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Groundwater Discharge through Springs with Well-Defined Outlets A Case Study from Jeløya – Moss, S. Norway

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From the area of Jeløya – Moss, southern Norway, five springs draining fissured-rock aquifers, and one artesian well draining confined water from a sand and gravel aquifer were studied during the year period 7 June 1977 to 6 June 1978. This study has given valuable information about discharge variations, the amounts of water stored in the aquifers, as well as about the residence-time of the water in the aquifers. The springs are fed from groundwater bodies with chemical compositions close to that of deep circulating groundwaters, 30-100 m below land surface. Brackish water in the artesian well is mainly due to the dissolution of fossil sea salts.

Introduction

The hydrogeology and chemistry of five springs and one artesian well in the area of Jeløya – Moss, southern Norway, were investigated over the period 7 June 1977 to 6 June 1978. These springs have supplied drinking water for several decades.

This work is part of a project dealing with the groundwater in Norway, and is supported by the Agricultural Research Council of Norway (NLVF) and the National Institute of Public Health (SIFF), Oslo.

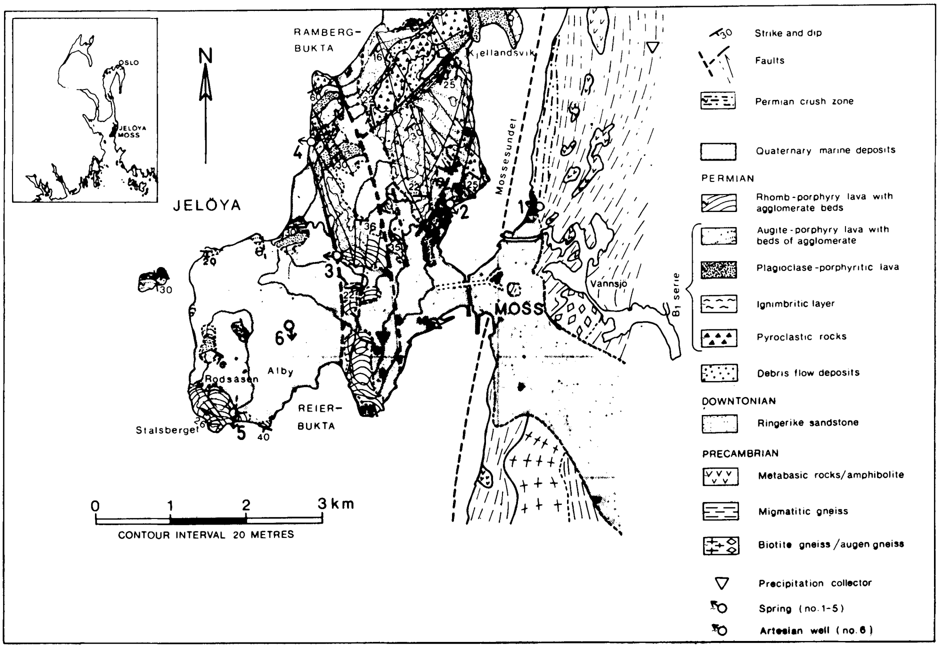

Fig. 1. Location of the investigated springs and the artesian well. The geology of Jeløya is taken from Schou Jensen (1974).

Geology

Jeløya is situated within and close to the eastern border of the Permian Oslo graben (Fig. 1). It has sunk at least 2-3.000 m relative to the Precambrian basement farther east (Larsen et al. 1978), and all rocks are thus strongly fractured.

The island Jeløya is build up of Downtonian sandstone overlain by Permian volcanic rocks. The Precambrian rocks, east of the large fault zone along Mossesundet, consist mainly of gneisses and amphibolites.

The area of Jeløya – Moss is below the Late-Postglacial sea level. Quaternary marine sediments and ice-edge deposits connected with the Ra moraine cover parts of the region.

Methods of Investigation

Water yields were measured at least once every week using a bucket and a watch. At the same time water was filled into plastic containers and brought to the laboratory for analysis. Parameters determined are (unfiltered samples): specific electrical conductance at 20 °C, and concentrations of Na^+, K^+, Mg^{2+}, Ca^{2+},

SO_4^{2-}, Cl^- and SiO_2. pH-value and temperature were measured in the field.

