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.

## 3.6.2. Suppositions and Methodological Aspects

The discharge of karstic spring consists of different components with different residence times in the aquifer. Usually it can be separated into two components, which are termed **base flow** and **direct flow** corresponding to their different residence time and flow behaviour. The direct flow component represents the portion of water infiltrated from precipitation, which flows directly with short retardation through the main channels in the karst system to the spring. The base flow component consists of water stored in microfissured zones of the the aquifer over a longer time.

The conventional hydrograph separation procedures using the exponential function after MAILLET (1905) and extrapolating this depletion function back under the peak of the total hydrograph allow an approximate separation of the two components base flow and direct flow (s. Chapter 3.5). This method gives only information about the hydraulic behaviour of the aquifer (MÜLLER & ZÖTL 1980; BEHRENS et al. 1992). The volumes of reservoir water calculated are corresponding to the volume of mobile water, not including temporarily stagnant water, i.e. water, which can only be discharged by hydraulic stimulation under increasing hydraulic head.

Contrary the measurement of natural tracers as stable isotopes and chemical parameters of input and output gives the possibility of estimating the portions of **older reservoir water** and **event water** discharged at the spring and provides information about the mixing and solute transport processes in the aquifer. The water volumes calculated by means of natural tracers include the volume of temporarily stagnant water in the system and are not directly comparable with the volumes of direct and base flow components computed by the classical hydraulic separation method. For hydrogeological investigations it has to be emphasised to include both methods due to their complementary information about the aquifer characteristics.

Therefore and contrary to the assumptions in Chapter 3.5. and according to previous investigations of the ATH-group in Karst aquifers of the Swiss Jura (MÜLLER et al. 1980) and of the Lurbach system (BEHRENS et al. 1992) it is important to emphasise the difference between

"older" reservoir water ≠ base flow and event water ≠ direct flow.

Assuming the existence of only two discharge components, they can be separated combining the simple mixing equations

$$Q_T = Q_E + Q_R \quad (6)$$

and

$$Q_T * C_T = Q_E * C_E + Q_R * C_R \quad (7)$$

to

$$Q_R = Q_T * (C_T - C_E)/(C_R - C_E) \quad (8)$$

where $Q_T$ = Total discharge at the spring in l/s
$Q_R$ = "Older" reservoir water in l/s
$Q_E$ = Event water component in l/s
$C_T$, $C_R$, $C_E$ = Corresponding tracer concentrations

The following suppositions have to be taken into account (HARUM & FANK 1992):

1. Sudden input of event water into the aquifer.
2. Significant differences in the contents in input and output.
3. No physical, chemical or biological reactions of the tracer during the transport in the aquifer.
4. Negligible or well known fluctuations in the background concentrations.
5. Exact measuring of discharge and tracer concentration.
6. Especially in karst systems as the Vipava aquifer sufficiently short interval of the measurements.

For most of the "ideal" tracers as the stable isotopes $^{18}O$, $^{3}H$ and some chemical parameters as i.e. $Mg^{++}$, $NO_3^-$ and $SO_4^-$ the exact determination of the time-concentration curves is hindered due to economic problems (especially in karstic regions with a quick response of discharge to precipitation events short sampling interval are necessary causing a high amount of expansive analyses). The electrical conductivity represents only a measure for the total mineralization, but it is has the big advantage that it can be measured on-line with relatively high accuracy. The disadvantage is that the dilution of certain chemical parameters due to the lower mineralised precipitation water is overlaid by increasing concentrations of other ions due to processes of out-washing of dunging substances and solution during the passage of the infiltrated precipitation water through the unsaturated zone (BEHRENS ET AL. 1992; HARUM et al. 1990; HARUM & FANK 1992; KENNEDY et al. 1986). Therefore the electrical conductivity cannot be considered as an ideal tracer, but the the analysis of the exactly recorded time series of discharge and conductivity can give approximate ideas of the processes of solute transport and mixing in the aquifer during the underground passage. Assuming that a part of infiltrated water is flowing directly without greater retardation and without processes of solution through karst channels to the outlets, the conductivity can be used for an estimation of the portion of this quick flow component (called event water) on the discharge of the springs and allows a relative comparison of the hydrodynamic behaviour of springs.

