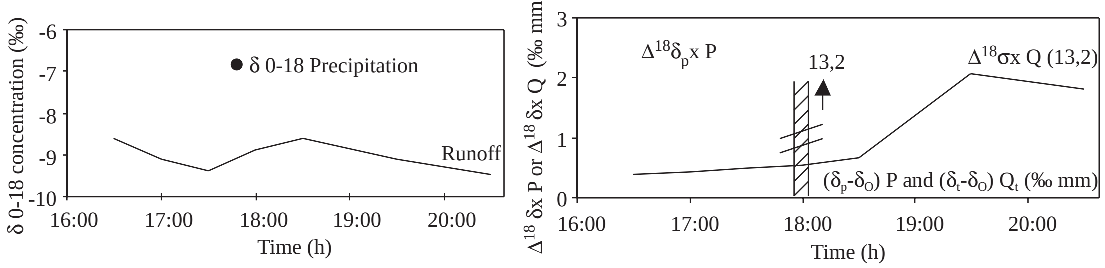
*graphical method **isotope method

Table 7. δ 0-18 values of single peak events for total, surface and baseflow.

Date and $^{18}\delta$ values	19.05.1998	27.05.1998	13.04.2000	24.05.2000	2.06.2000
$\delta_t(\%\circ)$	-8.90	-9.58	-9.10	-7.45	-8.65
$\delta_s(\%\circ)$	-7.60	-12.80	-5.60	-6.70	-8.5
δ_0 $(\%\circ)$	-8.80	-8.80	-9.65	-9.80	-9.80
Q_t(mm)	1.188	1.992	1.699	0.837	0.576
Eq.8	0.083	0.196	0.132	0ç76	0.88
Q_s/Q_t	0.082	0.530	0.057	0.65	0.32



a) Precipitation and runoff intensities (mm/h) in time



b) Concentration of P and Q

c) Amount of s 0-18 in the precipitation and runoff calculated by the formulas

Figure 3. δ 0-18 variations of precipitation (P) and total runoff (Q_t) in the Güvenç Basin for (13.04.2000).

Precipitation

We collected 10 rain samples. Two of five samples were produced from single-peaked runoff resulting from rainfall depths greater than 19 mm and the other 3 are produced from depths ranging between 9.5 and 11.7 mm (Table 1). The single storm observed on 19.5.98 produced a minimum rainfall depth 9.5 mm over 420 min. The produced runoff results from saturated soil conditions due to antecedent rainfalls. The multi-storms show rather large variations in rainfall depths from low to medium (6.8 mm to 28.5 mm).

Based on rainfall records collected over the last 10 years, precipitation creates surface flow regardless of rainfall duration and intensity when its depth becomes greater than 19 mm. On the other hand, if the precipitation falls between 2.4 and 10 mm, the production of surface flow depends on the time interval between 2 successive storms and their intensities (Denli, 1997).

The isotopic contents of rainfall vary greatly and are affected by the air temperature and evaporation. Sometimes, rainfall and surface flow contents do not match each other as mentioned by Kennedy *et al.* (1986). In this study only 1 rainfall sampling was collected during each to storm event. For that reason, it is not representative of the area's average effective rainfall corresponding to storm runoff in the basin. It may be more realistic to collect more than 1 precipitation sample during an event period and obtain the weighted average of isotopic concentrations. The other causes of isotope content deviations may be in the collection procedure itself and in poor storage procedures.

Streamflow

The analysis of runoff samples collected at about half-hour intervals from runoff station indicates that the single-peaked hydrographs are mainly produced from pre-event water, which may contribute subsurface plus groundwater flow to the stream. The instant surface flow was dominant in 2 events (27.5.1998 and 24.5.2000) due to high rainfall intensity and depth. Similar findings were also noticed by Sklash and Farvolden (1979) on hydrographs from short duration and high intensive storm events.

The δ 0-18 and δ D content analysis of subsurface and groundwater flow showed few variations due to a large mass of groundwater flow, which may not be affected by percolated rain water reaching the groundwater table. Normally, the hydrograph components are grouped under 2 categories as surface and baseflow. However, when the separation of 3 process elements into surface, subsurface and groundwater flow becomes the main interest for detailed studies, then trial and error procedures have to be followed in order to obtain the fractions of each component. The continuity equation is employed using deterium concentration analysis results for verification.

Comparison of precipitation with streamflow

The storms analyzed during 1996-2000 produced 5 single and other 5 multi- peaked hydrographs. All 3 components are processed in 5 of multi-peaked events (28.09.1996, 11.06.1997 and 13.05.1999). For the other multi-peaked events, only surface and base flow components are separated (Table 2a).

During the rising stage of hydrographs, the contribution of surface flow is noticed to increase up to 70-85% of the total flow before decreasing again down to 15- 20%. The baseflow (subsurface + groundwater) contribution is large at the initial time during the pre-event stage and then decreases within the multi-peaked time period and starts increasing again during the falling period (75-95%).

On the other hand, when single-peaked hydrographs are processed by the isotope method, the 3 parts of the total hydrograph are separated only into a signle event (19.05.1998), but in the remaining 4 cases base flow is considered as a separate flow from surface runoff (Table 2b).

The isotope results are compared for single-peaked events with the classical Barnes semi-log method, but such comparisons are not done for multi-peaked storm events. In 2 of the cases recorded (19.05.1998 and 13.04.2000), the separated components were matched in both methods due to single surface flow layer contribution. The surface flow contribution was less than 10% compared to the subsurface flow contribution from all multi-layers. When the surface flow contribution is more than 30%, both methods start deviating from each other. This is because isotope samples taken during the spring can only represent the contribution of subsurface flow located near a groundflow aquifer. No other flow layer contribution is taken into consideration (Figure 2 and Table 3).

