The short river Timavo, which flows into the Adriatic Sea about 20 kilometers north-west from Trieste, is fed by karstic springs. The problem, from where these springs receive the relatively abundant water quantities, has been technically studied for over 100 years. Yet "the mystery" of the Timavo has remained an unsolved problem up to the present, although its karstic region belongs to the most thoroughly explored areas. The results of the tracing of the subsurface water connection between the Notranjska Reka and the Timavo carried out in 1962 with tritium, have not been hydrologically correctly explained either, therefore the erroneous opinions about the water connections of the Timavo have not been completely done away with. Applying a thorough analysis of the hydrologic conditions and taking into account the different permeabilities of the particular regions the complicated system of the Timavo springs can principally be correctly solved. More accurate results of the water quantities that the Timavo springs get under various hydrologic situations from the basins of the Soča, Notranjska Reka, and from its own adjacent area, can be obtained only with a well organized hydrometric service and broader systematic investigations. Since the drainage basin of the Timavo lies on both sides of the Yugoslav-Italian border, the hydrologic investigations must needs be coordinated.

Due to deficient hydrological research and discussions the "mystery" of the Timavo persists

The intensive use of water nowadays demands much better and more exact information on water resources. The collecting of reliable hydrological data to rationalize water projects and economize the use of water is, in general, a difficult task. A special problem, however, is the collecting of data on Karstic springs. In a hydrological study of Karst territory with complicated underground drainage system we are concerned with certain questions, and no real advance can be shown. The reason for this state is,
first of all, the undeveloped hydrological science and the disorganised hydrological service. Instead of systematic and continuous research based on professional hydrological principles and conducted by a unified hydrological organization such research is carried out by several institutions independently. The hydrological study of Karstic region in the past was limited mostly to the study of underground-water connexions. There was very little done in the field of quantitative research. It is true that hydrological investigations in Karst areas require corresponding research on geological, morphological, chemical, and other questions, but the results of those, for the hydrological research auxiliary studies, have to be interpreted from the hydrological point of view.

A good example of previous inadequate methods and results of hydrological study of Karst areas are the experiments in the Timavo basin. Although the Timavo basin was one of the most extensively studied Karstic regions we are today still facing some basic problems of its hydrographic background, and we are still lacking reliable hydrometrical data on the main springs of the Timavo. Better information on the hydrology of this region is essential to several interests, such as the water supply of Trieste or the need for exact explanations of consequences provoked by possible interventions in the river régimes of the N. Reka or the Soča river as well, etc.

In order to get better and more complete hydrological data, it is necessary to conduct continuous and systematic professional hydrological research. Above all, we have to organize in the Timavo basin a good flow-measuring service, because such data are indispensable for all future experiments.

The history of hydrological research of the Timavo basin shows that people have been for a long time interested to know from where the short river Timavo, which has its outlet into the Adriatic sea about 20 kilometres north-east from Trieste, was receiving such large quantities of water. They were looking, first of all, for a connexion with the N. Reka river, which disappeared in the Skocjan Caves (fig. 1).

The first tracing experiments in this connexion were conducted in the 17th century, and sawdust was used as tracers. Those experiments and many others with different floating particles gave no results. Not before the beginning of this century was the connexion between the Timavo springs and the N. Reka river disclosed by tracing tests with different substances (marked eels, dyes, chemical substances, and radioactive isotopes). Most of these experiments were performed for the study of the water supply of Trieste by G. Timeus, professor of chemistry.

The problems of the Timavo “mystery” and the results of quite extensive research work were published in many papers, but the final form was given in the study by Boegan “IL TIMAVO”4. The entire catchment of the Timavo should occupy, according to Boegan, 874 km², of which 482 km² should belong to the N. Reka river (the upper Timavo), and 392 km² to the underground part of the Timavo. According to Boegan, the N. Reka river is connected with all the main Timavo springs, with the Sardotsch and Moschenizze springs, with the springs at Auresina, and with several other springs along the sea coast. Only the Bagnoli springs should not be connected to the N. Reka river.