## 3.6.3. Separation of the discharge components

### 3.6.3.1. Analysis of long-term fluctuations of the runoff year 1995

For the year 1995 discharge and conductivity data exist for the springs Vipava 4/6 - 4/7, 4/8 (total discharge) and partly 4/3. The discharge of the spring group 4/1-4/5 can be calculated by the difference between Vipava 4/8 and 4/6-4/7. For the analysis of the data mean daily values of discharge and conductivity were used.

The first step is a comparative analysis of the different springs. In Fig. 3.26 the weighted means over 30 days are plotted compared to the weighted discharges. It is clearly visible that the total discharge Vipava 4/8 and spring 4/3 have nearly the same fluctuations of conductivity, whereas the graph of Vipava 4/7 shows significant differences which are probably due to the partly different recharge area (mixing with karst water coming from the Bela creek (sinkhole downstream of the village of Sanabor) as indicated also by the results of the tracer experiment). The similarity of the EC-fluctuations of total discharge (4/8) and spring 4/3 indicate that the springs group 4/1-4/5, which represents the greatest part of the total discharge at the gauging station have nearly the same regime. This conclusion is also confirmed by the results of the tracing experiment and short-term conductivity measurements by data loggers at the other springs. Therefore the EC-values of spring 4/3 (no measurable discharge) are assumed to be representative for the group 4/1-4/5.

It is visible in Fig. 3.26 that the EC-curve measured at the total discharge shows sometimes stronger dilution effects. This effect can be explained by a

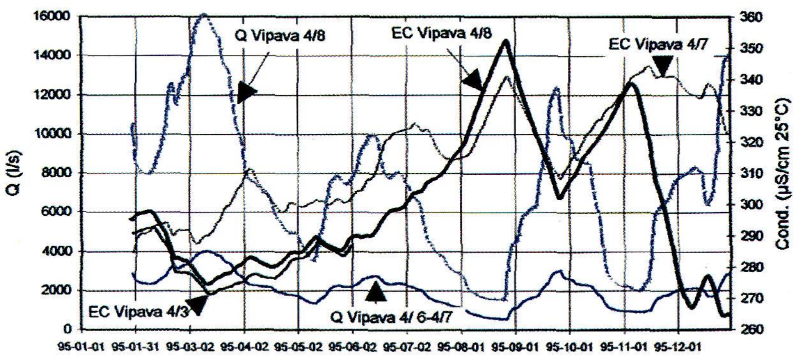


*Fig. 3.26: Weighted means over 30 days of discharge and electrical conductivity of the Vipava springs 4/3 (representative for the group 4/1-4/5), 4/7 and the total runoff at the gauging station (4/8).*

certain portion of surface water originating from local precipitation events in the village of Vipava (water from roofs and streets) which is situated upstream of the gauging station.

For the long-term analysis of the different discharge components it has to be taken into account that the background conductivity CB of the longer stored reservoir water in a karst aquifer has seasonal variations which have to be included in the mixing equation mentioned above. Therefore it was assumed, that the highest monthly conductivity values are representative for the "older" reservoir component.

The input concentration CE was assumed to be constant with a mean conductivity of CE = 30 $\mu$S/cm 25 °C. Variations of it of ± 10 $\mu$S/cm give no significant differences in the results.

From spring 4/3 only conductivity data from the first 6 months of the year 1995 exist. But a correlation analysis of the measured total discharges QT and computed reservoir discharges QR indicated a strong linear relation between both parameters. Therefore and for the reason of a comparison of the results of one annual runoff period the missing values could be estimated with sufficient accuracy using the linear regression equation in Fig. 3.27.