The single-peaked hydrograph recessions are replotted on semi-log paper in order to obtain their slope (m) and initial discharge (q) at each time step (Table 4) where the slope changes due to the flow contribution of different subsurface layers. The tabular values presented in Table 4 are used to derive storages (S) from the formula S = mq.

Three of the 5 storms from 27.5.1998, 24.5.2000 and 2.6.2000 clearly indicate that the isotope content analysis can only represent the contribution of lower subsoils, symbolized by q_3 and q_4, and their respective slopes, m_3 and m_4. The upper aquifer sub- layer contributions are not considered in this procedure. This is why the surface flow determined by the isotope approach provides larger percentages than the graphical method (32% or more). The uppermost geological layer represented by m_1 may indicate rapid subsurface flow with a mean storage (S) of around 0.293 mm. For those 3 storms, the upper subsurface flow is already added to the surface flow, and this is why the surface flow contribution was more than 30% (Table 3).

When we look more closely at the 3 individual events, the first one of which was on 2.6.2000, the percentage of surface flow contribution was 11% in the graphical method after extropolating back from the first break point at q_1 = 678 l/s, but the separation of subsurface flow occurs at q_3 = 184 l/s in the isotope procedure. Thus, the upper soil layer flow has been added to the surface flow in the graphical method, which found the large surface flow contribution to be 32% of the total flow (Table 4).

This study clearly indicates that the upper straight lines (1^{st} and 2^{nd} broken points) on hydrograph recession may result from the lateral subflow at root zone depth, which comes out quickly to the surface flow and is known as “rapid subsurface flow”. Thus, the water samples representing each subsurface layer contribution must be collected separately to identify this problem. In addition, water samples must also be poured into bottles during each event period using different springs. If possible more than one sampling procedure should be performed during each site visit to obtain water samples from groundwater and subsurface aquifers. Weiler *et al.* (1999) noted the same conclusion in their research.

The second event, observed on 24.5.2000, also showed differences in separation. The high amount of rainfall depth (22.3 mm) and large rainfall rate created a large amount of surface flow supply (65%) compared to 28% of the surface flow in the graphical procedure.

In the third event, recorded on 27.5.1998, the separation shown in Figure 2c provided 32% of the surface flow contribution compared with 53% of the surface flow in the isotope method, because of high intensive rain (64.8 mm/h) and rainfall depth (21.0 mm).

The other 2 single-peaked storms (19.5.1998 and 13.4.2000) produced 10% or less surface flow result from comparable low rainfall depth, but a high moisture content was distributed over the area. These hydrographs are mainly produced from a single aquifer layer so that the percentages of surface flow determined in both methods are comparatively low and almost equal.

Unit hydrograph (UH) derivation

Two single events are further processed in order to derive unit hydrographs produced from 10-min effective rain (UH_{10}).

The first event analyzed occurred on 19.5.1998 producing 9.4% and 8.2% of surface flow for each of the techniques used (Table 5). The graphical and isotope methods gave almost similar UH discharges with peak values of 1280 and 1300 l/s, respectively.

The second storm which took place on 13.4.2000, is also processed to obtain UH_{10} from 1 mm excess rainfall. The results shown in Table 6 indicate that the peak UH discharges are 1656 and 1322 l/s, respectively, for the graphical and isotope methods.

Conclusion and Recommendations

In this study, the hydrology of the Güvenç Basin was studied in detail. The flow components were determined by using the isotope and Barnes methods. For the major storm events in 1998 and 2000, the flow separations by means of the isotope method were found to be in good correlation with Barnes method. The contribution of subsurface flows originating from various sublayers of the basin was important in hydrograph separation when using the isotope approach. Part of the subsurface flow from the deep layers may contribute to the surface as slow flow and the remainder coming from the upper layers returns to the surface as rapid flow. If the flow contribution from sublayers is not considered and separated correctly, then the UH derived from surface flow will not be accurate. As a result, the small structure reservoir capacity will be overdesigned during project formulation. The recession stage, preceding the event water, is mainly composed of old water draining the deep layers of the geologic formations. The exact situation can only be better understood when more water samples from each subsurface are collected and analyzed during the individual event period. Various water samples must also be collected from precipitation and more frequent samples must be analyzed from streamflow to represent the rising and falling stages of hydrographs.

Additional single peak storms with high intensive rainfall uniformly distributed over the area must be processed in order to obtain more meaningful results. Well logs, if available, must be collected and examined. In addition, the number of springs under study must be increased to obtain a better representation of subsurface and groundwater aquifers, which are the main contributing flow elements to total runoff.

List of Symbols

W-17	sampling weir.
R-24	sampling raingauge.
δ	isotope content of water samples (‰).
δ	D deuterium.
δ	0-18 oxygen-18.
$\delta_t\delta_s, \delta_0$	isotopic composition of total flow, rainfall and base flow, respectively.
C	isotopes concentrations of water samples.
Q_t,Q_i,Q_s	total runoff, subsurface flow(soil water+groundwater), surface flow, respectively.
Q_{sb},Q_{gw},Q_o	subsurface flow, groundwater and base flow, respectively.
S	basin storage.
m	hydrograph recession slope.
q	initial and subsurface discharge corresponding to hydrograph recession slopes.

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