Precipitation was collected at four localities; two are within the map of Fig. 1, one in the northern part of Jeløya, and one about 5 km southeast of Moss. In addition, water samples were collected from 29 selected wells within the area; the water was extracted 30 to 100 m below the land surface.

Altogether 4 samples from each precipitation collector, 30 samples from each spring and artesian well, and 2 samples from each well were analyzed.

Hydrogeology

All springs drain fissured-rock aquifers where the groundwater surface is below the overlying Quaternary deposits. Their geologic and topographic position is determined by the occurrence of impermeable marine clay in contact with permeable bedrock (Figs. 1 and 2, Table 1). According to the terminology of Richter and Lillich (1975, p. 145) the springs are of the type »Stauquellen« or »overtopped unconfined springs« in the sense of Brown et al. (1975).

The springs have very well-defined water outlets probably due to one, or perhaps a few, main drainage fissures leading to the springs. Such fissures force the outflow lines to the surface.

Lakes are lacking on Jeløya, but to the east of Mossesundet Lake Vannsjø possibly supplies some water to the spring Halløkka (No. 1 in Fig. 1).

The artesian well on Jeløya (No. 6 in Fig. 1) drains confined water from a sand and gravel aquifer below marine clay (Fig. 2).

Discharge Variations

The springs and the artesian well show discharges varying with the rainfall (Fig. 3). During rainy periods the groundwater bodies are recharged, but, at the same time they discharge through the springs and wells. During prolonged dry periods the aquifers are not recharged, but emptying like any other reservoir.

The variation in discharge can be demonstrated by the variability index, the ratio of the lowest yield over the greatest. This value is typically highest in the confined sand and gravel aquifer of the artesian well and in fractured rocks with great storage capacity and low permeability (Table 1).

The time-lag between the first maximum recharge after the dry period 29 July – 1 September 1977, a rainfall of about 47 mm during the following 2 days, and the peak flow in the springs varies from one spring to another. The time is about 1-1.5 days for Refsnesstranda, about 3-4 days for Betongen, about 12-14 days for Halløkka, Refsnes and Alby, and more than 30 days for the artesian well at Alby gård.

