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Measurements of vertical flow in ground water borings and hydrological parameters for assessing ground water pollution

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ABSTRACT. Some measurements of vertical flow in borings in karst dolomite aquifer by the use of an electro-mechanical device are reported. Field studies undertaken to assess ground water pollution due to releases from a refinery complex, garbage disposal site and a heavily polluted river are described.

1. Introduction

Vertical flow in screened boreholes arises due to presence of different hydraulic heads in an aquifer. This normally exists when different permeable zones are encountered along the depth of a borehole. Vertical currents can also result in a screened borehole whose axis is not perpendicular to the ground water stream lines. Detection of vertical flow in ground water borings is very important as its measurement can furnish vital information in investigations of water production (Drost 1971a), seepage from dams (IfR, GSF 1963, 1964; Moser *et al.* 1963), location of permeable zones (Drost 1971 b) and hydrological communication (Mairhofer 1967). Radioactive tracer logging methods developed by Drost (1970) for detection and measurement of vertical flow have been found more efficient, sensitive and reproducible. For medium and high vertical currents, mechanical devices like described by Fielder (1928) and Meinzer (1928) have also been found efficient and simple to use. In this paper detection and measurement of vertical flow in ground water borings developed at a proposed dam site are described. The objective of determining vertical flow was to study the pressure distribution in the aquifer; inflow and outflow regions and extent of cracks and major fissures in the rock. Such measurements eventually give an idea of sealing measures required at the dam site. The measurements were carried out while using an electromechanical vertical flow measuring device developed at Institute of Geotechniques, Bundesversuchs and Forschungs Anstalt (BVFA), Arsenal, Vienna.

Studies of ground water pollution have been drawing special attention and priority elsewhere during the past few years. Limited use of coloured dyes or electrolytes as ground water tracers has been made in the past. Various radioactive tracers have been extensively used with added advantages in variety of ground water investigations. These investigations employed the recently developed borehole dilution techniques and associated instrumentation which are discussed in literature by Halevy *et al.* (1967) and Drost (1971a, 1973) in detail. It is thus possible to measure velocity and direction of ground water flow in a ground water field at any desired depth of a borehole. Investigations for determination of hydrological parameters, *viz.*, velocity and direction of ground water flow, while using radioisotopes, borehole dilution techniques and associated nuclear instrumentation, are described. These investigations were carried out to assess ground water pollution due to, releases from an oil refinery complex, garbage dump site and a polluted river.

2. Measurement of vertical flow in ground water borings

The site of investigation was a narrow valley about 200 km WSW from Vienna, where a dam was proposed to be constructed. It was proposed to determine the hydrological characteristics of the sub-surface strata and to arrest the discharge of a small river traversing through the valley. A series of boreholes were drilled across the valley. The diameter of boreholes was 4" and casings were provided only upto water table. General plan of the boreholes is shown in Fig. 1. The sub-surface strata of the valley consisted of dolomite rocks with many fissures. The joints were invariably filled with coarse and fine limestone.

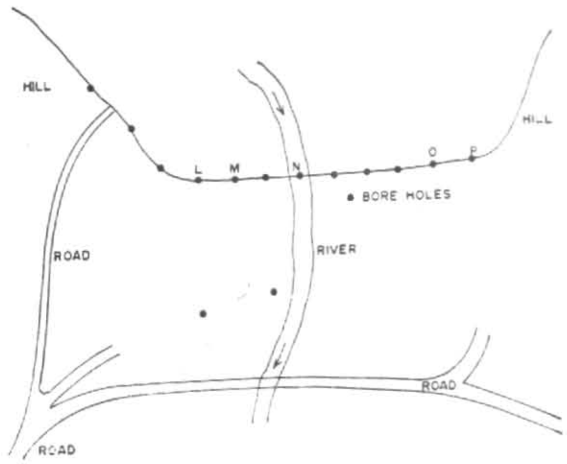

Fig. 1. Plan of boreholes at the proposed dam site

The vertical flow metering assembly developed at BVFA, Vienna (Fig. 2), consisted of a propeller standing vertically on frictionless supports at either ends, two miniatured infrared lamps and two photocells, preamplifier, cable, pulley; the depth meter and specially designed scaler unit. One end of the propeller was provided with semi-circular rubber washer which on rotation with the propeller cut intermittently the light transmission from either of the lamp to the facing photocell. The intermittent photo pulses were converted electronically. The number of rotations of propeller or the number of counts registered by the scaler gave the estimate of vertical flow. An initial calibration of the propeller with simulated flow in pies in laboratory could convert scaler counts into vertical velocity in cm/sec.

The probe rolled down into the borehole by water proof cable through a pulley. The pulley and the cable drum were supported by a detachable triangular stand. The axle of the pulley actuated a mechanical depth meter. The break arrangement provided with the cable drum could stop the descending probe at any desired depth.

