These similarities in functioning should be interpreted as an antagonistic effect between geological and geomorphological characteristics which may not facilitate the establishment of efficient networks, and as a potential for karstification which in this example remains very significant.

In fact the quantity of rainfall associated with dense vegetation that produces CO_2 permits that water achieves efficient drainage conduits and reorganises displacement into underground very quickly. Seemingly it happens faster than the incision of the valleys which would disorganise the endo karstic drainage (MARTIN 1991 a, b).

3.5. HYDROLOGICAL DESCRIPTION OF THE VIPAVA AND HUBELJ SPRING SYSTEMS

(S. SCHUMANN, C. LEIBUNDGUT)

3.5.1. Discharge Frequency Density

In order to classify the Vipava and the Hubelj spring systems hydrologically an evaluation for the discharge data of the years 1961 to 1990 of the hydrological flow parameters was carried out.

A discharge frequency density diagram was developed for both springs on the basis of daily discharge values. The diagram includes an abscissa-averaged duration curve, the calculated mean discharges, MQ, and the Q_{95} of the springs.

In order to arrive at an abscissa-averaged duration curve the number of days per class interval is averaged over the required period (MANIAK 1993). The Q_{95} represents a reference value for regional water use and summarises the discharge which is reached or exceeded in 95 % of the time, i.e. in 347 days of the year. As the daily discharge data of a 30 years period were used the data was not revised as "records of this length need no adjustment or standardisation as the period of data will probably provide a sufficient accurate flow duration curve" (INSTITUTE OF HYDROLOGY WALLINGFORD 1980).

The discharge frequency diagrams of the Vipava and the Hubelj springs for the period 1961 to 1990 are presented in Fig. 3.18 and Fig. 3.19. Both springs show similar pattern:

- About 260 days of the year the discharge stays below the mean discharge, MQ.
- The curve representing the probability that the discharge stays below a certain value shows only gentle sloping. I.e. the frequency of the occurrence of extremely high discharge values is low.

The diagrams also point out the differences of the spring behaviours:

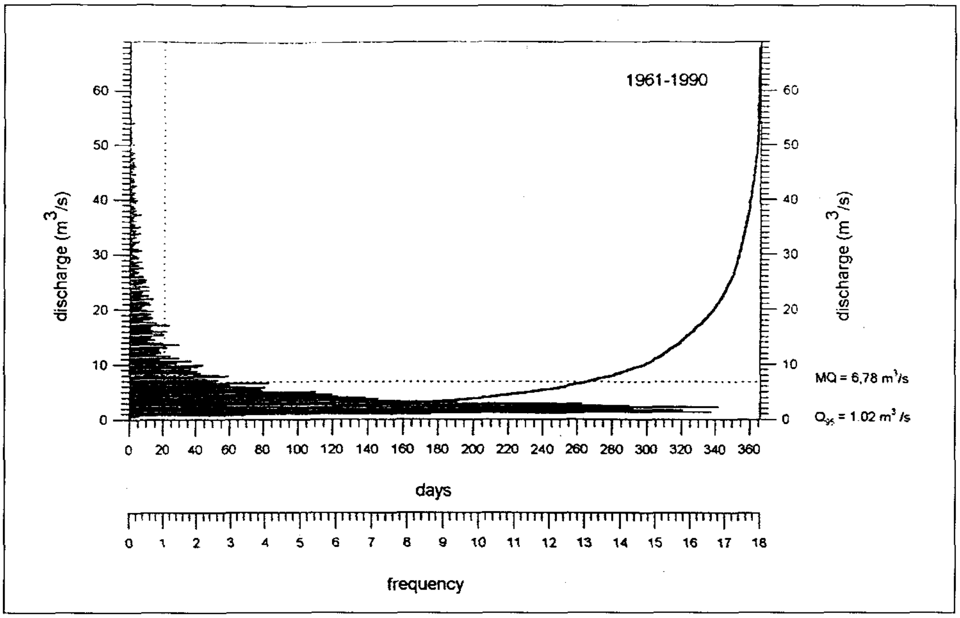

Fig. 3.18: Abscissa averaged discharge frequency diagram of Vipava springs for the years 1961 to 1990.