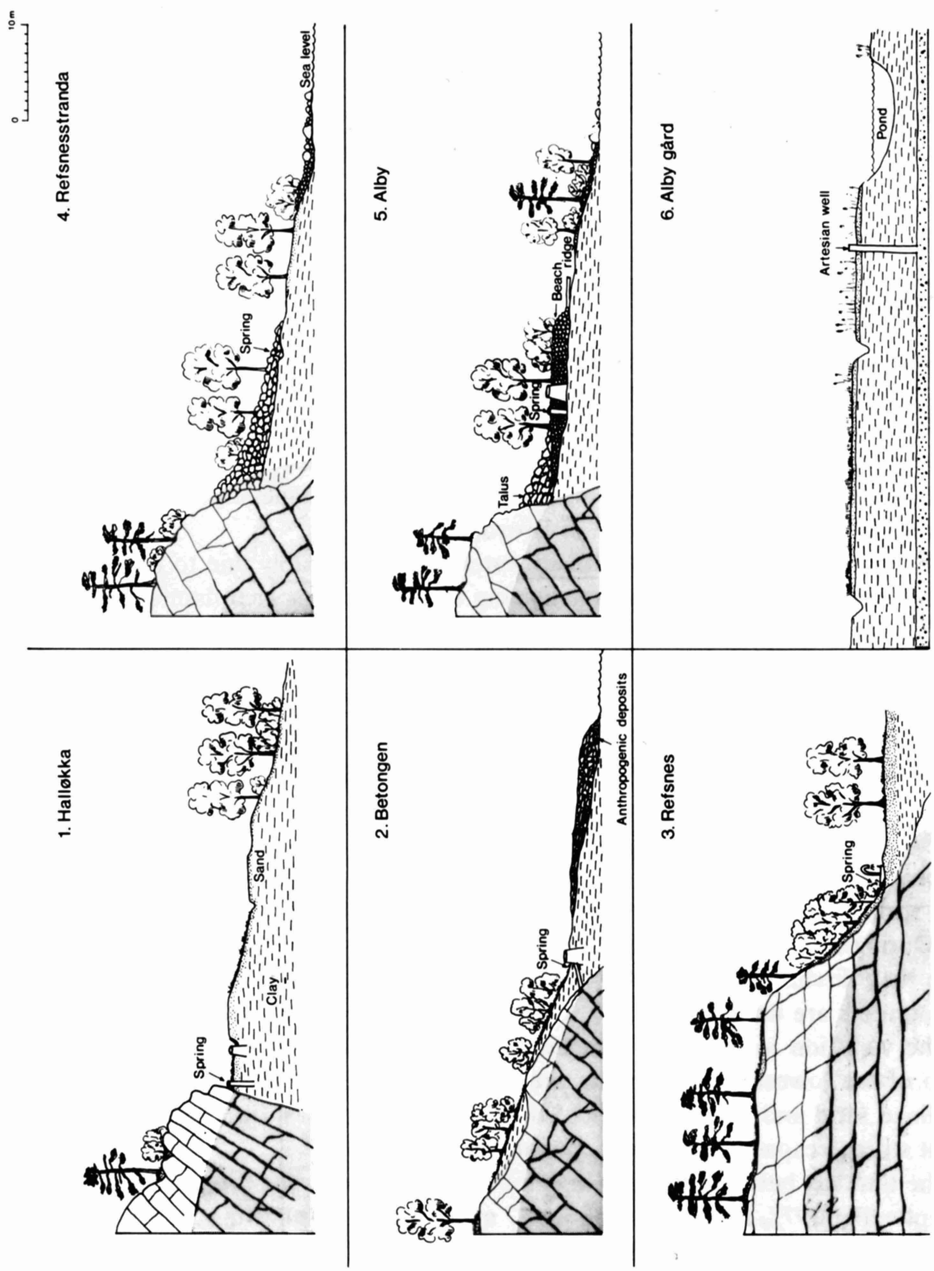

Fig. 2. Geological position of the investigated springs and the artesian well.

Table 1 – Some characteristics of the investigated springs and the artesian well.

Springs/artesian well	Geology	Discharge in l/h			Variability index, min/max. Obs.period 7/6-77 to 6/6-78	a-value ($\frac{1}{day}$) Obs.period 29/7-1/9-77
		Max	Min	Mean		
1. Halløkka	Gneiss/marine clay	378	150	229	0.40	0.0135
2. Betongen	Augite-porphyry lava/marine clay	1560	312	799	0.20	0.0230
3. Refsnes	Augite-porphyry lava/marine clay	900	480	603	0.53	0.0054
4. Refsnesstranda	Rhomb-porphyry/ Augite-porphyry lava/marine clay	1920	24	534	0.01	0.0736
5. Alby	Rhomb-porphyry lava/marine clay	600	258	399	0.43	0.0061
6. Alby gård	Marine clay above sand-gravel	2736	1944	2273	0.71	0.0030

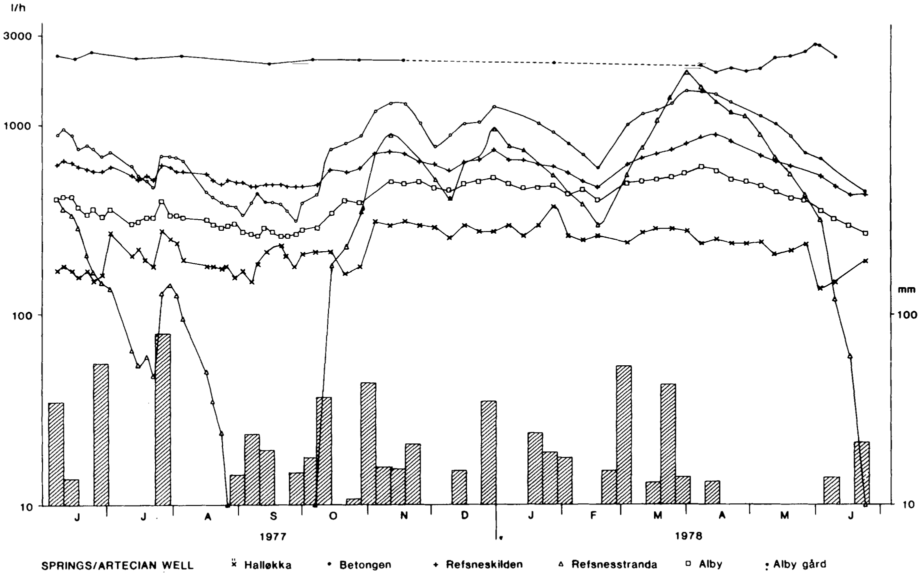

Fig. 3. Spring/artesian well hydrograms in relation to precipitation.