The upward or downward flow of water in the borehole rotated the propeller in anticlock or clockwise direction respectively and this direction could be indicated in the direction-indicating lamps provided with the scaler. The intermittent flashes of a central lamp provided in the scaler indicated that the propeller was rotating in the presence of vertical currents. In the absence of any vertical flow no lamp would consequently glow.

Measurement of vertical flow of ground water in the area was made by lowering the propeller assembly to the bottom of the borehole. The probe was raised in steps of 20 cm and the pulses, if any, registered by scaler were recorded, till the water level was reached. The upward or downward flow in the borehole was recorded by seeing the upper and lower lamp indicators of the scaler. Any change in direction of flow at particular depth was noticeable by recording the switching of light from one lamp to another.

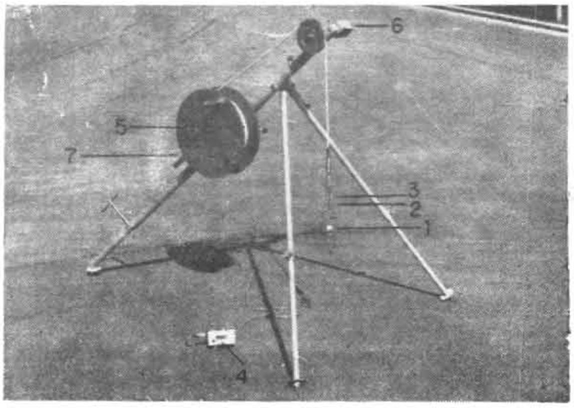

Fig. 2. Electromechanical assembly for detection and measurement of vertical flow of ground water (Courtesy: BVFA, Arsenal, Vienna, Austria)

(1) Propeller, (2) Infrared Emitters and Photocells, (3) Preamplifier, (4) Scaler, (5) Cable Drum, (6) Mechanical Depth Meter, (7) Break Arrangement

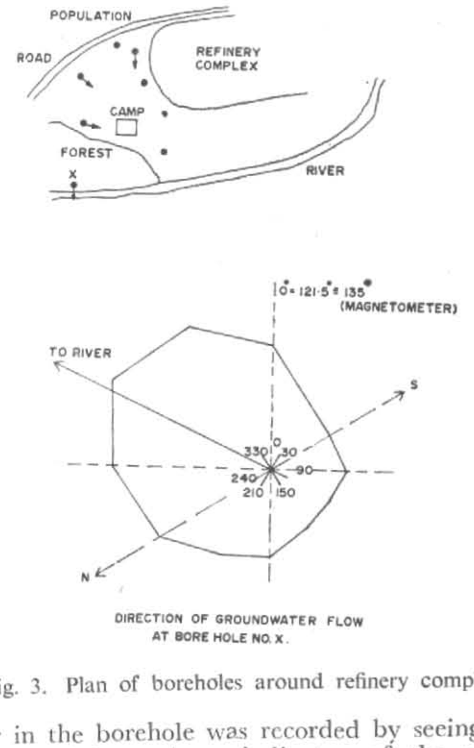

Fig. 3. Plan of boreholes around refinery complex

3. Measurements for assessing ground water pollution

3.1. *Investigations at a refinery complex site*

A number of boreholes of 6″ diameter were drilled around a refinery complex where the local population was using ground water for drinking purpose. Part of the general layout of the investigation site is shown in Fig.3. It was planned to

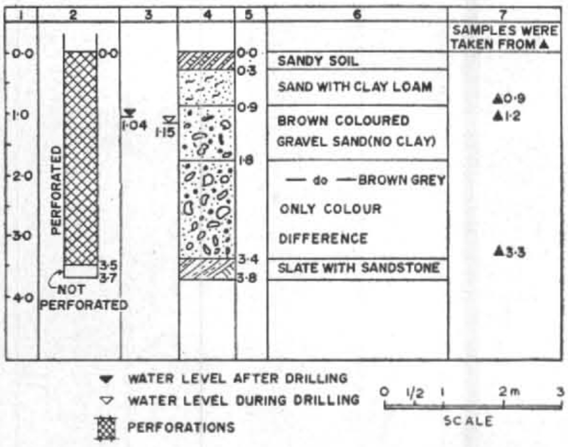

Fig. 4. Typical geological cross-section at borehole X

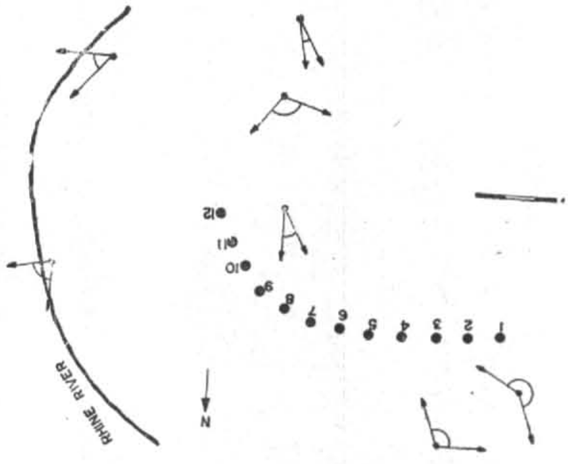

Fig. 5. Well gallery at the bank of river *Rhine*

determine direction and rate of ground water flow in the area so as to establish the hydrology of the area and to study the reported pollution of drinking water.