When, in 1956, the question arose as to what the effect would be on the Timavo discharge of a diversion of the N. Reka river into another hydrographic system, water balance analyses for the Timavo basin and the adjoining catchment areas were made. It was established, however, that the N. Reka river with the lowest discharge $Q = 160 \text{l/sec.}$ and an average low discharge $Q = 400 \text{l/sec.}$, respectively, could give but a very small contribution to the Timavo springs, which were presupposed to have a discharge of about $Q = 10 \text{m³/sec.}$ At low stage, the Timavo springs seemed to be fed mainly by water from the Soča river basin. Mr. d’Ambrosi, however, did not agree with this opinion, and attributed the large flow of the Timavo springs at low stage to the retention of the N. Reka river water in Karst.5
The experiments of the last years, as well as groundwater research in the Soča-Vipava region and the tracing of the underground connexions of the N. Reka river carried out in 1962 with tritium have, to a large extent, cleared the basic hydrological problems of the Timavo. Unfortunately, the results of the tracing in 1962 were not correctly interpreted in the papers\(^6\),\(^7\) where they had been published. In the reports of both papers the contribution of the N. Reka river to the Timavo springs is calculated too low. In the former report an excessive contribution is attributed to the Soča river. In the latter report, however, the contribution from the Soča river is reduced and contributions from Cicarija and the Podgrad region and from elsewhere are presumed instead.

Fig. 1 — Inflow of the N. Reka river into the Škocjan caves.
The flow deviations of the N. Reka river according to the results of the tracing in 1962

In discussing the Timavo springs, we have to take into account that they are fed partly by water from their own immediate catchment area, and partly by waters from the basins of the N. Reka and the Soča rivers as well. At different run-off conditions these different drainage basins may have different influences on particular springs. The conducting capacity of the underground drainage system of the Timavo is limited as regards the high flow quantities. In addition, the run-off of high flows of the N. Reka river is slowes if heavy rainfall occurs in the immediate area of the Timavo springs than it is if there are no local precipitations. Further, if at low water stage the discharge of the main Timavo springs suddenly increases as a result of high local rainfall, or if the main springs are artificially raised, the backwater produces, owing to the small water surface slope, a rise of water level in the Auresina springs and in the Trebiciano Cave. For each spring and river section studied in the Timavo basin we have to consider the constant changing of discharges and drainage circumstances in the hydrographic system.

The tracing of underground connexions of the N. Reka river in 1962 was planned to be carried out at steady low water stage. Actually at 13 hour on 3 July, when 200 C of tritium and 100 kg of fluorescein were injected, the discharge of the N. Reka river at the entrance into the Skocjan Caves was only 500 l/sec.

As a matter of fact, the N. Reka river starts disappearing a few kilometres before the Skocjan Caves, approximately 400 m downstream from the water-gaging station Cerkvenik mill (fig. 2), where the river channel crosses limestone strata. Water disappearing in this river reach has a connexion, according to Timeus' tracing, with the flow in the Skocjan Caves. Therefore, we have to take into account the total discharge

Fig. 2 — The schematical plan of underground waterconnections of the N. Reka river with the springs of the Timavo hydro-system after the tracing experiment in July 1962.


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of the N. Reka river as measured at the gaging station Cerkvenik mill. In the time of injection the discharge of the N. Reka river amounted, however, to $Q = 1.2$ m³/sec. On the same day heavy rainfall started after the injection and the N. Reka river rose considerably. The flood wave peak attained the value of $Q = 50$ m³/sec. at the gaging station Cerkvenik mill. This increase of flow ought to be taken into consideration in the tracing experiment.

During the tracing experiment samples were taken at 14 different points, which are shown in the plan (fig. 2) and indicated by numbers from 1 to 14.

The observation point No. 1 (the Skocjan Caves–Hanke bridge) was situated 470 m downstream from the point of injection and had the sole purpose verifying of the quantity of the passing tracer. As regards the computation of the quantity of the passing tracer, I would like to remark in general that Karstic underground channels with their large dead spaces as well as the manner of sample taking does not satisfy the basic conditions for an exact determination of the passing tracer, even if the accuracy of the sample analyses was assumed.

The 300 m deep Kačna Cave (fig. 2-5) has no flowing water. The bottom of the cave ends in a siphon where water fluctuates. This water could only be under the influence of the backwater in the channel system of the N. Reka river. Sampling at this observation point was not possible at the time because the access into the cave was established too late.