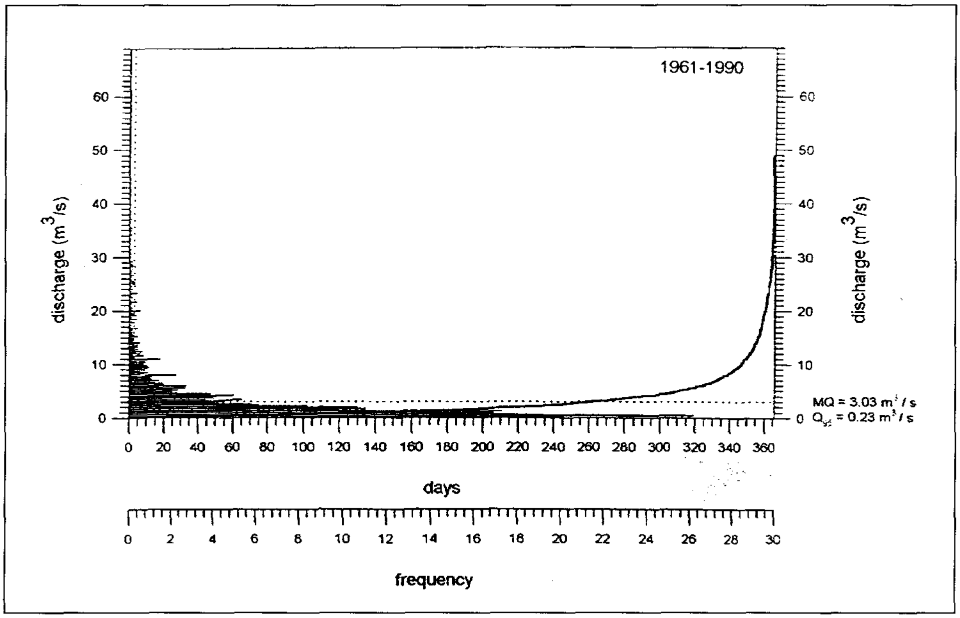

Fig. 3.19: Abscissa averaged discharge frequency diagram of Hubelj springs for the years 1961 to 1990.

- The factor of minimum to maximum discharge at the Vipava springs equals to 1:100 while this factor equals to 1:267 at the Hubelj springs.
- At the Vipava springs the Q_{95} accounts to approximately 1/7 of the MQ while at the Hubelj springs the Q_{95} accounts to approximately 1/13 of the MQ.
- The MQ at Vipava spring accounts to 1/10 of its highest discharge. At the Hubelj springs this accounts to 1/16.
- Very high discharges occur more frequently at the Vipava springs than at the Hubelj springs.
- Low discharges occur with similar frequencies at both springs. However, the range of low discharges at the Vipava springs is broader. At the Hubelj springs the low discharges occur with more changing frequencies.

The thirty year's time series were also interpreted using an autocorrelation analysis. An "investigation of sequential properties of a series by autocorrelation is already classical statistical technique. It is used to determine the linear dependence among successive values of a series that are a given lag k apart" (YEVJEVICH 1972). As the measure for the linear dependence between the two values the autocorrelation coefficient, rk is used.

The equation used for the analysis corresponds to the form proposed by Jenkins and Watts and used by (MANGIN 1984) during his analysis of three karstic flow regimes in the Pyrenees. The open-series approach was used for

