tions in the month of October 1993, and for the 1961-90 period. For these cases, the complex water balance analysis will be made. This problem is difficult because the gauged waters at the rims of the Trnovski Gozd and the Nanos do not represent the total quantity, because a part of the waters from this area drain underground towards the Soča (the Mrzlek spring). These quantities have not been determined so far, and it is very difficult to do it due to the reservoir of the Solkan hydropower plant.

3.4. CORRELATION AND SPECTRAL ANALYSIS

(PH. MARTIN, J. KOGOVŠEK, M. PETRIČ, S. ŠEBELA, C. MARTIN)

3.4.1. Methodology

The hydrodynamic functioning of the Hubelj and Vipava springs was studied also with the time series analysis - with correlation and spectral analysis (BOX & JENKINS 1976; JENKINS & WATTS 1968). For this purpose the STOCHASTOS programme, which was designed by MANGIN (1981a, 1981b, 1984) and written by D'HULST of the "Laboratoire Souterrain du CNRS" at Moulis (Ariège, France) was used. Presented results were obtained in a co-operative research of CNRS URA 903 (Aix-en-Provence, France) and Karst Research Institute ZRC SAZU (Postojna, Slovenia).

This approach is based on the concept of the karst system (MANGIN 1975). We can define a karst system as an underground carbonate basin, which can however integrate unkarstified superficial sub-basins in the background. In this karst flows form the drainage network, which has in general a branching structure. Such karstic system is a place of dynamic processes, determined by inflows (precipitation and/or loss of water from rivers, CO_2, etc.) and outflows (discharges, aqueous solutions and so on). The karstification efficiency must be defined as work capacity within the system, it means that in case of gravitational karst as a runoff product in regard to the altitude of gradient (the altitude difference between the inflow and outflow (spring) points). The heterogeneity of the area, the non-linearity of the flows and the contrast in hydraulic conductivity between the different parts of the aquifer (IURKIEWICZ & MANGIN 1994) are conductive to the adoption of the systemic and functional approach which is based on the study of the relations input - output.

The use of correlation and spectral analysis necessitates time series of precipitation and discharges which are uninterrupted and of an identical duration. This approach first of all aims to describe the structure of time series (with random and periodical components, tendencies etc.), and then to establish the form of unit hydrogram and finally to draw attention to the multiple relationships between input and output.

Graphs resulting from calculations made on each of the time series allow us to understand these structures. They are obtained using two initial choices: one is the maximum value of lag (m) which corresponds to the window of observation, the second, the step (k) corresponds to the amplitude of each change. The information of a duration less than 2k does not show up in the results.

The correlogram shows how events are linked together for increasing intervals of time. High values indicate the presence of a tendency, low values suggest that events are not linked. A rapid decrease in the values of correlative coefficients indicate an absence of liaison at the end of a relatively short period of time. The size of interval corresponding to a value of the correlative coefficient of 0.2 is known as the "memory effect" (MANGIN 1984).

The spectrum of density of variance which corresponds to a change in the variable (Fourier transform), expresses the components of the time series in the frequency domain. In order to avoid the possibility that the results are biased, it is necessary to balance the calculations with an function such as that of Tukey or Parzen which are both very appropriate for use in hydrology (MANGIN 1984). The function of Tukey filters out less than that of Parzen. It is therefore preferable in the first approach since less information is lost. Nevertheless, it can allow artefactual peaks to appear. In order to alleviate any doubt a second calculation using Parzen filter can be used. High values for frequencies around zero indicate the existence of a tendency. By dividing the maximum value by two, we can obtain the "regulation time" which represents the duration of the impulse response. Each peak indicates the presence of periodical phenomena. The frequency from which the values become negligible is known as the truncation frequency (f_c). Beyond this, towards the higher frequencies, the spectrum only indicates the presence of white noise. The smaller the value of truncation frequency, the more the system is inert, which is to say less karstified.

The cross-correlogram is calculated for the time series of precipitation and discharges. If the input signal is random, the cross-correlogram is a good image of the impulse response of the system, which is a good representation of the unit hydrogram. In the domain of frequencies, we reach on the one hand the amplitude function which establishes the relations between the input and output of the system, and on the other the phase function which for each frequency defines the phase lag between input and output. The phase lag (τ) is defined with the equation $\tau = \theta/2\pi f$.

This information can be completed by calculating the functions of coherence and gain in frequency domain. The first expresses the linearity of the system. One non-linearity often indicates that the output function is not uniformly determined by the input function which was used. The other, the function of gain, indicates phenomena of attenuation (value < 1) or amplification (value > 1) in the signal for each frequency. An attenuation in the higher frequencies is generally accompanied with an amplification of the lower frequencies.

