Nordic Hydrology 6, 1975, 63–72
Published by Munksgaard, Copenhagen, Denmark

THE RATE OF SPREAD OF FUEL OIL NO. 1

BJÖRN SELLBERG

Geological Survey of Sweden, Stockholm

Experiments have been made in the field to determine the way in which fuel oil No. 1 spreads in some common unconsolidated deposits in Sweden, such as esker material, bottom varves of glacial clay and sand on clay. In the investigations, the velocity of fuel No. 1 in reasonably homogeneous medium sand with a good ground water flow was found to be 1.0–1.6 m/day, but usually the velocity was as low as 0.1–0.2 m/day. Experiments covering a longer period showed that the maximum concentration diminished very much in transport up to a distance of about 20 m.

The problem of oil spill on soil is receiving ever increasing attention in connection with environmental problems and ground water conservation. This investigation was initiated at the Department of Quaternary Research, Stockholm University, to obtain some knowledge of the processes involved. The aim of the investigation was to illustrate the behaviour and the rate of spread of fuel oil No. 1 and petrol in various soils. The investigation consisted of 12 different experiments in different soils under different meteorological and hydraulic conditions, and the injected petroleum products were fuel oil No. 1 and petrol. A complete report is to be found in Sellberg (1972). I will here describe three of the experiments with fuel oil No. 1. Three geologically different areas were selected in the Stockholm area, namely Vårby, Frescati and Haga.

Paper presented at the Nordic Hydrological Conference 1974 at Aalborg, Denmark.

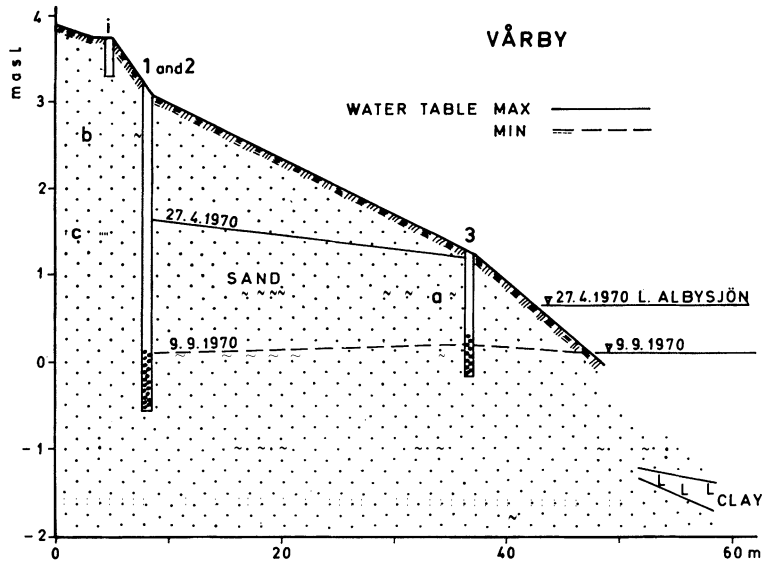

Fig. 1.
Section at Vårby. i ≡ position of injection pit. 1–3 ≡ observation tubes. Tube 2 was 3 m to the side and 4 m from the injection pit.

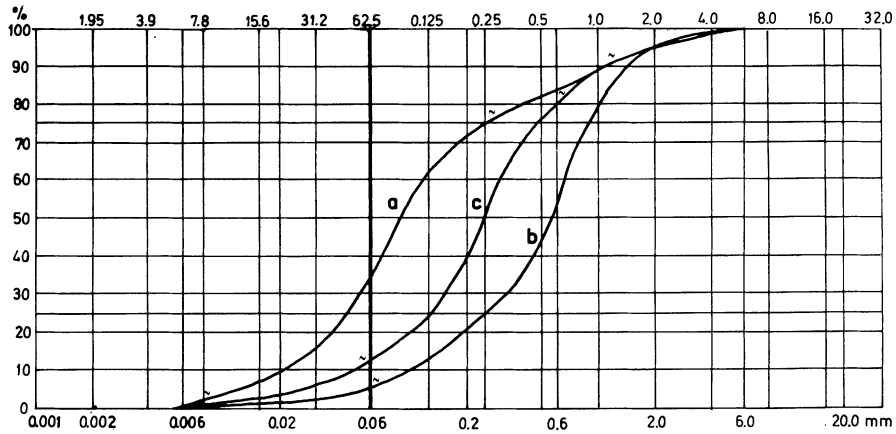

Fig. 2.
Grain size distribution of samples from Vårby. Samples a-c in the section, Fig. 1.

