Hydrogeological properties of the fine sand – coarse silt ('koppjord') in Solør, southeastern Norway

SYLVI HALDORSEN, PETTER DEINBOLL JENSSEN & JOHN MARTIN SAMUELSEN

Haldorsen, S., Jenssen, P. D. & Samuelsen, J. M.: Hydrogeological properties of the fine sand – coarse silt ('koppjord') in Solør, southeastern Norway. *Norsk Geologisk Tidsskrift*, Vol. 66, pp. 223–233. Oslo 1986. ISSN 0029-196X.

Along Glåma in Solør the silty surface soil is named 'koppjord' and has been of great agricultural importance for many generations. At Haslemoen measurements of the saturated hydraulic conductivity in the field and in laboratory gave values between $4 \cdot 10^{-6}$m/s and $5 \cdot 10^{-5}$m/s, the highest values obtained by field tests. Compared with other Norwegian Quaternary sediments the 'koppjord' has a very favourable pore system for plant-available water storage. A computer model shows that when the 'koppjord' is thicker than 0.5 m, there is no need for irrigation on cultivated land, even during dry summers. The average groundwater recharge estimate is 300 mm per year during the period 1970–83. A certain groundwater recharge normally occurs even during the summer months. The infiltrability of the 'koppjord' is high enough to prevent surface ponding during snow melt and heavy autumn rain falls.

S. Haldorsen, Department of geology, Agricultural University of Norway, P.O. Box 21, N-1432 Ås-NLH, Norway.
P. D. Jenssen & J. M. Samuelsen, Institute of Georesources and Pollution Research, P.O. Box 9, N-1432 Ås-NLH, Norway.

The surface soil along the river Glåma, between Kongsvinger and Våler in Solør, southeastern Norway, is dominated by coarse silt and some fine sand. The local name of this soil type is 'koppjord' (cup soil). The name indicates that frost upheaval makes the soil surface buckled, like upside-down plates. During many generations the soil has been known for its particularly large soil water storage capacity. This property makes it a very interesting soil type from both a hydrogeological and an agricultural point of view. The soil has been mapped and described in several papers (i.e. Bjørlykke 1901, Sortdal 1921, Holmsen 1954, Goffeng et al. 1980, 1981a, 1981b), and it has been pointed out that the soil has much in common with the silt at Romerike, southeast of Solør ('mjele'), and the silt in Østerdalen, north of Solør ('kvabb') (see e.g. Bjørlykke 1901, Myhr 1980).

The aim of this work has been to describe the hydrogeological characteristics of this special soil type and the dependence upon sedimentological properties.

Description of the studied sediments

Bjørlykke (1901) described the sediments along Glåma in Solør and found a general stratigraphy with a till overlain by clay and fine silt, which again was overlain by sand (Fig. 1). The fine-grained surface sediment, covering the sand, the 'koppjord', was found to have a thickness of 0.5–1 m, but was in some places lacking in the lower terraces along the river. This was later verified by Sortdal (1921). The fine-grained surface sediment cover was interpreted by Bjørlykke (1901) and Sortdal (1921) as having been deposited in a lake extending from Kongsvinger to Våler. Holmsen (1954) pointed out that the sediments might have been deposited in more local ponds. A marine origin was supposed by Nielsen (1983), while Høye & Sand (1983) found it more likely that the fine-grained cover represented fluvial overbank deposits.

The present study of the fine-grained surface sediments and hydrogeological aspects was carried out at Haslemoen (Fig. 1). The area studied consists of small terraces at different elevations above the river Glåma's present channel (150 m a.s.l.), and a greater terrace in the east at the 172–175 m level (Fig. 2). In the northeast a higher terrace is found at 180 m. A fine-grained surface layer covers most terraces and there is an abrupt boundary in grain size towards underlying coarser sand. The thickness of the fine-grained surface sediments generally varies between 0 and 50 cm on low-lying terraces and 50–100 cm on the