The results of calculations are plotted in Fig. 3.28 (total discharge Vipava 4/8), Fig. 3.29 (Vipava 4/6-4/7) and Fig. 3.30 (Vipava 4/1-4/5). All values are daily means except the background conductivity of the "older" reservoir water (highest monthly values). The discharge hydrographs are plotted in comparison to the event water component computed by the mixing equation.

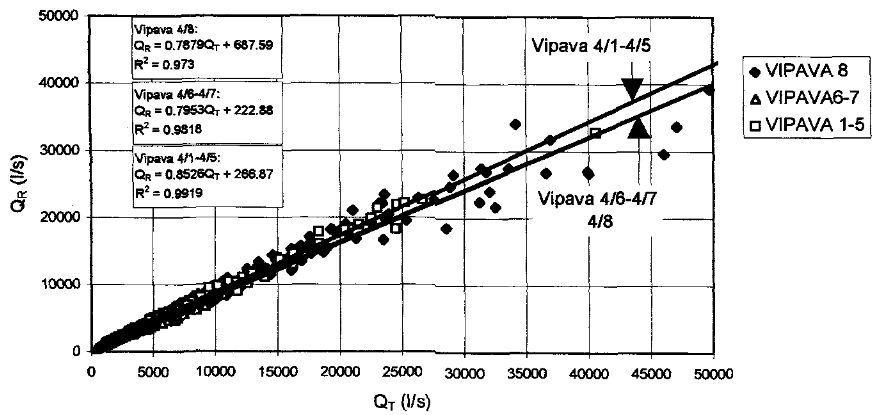


*Fig. 3.27: Relation total discharge $Q_T$ to reservoir component $Q_R$ for the Vipava springs.*

The results indicate for all springs that during flood events the greatest portion of discharge consists of "older" reservoir water. The portions of "young" event water, which are plotted in Fig. 3.31, reach maximum 27 % at the springs and 36 % at the gauging station Vipava 4/8, where surface water from roofs and streets in the village of Vipava is drained to the Vipava river. The mean annual portion of event water of the total discharge is only in the range of 10 % for the springs and 12 % at the gauging station including

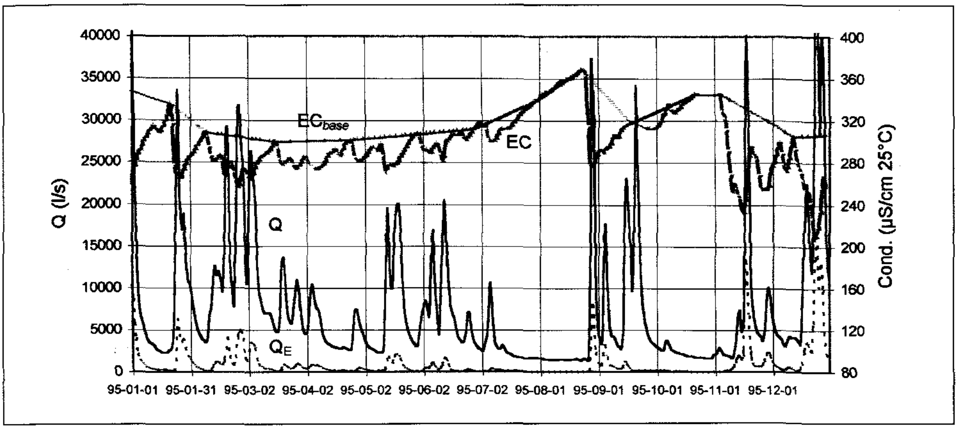


*Fig. 3.28: Mean daily values of discharge Q, event water component $Q_E$, electrical conductivity EC and estimated background conductivity $EC_{base}$ at the total outflow of the Vipava springs (gauging station Vipava 4/8) for the year 1995.*

