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## THE APPLICATION OF PERMANENT ELECTRODE SYSTEMS FOR GROUNDWATER SALINITY INSPECTION.

### 1. INTRODUCTION

Since 1963 a number of permanent electrode systems have been installed in the Netherlands for groundwater salinity inspection. They have been placed in boreholes in groundwater extraction areas and spread horizontally at a certain depth in infiltration areas.

The electrode systems consist of a multi strand special cable, onto which a number of electrodes are attached in pairs, each pair forming an observation point. By means of a simple earth resistivity meter or more elaborate equipment the electrical formation resistivity at the location of an observation point can be determined. From this resistivity the total salt content and, in many cases, the chloride content can be deduced.

The construction of the electrode systems, the method of operation and interpretation and some examples are described below.

### 2. DESCRIPTION OF THE MEASURING SYSTEM

An electrode system consists of a 14-strand or 26-strand cable, onto which helical electrodes are attached in pairs. The construction of the cable prevents the penetration of water, which may lead to corrosion and destruction of the system. The space between the strands is filled with a rubber compound; the cores of the strands consist of massive copper wire. Both ends of the electrodes, made of gold plated brass wires wound round the cable, are fixed at the cable by means of plastic muffs baked on the mantle of the cable. The maximum diameter of an electrode is less than 2 cm. The distance between two electrodes forming an observation point is usually 15 cm. The electrode pairs are placed at intervals of 1-10 m, depending on the local conditions and the requirements. As a rule no special measures have to be taken for the installation.

Plastic piezometer screens and tubes do not substantially affect the outcome of the measurements. The same holds true for gravel packs or other refill material. Metal conductors without isolation, however, are prohibited near the observation points.

When carrying out the measurements each time one pair of electrodes is connected with the instrument by means of a selection switch. Two kinds of electrode-

configurations can be applied:

- the two-electrode arrangement
- the four-electrode arrangement

A schematic representation of these configurations is given in fig. 1.

When the two-electrode arrangement is applied and both electrodes are in-hole, the measured resistance  $R_s$  is proportional to the formation resistivity  $\rho_f$ :

$$R_s = K \times \rho_f \quad (1)$$

The constant  $K$  is exclusively determined by the form and measures of the electrodes used and the distance between the electrodes if no polarization sets in at the surface of the electrodes.

Due to pollution of the electrode surfaces polarization is unavoidable. This affects the value of  $K$  in an uncontrollable way. For this reason the two-electrode arrangement is less suited for accurate resistivity determinations at long term. An important property of the arrangement, which in some cases can be an advantage, is the limited volume of material surrounding the electrodes that determines the resistance measured.

In the four-electrode arrangement the condition of the electrodes is theoretically of no importance. Moreover, the volume of material determining the resistivity measured can be varied.

If the two borehole electrodes are placed in a homogeneous medium and the surface electrodes are at an infinite distance, the following relation can be derived from Ohms Law:

$$\rho_f = \frac{\Delta V}{I} \times 4\pi r \quad (2)$$

$r$  = distance between borehole electrodes.

In practice the condition of the homogeneity of the medium will not be fulfilled for the following reasons:

- the medium is not homogeneous - there are varying geological formations; the salinity of the groundwater changes with depth
- at the location of the former borehole the composition and porosity of the material differ compared to the undisturbed formation
- after the drilling operations in the section round the borehole there exists an invaded zone that requires some time (month or years) to vanish.

The geohydrological inhomogeneity is the determining factor in choosing the electrode distance - a relatively small distance is favourable. For practical

reasons a distance of 15 cm has been selected.

As theory and practice point to little or no influence of the disturbed zone at the location of the borehole on the measuring results, the formation resistivity as calculated with formula 2 will be considered to be the true formation resistivity.

The relation between the formation resistivity ( $\rho_f$ ) and porewater resistivity ( $\rho_1$ ) is given by the formula:

$$\rho_f = F \times \rho_1 \quad (3)$$

The formation factor  $F$  is independent of the porewater resistivity for "clean" sands.