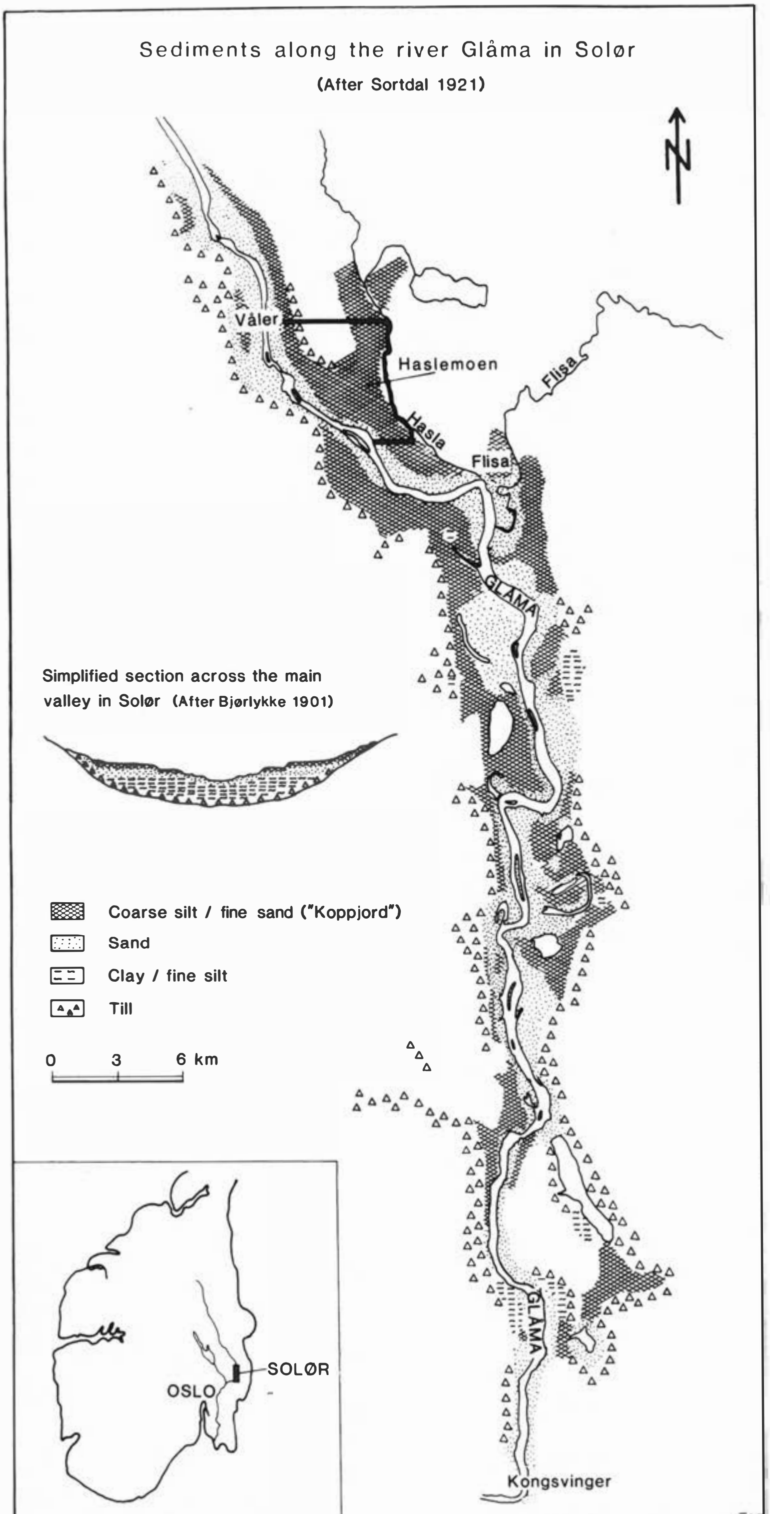


Fig. 1. Key map showing the main sediments along Glåma in Solør in southeastern Norway. Section through the sediments is shown in the lower left part. Studied area is framed.

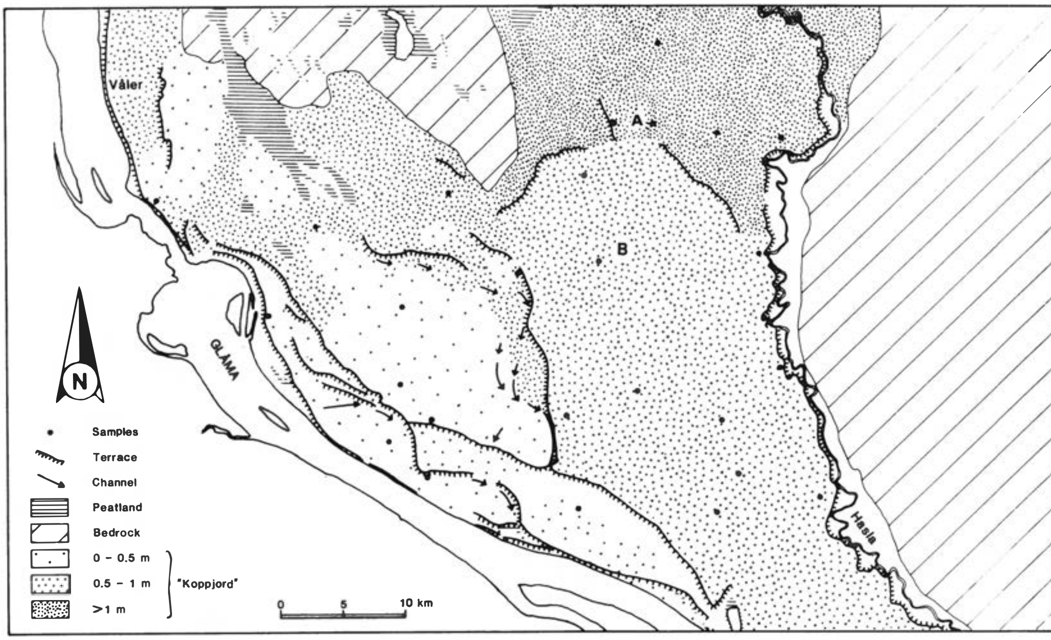


Fig. 2. Map of Haslemoen showing the thickness of the 'koppjord' position of main terraces and drainage channels, samples and main field study localities.

main terrace, while there are considerably greater thicknesses at the highest terrace in the northeast (Fig. 2).

The fine-grained sediment cover has a median grain-size diameter varying between coarse silt and very fine sand, and it is moderately well to poorly sorted (Fig. 3). Due to soil weathering processes, the upper half metre has a significantly poorer sorting than in deeper parts of the sediment.

The vertical variation was studied in more detail at a locality in the northeast (site A, Fig. 2). In this part of the area the thickness of the 'koppjord' is on the average more than two metres. A profile was excavated through a three metres thick section where 2.8 m coarse silt overlay a coarse sand. Underneath a 0.6 m thick zone disturbed by cryoturbation, the sediments showed a distinct planar lamination, with laminae of one to five centimetres thickness (Fig. 4). Each lamina has a normal grading. By means of the grain-size analyses, the sequence can be divided into at least three different parts, each with an upward coarsening and each formed by several laminae sets. Longva (1984, 1986) interprets silt sediments in the Romerike area and along the river Glåma as deposited during one flood event. This sequence, on the contrary, indicates a sedimentation of mainly suspended material in quiet water.

In the areas where the surface layer is thinner than one metre, all the original sedimentary structures are destroyed by weathering and frost activity. It is, therefore, impossible to tell if the sedimentary structures described above are representative for the fine-grained sediment cover in the entire area. River channels, which are frequent on terraces below 170 m a.s.l., indicate that the surface sediments at the lower terraces consist of fluvial material, and may represent overbank deposits.

Saturated hydraulic conductivity

Calculations of the saturated hydraulic conductivity were carried out from field and laboratory tests and from the grain-size measurements at locality A in the northeast (Fig. 2).