3.4.2. Characteristics of the Used Data

Basic hydrological characteristics of the studied karst area in the background of Vipava and Hubelj springs are presented in the previous chapters. Here we would just like to give some comments on the choice of the input function. For the purposes of this study, we selected the meteorological station at Otlica (820 m) which lies in the background of the Hubelj spring. An experience showed (MARTIN 1991 a, b) that it is useless to set up one rain-gauge station in a catchment area as rain is purely regional data that occurs at various places of the climatic micro-region as is Trnovski Gozd and Banjšice.

For the Otlica meteorological station the average daily precipitation for the period 1985 - 1995 are 6.28 mm. The maximum daily value is 170.6 mm and for the interval of three days 230.6 mm. In four three-days periods the amount of precipitation exceeded 220 mm. The wettest month was October 1992 with 580.5 mm. We can conclude (Fig. 3.10) that the period with highest amount of precipitation is between October and December, and the second maximum is from April to May. Regarding the dry seasons the interval January - February is more significant than the period between July and August.

The used data take account of the snow on the day of its fall, in a volume equivalent to that of meltwaters. In its natural environment, on the higher parts of the basin, the snow may last for several weeks. Based on the data gathered by the Hidrometeorološki Zavod RS, we counted for stations Otlica and Vojsko (1070 m) the number of days each year when the ground was covered by snow. From 1985 to 1995 the average number of days per year when the ground was covered with snow at Vojsko was 107. In 1985 the ground was covered for 166 days and in 1989 for only 49 days. At Otlica during the period of 1989 to 1995, the mean number of days when the ground was covered was 29 days with the maximum of 60 in 1995 (135 at Vojsko) and a minimum of 8 days. At the Postojna station (500 m), which lies further to the east, the ground was covered with snow for a period of 30 days in 1985; the snow represents 7 % of total precipitation. In 1991, the snow only accounted for 28 mm out of a total of 1681 mm.

The volume of persistence of snow must be seen in terms of the mean altitude of the basins. This can be determined by conducting a study of ^{18}O concentrations (URBANC & PEZDIČ 1995). These would be 900 m for the Hubelj basin with a confidence interval of 750 m to 1000 m. And for Vipava basin the figure would be 850 m (with the confidence interval between 700 m and 950 m).

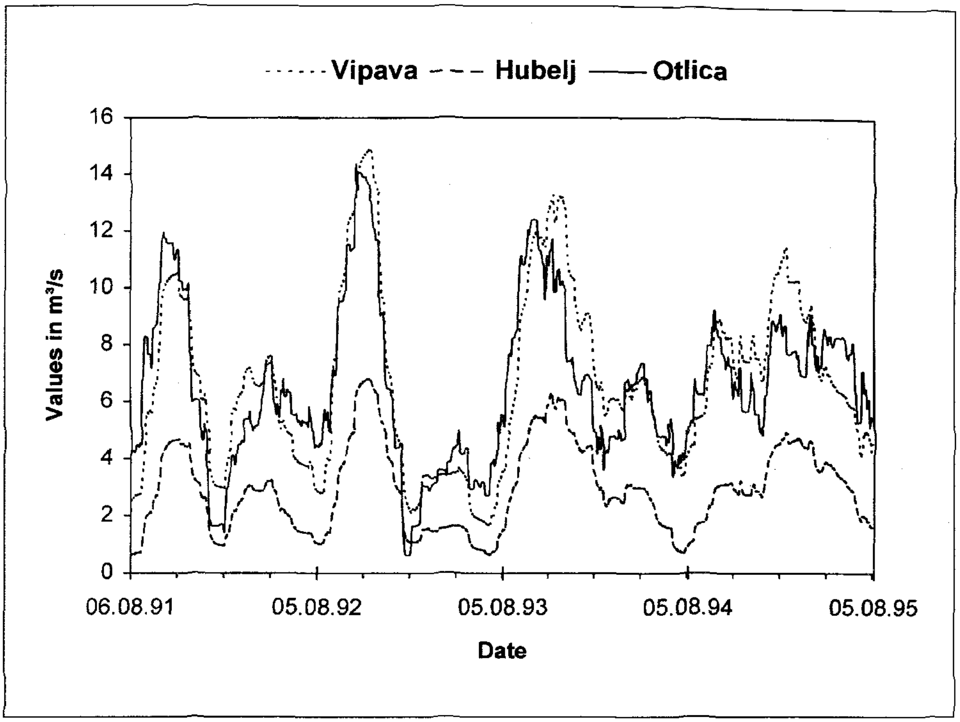

Fig. 3.10: The data of precipitation (Otlica) and discharges (Vipava and Hubelj springs) in the period 1991-1995 smoothed with the moving average (window of 93 days).

It appears that for medium and low altitudes like that of Postojna, the percentage of snow precipitation is negligible.

For the Hubelj and Vipava backgrounds the persistence of a covering of snow over several weeks each winter causes delay between the moment when the precipitation are measured (meltwater for the measuring apparatus) and the moment when the snow covering melts. Because the duration cover varies according to the different altitudes, we might conclude that the recharge of the aquifers is retained and that constitutes a sort of support of the hydrological phases in spring.