For clayey sands and clays the following relation has been found empirically by Hill and Milburn (1):

$$\log F = \log F_{.01} + b(\log 100 \rho_1)^2 \quad (4)$$

$F_{.01}$  is the formation factor extrapolated to a hypothetical salinity solution resistivity of 0.01 Ohmm;  $F_{.01}$  is determined by porosity.  $b$  is a function of cation exchange capacity and pore volume.

If the formation factor is known, the resistivity of the porewater can be calculated from the formation resistivity determined when dealing with clean sands. From the water resistivity the chloride content can be deduced if some additional information about the groundwater at a certain location is available.

The procedure described above will be elucidated in the following examples.

### 3. SOME EXAMPLES

#### a. Gauge in dune area (Isle of Goeree-Overflakkee)

The electrode system has been placed together with three piezometers in an observation well. Two of the piezometer screens are in the fresh water zone. The formation enclosing the lower part of the fresh water zone and the brackish zone consists of coarse sands. The formation factor of these sands can be calculated from the formation resistivity determinations by means of the electrode system and the resistivity of the water samples, taken through the piezometers.

#### Literature:

(1) Hill, H.J., and Milburn, J.D., Effect of Clay and Water Salinity on Electrochemical Behavior of Reservoir Rocks, Petroleum Transactions AIME, Vol. 207, 1956

As the formation is "clean" the formation factor can be considered to be a constant.

The fresh water in the area contains exclusively some sodium chloride and bicarbonates. The bicarbonate concentration varies between 250 and 550 ppm; an increase with high chloride concentrations cannot be established. For this reason the groundwater in the brackish zone can be taken as dilute seawater with a certain bicarbonate content.

The chloride content can be derived from the water resistivity with an accuracy of approximately 70 ppm chloride, being the equivalent of 200 ppm bicarbonate. The results obtained with the four- and two-electrode configurations immediately after completion of the well and after one year are shown in fig. 2. The two-electrode measurements immediately after completion of the well point to the presence of an invaded zone, which is dissolved after a year. At that moment the two- and four-electrode measurements give virtually the same results; this can be taken as a proof for the statement that the apparent resistivity found with the four-electrode configuration can be considered to be the true formation resistivity.

#### b. Gauge near injection well

An electrode system has been placed in an observation well situated at a distance of 5 m from an injection well (fig. 3).

The resistivity observations show an irregular expulsion pattern of the brackish water in the course of time, pointing to lenses of semi- or impervious sediments (fig. 5).

Fluctuations in the resistivity of the injected water enable the calculation of travel times from the injection well to the observation points of the electrode system (fig. 7).

The formation factor can be determined separately for each observation point. The values found point to a negligible clay content (with the exception of the first observation point); they can be considered independent of the resistivity of the formation water. The relation between water resistivity and chloride content has been established by means of the available water analyses (fig. 4).

The infiltration test has been followed by a recovery test. The brackish water boundary returns in a different shape (fig. 6).

#### 4. CONCLUSION

The results obtained by means of a permanent electrode system regarding ground-water salinity can, to a certain extent, be compared to conductivity measurements on watersamples collected from a number of filter screens. For this reason the permanent electrode systems should not be regarded as a complete alternative to the conventional method of salinity determination by means of filter screens. The main advantage of the use of permanent electrode systems can briefly be summarized as follows:

- The number of observation points is not limited by the diameter of the borehole
- A series of observations takes only a few minutes
- Observations can be done in pervious as well as semi or impervious formations
- The measurements do not affect the groundwater situation as the extraction of water samples does under unfavourable circumstances.

The application of permanent electrode systems leads to a better view on the salinity changes which may occur, and to a considerable reduction of the number of conventional analyses. This means more information at lower cost.

## ABSTRACT

By means of permanent electrode systems groundwater salinity changes caused by water extraction, injection or infiltration can be followed. A permanent electrode system consists of a multistrand cable onto which electrodes are attached in pairs. It is installed in a borehole or spread horizontally at a certain depth. The measuring system is described and some examples are given.