The field measurements were made by a variant of the inverse auger hole method (Kessler & Osterbaan 1974) described by Jenssen (1982). In this variant a constant head of water is used in the pits and a porous plastic pad supports the pit walls (Fig. 5A).

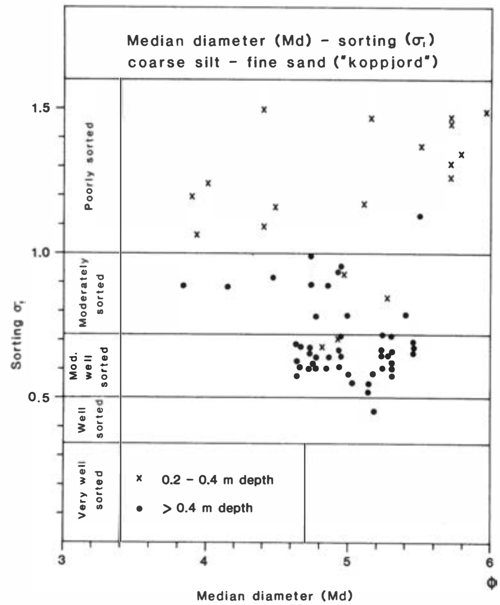


Fig. 3. Median diameter (Md) – sorting (σ_1) diagram for 'koppjord' samples. Sorting coefficient after Folk & Ward (1957).

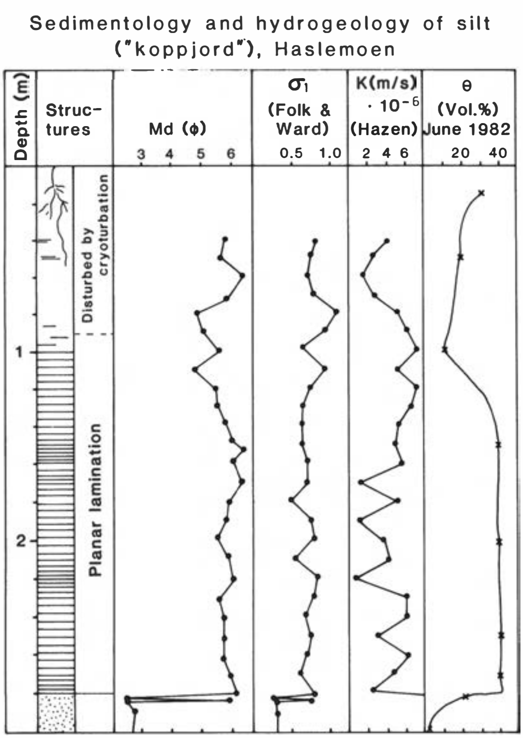


Fig. 4. Data from a section through laminated silt at site A (Fig. 2) showing grain-size variations (Md, σ_1) saturated hydraulic conductivity calculated according to Hazen (1893) and actual water content June 18, 1982.

The pits used were square, with a side length of 25 or 40 cm. Eleven pits were dug and the bottoms of the pits were approximately one metre below the ground surface. The distance down to the groundwater level was more than four metres.

The amount of water infiltrated per unit time was measured at a water level of 20 cm. An almost constant infiltration rate (I) (steady state) was reached after two-three hours, when the soil around the infiltration pit was nearly saturated (Fig. 5B). When assuming a constant head, a vertical one-dimensional flow and a hydraulic gradient equal to unity, the hydraulic conductivity can be calculated from the formula $K=I/A$ where A is the total wetted wall and bottom area in the pit (Reynolds et al. 1983). These requirements are never satisfied during a field infiltration test (e.g. Reynolds et al. 1985). However, a complete correction for three-dimensional flow around the pit and the capillary suction requires more detailed measurements than carried out in this field test (see Jenssen 1986). The infiltration test is time consuming. Its advantage is that it gives average values for a greater sediment volume than the other methods applied at Haslemoen, and that it also reflects the importance of macrostructures like cracks and root channels.

'Undisturbed' samples were taken by hammering steel cylinders of 5 cm diameter vertically and horizontally into the soil at different levels from 0.7 to 1.1 m below the ground. The hydraulic conductivity of these samples was measured by the constant head method (description of the method is given in Jenssen (1982)). The permeameter cylinders give the true hydraulic conductivity. The sampling is rapid and the laboratory measurements are easily carried out. It is less time-consuming than the infiltration test. It is well suited for laminated silt and sand. The cylinders are, however, too small to account totally for macrostructures like fissures and root channels.

Finally, the hydraulic conductivity was calculated from the grain-size distribution curves. The constraint $d_{60}/d_{10} < 5$ is valid for all samples, so that Hazen'sformula (Hazen 1893) $K = 0.0116 \cdot d_{10}^2$can be used. K is given as m/s when d_{10} is given in mm. Hazen's formula is developed for water at temperature 20°C. Also data from the infiltration test and the permeameter cylinder are calculated for this temperature.

Figure 6 shows the results of the different measurements. The field measurements give val-