In this case it seems that the influence of snow is felt at the margin only and it almost does not affect the global statistical approach presented below. Yet it does not exclude the possibility that increase of snow cover is determining in some cycles. It would be convenient to divide the observed periods into those with particularly lot of snow or without it and make the comparisons.

On the other hand, the evapotranspiration (on the base of Penman method the following values were calculated: 678 mm for the period 1959 -1979 (STAHL 1994), 637 mm for the year 1993 and 628 mm for 1994 (AVBELJ 1995)), which reaches about a third of the volume of precipitation during the year, reduces the available discharge with a maximum effect towards the end of spring and during the summer.

3.4.3. Analysis of Results and Comparative Study of Both Springs

The daily data of precipitation on the meteorological station Otlica and discharges of Hubelj and Vipava springs, which were gathered by the Hidrometeorološki Zavod RS, were used in the analysis. The observation period was 11 years or 4017 days from 1 January 1985 to 31 December 1995. The correlation coefficient and the spectrum values were calculated with the use of step k = 1 and the maximum value of lag m = 125.

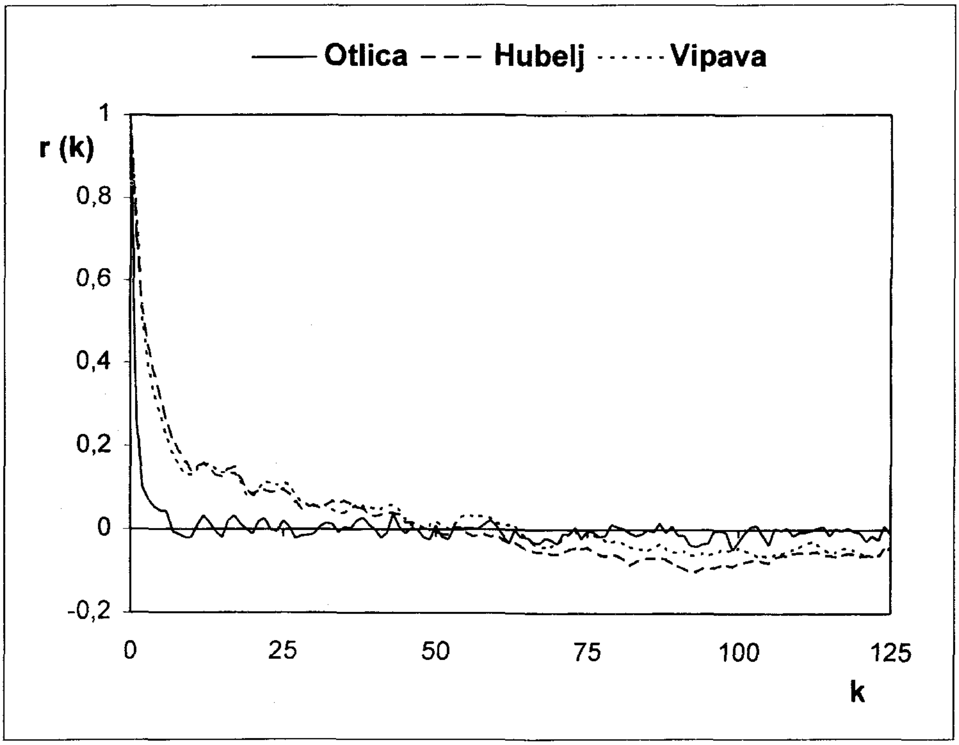

Fig. 3.11: Correlogram of precipitation (Otlica station) and discharges (Hubelj and Vipava springs) for the period 1985-1995 (n=4017 days, k=1, m=125).

The correlogram calculated according to the data of daily precipitation at Otlica (4017 days, average 6.2 mm, maximum 170.9 mm, minimum 0 mm, variance 244) shows an extremely rapid decrease in the values of correlative coefficients (Fig. 3.11). The value 0 was reached after 7 days. For the values of $k > 3$, only random fluctuations around 0 are persistently obtained. The interdependence of events is therefore very weak. It is nothing over 2-3 days which is the period corresponding to a climatic episode or to the passage of one perturbance.