VÅRBY

The Vårby site consists of sand with an almost horizontal unconfined water table (Fig. 1). The sand is layered with varying grain size distribution, (Fig. 2) and this was found to affect the way in which the oil spread. The injected amount was 50 l, allowed to drop over a period of 10 days. The result is shown in Fig. 3. Some 36 days after injection a very distinct concentration maximum is registered in tube 1. A calculation of speed gives the value of 0.14 m/day. The oil remained for a long time in the soil around this tube. Thus, 8 months after injection, a concentration of 0.36 mg/l was registered in tube 1 and this "last wave" gives a velocity of 0.03 m/day. At the end of April, 1970, a concentration of 0.3 mg/l was registered in tube 3, giving a velocity of 0.15 m/day, as the distance between this tube and the point of injection was 31 m.

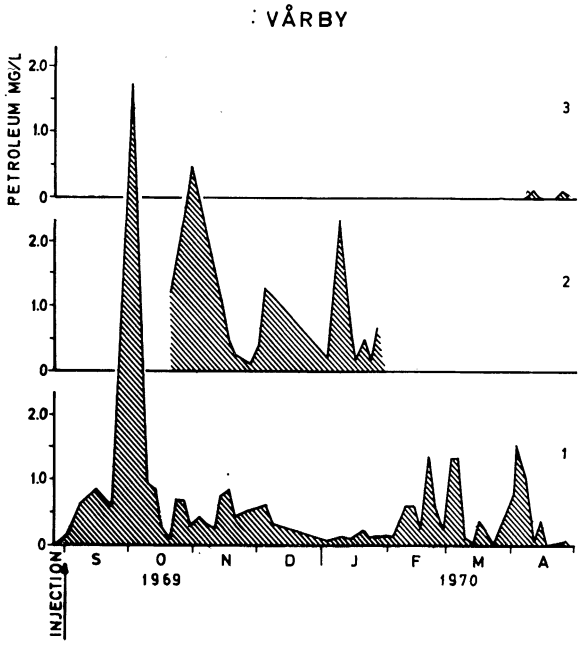

Fig. 3.
Graphs showing the variation in oil content in water samples collected at Vårby. 50 liters of oil were gradually injected drop by drop during the period from the 27th of August to the 5th of September, 1969. Samples were collected until the 27th of April, 1970, continuously in tube 1 and periodically in tube 3.

FRESCATI

At Frescati the sandy bottom varves of the glacial clay were studied. Here there is a confined ground water flow under the clay. The position of the perforated part of the observation tubes is marked with rings (Fig. 4). An amount of 40 l of oil was poured into the tube marked "i" and samples were taken in tubes 1–5. The experiment started on the 28th of August, 1969 and continued until the 25th of April, 1971. The concentration versus time in tubes 2–5 is shown in Fig. 5, calculated with moving averages of five values. The graphs illustrates