The same also occurred in the 329 m deep Trebiciano Cave, where sampling did not start in time. Only on 6 July, when the high water stage in the Trebiciano Cave was already in recession, was the first sample taken. The resulting incomplete record of the time-curve of concentration and the impossibility of establishing flow-rates of the flood wave, during the appearance of the tracer, did not permit determination of the quantity of the passed tracer. By means of visible trails in the Trebiciano Cave the

![Fig. 3 — Time-curves of concentration in the observed springs during the 1962 tracing of the N. Reka river connections.](image-url)
highest level at the peak discharge was determined to be $H = 14$ m. In figure 3 the approximate hydrograph is plotted in dotted line. If a stage-discharge curve for the Trebiciano Cave were available, it could be easily demonstrated that the rates of flow in the Trebiciano Cave must have been many times larger than the values computed in the reports$^{6,7}$.

The computations with assumed discharges in the Trebiciano Cave (400,000 m$^3$/day = 4,63 m$^3$/sec.) too low and the supposition that the N. Reka river was contributing only 500 l/sec. were the main causes of incorrect conclusions in the reports$^{6,7}$. Thus were brought to life again old and new hypotheses, that the underground flow of the Timavo draws waters from the Podgrad, the Čičarija and from other regions$^{7}$. Such hypotheses could not appear if a sounder hydrological analysis of the region had been worked out.

Fig. 4 - Discharges of the N. Reka river and of the observed springs during the 1962 tracing.

The abundant flow rates of the Rižana spring and the tracing test, already performed on the disappearing Odolina river by Timeus, indicate that the region of Materije belongs to the Rižana river basin. Likewise, special investigations and searching for an underground flow in the valleys of the Glinščica and the Osp rivers could be omitted. According to the theory of Professor Marussi$^{7}$, based on the study of some morphological features of terrain, which are regarded as a consequence of erosion of the “paleo” rivers, this underground flow ought to descend from the Čičarija region and be connected with the underground flow of the Timavo river. Such an imagined flow connexion, however, is not possible, because at high stage in the Trebiciano Cave the
water level rises for more than 100 m (fig. 5). Under such circumstances, in the valley of the Glinščica river, lying low above sea-level, springs would appear and ground would be flooded.

According to the results of the tracing in 1962, it can be assumed that the N. Reka river does have connexion with the Bagnoli spring (fig. 2—observation point 4), which is at variance with the results of previous tracings. Unfortunately, the sample taking did not start in time. The concentration level of the first samples (5.5 mpC), the comparison with the time variation of tracer concentration in the Trebiciano Cave, and the form of the regression curve of concentrations show that tracing matter appeared in this observation point. It is possible, of course, that only high waters of the N. Reka river flow over to the Bagnoli spring.

Fig. 5 — Schematic longitudinal profile of the N. Reka river from the place of disappearing to the Timavo springs Elevations above sea-level by Boegan (4).

The springs of the Osp river (fig. 2—observation point 5) and of the Rižana river (fig. 2—observation point 6) gave samples during the tracing in 1962 without any sign of tracer. The spring of the Osp river should be observed, nevertheless, in future tracing tests, especially in the case of high water stages in the N. Reka river.

In the Guardiella spring (fig. 2—observation point 7), which is supposed to get water directly from the local catchment area, no tracer was detected during the tracing in 1962.

In the springs at Nabrežina (fig. 2—observation point 8) the tracer appeared a few days later than in the main Timavo springs, in spite of the fact that the latter ones have an air-line distance from the point of injection 7.2 kilometres longer. Therefore, the time variation of concentrations and of levels of concentrations are more extended than is the case with the main Timavo springs.

In the three main Timavo springs (fig. 2—observation point 9) the concentrations appeared at the same time and passed away similarly in regular waves. The normal duration and form of the concentration waves of the main Timavo springs and of other observation points as well prove that no significant retention of waters running the regions of the N. Reka river and the underground Timavo takes place.
It is interesting to note that the samples taken from the Sardotsch spring (fig. 2—observation point 10), which feeds the water supply of Trieste, did not show any tracer. The Sardotsch spring seems, therefore, to get water from the Soča-Vipava groundwater basin and not from the N. Reka river, as considered up to the present.