The time-lag is greater in the larger aquifers and where the drainage capacity is low. In addition, soil cover with low infiltration capacities causes larger time-lags.

Dry Period Discharges

Discharge in springs during periods with no recharge can be expressed by an equation given by Maillet (1968) and Brown et al. (1975). A laminar flow is assumed.

$$Q_t \equiv Q_0 \, e^{-\alpha t} \tag{1}$$

where Q_t = discharge at time t; Q_o = discharge at time t_o (28 July 1977, in Fig. 4); α = recession constant, which can be obtained by plotting Q against t on a semi-logarithmic paper (Fig. 4).

From Eq. (1)

$$\alpha \equiv \frac{\lg Q_0 - \lg Q_t}{0.4343 \, t} \tag{2}$$

Strongly fractured rocks, as e.g. limestones, often show α-values in the range 0.0025-0.05, while sandstones with minor fracturing give values around 0.001-0.0024 (Richter and Lillich 1975, p. 149). From Table 1 it can be seen that among

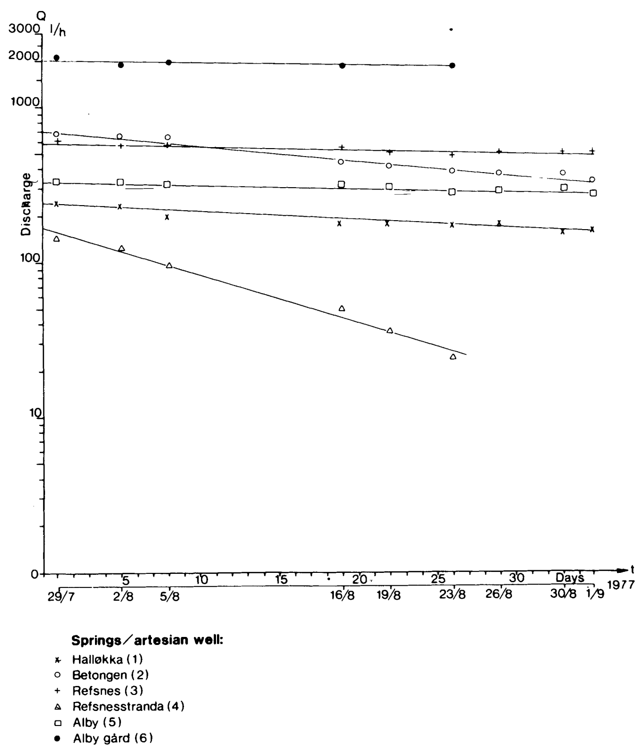

Fig. 4. Spring/artesian well discharges during the dry period 29 July – 1 September 1977.

the springs, Refsnes has the lowest α-value (0.0054), and the highest variability index (0.53), while Refsnesstranda has the highest α-value (0.0736) and the lowest variability index (0.01). This means that spring Refsnes is the most stable, and spring Refsnesstranda the least stable in periods with no recharge. Also the artesian well at Alby gård, with $\alpha=0.0030$ and a variability index of 0.71, is very stable in dry periods.

By knowing the recession constant α, it is now possible to calculate the time needed for reducing the discharge rate from Q_o (28 July 1977) to $Q_t \equiv 1$ l/h when recharge is lacking. Thus the spring Refsnes should yield water for more than three years even without recharge, while Refsnesstranda will become almost empty in the course of two months. The artesian well at Alby gård will yield water for about 6.5 years. Even though these values are of theoretical interest only, they give a picture of the stability of the springs and wells.