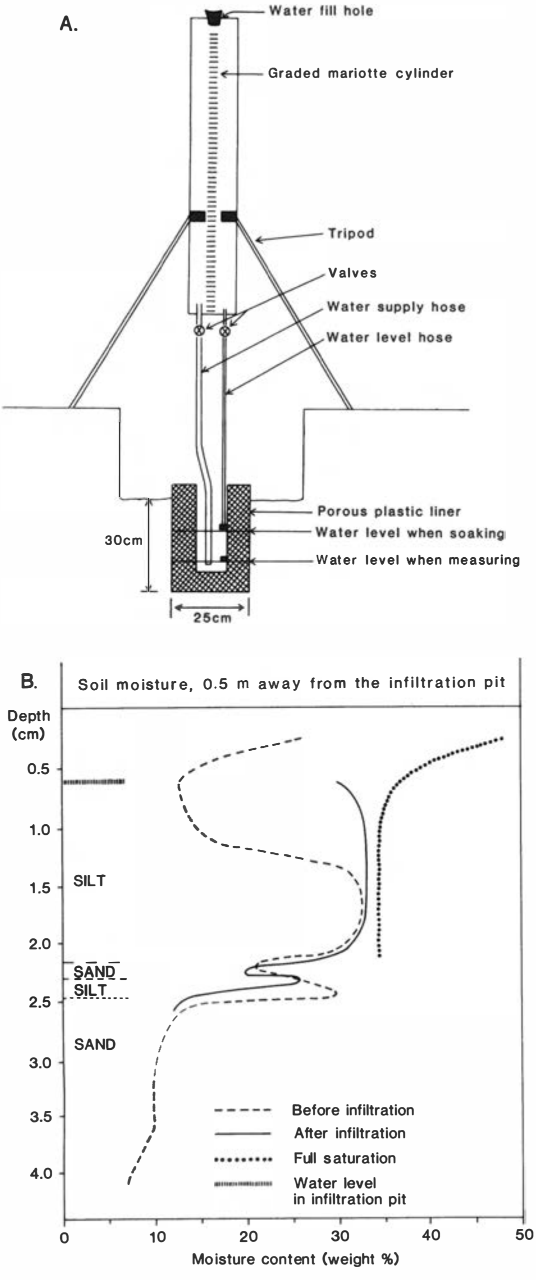


Fig. 5. A. Equipment for infiltration studies at site A. B. Water content in the silt in the vicinity of the pit before and after infiltration.

ues which are higher than those of the permeameter cylinders and values obtained by Hazen's formula. This difference may be due to the gradients around the pit being greater than unity (Reynolds 1985). Gravimetric measurements

Hydraulic conductivity K(m/s) of "koppjord" Haslemoen			
Method	Arithmetic mean $\bar{x}$	Range	Number of samples
Infiltration test	$4.3 \cdot 10^{-5}$	$3.0 \cdot 10^{-5}$ $6.4 \cdot 10^{-5}$	17
Permeameter cylinders			
vertical	$3.3 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$ $4.9 \cdot 10^{-6}$	14
horizontal	$6.8 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$ $1.3 \cdot 10^{-5}$	22
Hazen's equation			
20–40cm depth	$2.5 \cdot 10^{-5}$	$1.3 \cdot 10^{-7}$ $1.6 \cdot 10^{-5}$	30
> 40cm depth	$3.9 \cdot 10^{-6}$	$1.7 \cdot 10^{-6}$ $6.3 \cdot 10^{-6}$	50

Fig. 6. Hydraulic conductivity values of the 'koppjord' obtained from infiltration studies, permeameter tests for undisturbed samples taken in horizontal and vertical directions and calculated from grain-size curves according to Hazen (1893). All the values are calculated for water at a temperature of 20°C.

(Fig. 5B) show that the soil was less than 5% by weight from full saturation at the end of the infiltration period. According to Fig. 7 a significant soil suction can occur in the soil at this undersaturation. However, even though the infiltration test does not give the correct values for the saturated hydraulic conductivity, the results are of interest for the water movement above the groundwater level. They give the steady state infiltrability at 'field saturation', meaning that the values tell how much water can infiltrate into and percolate through each unit area of a previously unsaturated soil column, when it is wetted as much as possible (see Hillel 1980a, p. 218). As seen from Fig. 6 all the values from the field test are higher than the highest values obtained by permeameter cylinders. The suction in the soil thus results in the drainage of more water than what should be supposed by a full saturation and a hydraulic gradient equal to unity. The values are most representative for nearly saturated conditions above the groundwater level, as during snow melt or by artificial infiltration.

Hazen's formula on the average gives lower values and greater variations for the upper 40 cm of the sediment than for samples taken deeper down. This is due to weathering of the soil, which gives a poorer sorting and an increase in finer particles. However, the hydraulic conductivity is obviously higher in the upper 40 cm than in lower parts of the 'koppjord' due to macrostructures created by bio- and cryoturbation. Hazen's formula is, therefore, only to be recommended for the deeper layers where a secondary macropore system is absent.

The permeameter samples taken in a horizontal direction gave higher hydraulic conductivity values than those taken in a vertical direction (Fig. 6). This reflects the importance of the lamination. In horizontal directions the water flows parallel to the lamination. The hydraulic conductivity is then strongly dependent on the most coarse-grained laminae. During vertical flow, the most fine-grained layers restrict the hydraulic conductivity. This is further in accordance with the results obtained by Hazen's formula, where the highest values are of the same magnitude as the horizontal permeameter samples while the lowest values are of the same size as those from the vertical samples (Figs. 4 & 6). The values for horizontal samples are believed to be the most representative for flow below the groundwater table, where the water movement is nearly horizontal and where lamination is the most important structural feature.

Water retention and pore-size distribution

To give a more detailed description of the hydraulic characteristics of the soil, samples from different depths were taken at site A for water content and tension studies. Cylinders of 100 cm^3 and an ordinary pressure plate apparatus were used. The samples were weighted by full saturation, 0.01 bar, 0.1 bar, 1 bar and 10 bar tension. The water contents were later calculated by comparing the respective weights with the dry sample weight. Tension – water content curves were drawn on the basis of the measurements (Fig. 7). To give an idea of the pore-size distribution, the tension values were also converted to an equivalent pore-size scale by the formula of capillary rise. From the curves we calculated the content of drainable water (water retained by a suction less than 0.1 bar), water available for the