The two other correlograms were calculated using data of average daily discharges of Vipava (average 6.5 m^3/s, maximum 66 m^3/s, minimum 0.73 m^3/s; variance 69.9) and Hubelj springs (average 2.8 m^3/s, maximum 36 m^3/s, minimum 0.18 m^3/s; variance 15.2). These show an extremely rapid decrease in the values of the correlative coefficients with $r = 0.2$ for a very low value of k (Tab. 3.11). In these two cases the decrease is regular until $r = 0.15$ and $k = 11$. For higher k values, the correlative coefficients are always less than $r = 0.15$ and at $k = 50$ they reaches 0. Therefore there exists a statistical

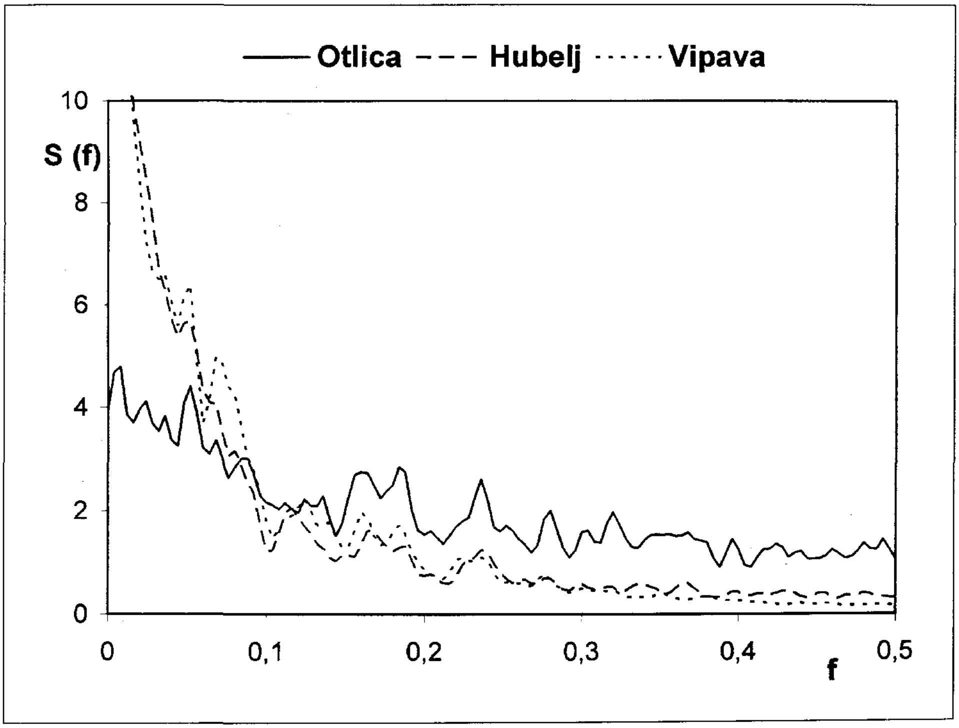

Fig. 3.12: Spectrum of precipitation (Otlica station) and discharges (Hubelj and Vipava springs) for the period 1985-1995 (n=4017 days, k=1, m=125) - calculated with the use of Tukey filter.

independence between the discharges which occur at about 12 days apart. We can conclude that the memory effect is considerably low, which would represent a small storage capacity and well developed karst drainage. Finally, let us note that the correlograms of the precipitation and discharges are very similar.

The spectrum of precipitation shows low values for all frequencies and very low values for frequencies of more than 0.1 (Fig. 3.12). Such spectrum corresponds to a random character of the function of precipitation, even if two small peaks appear at the points when f = 0.008 and f = 0.052. The first of these corresponds to a periodicity of 125 days, the second to a periodicity of 20 days. Both peaks can be seen also on the spectrum calculated using Parzen filter (Fig. 3.13). Therefore we can reject the possibility of artefacts and a certain periodicity which shows characteristics of the Mediterranean climate can be defined. The value of the periodicity (125 days) corresponds to four months, which is more or less the duration of the two rainy periods (autumn and spring) which are separated by two dry periods (winter and summer) of about two months (Fig. 3.10).

