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SURFACE WATER AND GROUNDWATER IN THE BASIN OF THE GULP CREEK – SOME MAJOR CHARACTERISTICS[1]

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ABSTRACT

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Within the framework of a training project for students from the Agricultural University in Wageningen, hydrogeological studies have been undertaken in the valley of the Gulp creek in the SE part of The Netherlands.

This report deals with the chemical characteristics of natural surface and groundwater; the analytical data cover a 4-years period of sampling. The water composition is studied not only to determine the overall chemical character of the water; the data of the water-analyses are primarily used as a tool to investigate the relation among basin geology and the groundwater and surface water regimes as a sequential dynamic unity.

The water bearing sequence in the Gulp Basin is not homogeneous, but a multiple layer aquifer composed of a Mesozoic series of fine grained sands, silty clays and limestones overlying the Palaeozoic bedrock. Generally, the surface water and groundwater are of the calcium-bicarbonate type. Differences found for samples from wells are related to the geological formations. Surface water samples show seasonal variations of the dissolved solid species that are related to the varying contributions of base flow and subsurface flow to the total discharge; the period of drought in 1975 and 1976 is also reflected.

INTRODUCTION

The Gulp Basin is one of the stream networks that drain the dissected plateau landscape in the southeastern part of The Netherlands. The study area is situated near the northern margin of the Ardennes uplands, where the Hercynian fold belt dips into the subsoil underneath a subhorizontal cover that consists of mainly Upper Cretaceous deposits. The consolidated folded rocks of Palaeozoic age that underlie the basin generally are interbedded fine grained sandstones and shales and are considered to form the base of the flow system in the overlying formations.

The geological framework of the Gulp basin and surroundings (cf. Figs. 1 and 2) and the properties of the Gulp catchment in relation to the passage of water through it have been discussed in two earlier reports to which reference is recommended. (NOTA & VAN DE WEERD, 1978, 1980).

This paper discusses some major characteristics of the chemical composition of natural water in the basin and precedes a more comprehensive treatment (cf. NOTA & BAKKER, in preparation). The data presented are based mainly on observations in the southernmost part of the Gulp catchment just across the Belgian-Dutch border, where most of the instrumentation has been installed. The study area comprises the upper reaches of the basin and includes a surface area of about 730 ha, while the total surface area of the basin is about 4600 ha. The average discharge in the upper reach measured at gauging station F6 near Hombourg amounts to 40 l/sec, the average discharge of the total catchment area, measured at F11 in the village of Gulpen, not far from the point where the Gulp creek joins as a tributary the river Geul, is about 350 l/sec.

The catchment begins as a dry valley at about 357 m, above sea level and carries surface water from around 285 m where groundwater discharges slowly over some area rather than from a definite localized source. The cross profile of the valley is asymmetrical (cf. Fig. 2). The steepness of the eastern slope amounts to about 17%, while the more gentle western slope averages 5%. Permanent pasture covers 90% of the area.

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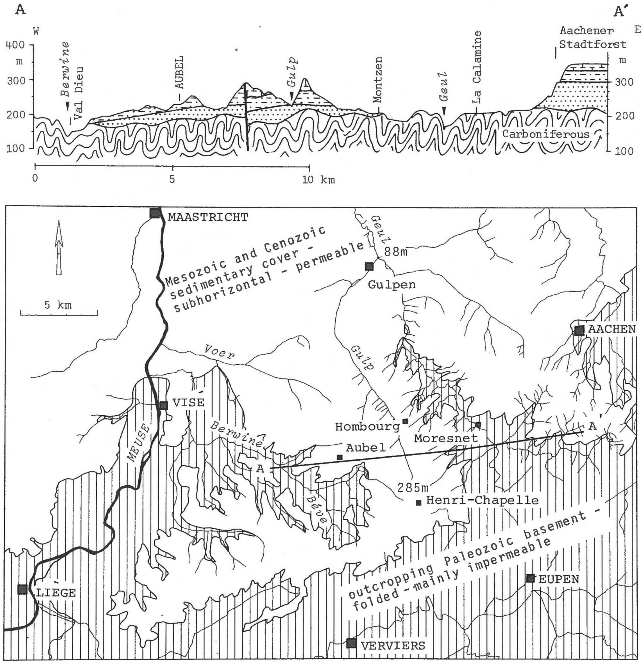

Fig. 1
Geological framework of the Gulp Basin and surroundings. For stratigraphic legend cf. figure 2.