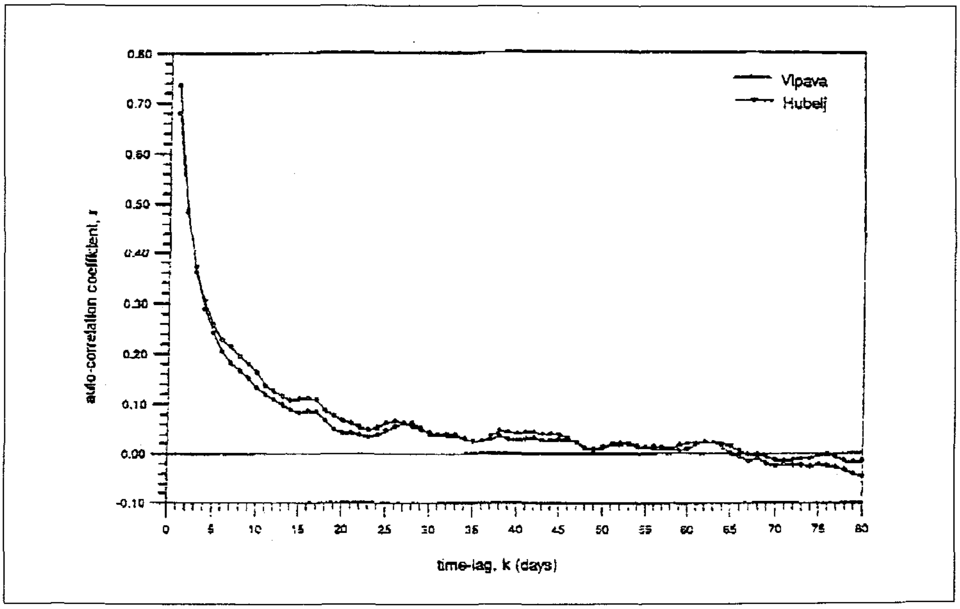

Fig. 3.20: Autocorrelation functions with time-lags 1 to 809 of Vipava und Hubelj discharges. As basis for the 30 year's time series was used.

the analysis since according to (YEVJEVICH 1972) it is not advisable to use a circular-series approach because the first and the last part of the series might be independent.

In Fig. 3.20 the results for the autocorrelation using a time lag from 1 to 80 is shown. Fig. 3.21 represents the autocorrelation functions with time-lags from 1 to 3650. The autocorrelation curves of the Vipava and Hubelj springs, considering a time lag k = 1 to 80 days, are very similar. They both show that the "memories" of the springs are bad, i.e. that the discharge depends only little on the discharge of the previous two to five days and that it is practically independent from the discharge of six or more days ago. However, Vipava shows a slightly higher k=1 autocorrelation coefficient than Hubelj. For the successive time lags the autocorrelation coefficient of Vipava drops faster. This means that the discharge of the Vipava springs is slightly higher influenced by the discharge of the previous day than in the case of Hubelj springs, while the memory of the Hubelj springs improves in comparison to the Vipava springs from the third day onwards.

The autocorrelation diagram for the Vipava and Hubelj springs with a time-lag, k=1 to 3650 shows once more that the correlation coefficients drop very fast during the first few k's. Thereafter they fluctuate sinusoidally around the zero-line.

Though their amplitudes reach only a rk of 0.08, the form of the correlation curve is interesting. It can be observed that the correlation coefficient

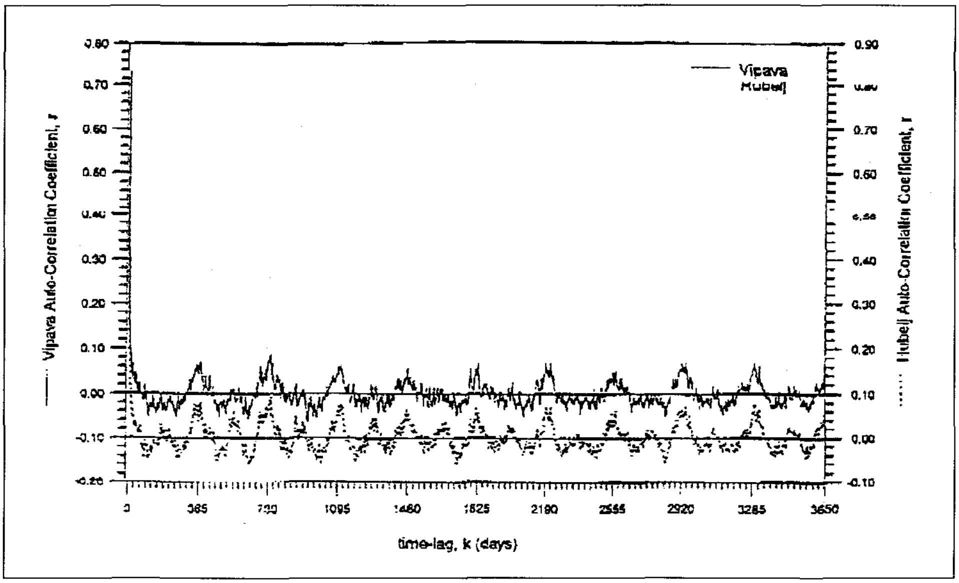

Fig. 3.21: Autocorrelation functions with time-lags 1 to 3650 of Vipava and Hubelj discharges. As basis for the 30 year's time series was used.

fluctuates with a period of exactly one year (both curves). This means that the yearly discharge values are correlated. Hence it can be supposed that the daily discharges do have a deterministic component and are not exclusively aleatory.