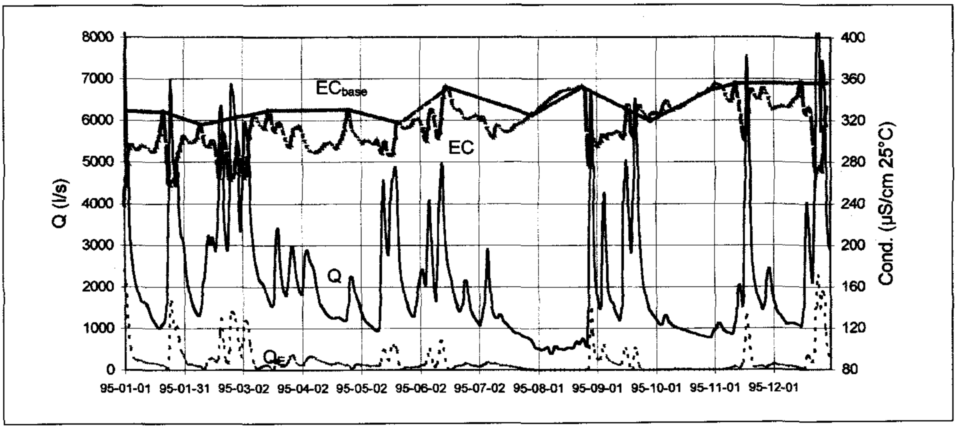


*Fig. 3.29: Mean daily values of discharge Q, event water component $Q_E$, electrical conductivity EC and estimated background conductivity $EC_{base}$ at the spring Vipava 4/7 (discharge = Vipava 4/6 - 4/7) ) for the year 1995.*

surface water. At higher discharges the spring group 4/1-4/5 seems to have a higher portion of "older" reservoir water, a fact, which is probably due to the greater distance of permanently active sinkholes. These results agree well with those of the isotope investigations (Chapter 5.), where the portion of event water on the discharge of the Vipava springs was calculated as 21 % for selected single events.

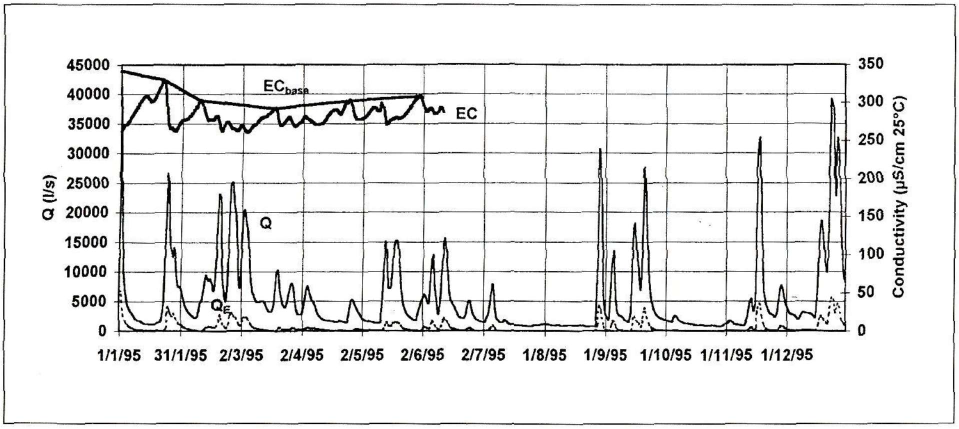


*Fig. 3.30: Mean daily values of discharge Q, event water component $Q_E$, electrical conductivity EC and estimated background conductivity $EC_{base}$ at the springs Vipava 4/1-4/5 (EC measured at Vipava 4/3) for the year 1995. The event water components $Q_E$ from June to December 1995 where calculated using the linear regression equation in fig. 3.27.*