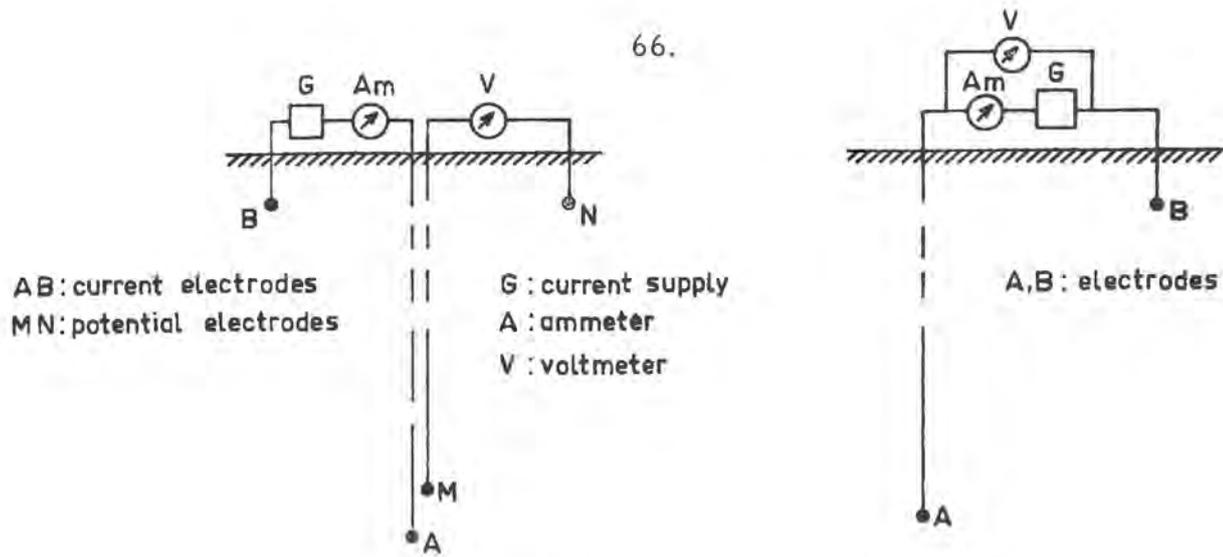


Fig.1 Schematic circuits

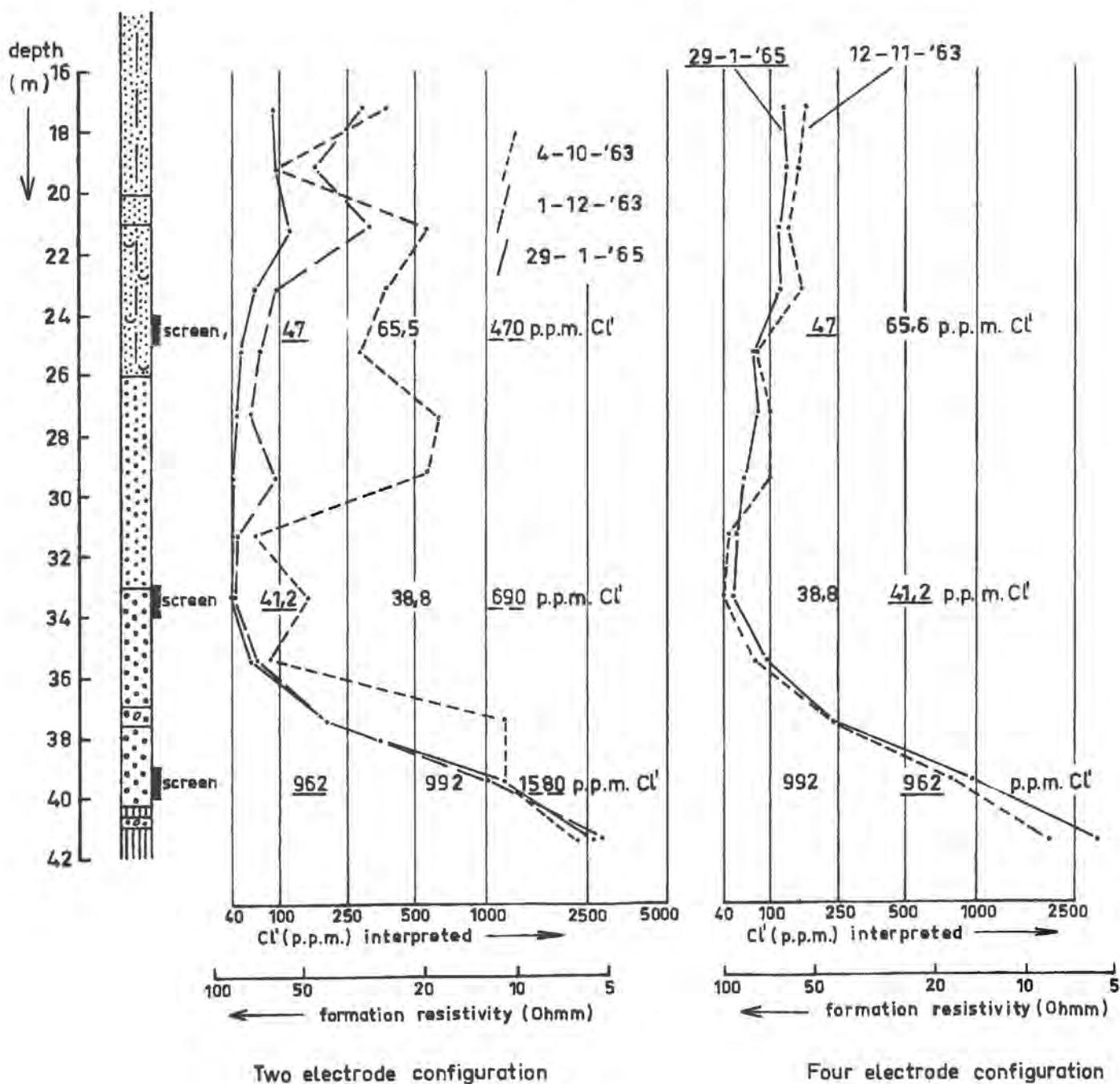