It is conspicuous that the Vipava springs autocorrelation curve fluctuates very little and that the Hubelj autocorrelation curve fluctuates, obviously, not only with a yearly period but also with a half-yearly period. The half-yearly amplitude though is less than for the yearly fluctuation. It actually means that the discharges of at least Hubelj springs are also correlated on a half-yearly basis, i.e.there is some sort of a relationship between the discharge today and half a year later.

Furthermore the mean discharge curves for the Vipava and the Hubelj springs were evaluated. Bases for the curves were once more the 30 years daily discharge data of the period 1961 to 1990. To emphasise on the course throughout the year a regression of the 10th grade was fitted. Additionally the 30 days running mean was calculated and plotted. The daily mean discharge curves are presented in Fig. 3.22 and Fig. 3.23. It is striking that the courses of the mean discharge curves of the two springs are identical. They both show minima in July/August and maxima in spring and autumn.

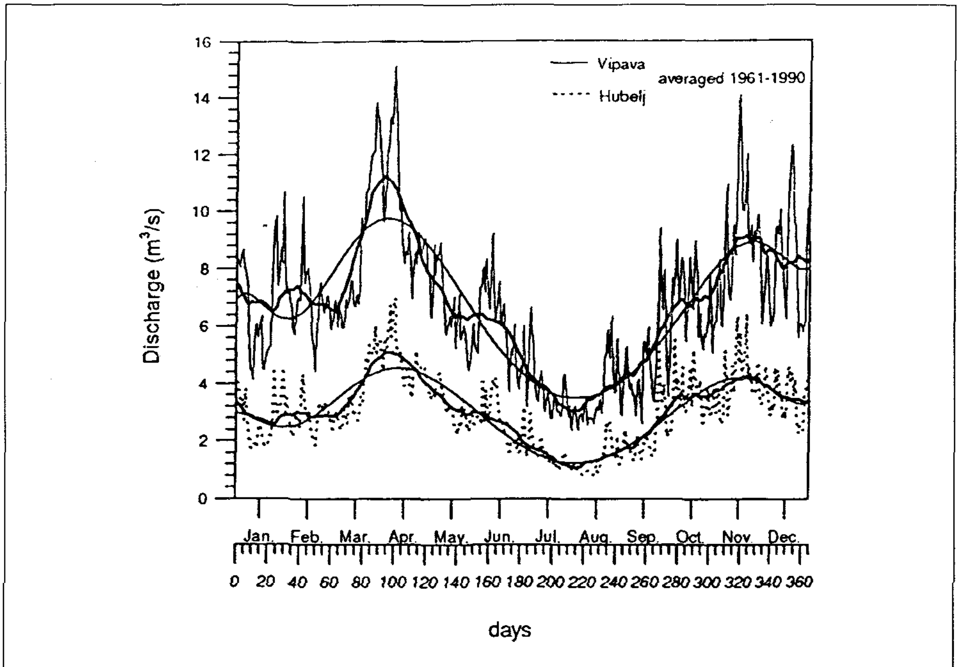

Fig. 3.22: Daily mean discharge curves of Vipava and Hubelj springs for the period 1961 to 1990. To emphasize the course a regression of the 10^{th} grade was fitted (thin line) and the 30 days running mean plotted (bold line).

These mean discharge curves should furthermore be compared with the mean precipitation curve shown in Fig. 3.23. The following is conspicuous:

- When the main precipitation occurs, i.e. in June, the mean discharge curve drops. This might be due to the high evapotranspiration in summer.
- The increase of precipitation after the precipitation minimum in July causes an increase in the mean discharge with a delay of approximately one month.
- Though the precipitation amount drops during the winter months, the mean discharge rises to a second peak in spring. This could be due to the snow melt, i.e. water which was stored as snow comes to a discharge.