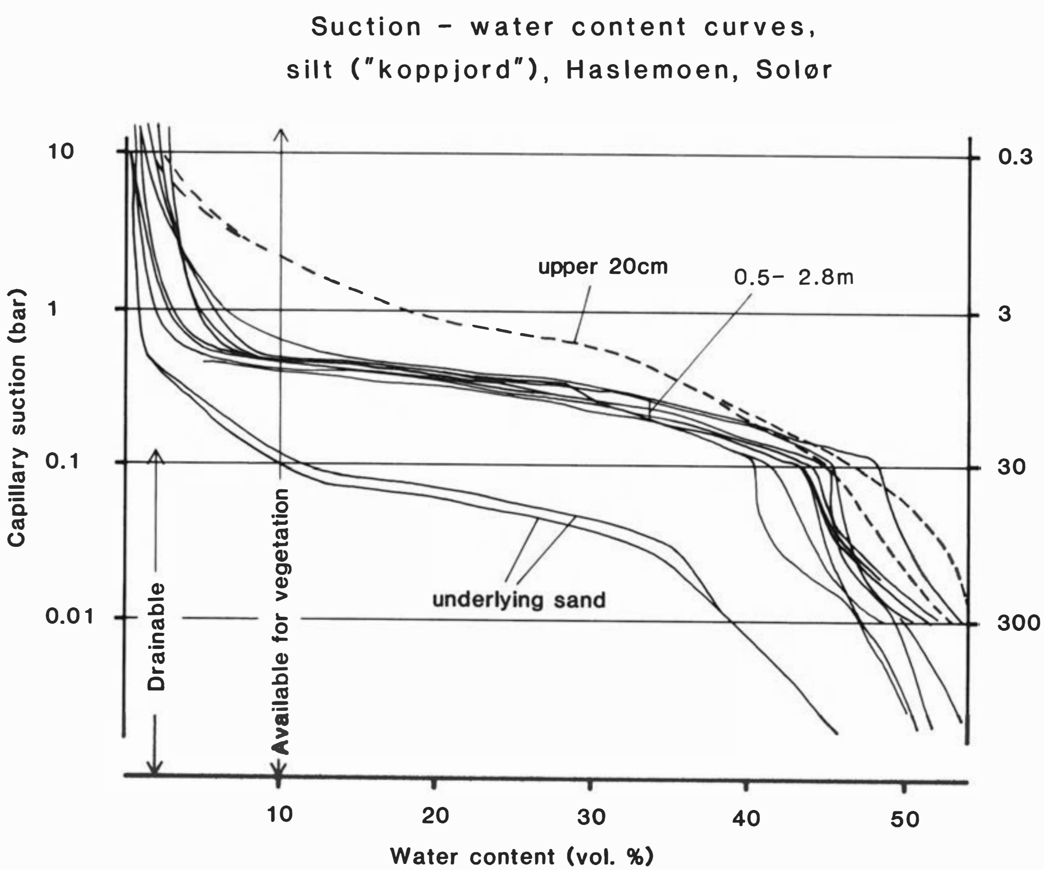


Fig. 7. Suction – water content curves for the 'koppjord' and the underlying sand at site A. Two curves are shown for the upper 20 cm, the rest of the 'koppjord' curves are from samples deeper than half a metre.

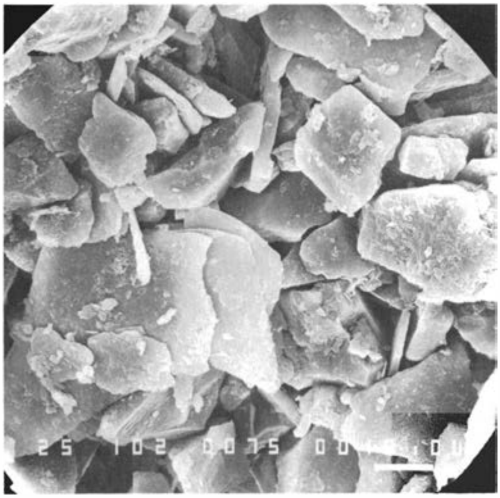


Fig. 8. Electron microscope photo of the 'koppjord', 1 m depth at site A, showing the fragile structure and open pore system. White line is 10 μm.

vegetation (water drained by a suction of 10 bar) and the water which is not available for the vegetation. The available water minus the drainage water roughly gives the maximum available water which can be stored in the soil by capillary forces.

The total porosity is very high (>50%), which is also illustrated by electron microscope photos (Fig. 8). The drainable water volume is between 10 and 20%. The available water volume is on the average about 50%. A water volume between 30 and 40% can thus be stored in the soil and utilized by the vegetation. There is a large amount of available water in the suction interval between 0.1 and 1 bars. This is the most easily available water for the vegetation, and it verifies that the 'koppjord' is very favourable to such water supply.

The upper 20 cm of the soil has been strongly modified by soil weathering. Here the pore system is more graded than deeper down, and there is no such abrupt loss of water in restricted suction intervals. As shown in Fig. 3, the upper part of the soil also has a more graded grain-size distribution. Except for this, it is not possible to find any marked variations in the water content – suction curves related to grain-size variations. And when the samples from high and deep horizons are compared, the total ability to store water is about the same. Small variations in grain-size distribution of the 'koppjord', as for instance due to lamination, thus seem to have only a limited influence upon the soil water retention curves. The difference between the 'koppjord' and the underlying sand is, on the other hand, very marked (Figs. 4 & 7).

Figure 9 shows characteristic soil water budgets for the 'koppjord' and for fluvial sand, marine clay/fine silt and till, which are also found as surface sediments in Solør (Fig. 1). The data are from fluvial sands with median diameters 250–500 μm and a medium content of organic matter, marine clay/fine silt sediments with a clay content of > 20% and silty tills with clay contents below 5%. The special hydrogeological properties of the 'koppjord' are clearly demonstrated and are explained by its sedimentological properties. The sorting is much better than for the till, and makes a much more uniform pore system. Compared with the clay/fine silt, the dominance of silt/fine sand results in a much coarser pore system with more plant-available water. The open and rather coarse pore system is due to the sedimentation in water with no later overconsolidation. In addition to this, the open and rather uniform pore system is also a result of the dominance of equidimensional mineral grains (Fig. 8). Compared with the sand, on the other hand, the 'koppjord' has a rather fine-grained pore system, due to the more fine-grained texture. The ability to store water by capillarity is, therefore, much greater (Figs. 7 & 9). Except for some other related silt soil types of which two were mentioned in the introduction, no other Norwegian soil type has such a high capacity for storing plant-available water.