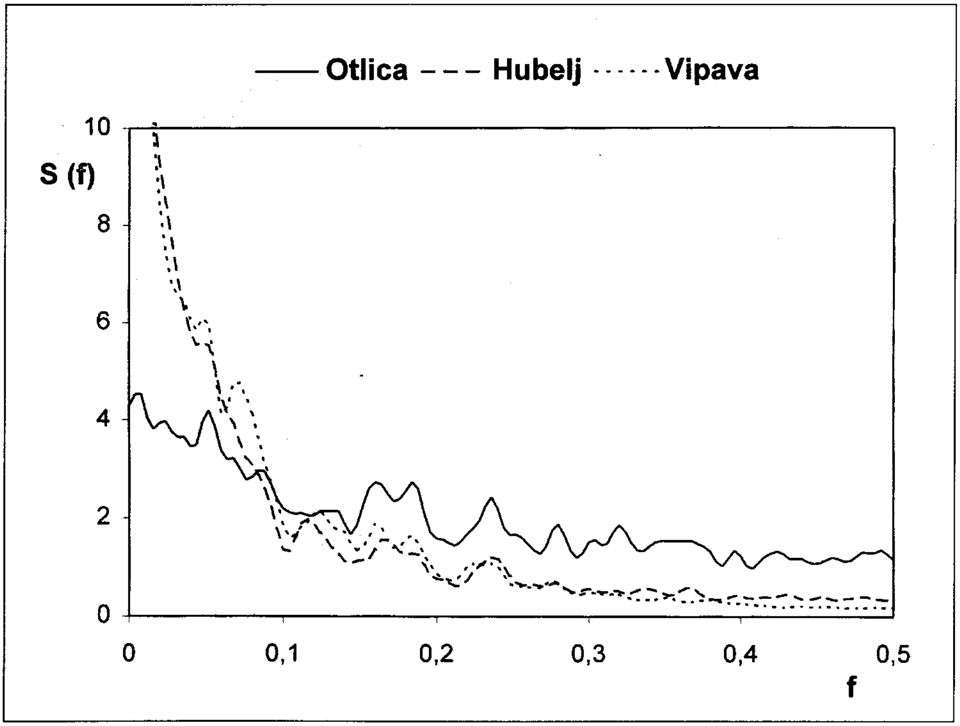

Fig. 3.13: Spectrum of precipitation (Otlica station) and discharges (Hubelj and Vipava springs) for the period 1985-1995 (n=4017 days, k=1, m=125) - calculated with the use of Parzen filter.

With the use of Tukey filter (Fig. 3.12) also the spectrums of discharges for both springs were calculated. They show a very strong levelling out of frequencies of more than 0.1 and a disappearance of all information for frequencies of more than 0.25. The values obtained for f = 0 (23.8 for Vipava and 22.1 for Hubelj, and the regulation time of 12 and 11 days respectively) points to a levelling out of the higher frequencies and a consequent pronouncing of the lower frequencies. Besides this, the Hubelj spectrum shows a peak at the frequency 0.004 which corresponds to a periodicity of about 250 days. This feature is not found in the Vipava spectrum. The utilisation of the Parzen filter (Fig. 3.13) causes this peak to disappear. In this case we are witnessing an artefact which is probably linked to the periodicity of four months which become evident through the precipitation data. The resulting graphs show that the drainage of these two karst systems is well organised.

A strong similarity (Fig. 3.14) is present in the cross-correlograms calculated using the precipitation occurring at Otlica and the discharges at Vipava and Hubelj springs (analyses of 4017 days). Both are tapered (the maximum

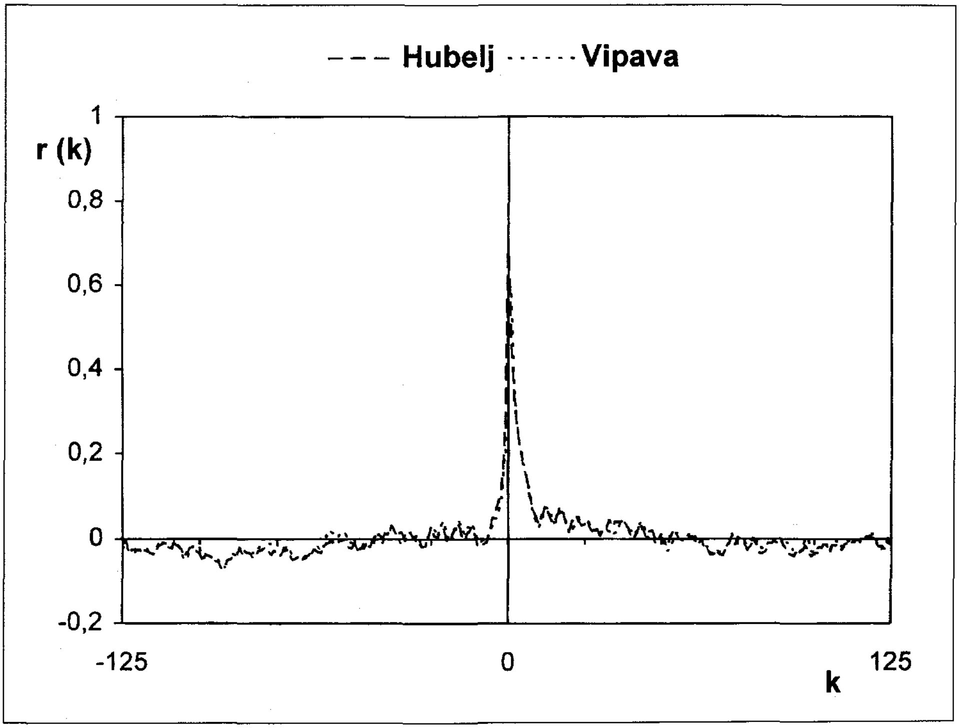

Fig. 3.14: Cross-correlogram between precipitation (Otlica station) and discharges (Hubelj and Vipava springs) for the period 1985-1995 (n=4017 days, k=1, m=125).

correlation coefficient for Vipava springs is 0.62 and for Hubelj springs 0.70) and descend after only 10 days to a very low r value (0.02 and 0.03). For greater intervals, the fluctuations are slight and random.