It appears though, that the amount of precipitation fallen during the autumn and winter times is too little to produce:

1. the rising mean discharge during winter time caused by rain and
2. the rising mean discharge in spring caused by the snow melt.

This can only be explained by too little precipitation measured in this period of the year. As reported by IVANCIC (1995) the Hydrometeorological Institute Ljubljana estimates the error due to wind influences during the measurements of snowfall to 50 %. This could explain where the lacking precipitation volume comes from.

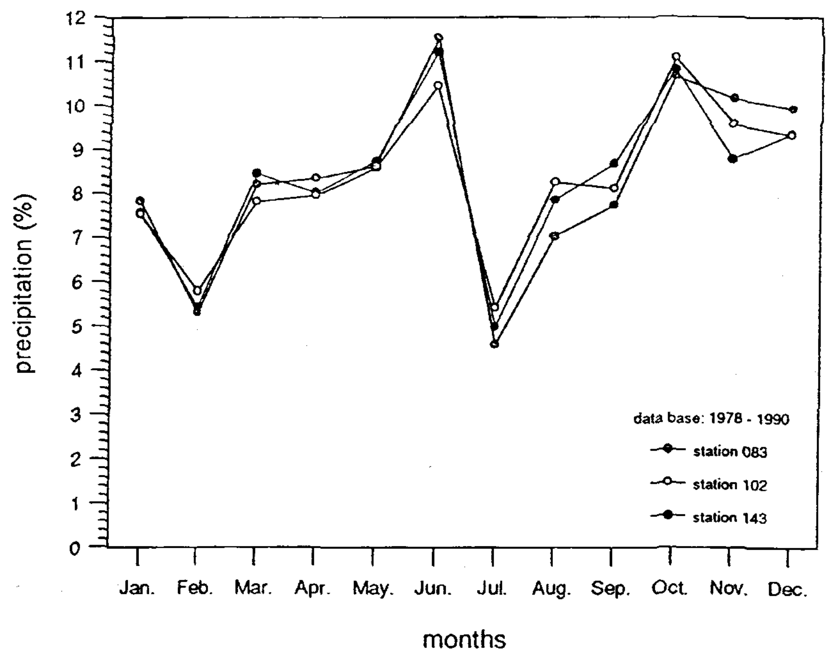

Fig. 3.23: Monthly mean precipitations as percentages of the annual mean presented for the stations 83, 102, 143. Data base is the period 1978 to 1990.

3.5.2. The Recession Curve Analysis

For both springs, the Hubelj and the Vipava springs a recession curve analysis was carried out based on the discharge data of the month July to October of the years 1961 to 1990. Aim of the analysis was to develop a master recession curve for each of the two springs.

The recession curve analysis dates back as far as 1905 when Maillet defined an analytical expression for recession curves of long-lasting dry periods (equation (3)):

$$Q_t = Q_0 \exp(-\alpha t) \qquad (3)$$

where Q_t is the discharge at time t; Q_0 is the previous discharge; t is the time elapsed between Q_0 and Q_t and a is the recession coefficient of dimension T^{-1} (FORD & WILLIAMS 1989).

Though this expression was actually designed for recession curves of porous aquifers it is widely used in karst hydrology, i.e under non-homogeneous and non-isotrope conditions. BONACCI (1987) as well as FORD & WILLIAMS (1989) have provided detailed reviews on the use of recession curves in karst aquifer analysis.

If the curve of the equation (3) is plotted semi-logarithmic (Q on the logarithmic ordinate) it is represented by a straight line with the slope $-\alpha$.

According to MARTIN (1973) a better concept to be used in hydrology is the use of the half-life of the discharge. The half-life $t_{(0.5)}$ corresponds to the time needed that the discharge is reduced by 50 %. The half-life corresponds to:

$$t_{0.5} = \ln(1/2) / \ln(\exp - \alpha) \qquad (4)$$

According to MILANOVIĆ (1976) the emptying of a karst aquifer is frequently characterised by recession curves that may be fitted by several short, straight lines, each being characterised by a different slope, hence having different recession coefficients (α_{01}, α_{02}, ..., α_{0n}). This type of recession curves reflect the complex hydrogeological characteristics of karstified rocks. Assuming the theory of the linear reservoir this complex recession curve can be mathematically expressed as:

$$Q_t = Q_{01} \exp(-\alpha_{01} t) + Q_{02} \exp(-\alpha_{02} t) + ... + Q_n \exp(-\alpha_n t) \qquad (5)$$