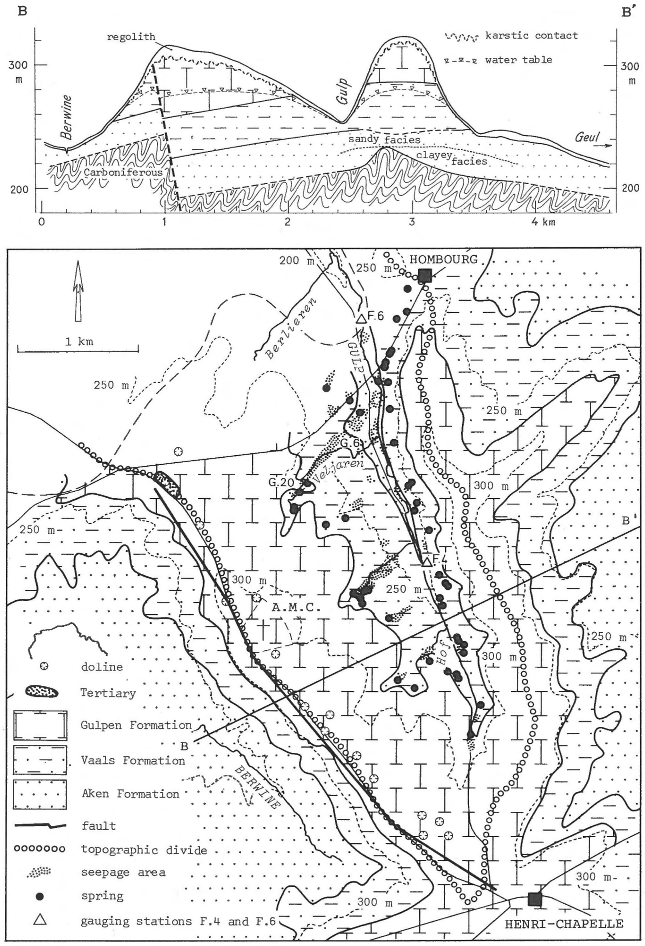

Fig. 2
Map and cross-section to show the general hydrogeological conditions in the southernmost part of the Gulp Basin; open circles represent dolines.

Precipitation is measured with a pluviograph and samples of surface water and of groundwater are regularly collected at key locations for chemical analysis. The samples discussed in this report were collected between October 1st 1975 and September 30th 1979. The groundwater samples have been obtained mainly from domestic dug wells with diameters usually of approximately 80 cm. Depth to groundwater varies from some 3 to 40 m. The shallow wells are located on the valley slopes, the deeper wells on the plateaus.

Continuous records of the surface water discharge and groundwater level fluctuations are gathered at selected sites in order to find out the behaviour of the hydrogeologic system. Precipitation and temperature data for the hydrogeologic field station at Hombourg have been given in previous reports.

LITHOLOGY

The Upper Cretaceous sequence that immediately overlies the Palaeozoic bedrock forms the greater part of the framework through which groundwater moves from its recharge area on the plateau towards the discharge zones in the valley.

To evaluate the relationship between the water chemistry and the lithology in the catchment, a number of selected rock samples have been analysed for their mineralogical and chemical characteristics using X-ray diffraction and fluorescence techniques.

Stratigraphically the Upper Cretaceous sequence can be subdivided into the Aken, Vaals and Gulpen formations, respectively (cf. Fig. 2).

The *Aken Formation* consists of non-indurated clays and silty clays in the lower part of the series and of light coloured fine grained well sorted quartz sands (Md values between 150-200 μm) in the upper part; the Aken sands consist of some 97% of quartz and are about 35 m thick.

The *Vaals Formation*, overlying the Aken Formation, is about 40 m thick. Generally it consists of silty clays and clayey silt with glauconite; at certain levels the clayey facies is interbedded with consolidated fine grained sandstone layers (10-20 cm) that are fractured. In this sequence quartz and clay minerals are predominant while calcite and pyrite are accessories. The coarser fractions consist mainly of quartz with glauconite, feldspar, muscovite and some calcite. The clay fraction is mainly montmorillonite with mica (glauconite and illite). The consolidated sandstone layers are cemented with silica, while calcite and pyrite are lacking.