The study of drilled cores indicated sub-surface layers consisting of gravel, sand and sandstone. Occassional sandy clay was encountered in depths near surface. A typical geological cross-section at borehole X is shown in Fig. 4. The boreholes were having perforated casings with pvc screen and were provided with graded gravel pack. The boreholes were cemented at the bottom. Seeing the geology of the area it was assumed that there would be little possibility of vertical currents and hence only horizontal flow (filtration rate) of ground was investigated regardless of any vertical flow. The filtration rates and directions of flow were measured at the middle of the water column in the boreholes.

Iodine-131 as NaI was used as the tracer. Filtration velocity was determined by manual recording of the counts registered by the scaler while following the dilution of the injected tracer radioactivity. Flow direction were determined by lowering a collimated probe at the depth of injection and recording the activity after manually turning the probe in different orientations.

The equipment used for these studies included, water proof scintillation probe for filtration rate and collimated G.M. probe for direction measurement; mechanical assembly for turning the collimated probe in different directions; tracer injecting device ; scaler ; water level recorder etc. The instruments were portable and battery operated.

3.2. *Investigations at garbage dump site*

The site used for disposal of Munich city garbage is located 15 km away from the city and has been in operation since 1954. Seriousness of the impact of such operation on ground water quality had been recognised for the last few years and many agencies have been operating in this area to evaluate the extent of pollution hazard, the population is beginning to face.

The garbage dump rests on detritus layers with a thickness of about 5 m composed of sandy fine-to-coarse gravels.

A direct contact between the garbage and ground water does not exist. However, numerous temperature and conductivity measurements, chemical and bacteriological tests (Exler 1972) carried out in the past have proved unmistakably that ground water is affected with respect to its chemistry and temperature as it passes through the detritus under the garbage dump.

Consequently series of measurements of various hydrological parameters by the use of radiotracers and associated instrumentation were undertaken. Some interesting findings of measurement of direction of flow at various points are being reported.

An absorbable radioactive tracer solution of chromium^{51} chloride was used. The tracer was injected just below water table by a battery operated device. Measurements of direction were carried out after 24 hours of injection so as to allow adequate absorption of the tracer in and around the boreholes. All boreholes were provided with perforated casings and well graded gravel pack ground them.

The battery operated water proof directional probe housed a scintillation detector and had an overall diameter of 2½″. The collimated shield of the detector could be rotated automatically over 360° by the motor provided in the probe. The other battery operated instrumentation used included, the scaler, recorder and motor starting assembly. Square aluminium rods were

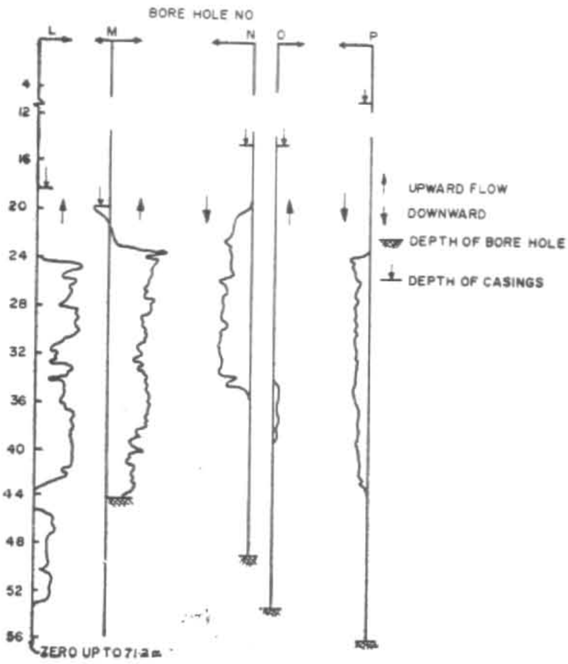

Fig. 6. Vertical flow measurements at the proposed dam site

attached to the probe and it was fixed at the depth of injection. The electronic assemblies mounted in the mobile van were started. The radioactivity registered by the detector while the collimated shield rotated was automatically recorded in the graph. The maxima of the radioactivity indicated in such readily available directional plots, yielded the direction of flow at a particular borehole.