MILANOVIĆ (1976) also states that under the conditions of a well-developed karst system, three recession coefficients may usually be expected a good fit. The greatest reflects the rapid outflow of caves and channels, the medium the outflow of well integrated karstified fissures and the smallest the drainage from pores and narrow fissures. BONACCI (1993) states that different segments of the recession curve might not only reflect a decrease in effective porosity but may also be a result of a decrease in the catchment area.

He showed a such caused decrease due to the decrease of the underground hydrogeological catchment area at three springs down the Neretva river in the Dinaric karst (BONACCI 1993).

The aim of recession curve analysis is to derive a characteristic recession of a particular discharge region. One of the problems most often encountered during such an analysis is the high variability encountered in the recession behaviour of individual segments. A physically based short-term or seasonal variation in the recession behaviour adds to the problem of deriving a characteristic recession (TALLAKSEN 1995). According to TALLAKSEN (1995) the master recession methods try to overcome the problem by constructing a mean recession curve. This is then known as the master depletion curve. All the information on variability is lost in this type of curve. There exist several methods of deriving a master recession curve. (McCUEN 1989) describes simple procedures to derive the master depletion curve. One, the analysis of covariance method, is described by BAKO & OWOADE (1988) for a field application. BONACCI (1993) states that in karst areas the last section of the recession curve (on semi-logarithmic presentation) actually represents the master depletion curve. He furthermore concludes that this latter section of the recession curve is significant and that its function is to define and predict the behaviour of the remaining groundwater reserves during drought periods.

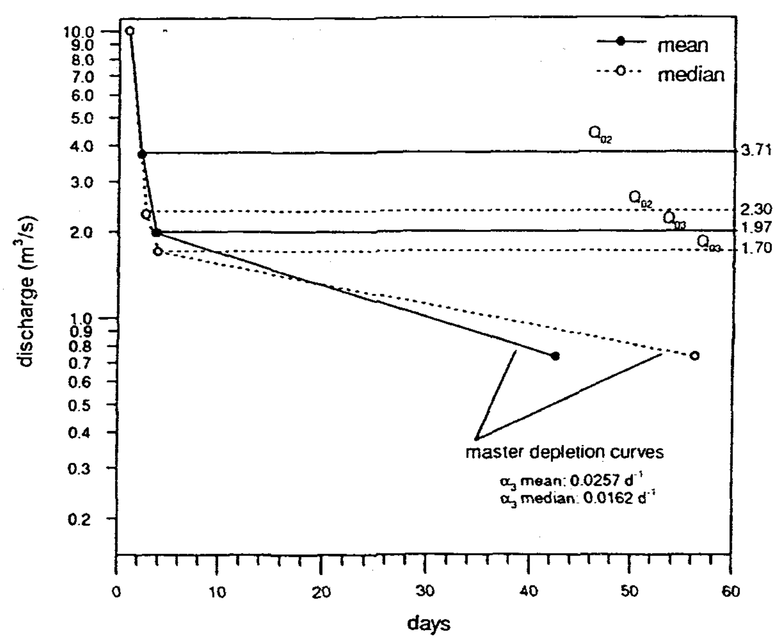

Fig. 3.24: Mean and median recession curves for Vipava, obtained by the results generated by the program FIEBEL assuming a starting discharge for reservoir 1 of 10 m³/s.