Fig. 2 Some results

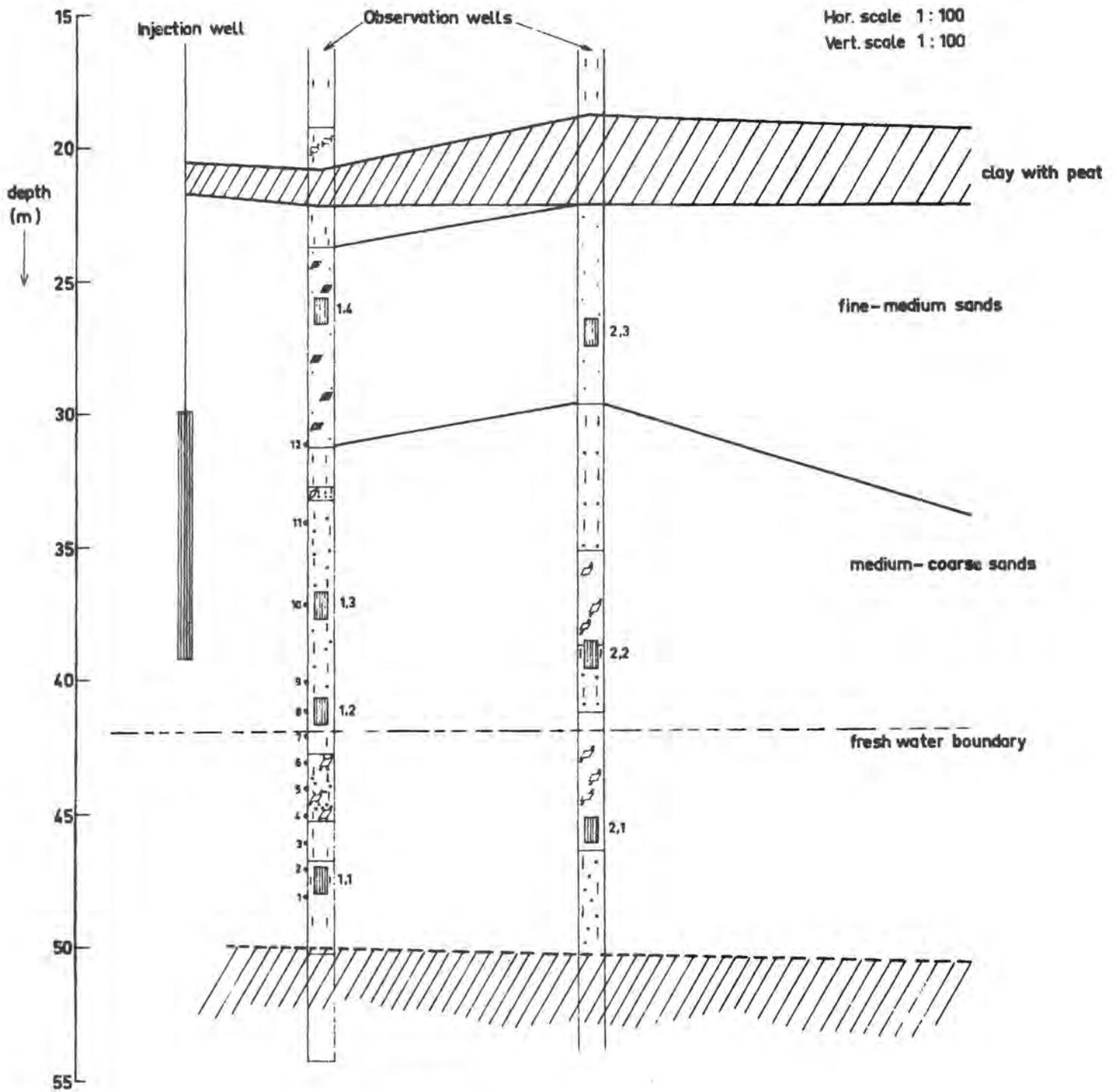


Fig. 3

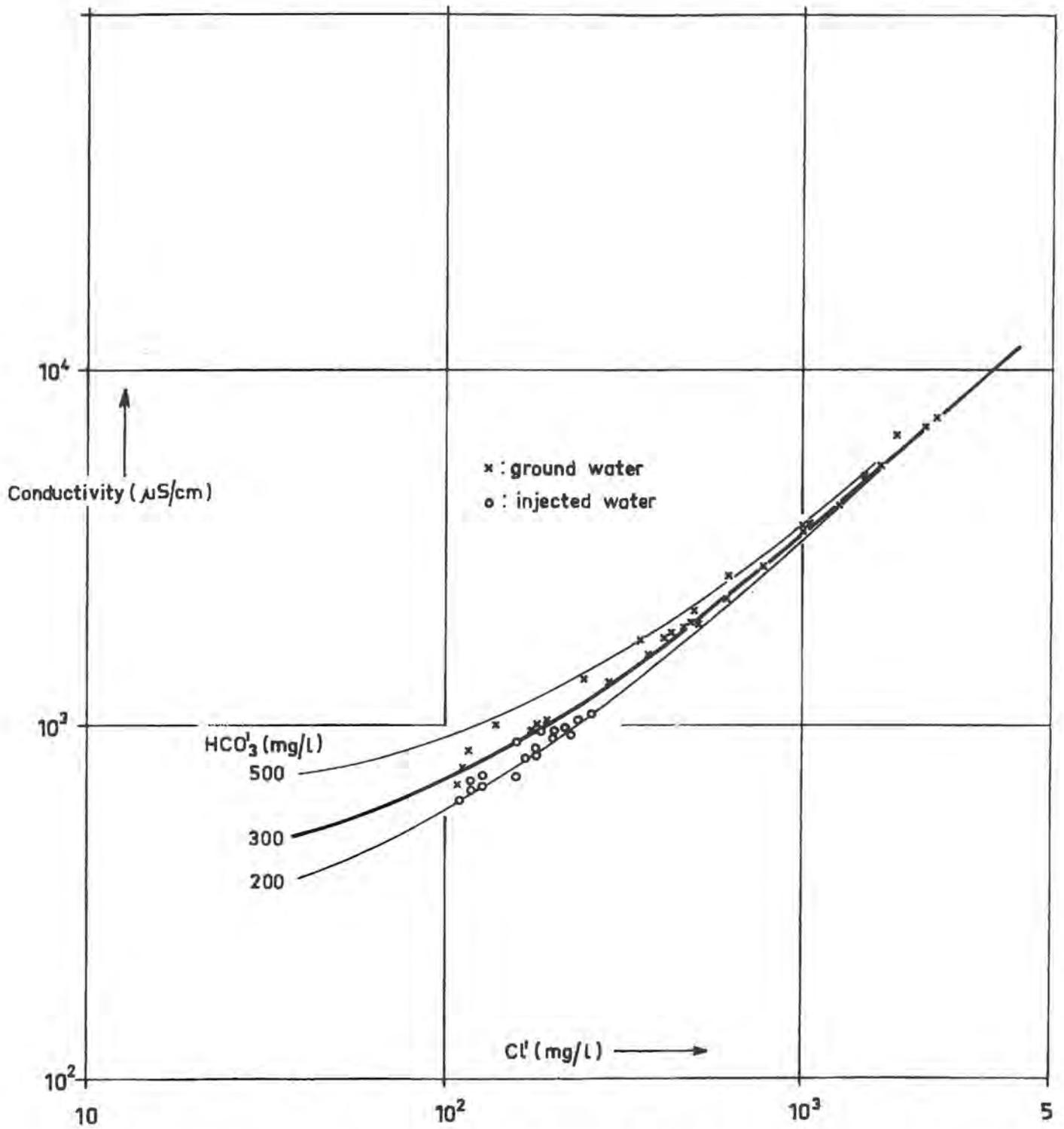


Fig. 4 Relation between conductivity and chloride content of ground water and injected water