The *Gulpen Formation* is a light coloured fine grained fairly homogeneous chalk with joints and fissures in places; its thickness measures approximately 40 m. The chalk consists for nearly 90% of calcite and the remaining 10% is largely quartz with some potash feldspar and glauconite. The limestone is soft and poorly bedded and silifications are rare.

The *regolith* overlying the various geological formations discussed above forms a blanket of variable thickness. It usually is less than 2 m thick on the steeper eastern slope and thicker on the more gentle western slope. The composition of the regolith varies greatly from place to place; in most cases it is composed of an admixture of chert nodules, clay size material and loess. The compositional relationship with the underlying formations can be recognized in most cases. The clay fraction from samples from the plateau shows an abundance of kaolinite with mica and chlorite, while samples down the slope are characterized by a predominance of montmorillonite; the coarser fractions contain chert fragments, potash feldspar, glauconite, mica, and calcite and pyrite at some places. Measurements have shown that the regolith is sufficiently permeable to permit infiltration. The saturated vertical permeability for the upper 50 cm was found to range between approximately 0.50 and 4.00 m/day, being dependent to a large degree upon the frequency of the bioturbations.

In a limestone terrain such as this, with a regional 1-2 degree northwesterly dip of the geological formations, problems exist in defining catchment boundaries. Interbasin flow is a major factor and a substantial groundwater loss occurs along a fault zone, that practically coincides with the southwestern edge of the catchment (cf. Fig. 2); on the other hand, there is no indication of any substantial groundwater contribution from outside the basin. The gross lithology is favourable for local recharge and precipitation is presumed to be the only source of the water that is eventually discharged into the valley.

WATER CHEMISTRY

The water samples were analysed for calcium, magnesium, sodium, potassium, bicarbonate, carbonate, sulfate and chloride. Non-ionized silica (H_4SiO_4), the pH and the specific conductance were also determined.

The annual precipitation upon the catchment averages some 800 mm. Total dissolved solids in the precipitation average some 16 ppm and vary from 6 to 41 ppm (cf. Table I). Sulfate and bicarbonate are the major anions measured, calcium is the principal cation. The pH varies from 3.7 to 6.9 and averages 4.7. The groundwater samples from the catchment generally contain between 300 and 600 ppm total dissolved solids; the surface water samples average some 500 ppm; pH values for groundwater range between approximately 6.1 and 7.5, for surface water between 7.5 and 8.1; calcium and bicarbonate are the dominant ions. Concentrations of the total dissolved solids vary with time and location in the flow system; total dissolved solids reported are the sum of the constituents analyzed.

The dissolved constituents in groundwater and its chemical type depend on the material through which the water passes and on the length of time the water is in contact with these materials. The chemical type of groundwater, at each point in the flow system of a multiple layer aquifer – as occurs in the study area – is a function of the chemical composition of the matrix rocks and of the antecedent water quality. Over and above that, the compositional relationship between the groundwater and surface water in a given catchment is controlled by the flow pattern by which groundwater is distributed, is discharged and eventually is mixed with other flow sources. These basic principles can be recognized in the diagrams represented in figures 3, 4 and 5. During the 4 years period of sampling some 600 samples of surface water and groundwater have been analyzed. The results of the analyses (cf. Figs. 3, 4 and 5) are given either in millimoles per litre or in milligrams per litre (ppm). In the trilinear diagrams the relationships among the major cations (calcium, magnesium and sodium + potassium) are given as percentages of total millimoles per litre in the left triangle; in the right triangle similarly major anions (bicarbonate + carbonate, sulfate and chloride) are given; each analysis is represented by one point on the triangular field. The diagrams in figure 3 show the relative amounts of the major dissolved constituents in groundwater, spring water and surface water.

The chemical composition of the *groundwater* samples shows that generally the water in the catchment is of the

Table I
Average dissolved constituents in water samples from the Gulp Basin (ppm.)

