

Profiles of Nitrogen Species in a Sand-Silt Aquifer at Haslemoen, Solør, South Norway

Paper presented at the Nordic Hydrological Conference
(Reykjavik, Iceland, August – 1986)

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Chemical profiles of water in the vadose zone and in the upper part of the groundwater from a water-table sand-silt aquifer at Haslemoen, South Norway, have been studied. Filter tips attached to steel pipes (BAT monitoring system) have been installed to different depths at two localities. The system makes it possible to measure pore pressures and hydraulic conductivities and to take samples under controlled conditions both above and below the groundwater level. One locality is characterized by forest, groundwater level at about 7 m below surface, and filter tips down to 13.2 m. Agricultural land surrounds the field installations at the other locality, the groundwater level is here about 4.5 m below surface, and filter tips are down to 10.4 m.

The chemical data demonstrate a) Higher concentrations of both total nitrogen and nitrate below agricultural land b) Decreasing concentrations downwards of both total nitrogen and nitrate in both profiles c) Iron and/or organic carbon seems to take part in the reduction of nitrate, probably to free nitrogen.

Introduction

The relationship between increasing fertilizer applications, especially of inorganic fertilizers, and high nitrate in groundwater is well documented from different parts of the world (Young 1983). A regional survey of nitrate in groundwater in south-eastern Norway during the years 1971-82 (Englund *et al.* 1985) has shown that unconfined aquifers are principally at risk, whereas confined systems remain relatively uncontaminated. Quaternary marine clayey silts are especially effective barriers against nitrate pollution of underlying aquifers.

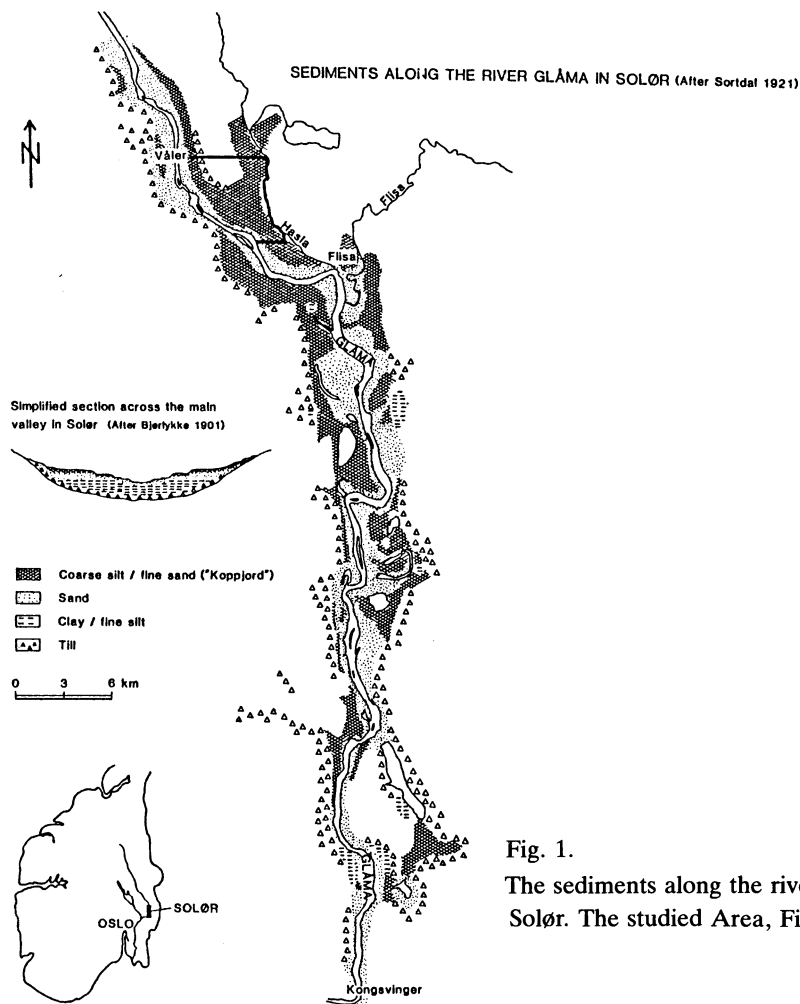


Fig. 1.
The sediments along the river Glåma in Solør. The studied Area, Fig. 2 is framed.