It can be assumed, likewise, that the springs Moschenizze (fig. 2—observation point 11), Lisert (fig. 1—observation point 12), Comarie (fig. 1—observation point 14), and Dolenca (fig. 1—observation point 13) are not connected to the N. Reka river, but are fed by groundwater from the Soča-Vipava region, although very low concentrations in the samples were detected, showing steadily variations up to ±3 mµC as the natural background.

INVESTIGATIONS OF THE SOČA-VIPAVA GROUNDWATER AND ITS DRAINAGE TOWARDS THE TIMAVO SPRINGS

While the N. Reka river disappears visibly through the mighty Škocjan Caves into the Karst underground, the disappearance of the Soča and Vipava rivers is not visible. The study of the percolation of groundwater into the Karst is therefore a more difficult problem, because the places of disappearing are hidden.

The Soča river begins losing water, that percolates into the groundwater system, immediately after Gorica, whilst the Vipava river shows water losses from Dornberk downwards. The Soča-Vipava groundwater is also recharged by precipitation on its own catchment area. Only by special investigations could it be determined whether this groundwater system is also recharged by the headwater of the Soča river and/or by the deep Karst streams of the plateau Banjščica and Trnovski Gozd territory. The direction of flow of the groundwater and the altitude above sea-level of its water-table at low stage in the Miren region is proof of the diversion of the Soča-Vipava groundwater into the Timavo springs.

Fig. 6 — General plan of the Soča-Vipava groundwater with approximate water-table contours at low water stage.
In future more detailed research must be established in which places does groundwater percolate into the Karst, what is the percolating amount, and with which springs of the Timavo region particular underground streams communicate. With this intention some investigations have been made already. The Geological Institute in Ljubljana, for example, employed in 1962 a geo-electric method in order to establish directions of groundwater flow in Karst. For this purpose two profiles situated about 1 km south of Miren, along the contour line of 100 m were investigated (fig. 6, profile I-I and profile II-II) and by the method of apparent specific resistivity zones of low and high resistivity were determined. Resistivity in the profile II-II was on the whole very low. In the profile I-I, at the point of the lowest specific resistivity, indicating supposedly a possible water flow, an 80 m deep hole was drilled by the Geological Institute (fig. 6—point M 1). In this borehole, penetrating fractured and porous limestone, no water was found at the time of drilling; on the contrary, between the depths from 63.9 to 80 m, drilling water was disappearing. In the borehole M 1 water appeared in periods of rainfall and rises very high, but at low-water stage it disappears through the bottom of the borehole, which lies 16.25 m above sea-level. Regrettably, the borehole is not deep enough to permit determination of the lowest level of the Karstic subsurface water at this point.

In the borehole M 2, made by the Geological Institute on the left bank of the Vipava river (fig. 6-7, point M 2), water appeared in the depth of 17 m, that is on the boundary between the Quaternary deposits and the limestone strata. In the 50 m deep borehole M 2, which had been chosen as a point of injection for the intended tracing test, the Bundesversuchs und Forschungsanstalt Arsenal, Wien, tried to establish flow direction and velocity of the groundwater by the method of dilution of the injected tracing substance, but no satisfactory results were obtained. These experiments would have had more success if they had been directed by hydrological criteria and if the already available hydrological informations on this region had been consulted.

The groundwater of the Soča-Vipava region does not flow into the Karst frontally through one or more trenches following the direction and remaining on the level, which is characteristic for this groundwater as long as it is mowing through the deep

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**Fig. 7 — Schematic longitudinal profile of the subsurface flow of the Soča-Vipava groundwater from the Miren region to the Timavo springs.**

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waterbearing gravel layer. On the contrary, the groundwater is percolating into the fractured and porous limestone in many places, at different altitudes, and in different geological and hydrological situations of its large swallowing zone. That explains why the water table in such a zone cannot be shown by a contour map.