	Ca	Mg	Na+K	HCO_3+ CO_3	SO_4	Cl	H_4SiO_4	pH	T.D.S.	No. of samples
Groundwater Gulpen Formation	133	2	7	315	29	24	34	6.7-7.5	544	140
Groundwater Vaals Formation	74	6	21	121	71	29	32	6.1-7.1	354	70
Groundwater Aken Formation	62	4	14	98	51	27	30	6.1	286	35
Water from springs	118	2	6	313	28	16	39	6.9-7.1	522	190
Surface water	114	3	12	289	45	17	31	7.5-8.1	511	190
Precipitation	1.1	0.1	0.6	1.3	6.2	1.1	—	3.7-6.9	16.6	241

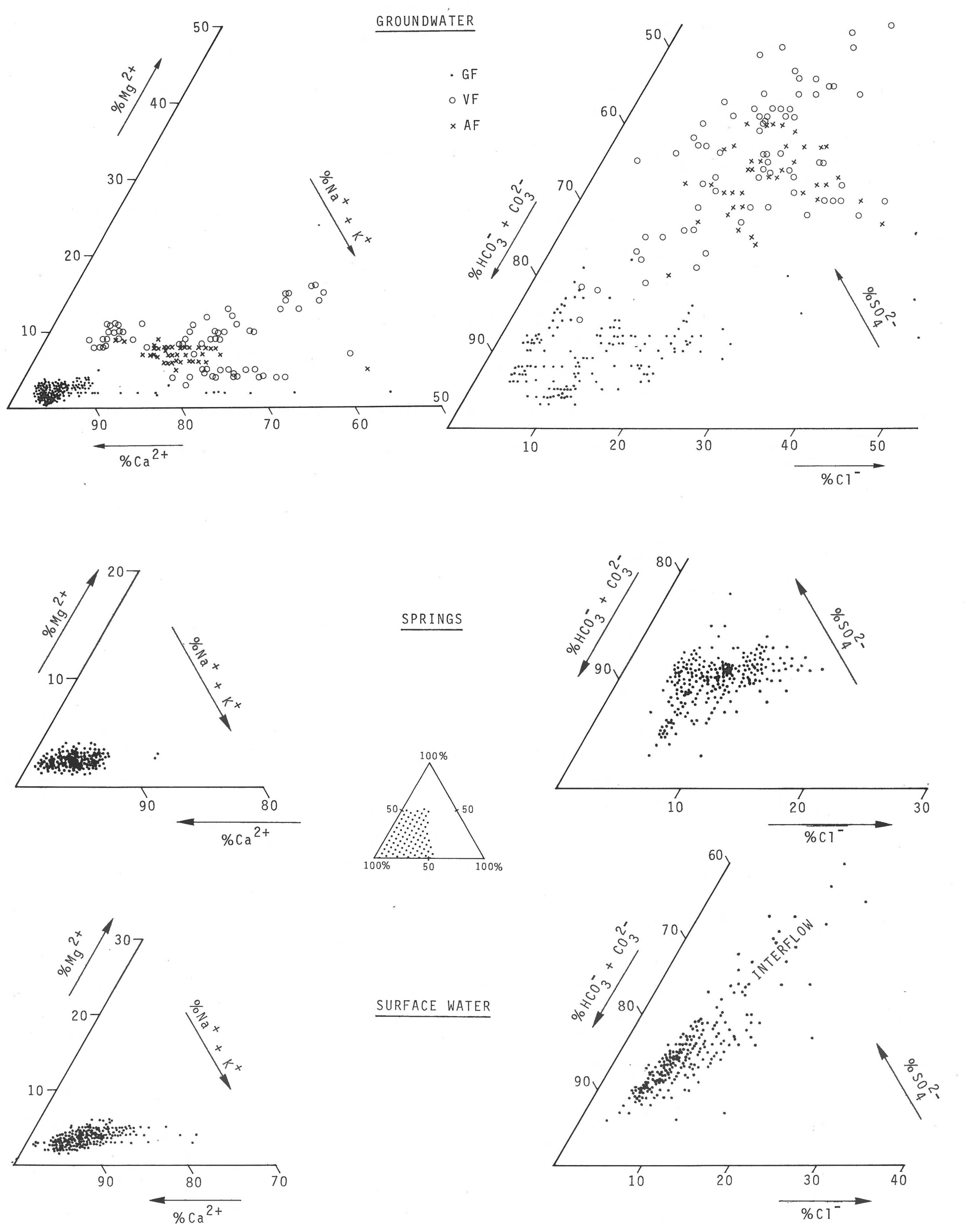

Fig. 3
Trilinear diagrams to show the relative amounts of the major dissolved constituents in groundwater, spring water and surface water; see text.
GF = Gulpen Formation; VF = Vaals Formation; AF = Aken Formation.

calcium-bicarbonate type. The spread in the relative amounts of the different cations and anions is related to the location of the water wells in different geological formations. As pointed out previously the Upper Cretaceous sequence through which groundwater moves is not homogeneous but composed of geological formations with different lithologies, viz. the chalk from the Gulpen Formation, the clayey silts and silty clays with glauconite and some pyrite of the Vaals Formation and the fine grained well sorted quartz sands of the Aken Formation respectively.