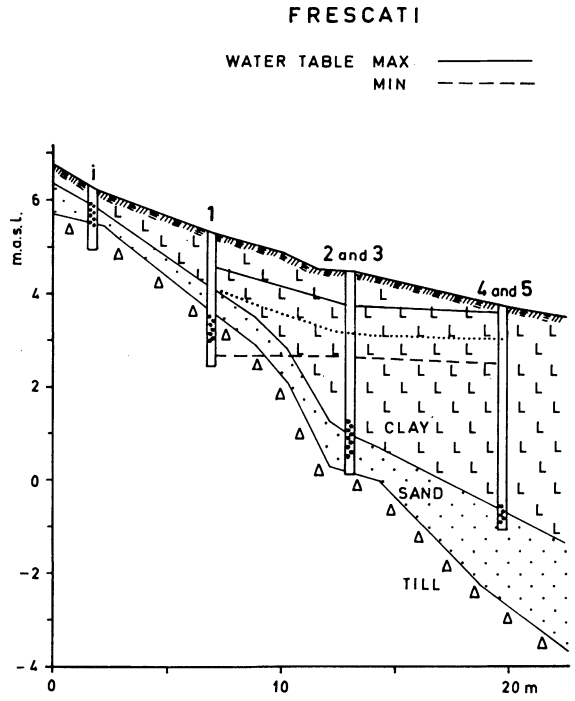

Fig. 4.
The Frescati section. i ≡ injection tube. 1–5 ≡ observation tubes. The rings on the tubes indicate the perforated part. The approximate depth of the dry surface layer of clay is indicated by dots. Tubes 3 and 5 were situated at the same distance as tubes 2 and 4 respectively, but were 4 m to one side.

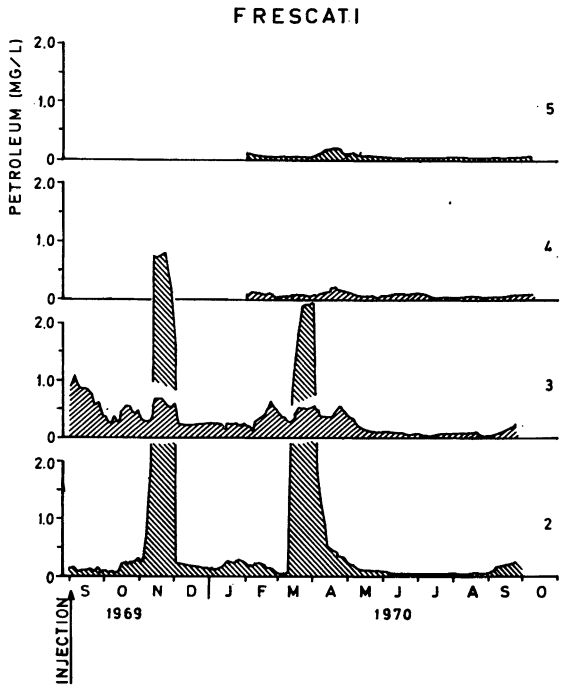

Fig. 5.
Variation in oil content at Frescati expressed in the form of moving averages of five values. 40 l of oil were poured into "i" on the 20th of August, 1969.

the variation up to the 24th of September, 1970. After that, samples were taken periodically. The figure shows clearly the high peaks in tube 2 during November 1969 and at the end of March and the beginning of April 1970. The first peak is probably connected with great amounts of rain during the autumn and the second one is probably connected with the snow melting. The first peak can be seen in tubes 4 and 5 in April 1970. The calculated speed in tube 2 is 0.16 m/day up to the first peak and about 0.05 m/day up to the second. It is interesting to note that the concentration is much lower in tube 3 than in tube 2, although the high concentration occurs at the same time. The concentration decreases considerably on the way from tube 2 to tube 4, probably due to dilution of the oil by ground water. The small peaks in tube 4 and 5 gave a velocity of 0.08 m/day.

HAGA

The third area, Haga, consists of sand on clay (Fig. 6) with a good ground water flow near the ground surface. The injected amount was 20 l. After 2 days a concentration of about 8 mg/l was registered in tube 2 while a concentration of about 1.5 mg/l was noted in tube 1 (Fig. 7). A calculation of speed here gives 0.3–1.6 m/day (1.6 m/day refers to the velocity of the oil front and the figure 0.3 m/day is the speed of the back part of the first peak). The second rise, occurring around the 20th of July, gave a velocity of 0.16 m/day. It is possible to discern a third rise at about the 10th of August in tube 2, having a speed of 0.09 m/day.