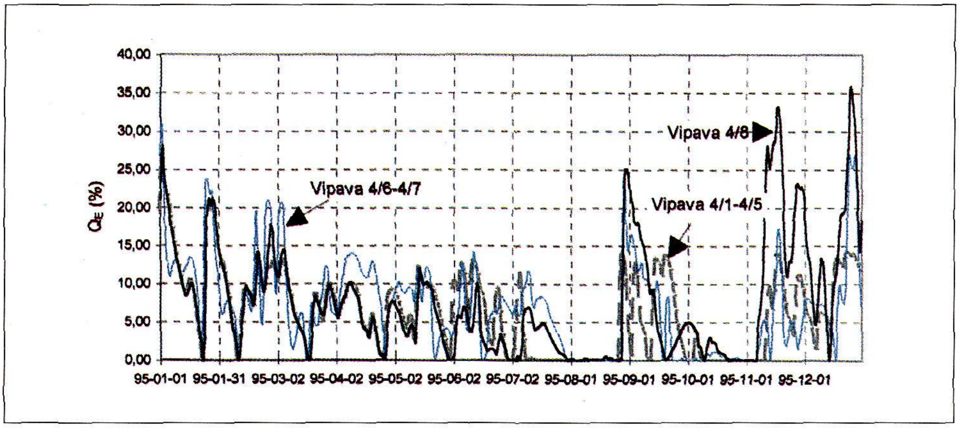


*Fig. 3.31: Mean daily values of the event water component $Q_E$ for the springs Vipava 4/6-4/7, 4/1-4/5 and the total runoff at the gauging station Vipava 4/8 for the year 1995.*

The water volumes, mean annual discharges and portions of the reservoir components are summarised in Tab. 3.14. They underline the great importance of the "older" reservoir water component, which is stored over a longer time.

*Tab. 3.14: Water volumes of the discharge components at the Vipava springs for the year 1995.*
*$V_T$ = total volume, $V_R$ = older reservoir water, $V_E$ = event water.*

| | | $V_T$ | $V_R$ | $V_E$ |
|---|---|---|---|---|
| VIPAVA 4/8 | $m^3/y$ | $2.46\ 10^8$ | $2.16\ 10^8$ | $3.06\ 10^7$ |
| | l/s | 7813 | 6843 | 970 |
| | % | 100.0 | 87.6 | 12.4 |
| VIPAVA 6-4/7 | $m^3/y$ | $6.80\ 10^8$ | $6.11\ 10^7$ | $6.89\ 10^6$ |
| | l/s | 2157 | 1938 | 219 |
| | % | 100.0 | 89.9 | 10.1 |
| VIPAVA 4/1-4/5 | $m^3/y$ | $1.78\ 10^8$ | $1.60\ 10^8$ | $1.87\ 10^7$ |
| | l/s | 5656 | 5062 | 597 |
| | % | 100.0 | 89.5 | 10.5 |

### 3.6.3.2. Analysis of single events

In Fig. 3.32 the measured discharges and conductivities of the springs 4/3 and 4/7 and the gauging station (4/8) are plotted for three selected events (period October 25th to December 26th, 1994). The values of the discharge of the spring group 4/1 - 4/5 were calculated as difference between total runoff and runoff of the springs 6 and 4/7. It shows, that the graph of conductivity of spring 4/7 differs fundamentally to the two other, especially during flood events. The reason is probably, that the discharge of this spring consists of two components, one draining the same catchment as the springs 4/1-4/5, the other containing a portion of water from the region of the Bela sinkhole near Sanabor. The conductivity of spring 4/3 is very similar to the conductivity at the gauging station of total runoff (4/8), which proves the assumptions of Chapter 3.6.3.1. that springs 4/1-4/5 drain the same well mixed drainage system and the conductivity of spring 4/3 is representative for this group. Their discharge is the main component of the total runoff measured at the gauging station (4/8).