The recession constant α is also useful for calculating the total volume of water V at time t_o (28 July 1977) which will discharge through the springs/wells. The following equation can be used

$$V \equiv \int_{t_0}^{\infty} Q dt \; ; \quad \text{where } Q = Q_0 \, e^{-\alpha t} \text{ and } Q_0 \equiv \text{discharge at time } t_0 \qquad (3)$$

This volume of water is stored in the active parts of the aquifers, that is at and above the spring's threshold. By neglecting the passive parts of the aquifers, which are probably of small significance for the discharge of the springs being studied, and setting $t_0=0$ one obtains

$$V = \frac{Q_0}{\alpha} \qquad (4)$$

By using mean discharges and the calculated volumes of stored water on 28 July 1977 one can estimate the average residence-time of the water in the aquifers (Table 2). These values must represent minimum values, because the percolation time within the unsaturated zone is not taken into account, and because a number of flow lines are forced to the surface from depths below those parts of the aquifers which are below the spring's threshold.

Table 2 – Calculated volume of stored water 28th July 1977 using Eq. (4). Given average residence-time of water in the aquifers.

Springs/artesian well	Stored water 28/7-77	Mean discharge	Residence time
1. Halløkka	18148·24 l	229 l/h	79 days
2. Betongen	30435·24 l	799 l/h	38 days
3. Refsnes	108333·24 l	603 l/h	180 days
4. Refsnesstranda	2309·24 l	534 l/h	4,5 days
5. Alby	54098·24 l	399 l/h	136 days
6. Alby gård	683333·24 l	2273 l/h	301 days

Table 2 indicates that the average residence-time for the spring Refsnes is around six months while only 4-5 days for the spring Refsnesstranda. The other springs have values ranging from one month to about 4.5 months, and the artesian well at Alby gård around ten months. The higher the recession constant (Table 1), the shorter is the residence-time (Table 2).

Quality of Water

Groundwater acquires dissolved salts mainly in the following ways: 1) weathering of minerals in soils and on joint fissures, 2) incorporation of fossil sea salts and perhaps also some fossil sea water left over from glacial time in sediments or in rock fractures, 3) by atmospheric deposition, 4) anthropogenic sources, 5) intermixing of sea water.

The city of Moss with its industry, as well as long-range transport of material, clearly influences the composition of the atmospheric deposition, but sources 3 and 4 are probably negligible relative to sources 1 and 2 (Englund and Myhrstad 1980). The intermixing of seawater probably can be neglected, while incorporation of fossil sea salts is the main reason for the brackish water in the artesian well at Alby gård.

Changes in Chemical Composition

Precipitation undergoes a sequence of changes as it infiltrates the ground, percolates to the groundwater surface, is stored in the aquifers, and finally moves to points of discharge. A number of complex processes operate within these regions, and the result of some of these can be illustrated by comparing the chemistry of the main water types investigated here (Fig. 5). An increase in the concentration of all constituents from precipitation to spring and groundwater is observed. Besides it can also be seen that the springs are fed from groundwater bodies with chemical compositions close to that of deep circulating groundwaters, 30-100 m below the land surface (Fig. 5).

On the Permian rocks at Jeløya, which have a mineralogy dominated by augite, plagioclase and K-feldspar, springwater chemistry shows that the longer the residence-time of the water in the aquifers (Table 2), the higher the concentration of dissolved solids (Fig. 5). Betongen has rather high values due to the partial influence of marine clays.

The approximate amounts of ions supplied to the aquifers from precipitation during the investigation period have been calculated by multiplying the concentration of ions in the precipitation (Fig. 5) with the mean discharges of the springs and wells (Table 1) over the one-year period. Similarly the amounts of ions passing through the springs in this period have been found by using mean discharges (Table 1) and mean concentrations in the springs (Fig. 5).

The results thus obtained (Table 3) show that most of the protons in precipitation are consumed, while the amounts of other ions generally increases from precipitation to springwater. The artesian well at Alby gård transports the greatest amount of ions per year, the springs Betongen and Refsnes have intermediate values, while Halløkka transports relatively small amounts.