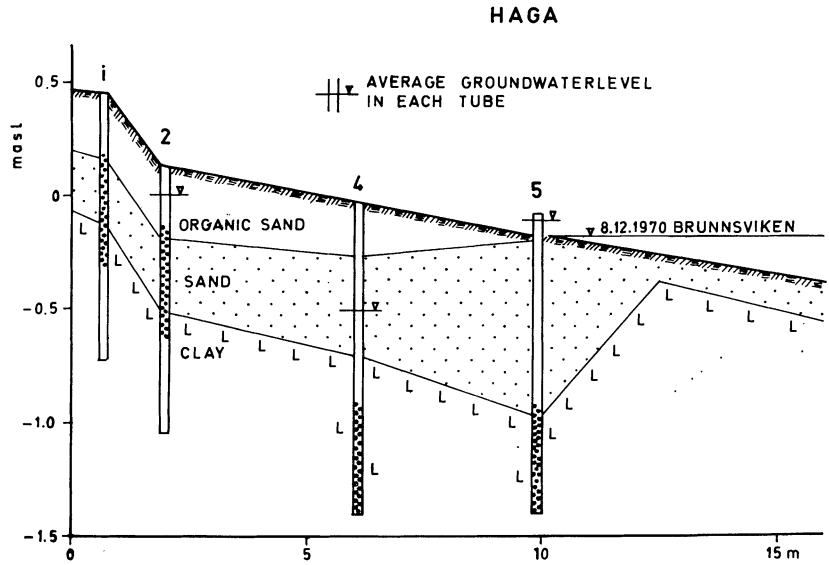

Fig. 6.
Section at Haga. i = injection tube. 1–5 = observation tubes. The rings on the tubes indicate the perforated part. Tubes 1 and 3 were situated at the same distances as 2 and 4 respectively, but were 3 m to one side.

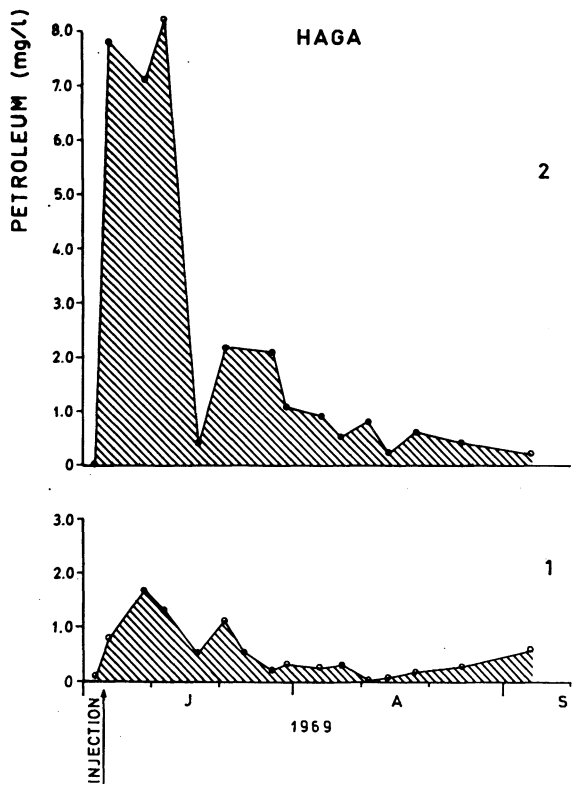

Fig. 7.
Graphs showing the variation in oil content after the injection of 20 liters of oil on the 2nd of July, 1969 at Haga.

METHOD OF ANALYSIS

All these samples were analysed on an IR spectrograph with a detection limit of 0.1 mg/l for water samples and 5 mg/kg for soil samples, although it was easy to discover concentrations far below the detection limit, especially in soil samples. The method has been developed by Lindgren, (1957) and proceeds as follows. The water sample (of about 1 liter) or soil sample (ca. 100 g) is extracted with tetrachloromethane (CCl_4) and then chromatographed through Al_2O_3 before analysing on the IR spectrograph. The chromatography is necessary to eliminate