The present study at Haslemoen, Solør, South Norway, (Fig. 1) deals with nitrate pollution of an unconfined sand-silt aquifer.

Area of Investigation

Precambrian gneisses and hyperites are the dominant rock types of the study area. They are overlain by thick Quaternary sediments, which have the following general stratigraphy along river Glåma, Fig. 1 (Bjørlykke 1901); a till overlain by clay and fine silt, followed by sand. Fine sand – coarse silt, the “koppjord”, is the surface sediment in many places. The sediments above the till have been fluvially transported and deposited in fjords, lakes and rivers. Haslemoen is situated on a flat terrace at 172-175 m a.s.l.

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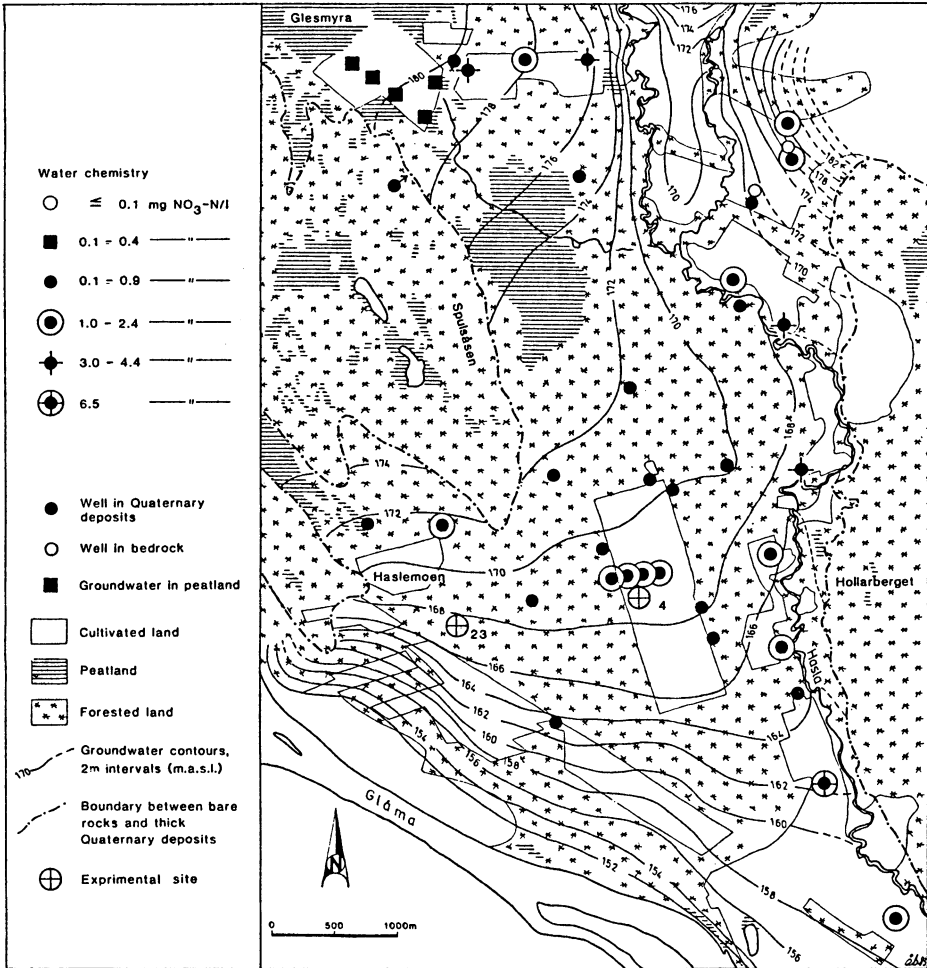


Fig. 2. The concentration of nitrate in groundwater at Haslemoen. Sampling depth of groundwater: 2-12 m in Quaternary deposits, 25-40 m in bedrocks. Sampling period: 1979-82. The groundwater contours are based on observations in the period 2-9 September 1982.

The fine-grained surface sediments, the "koppjord", have a soil water storage capacity of 200-300 mm and represent, therefore, an efficient barrier against groundwater recharge during the summer. It has been calculated that the yearly groundwater recharge for the years 1970-83 is approximately 300 mm (Haldorsen *et al.* 1986).