Soil water budget and soil water modelling

In order to calculate the soil water budget at Haslemoen, a root zone model established by Johansson (1974) has been applied. A computer programme developed by Riley (1984) was used. The model is constructed for calculation of the need for irrigation on cultivated land. It also calculated the percolation from the root zone to the deeper part of the sediment. The model can thus be applied for estimation of the groundwater recharge. So far very few such calculations have been carried out in Norway.

The model structure is shown in Fig. 10 A. The main model output factor is the time when irrigation is needed (IRR in Fig. 10 A). However, the model also calculated the actual evaporation (Ea) and percolation to deeper soil horizons

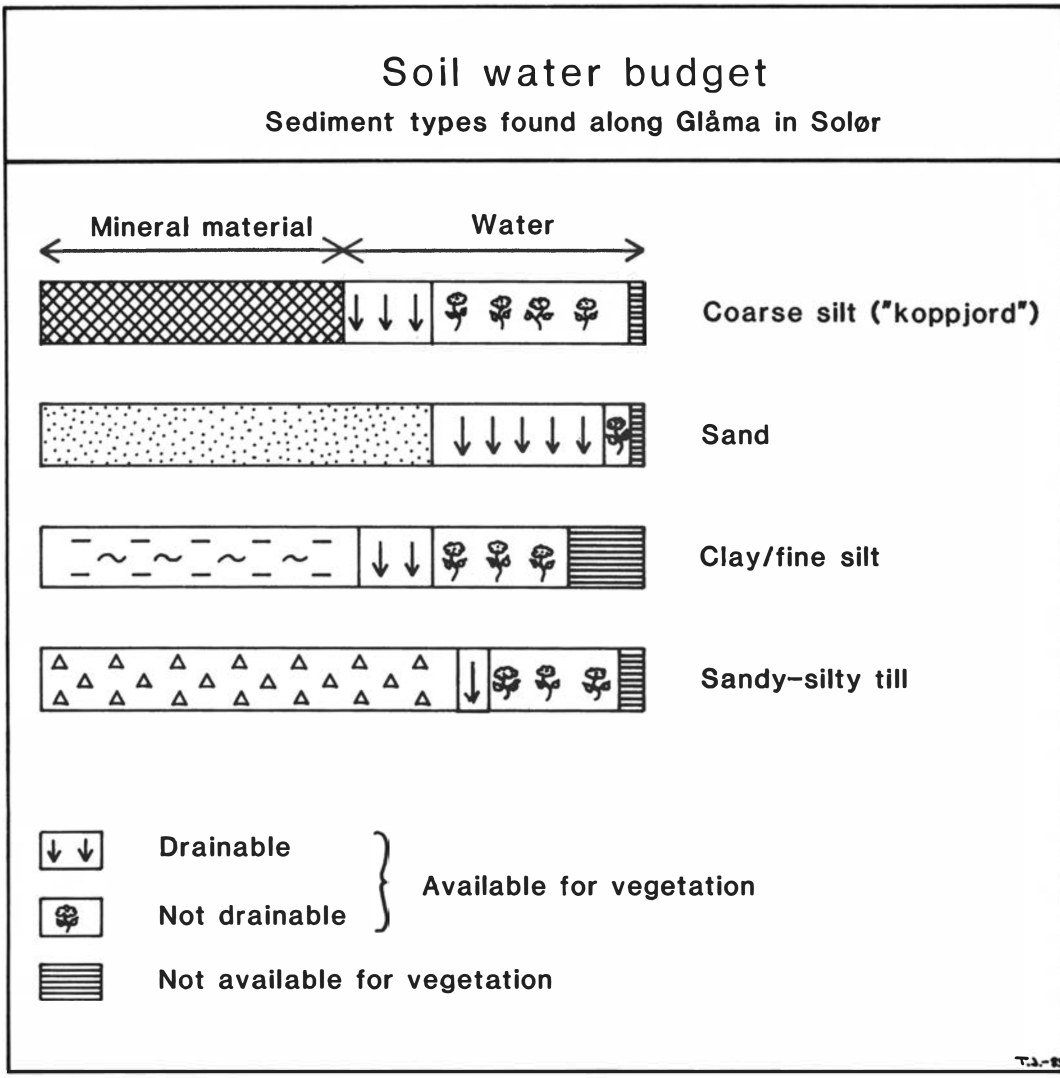


Fig. 9. Water budget for surface sediments of the same types as in Solør. The clay/fine silt data are taken from Njøs (1981), sandy-silty till data are from Myhr (1982) and Haldorsen et al. (1983).

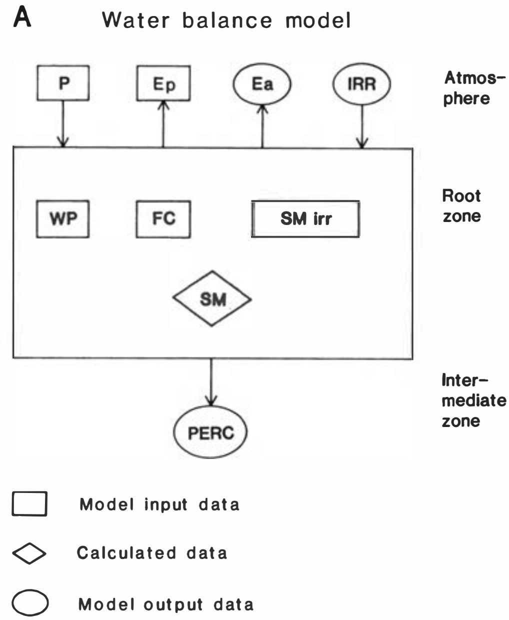
(PERC) from rather simple considerations of the development of the vegetation, the soil surface moisture and the water content in the root zone (SM). The input data for the model are the daily potential evaporation (Ep), precipitation (P), the water retention capacity of the soil (i.e. available but not drainable water in Fig. 7, 'field capacity' (FC) in Fig. 10 A), the soil water content when irrigation is needed (SMirr) and the wilting point (not available in Fig. 7, WP in Fig. 10 A). The type of vegetation, and the dates of sprouting, ripening and harvesting are necessary agricultural data. The basic assumption for the model is that the soil water magazine has a maximum content of non-drainable water ('field capacity', FC) at the beginning of spring (i.e. SM = FC). This water, and water supplied by the summer precipitation, makes up the water available for the vegetation during the growing season. If the water content is higher than FC, there is a percolation to the intermediate zone beneath the root zone (PERC > O), otherwise the loss of water is due to evapotranspiration alone (PERC = O).