The three flood events plotted in Fig. 3.32 show different responses of the total mineralisation represented by the electrical conductivity. The first two events with higher discharge peaks are characterised by different reactions of springs 4/1-4/5 and 4/7. At the group mentioned first the conductivity at the first event on October 1st, 1994 increases in a significant way with increasing discharge which proves that at first "older" reservoir water with higher mineralization is discharged hydraulically stimulated by the flood. The dilution starts about 5 h after the beginning of increasing discharge and reaches its maximum approximately one day after the discharge peak.

Contrary to group 4/1-4/5 the dilution starts at Vipava 4/7 with short retardation indicating the quicker outflow of low mineralised event water at the spring. Probably this is the portion of water from the Bela creek with an active sinkhole downstream of the village Sanabor, which is the nearest punctual input to the Vipava springs.

The same phenomena can be observed for the second flood event with comparable discharge peaks.

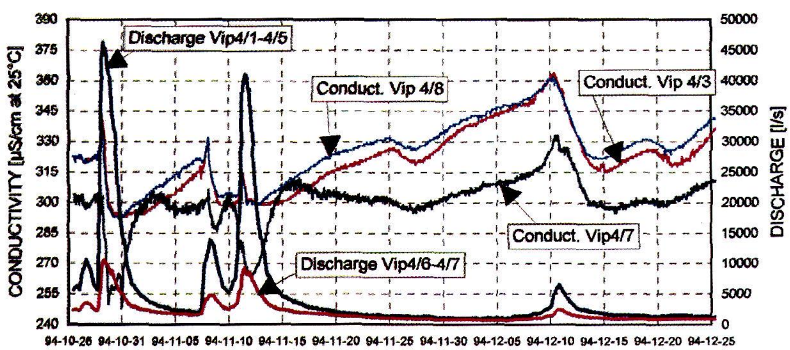


*Fig. 3.32: Discharge and electrical conductivity of the Vipava springs 4/1-4/5, 4/6-4/7 and the total runoff at the gauging station (4/8) during three flood events in autumn 1994.*

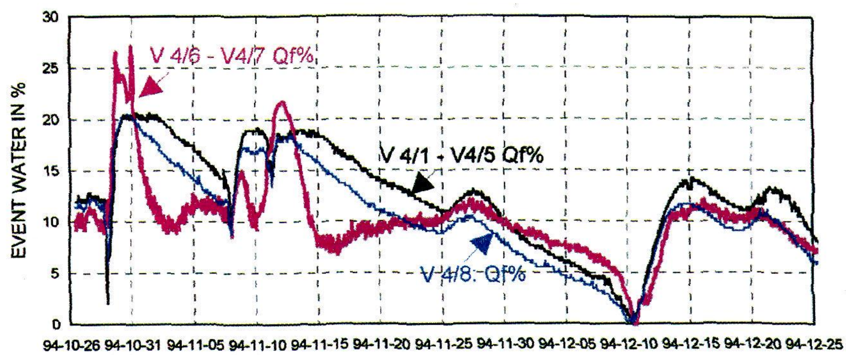


*Fig. 3.33: Event water component $Q_E$, for the springs Vipava 4/6-4/7, 4/1-4/5 and the total runoff at the gauging station Vipava 4/8 during three flood events in autumn 1994.*

The third event with lower discharges at all springs shows a completely different hydrodynamic behaviour. Due to the slower increasing discharge dilution starts with higher retardation, Piston effects are not so clearly visible.

In Tab. 3.15 the results of the calculations, based on the mixing equation (Chapter 3.6.2.) are summarised. An input concentration of 20 $\mu$S/cm (25 C) and a stable background conductivity were assumed. The values are calculated for the time from 26.10.1994 to 25.12.1994.

In Fig. 3.33 the calculated event water in % of the total discharge is plotted for the groups Vipava 4/1-4/5, Vipava 4/6-4/7 and Vipava 8. It shows, that the hydrograph of Vipava 4/6-4/7 differs from the two other groups especially during and after the events at the end of October and in November. The part of event water decreases below 10 % in two days. At Vipava 4/8 and Vipava 4/1-4/5 the decrease of event water under 10 % lasts 12 days.