Rosenqvist (1977) points out that the production of protons in the vegetation and the humic layer of Scandinavia is much larger than the amounts of protons

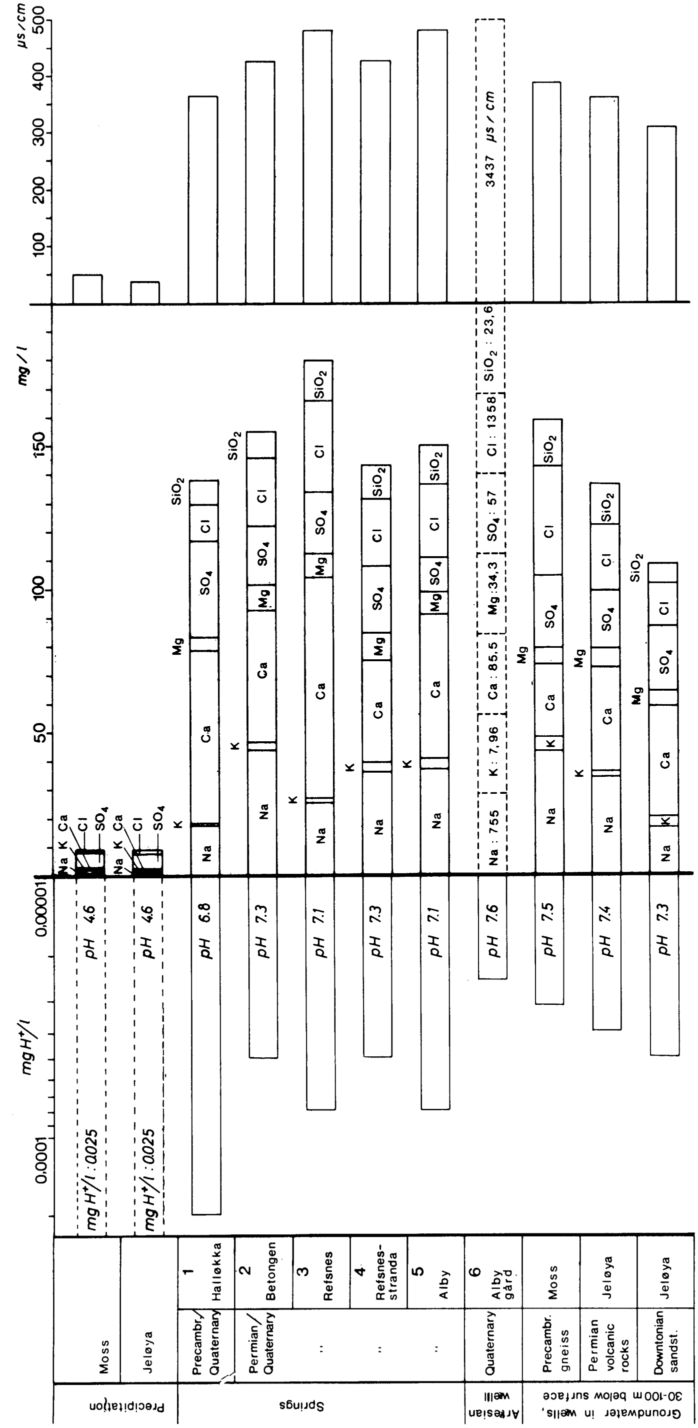

Fig. 5. Average chemical composition of some waters at Jeløya – Moss. Observation period 7 June 1977 to 6 June 1978.

Table 3 – Approximate amounts of ions (g/year) supplied to the aquifers from precipitation during one year (7[th] Jun. 1977 to 6[th] Jun. 1978), and amounts of ions passing through the springs during this period.