The calculations at Haslemoen were made for a barley field at the main terrace (Fig. 2, site B). Here the silt thickness varies between 55 and 70 cm. The whole silt horizon can be considered as a root zone, since the silt has a high content of easily available capillary water (Fig. 7) and an unsaturated hydraulic conductivity which is high enough to transport more than one mm each day to the soil surface from the lower parts of the silt (cf. Hillel 1980b, p. 115). By applying the curves in Fig. 7, the available but not drainable water content is minimum 35% and maximum 45% of the volume. A silt depth of 55 cm gives a water retention capacity (FC-value) of minimum 190 mm and a depth of 70 cm gives a maximum of 300 mm. These values were used in the model to give the maximum and minimum of available water. In addition a water content of 45% and a root zone depth of 60 cm were used to illustrate an 'average' situation. The calculations were made for the growing seasons 1970–83. The meteorological data used in the model are from a station at Flisa (Fig. 1), and the potential evaporation was calculated by S. L. Lystad, the Norwegian Meteorological Institute.

The criterion for start of irrigation (SMirr in Fig. 10 A) is a suction exceeding 1 bar. This is the most commonly used criterion in Norway at present. A quantity of 30 mm water is then supplied by irrigation.

The computer calculations showed that there was never any need for irrigation, not even in the years 1970, 82 or 83 when the middle of the summer was very dry (Fig. 10B). This was the result for all three input data sets (minimum, maximum and average situation) when the 'koppjord' is more than 0.5 m thick. This conclusion is also verified by the farmers at Haslemoen. As a comparison, calculations were done for sand, fine silt/clay and sandy – silty till of the same type as shown in Fig. 9 (Fig. 10B).

For the sand the model indicates on the average 14 days with tension above one bar per year, if there was no irrigation. When the sand is irrigated according to the criterion given above, there is an average need for irrigation of 30 mm each summer. The corresponding values for the clay are 30 days and 40 mm. Even for the till, which is the soil type most equal to the 'koppjord', the calculation indicates some days with need for irrigation during the driest years (Fig. 10B). The model thus very clearly reflects the special soil water characteristics of the 'koppjord', and verifies what was indicated by the water retention studies (Fig. 9).



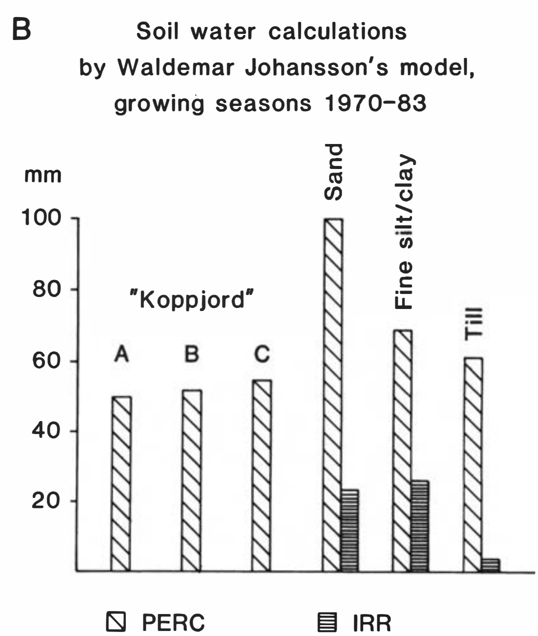


Fig. 10. A. Model structure showing input and output data in Waldemar Johansson's soil water model. P = percolation, Ep = potential evaporation, Ea = actual evaporation, IRR = date of need for irrigation, WP = wilting point, FC = 'field capacity', SMirr = water content when there is need for irrigation, SM = actual soil moisture, PERC = percolation to zones beneath the root zone, i. e. groundwater recharge. B. Results of the model simulation. Need of irrigation (IRR) and groundwater recharge (PERC) are given as annual averages in mm per year for the period 1970–1983.

The annual groundwater recharge is equal to the total percolation (PERC) during the year (Fig. 10B). From the harvesting one year to the date of sprouting the next year the evaporation was set equal to the potential evaporation (Ea = Ep). This gives a minimum recharge, since the evaporation may be less than Ep, even during the winter. An average percolation (PERC) for the years 1970–83 was found to be approximately 300 mm. Of this, a percolation of about 50–55 mm was the estimate for the growing season (Fig. 10B). In order to control these values, neutron access tubes have been used for measurements of the water content from the root zone down to the groundwater level. Measurements during the period 1982–1985 indicate that the model output data are realistic. In comparison, the model indicates a percolate of 100 mm each summer from the sand, 70 mm from the fine silt/clay and about 60 mm from the till. The values are calculated for the case in which there is no supply of water by irrigation. During summer the 'koppjord' is thus a more efficient magazine for storage of the supplied precipitation than the other sediment types.

A common idea has been that there is a deficit of water in the root zone during the summer months in southeastern Norway. It has been supposed that very little groundwater recharge then occurs (e.g. Englund 1980, p. 35) The applied model, in contrast, indicates that most years a significant groundwater recharge occurs even during the summer months.