The part corresponding to negative values of k also shows random fluctuations around 0. However, at similar analyses conducted on binary karst higher values of r for the negative values of k were observed. This characteristic doesn't indicate that the discharges precede precipitation (which has no sense), but that the input signal is not random. We know that the Vipava springs are partly recharged by the surface rivers, yet in the cross-correlogram the values of r are very low for the negative values of k. This indicates that the portion of the river recharge is very low and/or that the time series of river discharges have a structure similar to the one of the precipitation.

The function of precipitation is therefore random and each cross-correlogram constitutes a good image of the impulse response of the studied karst system and thus a good representation of its unit hydrogram. These cross-correlograms thus point to the existence of functional drainage structures which are capable of the rapid transferral of rainwater or meltwaters to the springs. In this case, these structures can only be karstic networks with shafts, galleries, etc.

Two obtained amplitude functions are very similar (Fig. 3.15) with positive values for all frequencies and larger values for $f < 0.1$. The curve for the Vipava springs is more smooth than the curve for the Hubelj spring. The existing functions within the frequencies of relations between inflow and outflow of the system must not be zero because otherwise other functions (phase, coherence, gain) cannot be interpreted as, when the relations are missed it is obviously impossible to study their properties. The zone of relation input-output or the zone of exchange is between $f = 0$ and $f = 0.168$. The small peaks correspond with periodicity. On both curves we can identify the peak at $f = 0.056$, which represents the period of 18 days. This periodicity is similar to periodicity, which was defined in the spectrum of precipitation for $f = 0.052$. For basic frequencies the peak for Vipava-curve is at $f = 0.008$ (125 days), and for Hubelj-curve at $f = 0.012$ (83 days). These two curves indicates the importance of phenomena of basic and middle frequencies on the relation precipitation - discharge.

The phase lag is 7 days for the Hubelj spring and 8 days for the Vipava springs (Tab. 3.11). Calculated for the boundary frequency of the zone of exchange ($f = 0.168$) the phase lag for the first spring is ½ day and for the second 1 day.

In the zone of exchange the coherence functions ranges between 0.75 and 0.95. These values indicate good linearity of the system for basic frequencies, which essentially reflect the general functioning of the system.

The gain functions show amplificated values for periods greater than 16 or 17 days. For other frequencies the values are attenuated. The maximal amplification for the lowest frequencies is limited.