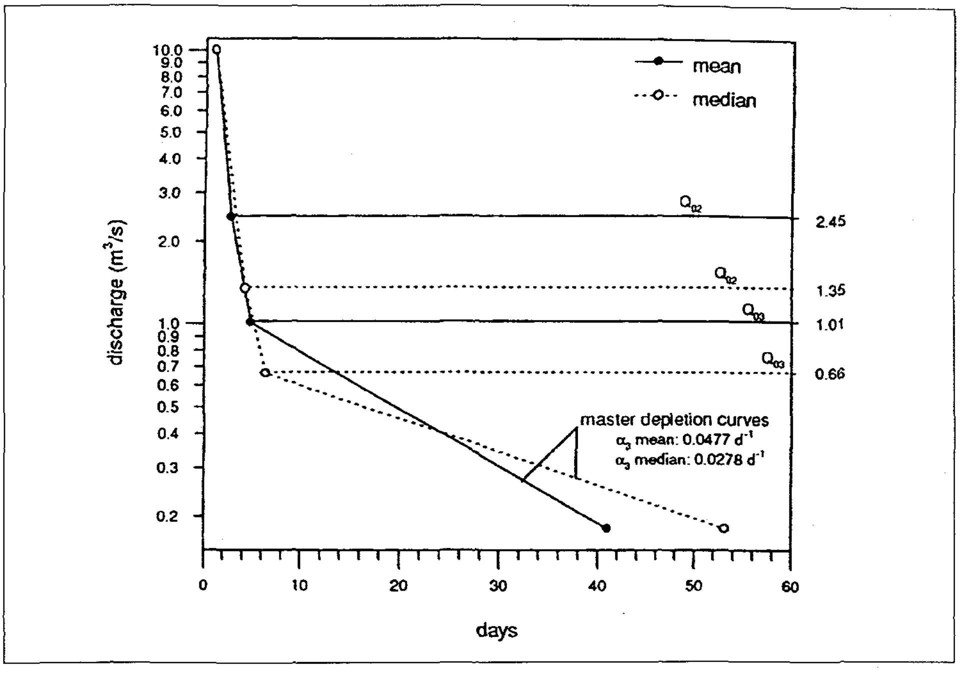

Fig. 3.25: Mean and median recession curves for Hubelj, obtained by the results generated by the program FIEBEL assuming a starting discharge of 10 m³/s for the first reservoir.

The master depletion curve was determined on the basis of long term valuations of recession parameters. For this purpose an objective programme, called FEIBEL was used (SCHUMANN 1995). It automatically selects the recession branches to be used for the analysis according to the following criteria:

1. They have to begin underneath the mean discharge and have a length of at least 8 days.
2. The discharge values need to reduce continuously (error limit being 5%)
3. The second discharge value of a beginning recession branch needs to be really smaller than the first one (i.e. the error limit is only valid from the third discharge value onwards).

Since using this method one gets for each recession branch considered one a-value, out of these one representative a-value needs to be calculated. This has been done by using the mean and the median values. The results of the recession curve analysis are shown in Tab. 3.12 (Vipava) and Tab. 3.13 (Hubelj) as well as in Fig. 3.24 (Vipava) and Fig. 3.25 (Hubelj).

Tab. 3.12: Results obtained for the spring Vipava, using the program FEIBEL.

		no. of branches	α	range of α	mean starting Q	half life [days]	volume [m³]
mean	α_1	3	0.7951	0.6288	?	0.9	-
	α_2	113	0.4164	1.1895	3.71	1.7	-
	α_3	164	0.0257	0.1835	1.97	27.0	$6.62 * 10^6$
median	α_1	36	0.8605	1.4291	?	0.8	-
	α_2	146	0.2595	0.8607	2.30	2.7	-
	α_3	164	0.0162	0.1835	1.70	42.8	$9.07 * 10^6$

Tab. 3.13: Results obtained for the spring Hubelj, using the program FEIBEL.

		no. of branches	α	range of α	mean starting Q	half life [days]	volume [m³]
mean	α_1	10	0.7944	1.1609	?	0.9	-
	α_2	93	0.4360	1.1895	2.45	1.6	-
	α_3	167	0.0477	0.2834	1.01	14.5	$1.80 * 10^6$
median	α_1	28	0.6253	1.0785	?	1.1	
	α_2	134	0.3287	0.7463	1.35	2.1	
	α_3	167	0.0278	0.2834	0.66	24.9	$2.05 * 10^6$

Both tables Tab. 3.12 and Tab. 3.13 show for each reservoir the number of branches used for the calculations, the calculated a-values, the range of the occurring a-values, the mean starting discharge of the recession branches, the half-life according to the a-value and the volume of groundwater left above the spring water level when the reservoir begins to empty. The volume was only calculated for the third recession branch as the calculation of the volume presumes diffuse flow. This is only valid during the low flow period i.e. when the last reservoir is exclusively discharging. The tables do not allow a conclusion which calculation procedure (mean or median) is the better one. However, it can be stated that range of a decreases for the second and first reservoir when the median is used to determine the representative a. Furthermore a higher number of branches are left to calculate the recession coefficients of the second and first reservoir as the values for the representative a and mean starting discharge are lower when using the median as the representative recession values. From the statistical point of view the median value is to be preferred, hydrologically though it can not be decided which value is the more appropriate.