The water samples from the *Gulpen Formation* (GF) show a fairly limited spread in their chemistry and are typical calcium bicarbonate waters. The calcium concentrations average 130 ppm, the bicarbonate content averages some 310 milligrams per litre; typical chalk waters contain about 15 to 30 ppm sulfate (cf. Table I). The wells in the Gulpen Formation are located on the high land and their depths vary usually between 20 and 40 m.

The waters from the underlying *Vaals Formation* (VF) with their wells successively downslope from those of the Gulpen Formation show trends away from the calcium and bicarbonate corners,toward the sodium + potassium and sulfate corners respectively; calcium remains dominant,however, but sulfate mostly varies here between 40 and 60%. The calcium concentrations average 75 ppm, the bicarbonate content is about 120 ppm while the sulfate content averages some 70 ppm; the sulfate concentrations have been found to vary widely in some of the wells however (cf. Fig. 4). The wells are shallow and rarely exceed 5 m. The relative amounts of the major dissolved constituents in water samples from the *Aken Formation* (AF) show plots that are more or less intermediate between those of the Gulpen and Vaals Formation. The concentrations for the various dissolved solid species are lower as compared to those from the overlying Vaals and Gulpen formations; the calcium content averages 60 ppm, the bicarbonate content is about 100 ppm and the sulfate content occurs in concentrations that average 50 ppm. The wells are shallow and here again rarely exceed depths of more than 5 m.

Summing up the chemical composition of the *groundwater samples* it can be concluded that (1) the differences between the water types reflect a tendency towards equilibrium with the distinguished geological formations, that (2) owing to the absence of dividing impermeable clay horizons of large extent the waters are interconnected so that transitions between the water types exist; that (3) the particularly soluble chalk of the overlying Gulpen Formation causes a massive contribution of calcium and bicarbonate so that these chemical components of higher solubility will be found in abundance throughout the whole water bearing Upper Cretaceous sequence; that (4) differences in well depth and the location on the valley slope account for a greater variation in chemical composition for the waters from wells within the Vaals and Aken formations as compared to those of the Gulpen Formation.

A comparison between the chemical composition of *surface water* samples and samples of *springs* (cf. Table I and Figs. 4 and 5) reveals a striking relationship. This feature is supported by the fact that baseflow comprises approximately 70% of the total discharge in the catchment.

The analysis of the spring waters clearly shows that they originate mainly from the drainage of the chalk waters of the Gulpen Formation; the concentrations for calcium amount to 120 ppm, for bicarbonate to 310 ppm, while the sulfate content is around 25 ppm. A comparison of the individual analyses of surface water samples reveals that the samples with *higher sulfate concentrations have been obtained during the wet season when subsurface runoff* (cf. KIRKBY, 1979) *is an important flow route* followed by water passing through the basin (see below); in times of base flow only, the overall chemical composition of the surface water is very much alike to the chemistry of the chalk waters.

Groundwater outflow occurs through springs and seepages near the permeability break between the Gulpen and Vaals formations, but also through fractured consolidated sandstones that are intercalated between low permeable silty clays of the Vaals Formation. It is significant that from both spring and seepage locations typical chalk waters are discharged. The study of the water chemistry in the Gulp drainage basin thus reveals *that baseflow of the Gulp creek is largely sustained by the drainage of the chalk of the Gulpen Formation.* Apparently the groundwater circulation within the Vaals Formation is too sluggish to play a very active part in the hydrological cycle in the catchment; the intercalated fractured sandstones merely act as passageways to transmit chalk water. *It is obvious, that the drain function of the fractured sandstones is of great practical importance for the groundwater development,* viz. *locating of water wells.* The surface extent of the Aken Formation in the study area is very limited and hence its contribution to the baseflow is only of local importance (cf. Fig. 4, F6; see also NOTA & BAKKER, in preparation).

The predominance of the calcium bicarbonate waters during baseflow conditions is thus explained.

There is a variety of flow routes which may be followed by water passing through a particular basin. Hydrographs of outflow from the catchment have shown that the total runoff consists of a superposition of relatively short peaks due to a fast response to precipitation upon a delayed and slowly changing groundwater discharge (cf. Fig. 5). Some hydrologists thus make a meaningful distinction between quickflow and delayed flow though there is really a continuum of flow types through the unsaturated zone and through groundwater. In particular due to the pronounced relief in the study area it can be expected *that subsurface runoff on the hillslopes will be a determining factor.* This suggestion is verified by a number of observations in the study area. First, frequent fluctuations of the groundwater level have been ascertained with the aid of float recorders that are installed in wells on the valley slopes; quick responses after rainfall with fluctuations of low amplitude and of relatively short duration are considered to reflect the passage of water that moves downslope as

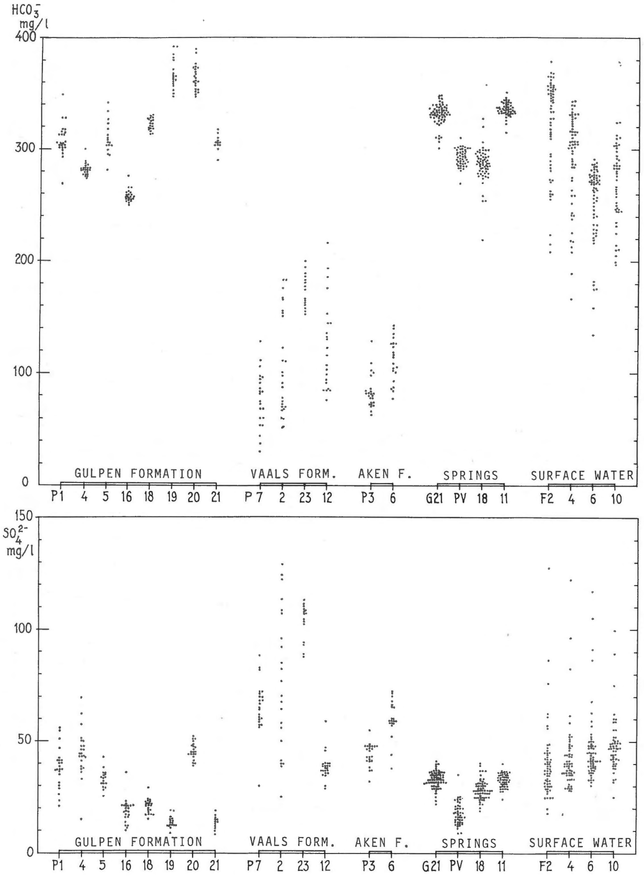

Fig. 4
Diagram to show bicarbonate and sulfate concentrations (in milligrams per litre) for groundwater, spring water and surface water.

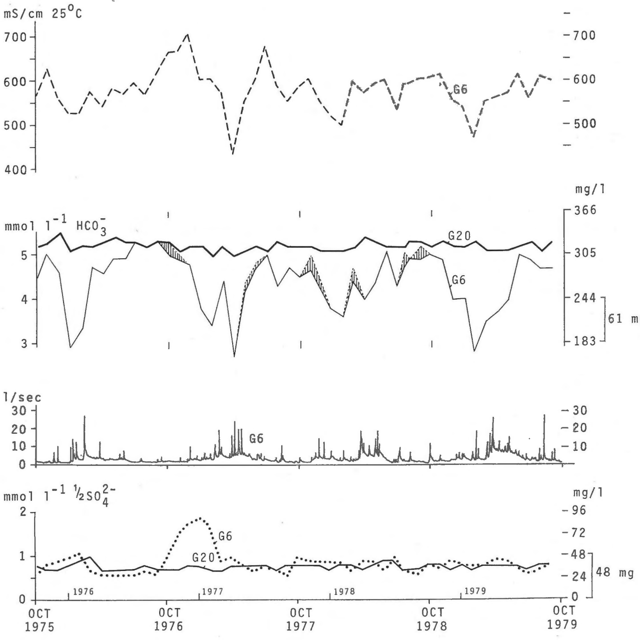

Fig. 5
Seasonal variations in discharge (at gauging station G6) and in concentrations of bicarbonate and sulfate for spring water (G20) and surface water (at station G6). Hatched areas indicate carbonate concentrations. Concentration of ions is given in millimoles and in milligrams per litre; specific conductance in mS/cm at 25°C. For location see figure 2.