Springs/ artesian well	H^+	Na^+	K^+	Ca^{2+}	Mg^{2+}	SiO_2	Cl^-	SO_4^{2-}	
1. Halløkka	51,56	$1,8\cdot10^3$	$2,4\cdot10^3$	$0,9\cdot10^3$	$0,3\cdot10^3$	$0,4\cdot10^3$	$2,3\cdot10^3$	$10,6\cdot10^3$	Supplied from precipitation
	0,33	$34,5\cdot10^3$	$2,6\cdot10^3$	$121,8\cdot10^3$	$8,4\cdot10^3$	$17,5\cdot10^3$	$24,7\cdot10^3$	$69,9\cdot10^3$	Leaving the spring
2. Betongen	179,91	$6,3\cdot10^3$	$7,8\cdot10^3$	$3,1\cdot10^3$	$0,9\cdot10^3$	$1,4\cdot10^3$	$8,1\cdot10^3$	$37,2\cdot10^3$	Supplied from precipitation
	0,35	$305,2\cdot10^3$	$19,1\cdot10^3$	$323,8\cdot10^3$	$63,5\cdot10^3$	$68,2\cdot10^3$	$164,1\cdot10^3$	$142,8\cdot10^3$	Leaving the spring
3. Refsnes	123,83	$5,3\cdot10^3$	$3,5\cdot10^3$	$4,7\cdot10^3$	$1,1\cdot10^3$	$1,2\cdot10^3$	$7,6\cdot10^3$	$26,4\cdot10^3$	Supplied from precipitation
	0,44	$134,7\cdot10^3$	$7,4\cdot10^3$	$407,1\cdot10^3$	$43,2\cdot10^3$	$72,9\cdot10^3$	$168,6\cdot10^3$	$113,0\cdot10^3$	Leaving the spring
4. Refsnesstranda	109,66	$4,7\cdot10^3$	$3,1\cdot10^3$	$4,2\cdot10^3$	$0,9\cdot10^3$	$1,1\cdot10^3$	$6,7\cdot10^3$	$23,3\cdot10^3$	Supplied from precipitation
	0,24	$167,3\cdot10^3$	$14,8\cdot10^3$	$168,2\cdot10^3$	$44,6\cdot10^3$	$57,3\cdot10^3$	$108,8\cdot10^3$	$109,5\cdot10^3$	Leaving the spring
5. Alby	81,94	$3,5\cdot10^3$	$2,3\cdot10^3$	$3,1\cdot10^3$	$0,7\cdot10^3$	$0,8\cdot10^3$	$5,0\cdot10^3$	$17,5\cdot10^3$	Supplied from precipitation
	0,26	$128,6\cdot10^3$	$11,8\cdot10^3$	$179,4\cdot10^3$	$27,5\cdot10^3$	$48,3\cdot10^3$	$88,6\cdot10^3$	$40,9\cdot10^3$	Leaving the spring
6. Alby gård	466,77	$19,9\cdot10^3$	$13,1\cdot10^3$	$17,3\cdot10^3$	$4,2\cdot10^3$	$4,5\cdot10^3$	$28,6\cdot10^3$	$99,5\cdot10^3$	Supplied from precipitation
	0,55	$15032,0\cdot10^3$	$158,5\cdot10^3$	$1702,1\cdot10^3$	$683,6\cdot10^3$	$470,0\cdot10^3$	$27045,8\cdot10^3$	$1135,0\cdot10^3$	Leaving the spring

supplied with the precipitation. Most chemical weathering processes are proton-consuming (Rosenqvist 1977, Englund et al. 1977, Rueslåtten and Jørgensen 1978). The amounts of protons supplied with precipitation can be compared with the amounts of ions released by weathering (Table 4). For these groundwaters less than 1-2% of the protons needed to supply the weathering-derived ions to these groundwaters come from the precipitation.

Table 4 – Amounts of cations (g eq./year) in the springs due to weathering and other processes within the unsaturated/saturated zone.

Springs/ artesian well	H^+ from precipitation	Na+K+Ca+Mg -(Na+K+Ca+Mg) in precipitation	Na+K+Ca+Mg -(H^++Cl^+)	Contribution of precipitation H^+ to the weathering
1. Halløkka	52	8138	7455	0,7 %
2. Betongen	180	34460	29886	0,6 %
3. Refsnes	124	29300	24641	0,5 %
4. Refnesstranda	110	19150	16164	0,7 %
5. Alby	82	16700	14263	0,6 %
6. Alby gård	467	796350	35302	1,3 %

Concluding Remarks

Springs provide evidence of the existence of shallow groundwater bodies. The rate of discharge depends on the difference between the elevation of the water table (or piezometric head) in the aquifer near the spring and the elevation of the spring's threshold. The five springs and one artesian well show discharges varying with the rainfalls.

During dry seasons, discharge of the springs comes from water stored in the aquifers. It has been calculated that the spring Refsnes will yield water for more than three years without recharge, while Refsnesstranda will become almost empty during two months. The artesian well at Alby gård will give water for about 6.5 years without recharge.

The average residence-time of the water in the aquifers is estimated at about six months for the spring Refsnes and only 4-5 days for the spring Refsnesstranda.

The other springs have values varying from one month to about 4.5 months, and the artesian well around ten months.

These springs are fed from groundwater bodies with chemical compositions close to that of deep circulating groundwaters, 30-100 m below land surface.

Less than 1-2% of the protons needed to supply weathering-derived ions to these groundwaters come from precipitation.

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