It is striking that the volume of water left above the spring water level in the aquifer of Vipava is about four times larger than the volume of the water left in the aquifer of the Hubelj springs. This could be due to:

- A higher effective porosity in the Nanos karst aquifer than in the Trnovski Gozd karst aquifer.
- A greater thickness of the high water stand zone above the spring water table in the Vipava springs aquifer than in the Hubelj springs aquifer.
- A greater 'surface area' of the high water stand zone of the Vipava springs aquifer than the Hubelj springs aquifer.

Fig. 3.24 and Fig 3.25 show the results obtained in a graphical form. The starting discharge of 10 m^3/s for the first reservoir is assumed to visualise the situation. The lowest discharges correspond to the springs' minimum discharges of the period 1961 to 1990.

They primarily show that for the first and second reservoirs of the spring groups do not exist remarkable differences when considering the ranges of the occurring α-values. The recession coefficients of the two reservoirs are alike, hence their half-lives. A statement to the first reservoir should anyway be made very carefully as the number of recession branches left over for the analysis, (using the mean values) was with 3 and 10 very low. But still it might be stated that the median recession coefficients are alike. A difference in the mean starting discharges can be noted. For the Vipava springs the mean starting discharge (of the mean and median calculation procedure) of the second reservoir (i.e. when the first reservoir stops emptying and the second reservoir becomes the dominating one) is about 1 m^3/s higher than for the Hubelj springs.

A different situation can be observed for the outflow of the third reservoir. The mean starting discharge for the exclusive outflow of this reservoir, which corresponds to the base flow generating reservoir is about 1 m^3/s lower at the Hubelj springs than at the Vipava springs. This is about the same situation as for the second reservoir. In both cases this correspond to approximately 2/7 of their MQ's. The recession coefficients, however, for these third reservoirs are remarkably different for the two spring groups Vipava and Hubelj. The Vipava recession coefficients (mean and median values) are close to half of the Hubelj springs recession coefficients. Hence the half-life for the Vipava springs is about double the half-life of the Hubelj-springs. Assuming that these master depletion curves are exclusively a result of diffuse flow this situation allows two possible interpretations:

- The hydraulic gradient at the Vipava springs is smaller than at the Hubelj springs.
- The permeability of the aquifer discharged by the Vipava springs is smaller than the permeability of the aquifer discharging the Hubelj springs. A very high hydraulic gradient of the underground water behind the Hubelj springs is confirmed by (HABIČ 1985 as quoted in JANEŽ 1994) but no explicit statement has been made on the hydraulic gradient of the underground water behind the Vipava springs.

3.6. THE ELECTRICAL CONDUCTIVITY AS INDICATOR FOR HYDRODYNAMIC PROCESSES IN THE VIPAVA SYSTEM (T. HARUM, H. STADLER, N. TRIŠIČ)

3.6.1. Measuring Equipment

In Vipava dataloggers were installed at the spring 4/7 (water level, electrical conductivity and temperature), 4/3 (conductivity and temperature) and at the gauging station for total runoff (4/8, conductivity and temperature). The discharge of the Vipava springs is being measured at two gauging stations: springs 6-4/7 and total runoff 4/8. Therefore it is only possible to separate two groups concerning the discharge of the 4/7 main outlets. The group of the springs 4/1 to 4/5 can be calculated as the difference between the total discharge of no. 4/8 and the measured discharge of the springs no 4/6 and 4/7 (compare Chapter 4, Fig. 4.12). The conductivities are compensated to 25° C, temperature effects can be neglected.

The dataloggers measured every 5 minutes and stored an average value every 15 minutes. The gauging station no. 4/8 is being equipped with a water level recorder by HMZ Ljubljana, long-time series from 1960 - 1995 are available.