The present paper is mainly based on data obtained from two experimental sites; Nos. 4 and 23 in Fig. 2. They have the following field characteristics:

Table 1 - Chemical composition of water in the unsaturated and saturated zone, Haslemoen, Solør, S. E. Norway

Locality	Sampling	Depth below surface, m	Conductivity MS/M at 25°C	pH	mg/l														
					Tot.N	NO ₃ -N	NO ₂ -N	NH ₄ -N	SO ₄	Cl	HCO ₃	TOC	TOT.Fe	TOT.Mn	Ca	Mg	Na	K	
Loc. 4, Cultivated land	15-10-85	2.5	16.3	7.1	1.5	1.2	0.006	<0.005	10.0	11.0	95.2	2.3	0.03	<0.02	8.5	1.0	1.5	6.0	
		3.5	20.4	7.3	2.6	2.1	0.016	<0.005	9.5	11.3		2.0	0.03	<0.02	25.0	0.9	2.2	9.5	
		3.6	Gr.w.table																
		5.1	21.5	7.2	1.1	0.8	0.031	0.022	17.0	32.0	18.9	9.7	0.07	0.03	10.0	0.8	2.4	27.0	
		5.5	12.1	7.0	0.9	0.8	0.007	0.018	5.5	18.5	12.8	1.2	0.03	0.03	2.5	0.6	2.4	18.0	
		6.2	11.9	6.6	1.7	1.3	0.013	0.015	13.0	13.0	12.8	0.9	0.1	0.05	11.5	0.5	3.5	1.6	
		10.4	10.0	7.2	0.3	<0.05	0.007	<0.005	3.5	3.6	9.2	0.9	0.6	0.05	2.5	0.5	2.6	3.2	
		1.5	4.8	6.6	0.32	<0.05	0.005	0.006	3.0	1.3		6.0	0.03	0.02	1.5	1.2			
		2.5	3.2	6.4	0.15	<0.05	<0.005	<0.005	3.0	1.2		6.2	<0.02	0.06	< 1.0	0.6	1.7	0.7	
		3.5	4.2	6.4	0.19	<0.05	<0.005	<0.005	6.0	1.3		8.4	0.03	0.08	1.0	0.8	1.7	1.3	
Loc. 23, Forested land	24-6-85	6.5	3.9	6.4	0.24	<0.05	<0.005	5.0	3.2		3.3	0.03	0.07	< 1.0	0.9	1.9	1.3		
		6.7	Gr.w.table																
		8.5	2.3	5.6	0.31	0.20	<0.005	<0.005	3.5	1.1		1.5	0.07	<0.01	< 1.0	0.4			
Loc. 23, Forested land		10.4	5.0	6.0	0.12	<0.05	<0.005	<0.005	1.0		1.9	0.75	0.03	1.5	0.8	2.2	1.0		
		13.2	6.0	6.5	0.16	<0.05	<0.005	<0.005	11.0	2.1		1.7	8.0	0.10	1.0	0.6			

Nitrogen in a Sand-Silt Aquifer

Site No. 4 is surrounded by cultivated land where production of wheat and oat, based on inorganic fertilizers, has occurred since 1953. This area was forested before that time. The sedimentary sequence down to 11 m consists of fine sand to coarse sand with ca. 0.6 m of fine sand and silt, the "koppjord", at the top (Fig. 4). This profile description is based on sediments brought to the surface by drilling. Grain-size distribution curves and the formulae of Hazen (1893) have revealed large variations in the saturated hydraulic conductivity toward depth.

Site No. 23 is surrounded by forested land, mainly pine and spruce. The sedimentary sequence is also here characterized by ca. 0.6 m of "koppjord", underlain by fine sand to coarse sand (Fig. 4).

Both experimental sites are located within groundwater recharge areas, and the soil profiles are therefore well developed podzols.

Instrumentation

In order to study the profiles of nitrogen species, in situ probes of the type BAT MK II Filter tips were used (Fig. 3). The equipment can be used in a wide range of hydrogeological conditions, from saturation to almost a full atmosphere of tension. A presaturated filter tip attached to an extension pipe was installed by pushing it into the soil. The design of this equipment ensures a good hydraulic connection between the water in the sediment and the fluid in the tip, facilitated by a porous filter sleeve. The tip is hermetically sealed by a septum at its upper end. Test adapters were connected using hypodermic needles providing a temporary, leak-proof hydraulic connection. It should be noted that the filter with attached adapter form a completely closed-system extension of the soil.