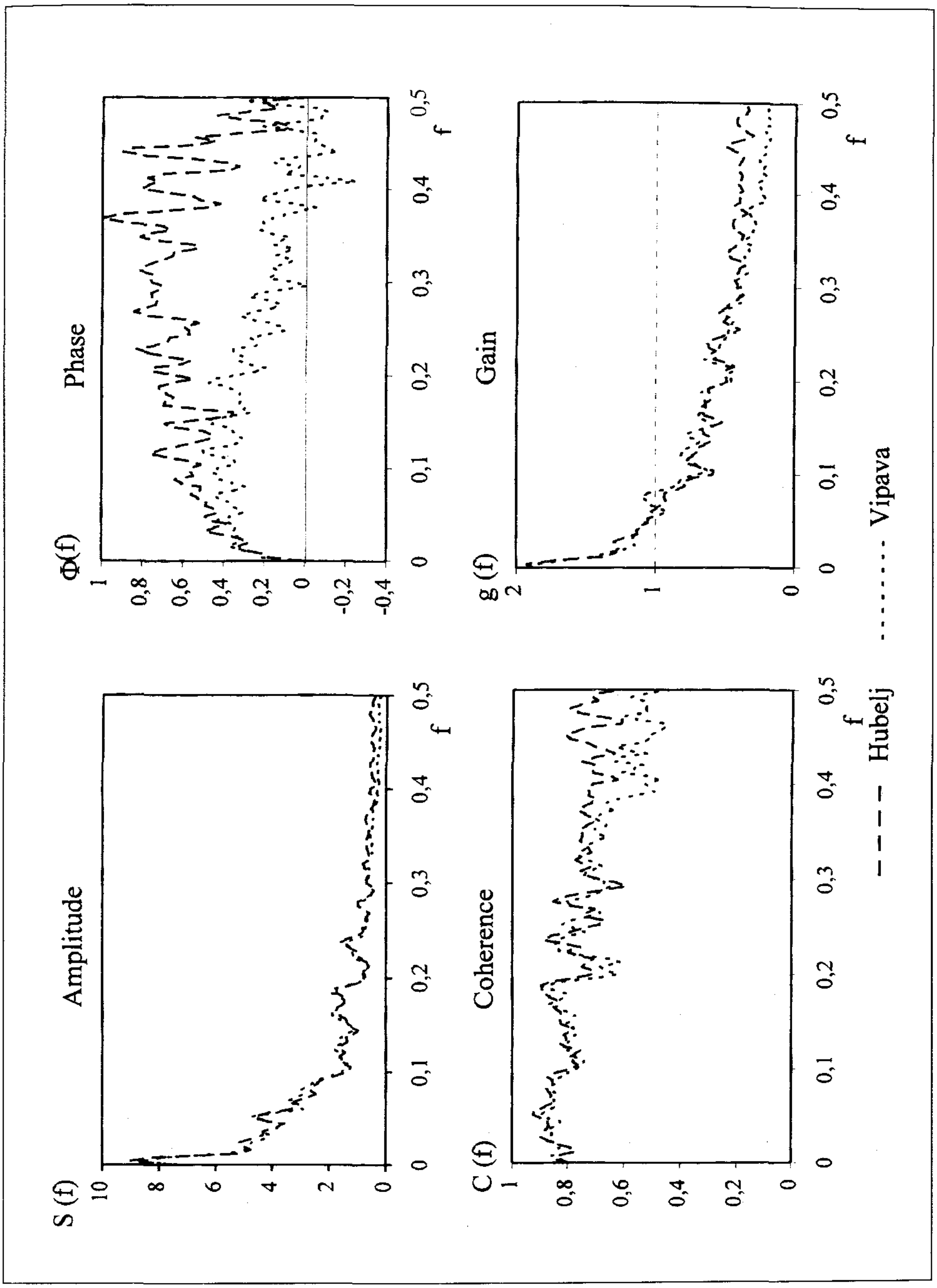

Fig. 3.15: Functions of amplitude, phase, coherence and gain for the period 1985-1995 (n=4017 days, k=1, m=125).

Tab. 3.11: Classification of karstic aquifers from the results of correlation and spectral analysis

	memory effect (r=0.2)	truncation frequency	regulation time	phase lag (f=0.004)	system type	unit hydrogram
Hubelj (4017 days)	8	0.25	11	8	ALIOU	
Vipava (4017 days)	7	0.25	12	7	ALIOU	
Hubelj (2 cycles)	11	0.35	12	13	Aliou	
Vipava (2 cycles)	5	0.35	11	12	Aliou	

3.4.4. Separate Analysis of the Cycles 1993-1994 and 1994-1995

The study was carried out with the aim to providing, for a period corresponding to the tracing tests, elements for comparison (for example, a cross-correlogram which is to be compared with the residence time). The calculations were based on data of precipitation (at Otlica) and the discharge (at Vipava and Hubelj springs) which were gathered during the hydrological cycles of 1993-94 and 1994-95, beginning and ending with the period at which the water was at its lowest level on the day of minimum discharge. For the Vipava springs two hydrologic cycles were defined in the interval from 24^{th} August 1993 to 23^{th} August 1995 (average discharge 7.5 m^3/s, variance 65.8), and for the Hubelj springs between 18^{th} August 1993 and 19^{rd} August 1995 (average discharge 3.3 m^3/s, variance 15.5). So for the first spring 730 daily values and for the second 732 daily values of discharge were compared with the same interval of precipitation at the Otlica station.

The correlograms obtained are very similar to those calculated on the basis of the report of the 4017 days (the memory effect in Tab. 3.11, Fig. 3.16).

The spectra have maximum values which are little different (the regulation time in Tab. 3.11) but which in contrast present a very significant peak at the point f = 0.04 (25 days) whichever filter is used, and a secondary peak for f = 0.052 (20 days). This last figure corresponds to a well defined periodicity