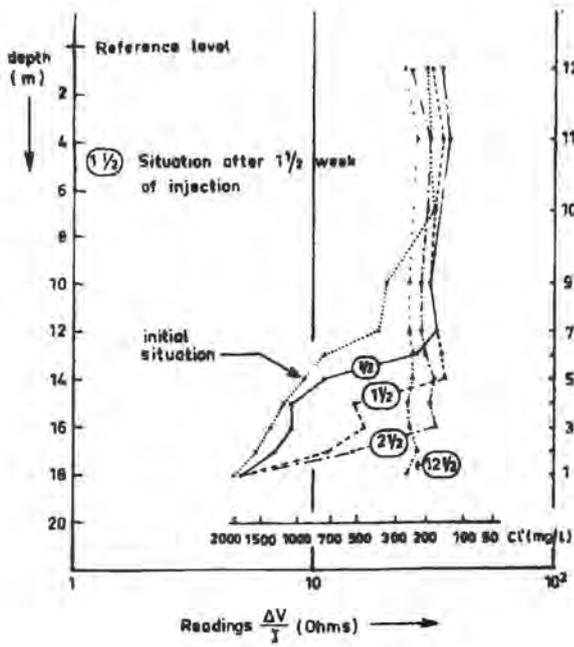


Fig. 5

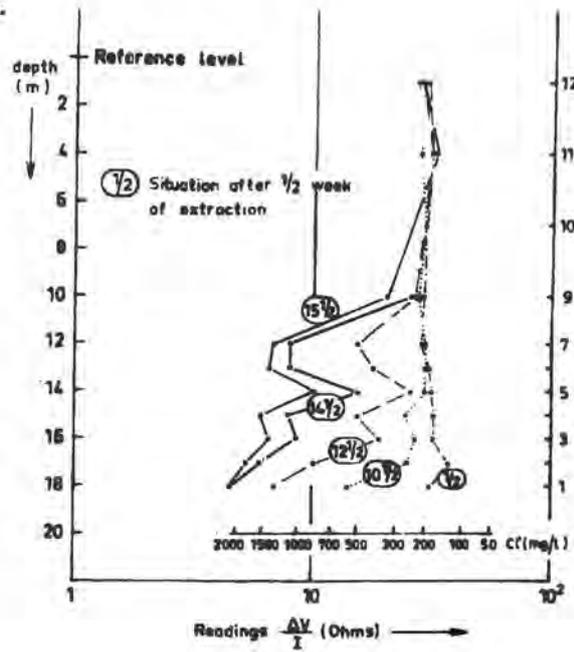