In the swallowing zone of Miren, south of the Vipava river, along the reach from the village Vrtoče to the State border, there are numerous wells for local water supply. (fig. 6) The fluctuation of the water level in these wells (fig. 8), their specific yield and the chemical properties of water indicate a variety of origins of the groundwater in this region. Some of the wells are recharged from the Karst only, that is from the opposite southern direction (fig. 6 and 8, wells X, N, VI), in others, however, groundwater of the Soča-Vipava region prevails. In some of these latter wells, dependent on the actual hydrological situation, water is mixed more or less with water flowing from the Karst. In view of the large and fast water level oscillations in the wells X and P as in the borehole M1 as well, one can conclude that this water has weak outflow and insufficient connexion with the main drainage arteries. In spite of the low permeability of the terrain, the well P and especially the borehole M1 may have connexions with deep-lying drainage arteries, which is inferred from the lowest water stages attained here.

![Fig. 8 — Water levels and hardness of the ground water in the wells of Miren-region south of the Vipava river.](image)

In the water flowing only from the Karst (the well N) the hardness rises when the water stage is receding; in the wells recharged mainly from the groundwater of the Soča-Vipava basin, however, the hardness is falling when the inflow from the Karst is diminishing (fig. 6 and 8). Analyses of chemical and other properties of water can be very helpful if they are conducted in connexion with other hydrological research.

Even the most recent interesting research of the Timavo origins by Professor Tongiorgio in Pisa, who is analysing and characterizing samples of water taken in different places of the Timavo hydrographic system, by the structure of the atomic nucleus of oxygen cannot give quantitative results by itself and requires a parallel basic hydrological research.

As was shown for the Soča-Vipava groundwater, the origin and the properties of water are changing very fast. Taking samples for water quality analyses demands, therefore, that not only the profile but also the point of sampling be examined critically.

For the determination of flow quantities an adequate flow measuring service should be organized first and charged with the task to establish the amounts of water seeping
from the rivers Soča and Vipava and percolating as groundwater into the Karst, as well as the amounts of water discharged by springs in the Timavo region, the origin of which is still uncertain. The lowest discharge of the main Timavo springs was estimated in papers published to the present to be 10 m³/sec. In view of this lowest discharge the contribution of the Soča river would be proportionally large. In accordance with later estimates that the main Timavo springs discharged only one half of that quantity, 5 m³/sec., approximately, at low stage attained in October 1962, the contribution from the Soča basin would be proportionally smaller. For the Moschenizze springs, which discharge relatively large amounts at low stage, and could therefore be taken into consideration for the solving of water supply problems, there are no usable data on characteristic flow quantities at our disposal.

On the other hand, the water losses of the Soča and Vipava rivers must be determined by simultaneous flow measurements. These losses, being dependent on the piezometric level of the water table, can be different even at the same river stage. Simultaneous flow measurements on the Vipava river show losses up to 1.0 m³/sec. (fig. 9).

Fig. 9 — Lines showing discharge distribution along the Vipava river as established by simultaneous flow measurements.

Analysing the results of simultaneous flow measurements we have to be careful and take into account the accuracy of such measurements, the variations of the water stages and of the water surface slope, etc. The results of more detailed and co-ordinated hydrological investigations of the Soča-Vipava groundwater system (water table elevations, direction and velocity of flow, discharge) covering the entire pertinent Yugoslav-Italian territory, will by themselves solve the question of the groundwater percolation into the Karst. These results will also be necessary for future tracings of the underground flow connexions.

From previous research of the groundwater it can be deduced that the main amounts of water lost by the Soča river on Italian territory percolate into the Karst. Large outflow apparently occurs at the well 31 (fig. 6) and in some places downstream from the Vipava river mouth. The circumstance, that the groundwater flowing from the Karst has in some places along the left bank of the Soča river its water table at a higher level than the level of the Soča river stage does not exclude the possibility of groundwater
percolation into the Karst either at another depth or in another place nearby under specific local outflow conditions.

On Yugoslav territories, the well II (fig. 6) and the adjoining wells reveal best the character of the Soča-Vipava groundwater. They have large yields, and it would be advisable therefore to seek here a location for boreholes that would serve as injecting points for possible tracing of underground connexions. Injecting the tracer directly into the Vipava or Soča rivers would cause loss of great quantities of the tracing substance, but it would not establish through which swallow holes the tracer comes into the Timavo springs.

The hydrological research of the complicated hydro-system of the Timavo springs will be more successful if we get a clear insight into all hydrological problems of the Timavo basin which were in this report but briefly stated, due to limited space, and if we start with extensive and systematic research co-ordinated perfectly on both sides of the Yugoslav-Italian border.

REFERENCES