When the filter tip is connected with a pressure transducer, it is used for measuring pore pressures. Both positive pressures and suctions can be measured (Torstensson *et al.* 1984, Haldorsen *et al.* 1985).

The sampling adapter (Fig. 3) is based on an evacuated sample vial sealed by a flexible septum. A quick-coupling unit containing a double-ended hypodermic needle is used to connect the vial to the filter tip. The design of the unit ensures that the pressure in the vial is maintained; only the gradient between the interior of the vial and the soil pores can affect the pressure level.

As the vial becomes filled with water, the pressure in it will increase until it finally equals the pore pressure of the soil. At this point, the sampling process will terminate. The sample is then kept in the sampling cylinder under the original pressure and is hermetically sealed and thus very well suited for chemical analysis in the laboratory.

In order to measure the hydraulic conductivity (permeability) of a soil, the BAT system combines the components used for sampling and for pressure measurements.

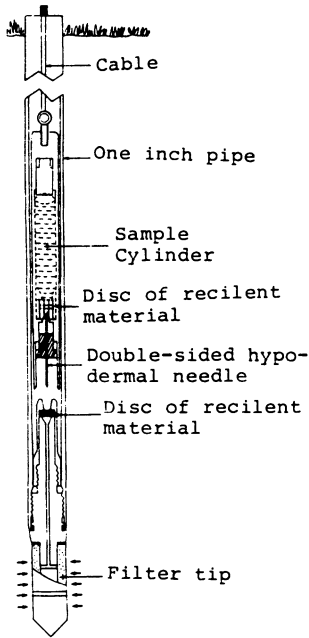


Fig. 3. The BAT-equipment for water sampling.

Table 2 – In situ measurements of unsaturated hydraulic conductivity at Haslemoen, summer 1985

Site	Depth (m)	Date	Pore press. before test (m H ₂ O)	Pore press. after test (m H ₂ O)	Unsaturated hydraulic conductivity (m s ⁻¹)
4	1.5	Jun25	-0.61	-0.64	9·10 ⁻⁹
4	1.5	Sept 4	-0.42	-0.44	8·10 ⁻⁸
4	3.5	Jun 25	-0.55	-0.60	2·10 ⁻⁸
4	3.5	Sept 4	-0.37	-0.40	1·10 ⁻⁷
23	1.5	Jun 26	-0.50	-0.50	8·10 ⁻⁹
23	1.5	Sept 4	-0.40	-0.43	2·10 ⁻⁸
23	2.5	Jun 26	-0.34	-0.34	5·10 ⁻⁸
23	2.5	Sept 5	-0.40	-0.40	3·10 ⁻⁸
23	3.5	Jun 26	-0.37	-0.40	7·10 ⁻⁸
23	3.5	Sept 5	-0.33	-0.35	5·10 ⁻⁷
23	6.5	Jun 26	-0.36	-0.36	6·10 ⁻⁸
23	6.5	Sept 5	-0.32	-0.33	1·10 ⁻⁷

The pressure transducer is in this configuration used to measure the gas pressure in the test vial. This pressure will change in accordance with Boyles-Mariottes law (the product of pressure and volume is a constant) as liquid flows into or out of the vial. The rate of pressure change – and therefore of liquid flow – is a function of the soil permeability.

The BAT system uses this arrangement to perform a closed system version of a falling or variable head test. The theory for such tests was described by Hvorslev (1951).

The upper limit of permeability, which the system is capable of measuring, is 1.10⁻⁴ cm s⁻¹. This restriction is due to the maximum flow rate that can be achieved through the double-ended hypodermic needle.

There is nothing in the theory of Hvorslev that precludes its use for unsaturated or saturated soils. The decrease in effective porosity caused by emptying the large pores simply reflects the corresponding decrease of the hydraulic conductivity of the unsaturated soil. Pressure is still thought to be transmitted via the hydraulically interconnected pores in the manner visualized in the theory (Haldorsen *et al.* 1985).