Fig. 6

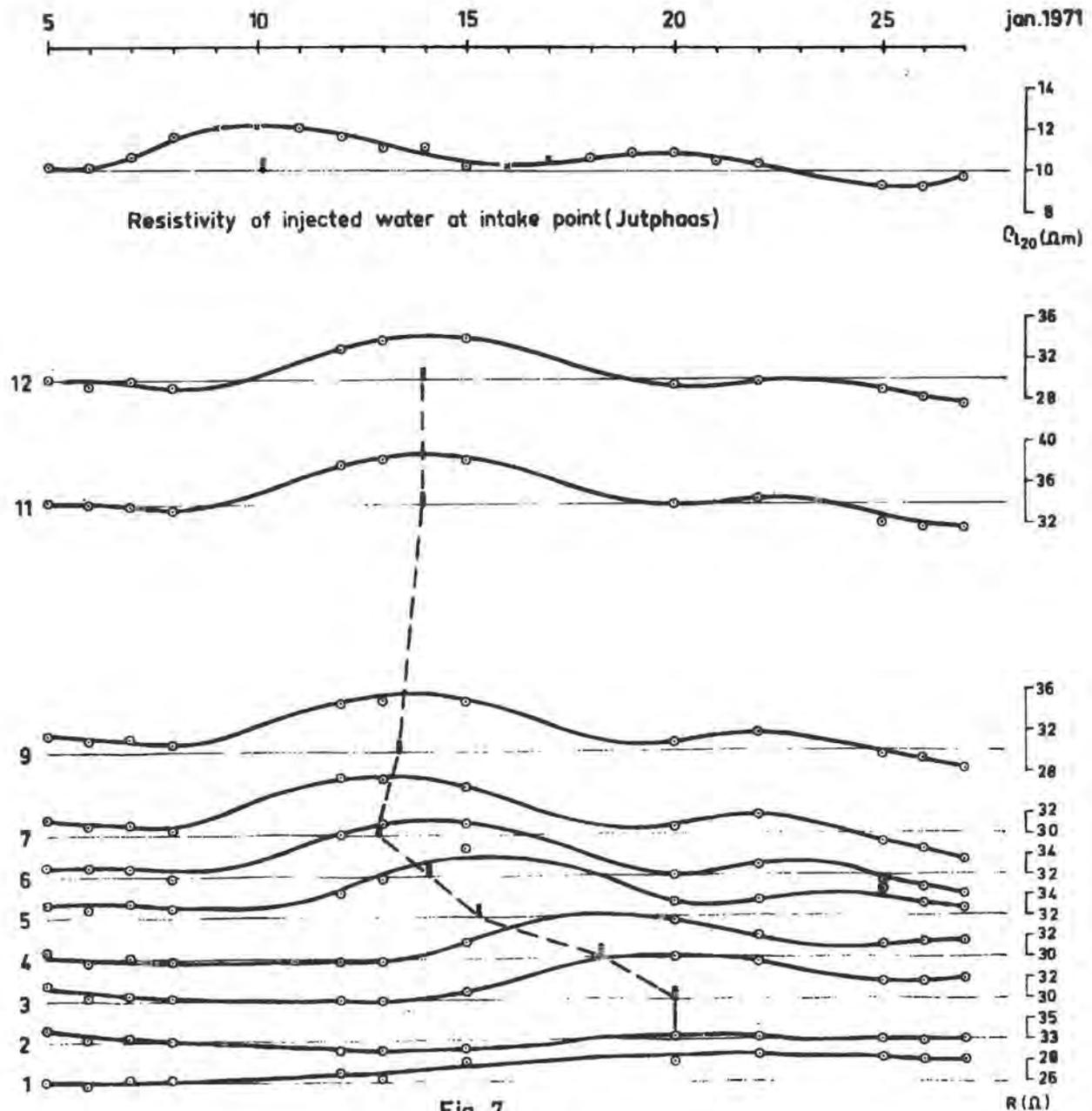


Fig. 7