These two events in October and November 1994 show different hydrographs between the groups of Vipava springs. The event at Dec. 11th shows a similar shape of the time series for all groups. This small flood event increases the discharge of "older" reservoir water, the increase of event water starts after the discharge peak. This means, that the infiltrated precipitation water does not directly contribute to the discharge, but increases the discharge by hydraulic stimulation due to the increasing water head in the karst aquifer. Greater events increase the discharge partly directly.

*Tab. 3.15: Water volumes of the discharge components at the Vipava springs for three single flood events in autumn 1994. $V_T$ = total volume, $V_R$ = older reservoir water, $V_E$ = event water.*

| MAXIMUM VALUES of Background 26.10.94 12:00 bis 27.10.94 23:00 | | | |
|---|---|---|---|
| Input Conductivity: | | 20 | µS/cm at 25°C |
| Backgr V4/3 | MAXIMUM | 364 | µS/cm at 25°C |
| Backgr V4/7 | MAXIMUM | 333 | µS/cm at 25°C |
| Backgr V4/8 | MAXIMUM | 362 | µS/cm at 25°C |
| | | | |
| VOLUMES in ml | | | |
| | VT | VR | VE |
| Vip4/3 | 26 546 408 | 22 594 783 | 3 951 626 |
| Vip4/7 | 10 790 000 | 9 412 808 | 1 377 192 |
| Vip4/8 | 37 336 398 | 32 177 979 | 5 158 419 |
| | | | |
| VOLUMes in % | | | |
| | VT | VR | VE |
| Vip4/3 | 100.0 | 85.1 | 14.9 |
| Vip4/7 | 100.0 | 87.2 | 12.8 |
| Vip4/8 | 100.0 | 86.2 | 13.8 |

The results for single events are well comparable with those of the isotope (Chapter 5.) and of hydrodynamic investigations (Chapter 3.6.3.1.). They indicate the important role of "older" reservoir water which is stored for longer time in the great catchment area of Vipava. Even during high flood events the greater portion of discharge consists of "older" reservoir water.

## 3.6.4. Reservoir water volumes and aquifer characteristics

The isotope investigations (Chapter 5.) indicate a mean transit time for the Vipava springs of $T_m$ = 4.4 months. The total volume of reservoir water can be calculated using the equation (9):

$$V_R = T * MQ = 8.91 \cdot 10^7 \ m^3 \qquad (9)$$

The total aquifer volume of the Vipava catchment including the unsaturated zone can be estimated by the following equation (10):

$$V_A = A * (H_m) = 1.12 \cdot 10^{11} \ m^3 \qquad (10)$$

where Hm = 800 m = roughly estimated mean thickness of the karstified rocks,
A = 139.4 $km^2$ = estimated surface of the recharge area.

On this basis the effective porosity Ne referring to the total volume of mobile water (including portions of periodically stagnant water mainly in the unsaturated zone can be estimated (11) as:

$$Ne = V_R / V_A = 0.08 \ \% \qquad (11)$$

On the basis of the α-values (from the analysis of discharge recessions after MAILLET (1905, s. Chapter 3.5.) the freely dischargeable volume can be estimated (12) as

$$V_{fd} = MQ * 86.4 / \alpha = 9.83 - 3.35 \cdot 10^7 \ m^3 \qquad (12)$$

giving with α-values between 0.00687 and 0.0201 $d^{-1}$ (Chapter 3.5.) an effective porosity ($N_{efd}$ )of

$$N_{efd} = V_R / V_{fd} = 0.03 - 0.09 \ \%. \qquad (13)$$

In contrast to the analysis of discharge recessions including only the water volume which can flow out without hydraulic stimulation the volume computed by modelling of the isotope data includes also temporarily stagnant water which can only be discharged under increasing hydraulic head. Therefore the water volumes computed from isotope data usually give significantly higher results than those of the discharge recessions. Taking into account the high thickness of the unsaturated zone of the karst massif (up to 1000 m) and the fact that the volume of greater flow channels in karst massifs is usually significantly smaller than the volume of the microfissured less permeable zones much higher values of VR corresponding to a higher effective porosity are expectable.