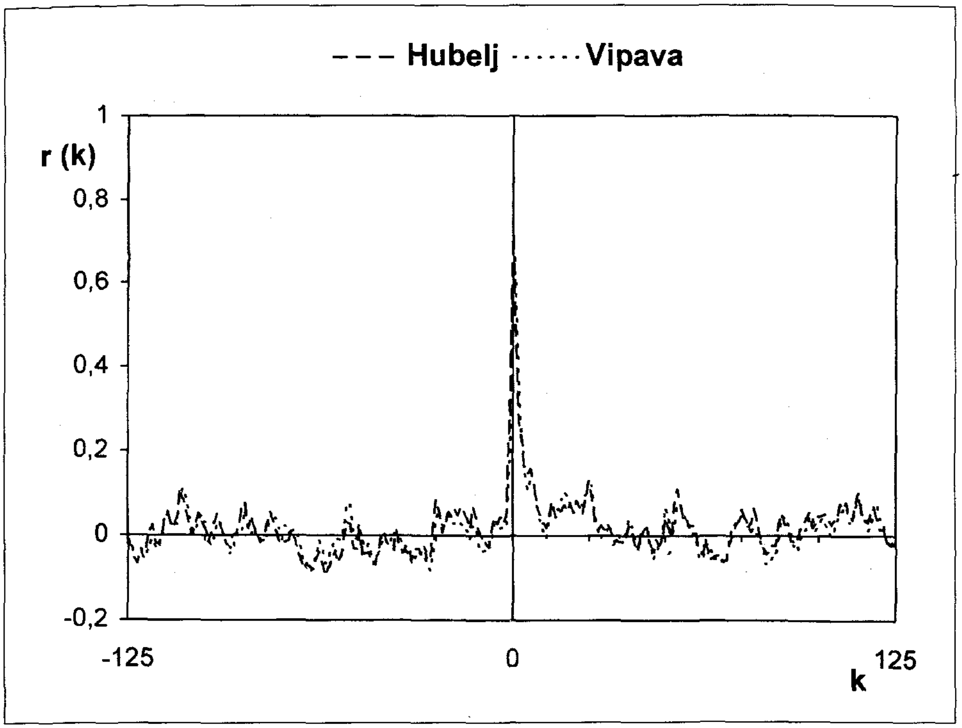

Fig. 3.16: Cross-correlogram between precipitation (Otlica station) and discharges (Hubelj and Vipava springs) for two hydrological cycles 1993-1995.

in the two short time series. In contrast to this, the latter clearly show the periodicity of 125 days. This should perhaps be linked to the major periodicity in the discharge time series.

3.4.5. Conclusions

The study of the discharge time series of the Vipava and Hubelj springs demonstrate that these hydro-systems are karstic systems of the Aliou type. They are well drained by efficient drainage structures which can be geomorphologically assimilated to a drainage network made up of a succession of sectors whose geometry facilitates the running off of rain and meltwaters.

The hydrodynamic functioning which is identified by the correlation and spectral analysis appears to be - in contrast with the results obtained in Provence (France) at the Sainte Baume (MARTIN 1991 a, b, c) - very similar, even though other hydrological indicators show significant differences.

A quick comparison of 1994 hydrograms of these two springs clearly shows (Fig. 3.17):

- a synchronisation of hydrological phases is also temporally very reduced (some days);
- steeper recession curve for Hubelj low waters than for Vipava low waters;
- during low water level the discharge in the Vipava is always higher than this in the Hubelj;
- a remarkable difference of high waters quantity in the moment of aquifer recharge; high waters at Vipava are much higher and similar during the year which is not a case at Hubelj.

The presented characteristics are not quantitatively defined, but with their description we tried to emphasise that on one hand it is not good to be limited only on one researching method and on the other that some important differences in the hydrodynamic functioning can not be detected with the methods of correlation and spectral analysis.

Although we consider the above remarks and although the altitude location of each spring is different, the uniformity functioning as it is described (Tab. 3.11) opens a problem in respect of certain karsts where the variations of functioning may be considerable (MARTIN 1991 a, b).

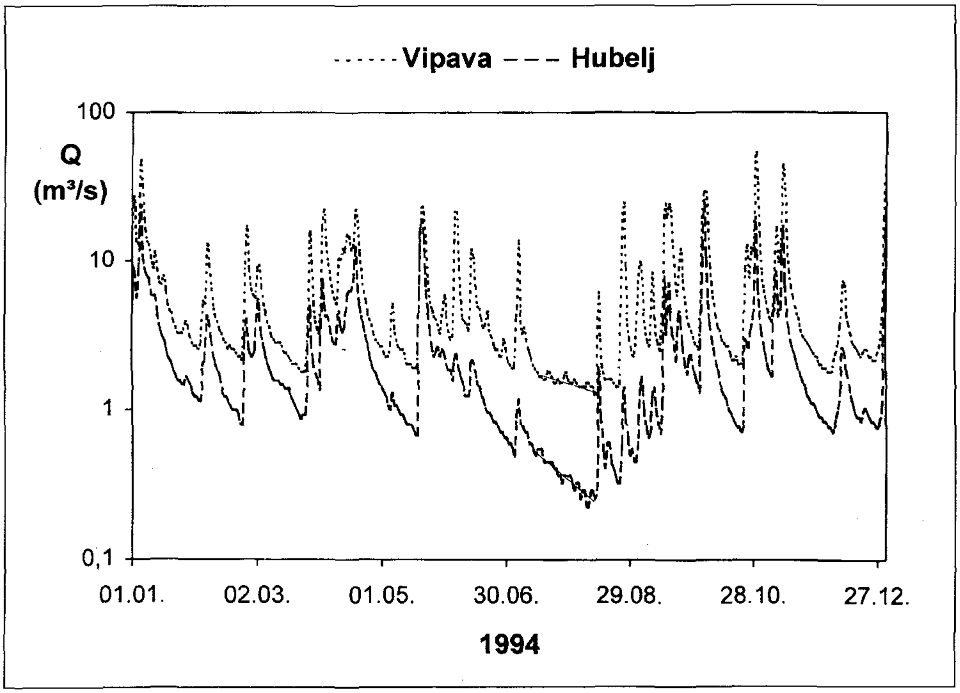

Fig. 3.17: Comparison of the hydrograms of Vipava and Hubelj springs for the year 1994.

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: