FACTORS AFFECTING WATER QUALITY OF SMALL MOUNTAIN CATCHMENTS

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ABSTRACT

Five small catchments in the north-eastern Prealps of Switzerland were investigated for variations of stream water chemistry during the years 1967 and 1968 using the stepwise multiple-regression technique. Concentrations of magnesium, potassium, silica, sulphate, chloride, nitrate, ammonium and pH value show little variation. Measurements of electrical conductivity, total hardness, and calcium, carbonate, and sodium concentrations indicate considerable variation.

Discharge rate is found to account in three of the five streams for 80% or more of the variation of the five chemical components. However, the compound effect of discharge, water temperature and a factor estimating seasonal change of soil moisture conditions accounts in all five catchments for 71% to 95% of the variation. Differences between streams seem to be due to differences in vegetation cover and soil conditions of the respective catchments.

INTRODUCTION

The quality of water resources is becoming increasingly important. Climate, geology, topography as well as vegetation cover, soil, and land use conditions are the main groups of factors affecting the quality of water discharged by small mountain streams. Under given geological and climatic conditions water quality varies with time and location. In a small region of nearly uniform climate and geology in the north-eastern Prealps of Switzerland, five streams and their catchments are investigated for factors affecting the variability of stream water chemistry (Keller, 1970). Biological factors of water quality as well as sediment transport are excepted.

The study area is situated in the north-eastern Prealps of Switzerland at a latitude of 47°04′ north and a longitude of 8°43′ east. The topographic situation is given in Figure 1. Annual precipitation is about 2,000 mm. During the winter months (October through April) about 70% of the approximately 800 mm of precipitation falls as snow. The remaining summer precipitation (May through September) includes a number of thunderstorms. Elevations

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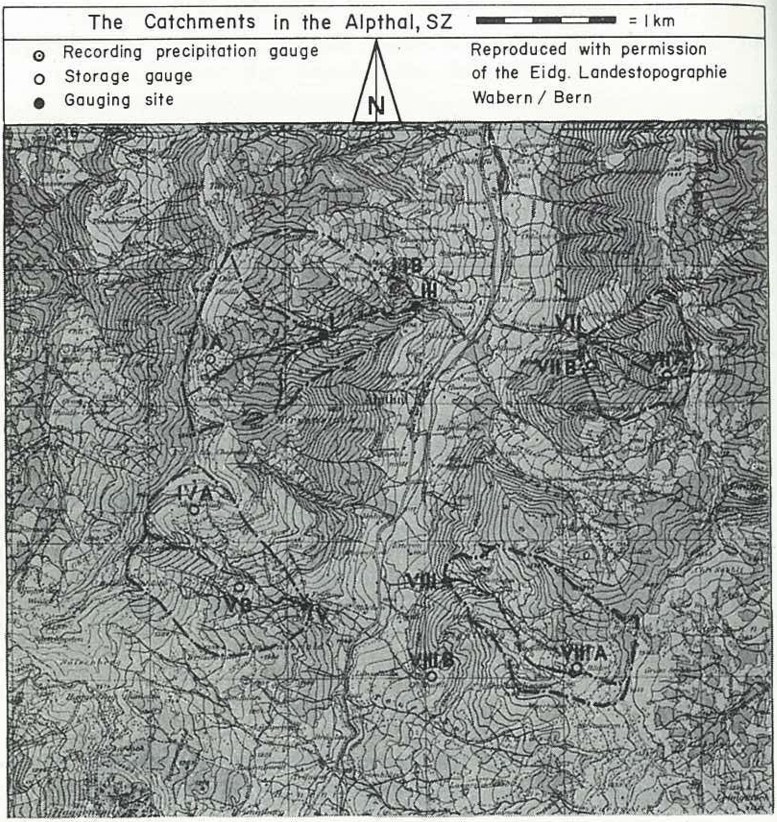

FIG. 1 — Topographic situation of study area.

range from 1,100 to 1,550 m above sea level, with a mean annual air temperature of about 5.0°C. The hydrology of the area is characterized by about 4 months of winter low flow (December–March), the melt season April–May, and the very changeable flows during the summer and autumn months (June–November) with occasional one- or two-week low-flow periods.

THE CATCHMENTS

All five study streams are branches of the Alp River (Figure 1), near Einsiedeln. In Table 1 the main catchment characteristics are summarized.

Agricultural land use concentrates on cattle pasture during 3–4 months in summer on partly improved pasture land. The forests

TABLE 1 — Characteristics of 5 small catchments in the Alpthal, Switzerland.

	Catchment				
	I *Vogelwald*	*III* *Vogelwald*	*V* *Frifang*	*VII* *Gämsch*	*VIII* *Etteren*
Area (km^2)	0.72	1.55	1.08	0.52	0.94
Mean elevation (m)	1405	1365	1340	1360	1360
Mean slope (%)	38	44	39	65	37
Mean channel slope (%)	24	22	29	46	23
Exposure	ENE	ESE	E	WNW	WNW
Forest cover (%)	56	63	38	93	60
Pasture (%)	7	12	42	3	–
Swampy area (%)	37	25	20	4	40

are managed on a sustained-yield basis and no clearcut is allowed. Most of the swamp lands are now no longer used for harvesting straw.

Layers of calcareous sandstones alternating with argillite and silt schists form the so-called Flysch formations of very low permeability (Frei, 1963; Jaeckli, 1967). Soils are imperfectly drained. Humus horizons of variable depth (10–50 cm) lie on fine-textured mineral horizons of generally low permeability. Soil water storage is relatively low resulting in frequent flood flows consequent to intensive rainstorms. All five streams are of torrential nature.

METHODS

In 1967 and 1968 water samples were taken once a week from all five streams for chemical analysis of the following components: pH, electrical conductivity (at 20°C), total hardness, calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), ammonium (NH_4), silica (SiO_2), carbonate (CO_3), sulphate (SO_4), nitrate (NO_3), and chloride (Cl). At the time of sampling discharge was determined with the salt-dilution method using sodium dichromate (Dumas, 1952; Dodero, 1953; British Standards Institute, 1964). Air and water temperature were also taken at the gauging sites at time of sampling.

Statistical analysis consisted of computing means and variances for all components. For components with considerable variation in time and location, a stepwise multiple regression was done with discharge rate, season factor, and water temperature as independent variables.

RESULTS

Average values and standard deviations (s) of 13 chemical components in the five stream waters are given in Table 2.

TABLE 2 — Average values and standard deviation (s) of 13 chemical components in stream waters of 5 catchments in the Alpthal, in 1967/68.

	Catchment I		III		V		VII		VIII*	
	Av.	*s*	*Av.*	*s*	*Av.*	*s*	*Av.*	*s*	*Av.*	*s*
pH	8.1	0.2	8.1	0.2	8.1	0.2	8.0	0.2	8.0	0.1
conductivity (μmhos/cm)	176	45	176	51	242	47	263	38	190	50
total hardness (mg $CaCO_3$/l)	0.96	0.24	0.97	0.27	1.36	0.25	1.47	0.18	1.02	0.27
Ca (mg/l)	34.9	8.9	38.0	10.3	51.8	8.8	53.8	6.9	37.6	10.0
Mg (mg/l)	2.1	1.0	2.2	0.9	3.0	1.4	3.4	1.2	2.4	0.9
K (mg/l)	0.6	0.2	0.5	0.2	0.7	0.3	0.8	0.3	0.7	0.3
Na (mg/l)	1.7	0.7	1.6	0.7	1.9	0.7	2.2	0.6	2.4	1.0
SiO_2 (mg/l)	3.1	0.5	2.9	0.5	3.2	0.7	3.2	0.6	3.0	0.4
NH_4 (mg N/l)	0.05	0.05	0.04	0.05	0.03	0.03	0.02	0.02	0.05	0.05
NO_3 (mg N/l)	0.15	0.06	0.16	0.06	0.23	0.08	0.20	0.09	0.14	0.06
CO_3 (mg/l)	53.5	13.9	58.1	15.9	78.7	13.9	82.1	10.5	58.2	16.5
SO_4 (mg/l)	5.0	3.0	6.1	3.7	7.6	2.9	10.3	3.5	n.m.	
Cl (mg/l)	0.7	0.3	0.6	0.2	0.6	0.3	0.6	0.3	n.m.	

* only data 1968; few sulphate and chloride determinations.

Obviously, a few components show very little variation and are therefore not considered for further regression analysis; these are pH, Mg, K, SiO_2, SO_4, and Cl. Mean values of these concentrations may therefore be considered representative for the chemistry of the streams in the region. Nitrogen compounds seem to vary between streams even though total nitrogen is about equal in all five streams. Relatively low concentrations of ammonium are found in catchments V and VII. Nitrate concentrations in the same streams are relatively high. Streams I, III and VIII, however, show relatively high ammonium and low nitrate concentrations. It is suggested that these differences are due to the amount of swampy land in the catchments. Nitrification in soils with high water table (swamps) is not complete and therefore more ammonium is found in these streams than from catchments with few swamps (Table 1).

The remaining components with considerable variation were tested with multiple-regression analysis: electrical conductivity, total hardness, Ca, CO_3, and Na. The regressions were calculated using the model.

$$y = a + b_1 \ln Q + b_2 S + b_3 T \qquad (1)$$

where y is the chemical component (concentration in mg/l), Q is specific discharge in l sec^{-1} km^{-2}, S is a season factor, T is water temperature of the stream at the time of sampling (in °C), a is the regression constant, and b_1, b_2, b_3 are regression coefficients. The season factor (S) was used to estimate soil moisture conditions during the course of the year. With onset of snowmelt (mean date of 16 years is 19 March) recharge of soil moisture is assumed to begin. Maximum soil moisture storage would take place at the end of the melt season and the beginning of the vegetation period. Depletion would take place until the end of the vegetation period in autumn. If sufficient late autumn rain occurs, soil moisture may again be recharged before early winter snowfall and further replenishment of soil moisture is excluded. S is therefore determined by

$$S = \sin[(\text{day of the year}.4\pi)/365 + 5.38] \qquad (2)$$

where days of the year start with 1 January.

In Table 3, regression constants, regression coefficients, and their standard errors (s_b) are given for the five streams. For all five chemical components and for all five streams b_1, the discharge coefficient is highly significant, standard errors being in most cases less than 10% of b_1. The variation of these components may therefore be partly due to the variation in stream flow (discharge). Table 4 gives the coefficients of determination (r^2) for the regression on discharge only, and for the three variables. For most of the five chemical components in catchments I, III and VIII, 80% or more of the variation may be explained by variation in stream flow. In catchment V and VII it is more than 73% and more than 63% respectively.

The variable of season (S) is in only a few cases not significant. Standard errors (s_{b2}), however, are large; they vary for four of the five components between 12% and 30% of b_2. Streams III and V show errors (s_{b2}) of about 15%; for the other streams, errors are larger. Sodium shows hardly any significant relationship to the season factor S (Table 3).

Water temperature is the least significant to variation of the five chemical components. It is not important for conductivity, total hardness, and Ca. However, it shows a significant relationship to CO_3 in streams V and VII and to Na in I, III and V.

The effect of both the season and water temperature on the regression result is relatively small. In most cases the difference between coefficients of determination (Table 4), $r^2_{tot} - r^2_Q$, is from

TABLE 3 — Stepwise muliple-regression parameters for five streams in the Alpthal. Coefficients and standard errors (s_b) from regressions on conductivity, total hardness, Ca, CO_3 and Na.

		Catchment									
		I		III		V		VII		VIII	
		coeff.	s_b	*coeff.*	s_b	*coeff.*	s_b	*coeff.*	s_b	*coeff.*	s_b
Conductivity											
	a	291		310.9		373.9		356.9		271.9	
	b_1	−36.3	1.93	−37.8	1.28	−38.7	2.34	−31.6	2.21	−29.9	3.14
	b_2	11.8	3.21	12.1	2.37	12.9	3.66	14.7	3.23	n.s.	–
	b_3	n.s.	–	n.s.	–	n.s.	–	1.4	0.78	2.2	1.31
Tot. hardness											
	a	15.7		17.1		20.5		19.6		15.7	
	b_1	−1.94	0.08	−2.07	0.06	−2.09	0.10	−1.60	0.09	−1.91	0.08
	b_2	0.61	0.14	0.81	0.11	0.87	0.16	0.86	0.13	0.83	0.18
	b_3	n.s.	–	n.s.	–	0.04	0.02	0.05	0.03	0.11	0.03
Ca											
	a	57.4		62.0		74.1		71.5		56.4	
	b_1	−7.32	0.29	−7.81	0.20	−7.56	0.32	−6.12	0.32	−6.92	0.32
	b_2	2.16	0.50	2.67	0.37	3.12	0.51	3.11	0.47	3.06	0.69
	b_3	0.10	0.08	0.14	0.06	0.20	0.07	0.29	0.11	0.48	0.13
CO_3											
	a	88.4		94.3		113.1		104.9		88.4	
	b_1	−11.5	0.44	−12.0	0.32	−11.9	0.50	−9.0	0.49	−11.4	0.51
	b_2	3.53	0.78	3.85	0.59	4.41	0.79	4.36	0.71	5.08	1.10
	b_3	0.24	0.12	0.37	0.09	0.53	0.12	0.97	0.17	0.87	0.21
Na											
	a	3.63		3.45		4.07		4.04		4.85	
	b_1	−0.486	0.037	−0.504	0.023	−0.610	0.023	−0.542	0.021	−0.681	0.048
	b_2	0.100	0.064	n.s.	–	0.055	0.036	0.162	0.032	0.292	0.110
	b_3	−0.044	0.010	−0.036	0.007	−0.029	0.005	−0.016	0.007	−0.046	0.018

0.03 to 0.04. Exceptions are total hardness, Ca, and CO_3 in catchments V, VII and VIII, where the difference ranges from 0.07 to 0.16. Season and water temperature may account for 7% to 16% of the variation of these components.

Table 4 — Coefficients of determination (r^2) from regressions of discharge (r^2_Q) and from three variables (r^2_{tot}) on five chemical components (conductivity, total hardness, Ca, CO_3, Na) in five streams in the Alpthal.

	Catchment									
	I		III		V		VII		VIII	
	r^2_Q	r^2_{tot}	r^2_Q	r^2_{tot}	r^2_Q	r^2_{tot}	r^2_Q	r^2_{tot}	r^2_Q	r^2_{tot}
Conductivity	0.83	0.86	0.87	0.90	0.73	0.76	0.63	0.71	0.73	0.75
Total hardness	0.87	0.90	0.89	0.93	0.77	0.84	0.67	0.79	0.87	0.95
Ca	0.89	0.92	0.90	0.94	0.80	0.87	0.70	0.82	0.86	0.94
CO_3	0.88	0.92	0.89	0.93	0.79	0.87	0.66	0.82	0.85	0.95
Na	0.78	0.82	0.80	0.84	0.87	0.91	0.85	0.89	0.86	0.90

The multiple regressions indicate that most of the variation of the five components may be accounted for by variation in stream flow, and some variation to season (soil moisture conditions) and temperature of the stream. With the three variables for all five components more than 80% of the variation is statistically explained, excepting conductivity (>71%).

Considering the discharge regression coefficients b_1 (Table 3) as they vary between streams, coefficient b_1 of stream VII appears always smaller than of stream III (except Na). The other streams show intermediate values. The corresponding catchments I and III have large areas of wet land (swamps) and VII very little (Table 1). We may therefore conclude that a steeper dilution process of ground-water discharge with surface and subsurface runoff takes place in swamp areas of low permeability than in less wet areas with relatively good percolation conditions (VII).

SUMMARY AND CONCLUSIONS

Chemical components of stream water have been tested for their variation in time and location during two years in five different catchments. A number of components showed little variation, mean concentrations ranging within the following limits in all five streams: pH 8.0 to 8.1; Mg 2.1 to 3.4 mg/l; K 0.5 to 0.8 mg/l; SiO_2 2.9 to 3.2 mg/l; SO_4 5.0 to 10.3 mg/l; and Cl 0.6 to 0.7 mg/l. Sulphate concentrations are higher in streams V and VII than I and III, similarly for nitrate which is also found in higher concentrations in catchments V and VII with 0.23 and 0.20 mg N/l, than in I, III, and VIII with 0.15, 0.16, and 0.14 mg N/l, respectively. Vegetation cover and soil conditions of the catchments may be the prime factors causing these differences in stream water chemistry. A reverse trend is observed in NH_4 concentrations which are higher in catchments I, III and VIII than V and VII (see Table 2).

The remaining five components of the investigation (conductivity, total hardness, Ca, CO_3 and Na) varied considerably during the course of the study, and between streams. Discharge rate, water temperature and a factor estimating seasonal change of soil moisture conditions were found to affect the variability of the above-mentioned components. Most important was discharge, accounting for more than 63% of the variation in the five catchments. In streams I, III, and VIII, more than 80% of the variation was explained. In these catchments swampy areas cover more than one quarter of the total surface. In relatively poor infiltration and percolation conditions, direct runoff is assumed to be frequent. Consequently, the steep dilutions, as observed in the discharge regression coefficients b_1 (Table 3), and its high significance, as well as low average concentrations (Table 2), may be due to specific conditions of the catchments (i.e. vegetation and soil). In catchments V and VII, however, with less than 80% of the variation of the five components accounted for by discharge, swamp surfaces are less than one fifth of the area. Infiltration and percolation conditions seem to be better than in I, III and VIII, which is indicated by less steep dilutions (b_1, Table 3) and relatively high average concentrations (Table 2).

Water temperature and seasonal change of soil moisture conditions are of limited significance in reducing variability of chemical components in stream water. Considerable effects are observed only in the two streams V and VII, where the two factors together may, in addition to discharge, account for 7% to 16% of the variation of conductivity, total hardness, Ca, CO_3, and Na.

Dilution effects as described, among others, by Durum (1953), Hendrickson and Krieger (1960), Keller (1967), Pinder and Jones (1969) and Johnson *et al.* (1969) have also been observed in the Alpthal streams. It is possible that variations of this dilution between streams may be affected by soil and vegetation conditions of the catchments. However, further research is necessary to prove this hypothesis.

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