Land Use – General Groundwater Chemistry

The impact of agricultural activity on the nitrate content in the shallow groundwaters near Halsemoen is obvious; the highest concentrations are found below cultivated land areas (Fig. 2). In general, this trend reflects the heavy use of inorganic fertilizers. The highest concentrations of nitrate are found, however, in wells contaminated from feedlots.

At our two experimental sites, higher concentrations of tot. N, $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, SO_4 , Cl, Ca and K, as well as higher specific electrical conductance, are found at locality No. 4 compared to locality No. 23. The source for most of the nitrogen, sulfate, chloride and potassium is inorganic fertilizers; about 8-10 kg tot. N da^{-1} . years^{-1} . Calcium is largely derived from liming, which occurred in 1953, 1962, 1971 and 1979.

Chemical Profiles

The content of chemical constituents in waters towards depth is shown in Table 1 and Fig. 4. Special attention should be paid to the following trends:

- A) At locality No. 4 the concentrations of all nitrogen species are at a maximum near the groundwater surface and decrease towards depth. Similar trends have been found in groundwaters from different places in southeastern Norway (Englund *et al.* 1985).
- B) Bicarbonate is the quantitatively most important anion in the shallow waters at locality No. 4, together with sulfate and chloride. Their concentrations decrease toward depth.
- C) The concentration of total iron characteristically increase towards larger depths.
- D) The concentration of total dissolved organic carbon varies, but shows a general decrease towards depth at both experimental sites.
- E) The pH of waters below forested land, locality No. 23, is generally lower than below cultivated land, locality No. 4. This is mainly due to the neutralizing effects of liming on cultivated land.

Discussion of Results

The presented data are preliminary results (Table 1 and Fig. 4). Solute concentrations in pore water from the unsaturated zone as well as groundwater chemistry from the underlying unconfined aquifer are discussed in relation to land use and hydrology:

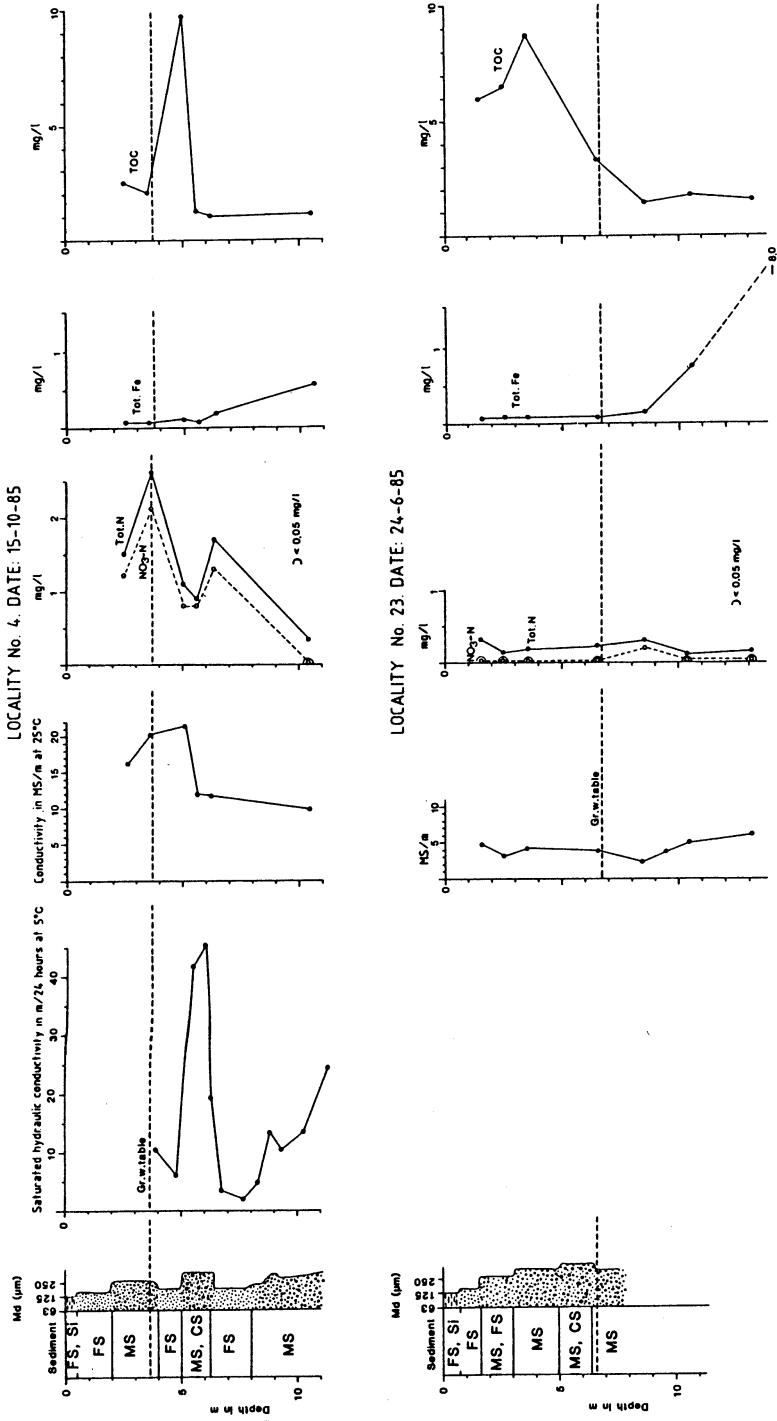


Fig. 4. Section through the sediments, hydraulic conductivity and chemistry of water at two localities, No. 4 and No. 23 (Fig. 2). Si = silt, FS = fine sand, MS = medium sand, CS = coarse sand.

Nitrogen in a Sand-Silt Aquifer

- A) A yearly groundwater recharge of 300 mm, corresponding to about 1 m groundwater depth, and an unsaturated hydraulic conductivity of the sand of 10^{-7} – 10^{-9} m/s measured during 1985 (Table 2), indicate that the water movement through the unsaturated zone took at least 2 months at locality No. 4 and 3 months at locality No. 23.
- B) The studied groundwaters at locality 4 and 23 are within the zone of active groundwater circulation. They have moved from a few metres to more than 100 m within the saturated zone before sampling; the deeper down the longer the travel distances and the higher the ages (may be up to 7-10 years).
- C) There is a clear relationship between the use of inorganic fertilizers on the crop area around site 4, and nitrate concentrations in the groundwater. Nitrate is being leached from this area annually; at least for the last 7-10 years. Whether the nitrate is being leached directly from the fertilizers or/and is the result of mineralization of soil organic material, is unknown. Both processes seem possible according to studies from other countries (Foster and Crease 1974, Kreitler and Jones 1975, Yong *et al.* 1979).
- D) The clear drop in the nitrate concentration at a depth of 10 m below the cultivated area is probably largely due to denitrification. From the Karup basin in Denmark, Andersen *et al.* (1980) postulated that the vertical penetration of nitrate into the aquifer was limited by reduction of nitrate by ferrous iron present in solution. This mechanism seems reasonable also at Haslemoen since the content of dissolved total iron increases simultaneously with the drop in nitrate. Such inverse relationships between nitrate and iron are rather common in groundwaters in southeastern Norway (Englund *et al.* 1985).
- E) Nitrate is by far the dominant nitrogen species lost from the cultivated land, with nitrite (NO_2^-) and ammonium (NH_4^+) in subordinate amounts. Parts of the nitrite could form by denitrification. Also ammonium can partly be the result of nitrate reduction, but for biochemical reasons only a small fraction of the nitrate that undergoes reduction in groundwater zones follows this reduction path (Freeze and Cherry 1979).
- F) The decrease in nitrate concentration within coarsegrained beds, 5-6.4 m below the surface at site 4, is most probably the result of denitrification involving organic substances. The content of dissolved organic carbon can be rather high within these beds (Table 1). The input water to this very permeable part of the strata is strongly polluted, as shown by high contents of dissolved chloride and partly sulfate. The reduction of sulfate occurs at a lower redox-potential than denitrification (Stumm and Morgan 1981), and sulfate will therefore persist in the water until all nitrate has disappeared.

Acknowledgements

This paper forms part of a project, mainly supported by the Agricultural Research Council of Norway (NLVF), the Norwegian National Committee for Hydrology (NHK) and the Norwegian National Institute of Public Health (SIFF).

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Received: 1 October, 1986

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