throughflow and interflow. Second, the variations in the chemical composition of individual samples from water wells in the Vaals (and Aken) Formation located on the valley slopes were found to be much more pronounced than the variations that were observed in samples from the Gulpen Formation (cf. Fig. 4); here again subsurface flow is considered to be a determining factor; *it is noticeable that the variations are nearly as large as those from surface water samples.*

Finally, a striking effect is illustrated in figure 5, which shows the results of measurements carried out in the Veljaren tributary valley (cf. Fig. 2). The data of figure 5 are largely self explanatory but a few comments may be given. G20 represents one of the springs that feed the Veljaren tributary; the discharge of the tributary stream is continuously recorded at station G6; the hydrograph from station G6 is represented as well as some chemical parameters of G6 and G20. The nearly constant chemical composition of the spring water contrasts clearly with the strongly varying surface water and the seasonal variations are well recognizable. During the wet season bicarbonate concentrations of G6 show a decrease; they represent the contribution of the chalk waters. The sulfate concentration shows generally a slight increase during higher discharges due to increased subsurface runoff through the regolith and the underlying pyritiferous Vaals Formation. A conspicious increase in the sulfate concentration was measured during the wet season between October 1976 and March 1977 after an exceptional period of drought. There are two sources for the supply of sulfate. Sulfate is the major dissolved constituent in (polluted) atmospheric precipitation and it is also produced from the solution of sulfides in the pyritiferous sediments of the Vaals Formation (see Table I). Sulfate brought in precipitation in the study area was found to range usually between 2 and 12 ppm, averages 6 ppm (cf. Table I) and showed a maximum of 23 ppm (number of samples 241). The period of drought in 1975 and 1976 will have produced through evaporation an unusual increase of the concentration of the solutes, particularly in the zone of groundwater outflow near the permeability break. As another result of the drought the decline of the groundwater table must have caused an increase of sulfate production from the oxidation of pyrite. Under normal humid conditions in the area, the soluble products are removed regularly, because the amount of water available is large in proportion to the supply of solutes. Altogether, during the wet season that followed after the period of drought the sulfates were being flushed out and thus contributed subsurface runoff water, rich in sulfates, to the stream. A maximum sulfate concentration of 128 ppm was found in January 1977 in another tributary valley, the socalled Hofdal (cf. Fig. 2). After a relatively short period the anomalous sulfate accumulation was carried away and adjusted already before the wet season was over.

The above clearly illustrates the possibility to distinguish the separate flow sources of surface water passing through the catchment: *briefly, (polluted) sulfate waters of hillslope origin are superposed upon (natural) bicarbonate baseflow waters* (cf. Fig. 3).

SUMMARY AND CONCLUSIONS

The study of the chemical characteristics of natural water in the Gulp Basin was found very helpful to define the following conclusions on the interrelationship between basin geology and the dynamics of the groundwater and surface water regimes.

1) The baseflow which comprises approximately 70% of the total discharge of the Gulp stream is largely sustained by the drainage of the chalk waters from the Gulpen Formation; the groundwater circulation within the silty clays of the Vaals Formation is too sluggish to contribute substantially to the stream.
2) The groundwater circulation is mainly through the chalk, because it is underlain by low permeable silty clays; the pronounced relief, with relatively deep incised valleys, and the position of the permeability break well above river level have created favourable conditions for the effective drainage of the chalk waters.
3) *There are two separate preferential flow routes through which the chalk waters are being discharged:* through springs and seepages in the zone of the permeability break, and through fractured sandstones interbedded in the Vaals Formation.
4) The groundwater circulation through the chalk is relatively rapid, as is evidenced by radio-isotope determinations; the residence time of the groundwater is estimated to be in the order of some 10 years (W. G. MOOK, personal communication); it is noticeable that the discharged waters are mixed waters of different isotopic ages: from rapid moving water through interconnected fissures and slow moving intergranular water.
5) The study of the chemical composition of natural surface and groundwater has enabled to identify the different flow sources and to understand the seasonal variations of the dissolved solid species.
6) *Subsurface runoff, viz. interflow, along the valley slopes has been recognized as a marked phenomenon in the study area;* it effects the complex composition of the surface water.
7) In passing through the catchment the water carries calcium and bicarbonate as the major ions; between 400 and 600 tons of calcium carbonate are removed every year from the study area (730 ha); erosive effects of groundwater solution are well expressed by the occurrence of a series of dolines, and result in an ultimate lowering of the relief. Precipitation contributes not more than 5% of the calcium and bicarbonate material in stream water leaving the catchment.

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