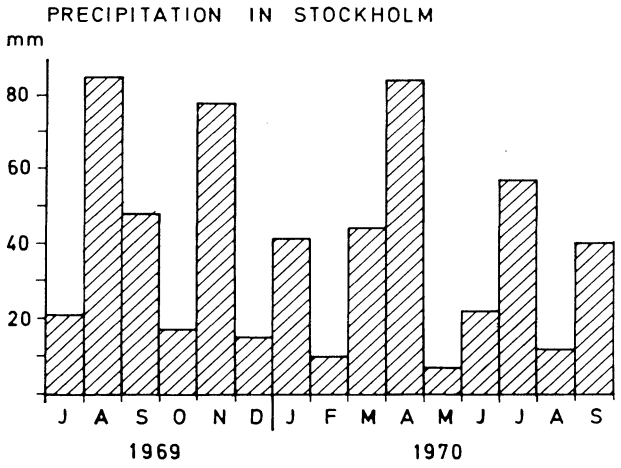

Fig. 8.
Monthly precipitation in Stockholm, July 1969 – September 1970. (Information from Swedish Meteorological and Hydrological Institute, Stockholm).

the polarized hydrocarbons, which originate from the soil and not from the pertoleum product injected. This method does not tell us how much of the fuel oil is dissolved in water. According to Carlsson (1966), the solubility of fuel oil No. 1 in water is about 20 mg/l. The maximum concentration found in water samples was 23.6 mg/l.

CONCLUSIONS

The velocity calculations are based on the shortest route from the injection point to the sampling point. The soil might have followed a longer route, but the figures will still answer the question of how long it took for the oil to spread from one point to another in the described sections. The rate of spread may to some extent be influenced by the rate of ground water movement. However, if there is an accidental oil spill on soil, the point of interest is the total rate of spread, irrespective of the mechanism.

The route of spreading via ground water has been deduced from the existence of permeable layers and their gradients. The route followed by the oil above the water table showed a more irregular pattern, being dependent on local factors such as the slope of the layers, cracks, and holes left by worms and roots.

The results give some idea of the way, and the speed at which, oil spreads and becomes diluted in unconsolidated deposits and ground water. An interesting observation was that considerable increases in oil concentration were repeatedly registered in the observation tubes. The oil must have advanced at an uneven rate, probably corresponding to the varying permeability of the layers through which it passed while following different routes. Large and varying amounts of rainfall have probably also penetrated the upper soil layers and transported the oil to the tubes with accordingly different velocities (Fig. 8).

DISCUSSION AT THE CONFERENCE

The comparison between fuel oil No. 1 and other hydrocarbons, for example petrol, was discussed, and my experiments, (Sellberg 1972), with petrol showed that petrol moves much slower than fuel oil No. 1, e.g. 0.03–0.04 m/day compared to ca. 0.14 m/day for fuel oil No. 1 in the same medium.

There was also a question about the spreading route in Frescati (Fig. 4). The route might follow the sandy layer between "i" and tube 1, but as I got quite a high concentration in tube 1, a considerable amount of the injected oil must have percolated down into the till and been transported to the tube that way.

ACKNOWLEDGEMENTS

Professor Carl G. Wenner, head of the Department of Quaternary Research, Stockholm University, has initiated and supported this investigation with interest.

The oil analyses have been carried out with the IR spectograph at the National Institute of Public Health, now National Environment Protection Board.

The investigation has been mainly financed by grants from the National Environment Protection Board.

REFERENCES

Carlsson, A. (1966) Oljeskador på yt- och grundvatten. Ing. vetensk. Akad. Medd. Oljeskadegrupp, Stockholm.

Lindgren, C. G. (1957) Measurements of small quantities of hydrocarbon in water. *J. A.W.W.A. 49,* 55–62.

Sellberg, B. (1972) Petroleumprodukters spridning i jordlager. Summary: The spreading of Petroleum Products in Earth Layers. Thesis, The Department of Quaternary Research, Stockholm University.

Received September 1974.

Address:
Dr. Björn Sellberg,
Geological Survey of Sweden,
Box 2048,
S-183 02 Täby,
Sweden.