Furthermore the water volume calculated from the discharge recessions gives always a too low volume and effective porosity. The reason is, that the discharge recession periods without input due to precipitation or snow melt are usually too short in humid climates such as in the area under investigation. As it was also the case in previous investigations of the ATH-group in the karst of Lurbach system even the longest discharge recessions include still parts of the karst reservoir with a steeper recession limb which do not reflect the depletion function of the reservoir parts with the highest storage capacity (BEHRENS et al. 1992). The comparison of the similar depletion coefficients of the karst systems of Lurbach aquifer (BEHRENS et al. 1992) and Vipava with those computed from long discharge recession limbs of karst springs in the semiarid climate of Central and Eastern Peloponnesus (MORFIS & ZOJER 1986) shows that the depletion coefficients of these springs mentioned at last are partly about 10 times lower during the long dry season reflecting the depletion characteristics of the reservoir parts with higher storage capacity more significantly.

The drainage systems of the karst springs of Vipava are partly well comparable with those of the springs in the Lurbach area (BEHRENS et al. 1992), both draining mainly forested plateaux with a soil cover and a high thickness of the unsaturated zone (Lurbach: 300 - 350 m, Vipava: 1000 m) and both having a portion of water from permanently active sinkholes which is drained with short residence time through larger karst channels to the springs (compare Chapter 6).

The investigations in the Lurbach system showed, that only a small amount of precipitation water infiltrating on the forested karst plateau reaches with shorter residence time the flow channels of the saturated zone. Tracing experiments with injections in dolines on the plateau gave in spite of the long observation period only recovery rates in the range of 2 - 3 % (BEHRENS et al. 1992). The mean residence times of the water from the unsaturated zone computed by modelling of the Tritium data (40 years for water from the unsaturated zone, 20 years for the total flow of the main spring including an important component of quick channel flow) confirm that a high portion of precipitation water infiltrated on the karst plateau is being stored over a longer time in microfissured zones, fine-clastic cave sediments and in periodically inactive cave parts. The isotope investigations in Vipava indicate only a mean transit time of 4.4 months in spite of the 10 times greater recharge area and the higher thickness of the unsaturated zone.

The total volume of water stored in the Lurbach karst massif computed by the isotopic investigations corresponds to a total porosity of 4.9 % (BEHRENS et al. 1992), in the Vipava system only 0.08 %. The analysis of discharge recessions from the Lurbach springs gives with α-values similar to

Vipava a 93 times smaller volume comparing to the total water volume (at Vipava nearly the same or maximum 1.5 times smaller) corresponding to a an effective porosity comparable to Vipava (< 0.1 %).

The contradiction of these results can be explained as follows:

1. The mean transit times of the Vipava system are underestimated due to the relatively wet years of the investigation period. Therefore the component of reservoir water stored over long time mainly in the thick unsaturated zone is "hidden" by young water coming from the frequent precipitation events. In this case the mean transit time of 4.4 months calculated from the stable isotope $^{18}O$ (Chapter 5) is mainly representative for the younger component (precipitation water which reaches the karst channels in short time). An important portion of water is stored over very long time (some decades) mainly in the thick unsaturated zone. Its tritium concentration (Chapter 6) does not correspond to the actual one in the precipitation but to a mixing to very old infiltrated water with low tritium contents.
2. The volume of water stored in the unsaturated zone in microfissures and in the vegetation covered soil is of less importance. It means that in the great catchment area of the Vipava springs quick channel flow is predominant. This explication seems to be plausible comparing to other investigations