During those parts of the year when soil moisture (SM) > 'field capacity' (FC), the infiltration, percolation and thus also the groundwater recharge are controlled by the maximum infiltrability of the 'koppjord'. Those parts of the sediment which are not altered by soil weathering have the lowest steady state infiltrability. The field tests carried out at one metre depth should thus give the infiltrability values of interest. The tests indicate that at least 100 mm water can be drained through each unit area (m^2) of the 'koppjord' each day when the values given in Fig. 6 are recalculated to a temperature of 5°C. The 'koppjord' has thus not only a particularly high water retention capacity, but it also has a pore system which allows a rapid drainage of excess water. Surface ponding does not therefore occur, even in the spring, in areas where the 'koppjord' is found in its natural condition and is not artificially compacted by heavy vehicles.

Acknowledgements – Valuable comments and constructive criticism have been given by Per Jørgensen and Jens-Olaf Englund. Åslaug Borgan drafted the figures and Marie-Louise Falch typed the manuscript. Linda Hjeljord corrected the English text. To these persons we tender our sincere thanks. Financial support was provided from the Norwegian Research Council for Agriculture and from the Norwegian National Committee for Hydrology.

Manuscript received March 1986.

References

Bjørlykke, K. O. 1901: Om jordbunden i Solør. *Tidsskr. f. det nor. landbrug 8,* 604–613.

Englund, J.-O. 1980: *Generell hydrogeologi.* Landbruksbokhandelen, Ås, Norway. 136 p.

Folk, R. L. & Ward, W. C. 1957: Brazos river bar: A study in the significance of grain size parameters. *J. Sed. Petr. 27,* 3–26.

Goffeng, G., Haugen, L.-E. & Løwe, A. 1980: Løsmassekart Flisa, DC061 1:10 000. Prøvekart, Jordregisterinstituttet. *Nor. geol. unders.*

Goffeng, G., Løwe, A. & Haugen, L.-E. 1981a: Løsmassekart Hovelsåsberget C 061 1:10 000. Prøvekart, Jordregisterinstituttet. *Nor. geol. unders.*

Goffeng, G.-E., Løwe, A. & Haugen, L.-E. 1981b: Løsmassekart Hovelsåsberget & Hollarberget, CY061-CY062, 1:20 000. Prøvekart, Jordregisterinstituttet. *Nor. geol. unders.*

Haldorsen, S., Jenssen, P. D., Køhler, J. Chr. & Myhr, E. 1983: Some hydraulic properties of sandy/silty Norwegian tills. *Acta. Geol. Hisp. 18,* 191–198.

Hazen, A. 1893: Some physical properties of sands and gravels with special reference to their use in filtration. *Ann. Rep. Mass. State Bd. Health 24,* 541–556. Boston.

Hillel, D. 1980a: *Fundamentals of Soil Physics.* Academic Press, New York. 413 p.

Hillel, D. 1980b: *Applications of Soil Physics.* Academic Press, New York. 385 p.

Holmsen, G. 1954: Oppland. Beskrivelse til kvartærgeologisk landgeneralkart. *Norg. geol. unders. 187,* 58 p.

Høye, T. & Sand, M. 1983: Geofysiske undersøkelser av kvartære sedimenter ved Haslemoen og Flisa, Hedmark. *Unpubl. thesis. Dept of geology, Univ. of Oslo,* 125 p.

Jenssen, P. D. 1982: Selection of disposal sites in Norway. *In:* Eikum, A. S. & Seabloom, R. W. (eds.): *Alternative Wastewater Treatment,* 199–212. D. Reidel Publ. Co. London.

Jenssen, P. D. 1986: *Infiltration of wastewater in Norwegian sediments – some design criteria for wastewater infiltration systems.* Dr. Scient. thesis, Agricult. Univ. Norway.

Johansson, W. 1974: Metod för beräkning av vatteninnehåll och vattenomsättning i odlad jord med ledning av meteorologiska data. *Grundforb. 26,* 57–153.

Kessler, J. & Oosterbaan, R. J. 1974: Determining hydraulic conductivity of soils. Drainage principles and applications. *ILRJ. Publ. 16. Vol. III,* Wageningen, Netherland.

Longva, O. 1984: Romeriksmjelen danna ved ein storflaum på Austlandet for vel 9000 år siden. *Nor. geol. unders. – Årsmelding 1984.*

Longva, O. 1986: Ullensaker. Beskrivelse til kvartærgeologisk kart 1915 II – 1:50 000. (With colour map). *Nor. geol. unders. Skr. 76.* (in print).

Myhr, E. 1980: Glommas innvirkning på grunnvatn og avling i Odalsområdet. *Meld. Norg. Landbrukshøgsk. 59,* 56 p.

Myhr, E. 1982: Virkningen av Otta på grunvatn, markvatn og avling. *Dept. of agricult. hydrotechnics. Agricult. Univ. Norway,* Rep. 2 – 1982, 98 p.

Nielsen, J. T. 1983: *Kvartærgeologi og hydrogeologi i Haslaområdet, Våler i Solør.* Unpubl. thesis, Dept. of Geol. Univ. of Bergen, 85 p.

Njøs, A. 1981: *Jordfysikk. Notater om definisjoner og formler, størrelser og enheter, lagring av vann.* Landbruksbokhandelen, Ås, Norway.

Reynolds, W. D., Elrick, D. E. & Topp, G. C. 1983: A reexamination of the constant head well permeameter method for measuring saturated hydraulic conductivity above the water table. *Soil Sci. 136,* 250–28.

Reynolds, W. D., Elrick, D. E. & Clother, E. B. 1985: The constant head well permeameter: Effect of unsaturated flow. *Soil Sci. 139,* 172–191.

Riley, H. 1984: Modeller til beregning av vanningsbehov hos jordbruksvekster. *In:* Ziegler, T. (ed.): Aktiviteter på markvannssektoren i Norge. *Norsk hydr. komité rapport 16,* 13–27.

Sortdal, K. K. 1921: Jordbunden i Solørdalføret. Det kgl. Selsk. for Norges Vels jordbundsutvalg. *Jordbundsbeskrivelse 18,* 39 p.