By the use of such an advanced instrumentation and right choice of radiotracer it was possible to inject the isotope in eighteen boreholes scattered in a large area just in three hours and then carry the direction measurements the next day — the measurements totally taking about eight hours to complete.

3.3. *Investigations at the bank of polluted river*

During the last decade the pollution in *Rhine* water has been increasing due to release of both organic and inorganic effluents. This consequently affected many well galleries which are used for supplying drinking water. One of the pumping galleries consisting of twelve wells which are intercepting 20 m thick permeable layers of the aquifer is shown in Fig. 5. The objective of the investigations was to the study the pattern of exchange of ground water and river water.

The field measurements consisted of determining flow directions by single borehole dilution techniques at various depths in the boreholes. Extensive investigations in this area are described in detail by Chandra *et al.* (1977) and Drost *et al.* (1977).

4. Results and discussion

4.1. *Measurement of vertical flow*

Plots of pulses registered by the scaler along the depth of few boreholes are shown in Fig. 6. Upward or downward flow has been represented by plotting the data on right and left hand side of the vertical line respectively. It was interesting to record strong vertical currents which gave vital information of pressure distribution in the typical water bearing karst aquifer; extent of cracks and major fissures in the rock; outflow and inflow regions; possible interconnections and sealing measures required. Regions of no vertical flow were identified with core samples having no joints and cracks. At many points water was just gushing out or in and these depths were located for further detailed investigations, *viz.*, orientation of cracks and faults, population of fissures, filtration rate of water, interconnections etc.

4.2. *Pollution around refinery complex*

Directions of ground water flow measured at the boreholes are indicated by the arrows at the location of a particular borehole (Fig. 3). The counts detected by the collimated G.M. probe at various orientations were plotted and a typical plot for the borehole No. X to deduce the direction of flow is also shown in Fig. 3. The typical dilution curve for the borehole No. X is shown in Fig. 7. The filtration rate at borehole X was quite low as compared to other places. The direction of ground water flow was varying at different places, the direction of flow at borehole X

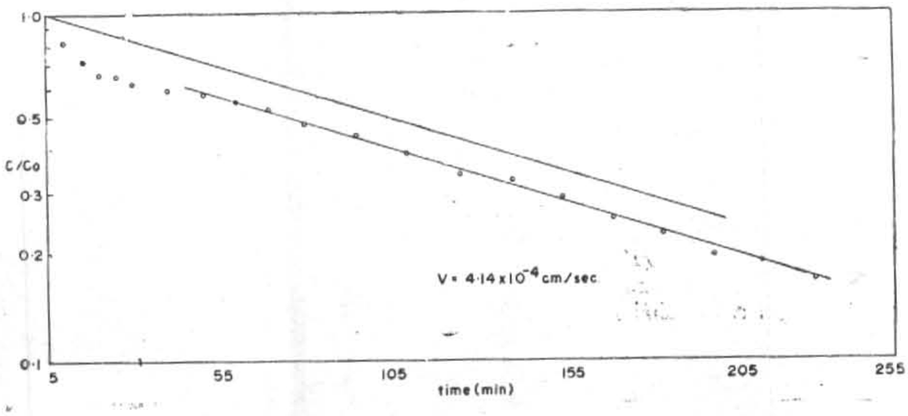

Fig. 7. Filtration velocity measurement at borehole X

being markedly different than at other places. Few boreholes indicated a direction of flow towards a pumping site from where ground water was being used for routine operations of the refinery. Borehole X was outside the influence of the pumped well and the water nearby it appeared to be feeding the river. The filtration rates and direction of flow at other boreholes appeared to be induced by the pumped well. As such there was less evidence of possible pollution of ground water at this part of the complex.

4.3. *Pollution around garbage dump*

The observed flow directions were coupled with the filtration rate data obtained by Drost (1973). The velocity vectors thus obtained at each borehole are shown in the Fig. 8.

The data indicate that beyond 3000 m distance the ground water flows uniformly in a northerly direction. Within this distance most of the flow directions ascertained vary from the main-run-off direction and are also inconsistent in relation to each other. This perhaps is due to the fact that the observation wells are located in part, at the edge of polluted ground water stream where it mixes with colder, less dense ground water and thereby deviates within local limits from general flow direction. Studies by Drost (1973) using radio tracer (NaBr-82) indicated filtration velocities in the range of 1.5 m/day around the garbage dump.

4.4. *Exchange of ground water and polluted river water*

The data of range of variation of direction of flow of ground water from various depths in a borehole are shown in Fig. 5. The data indicate that water from southern part of the catchment area is flowing towards the gallery. Investigations carried out in the eastern region indicate that the boreholes are not within the influence of the pumping gallery as they are exchanging water directly with the river. In the northern part only the bottom

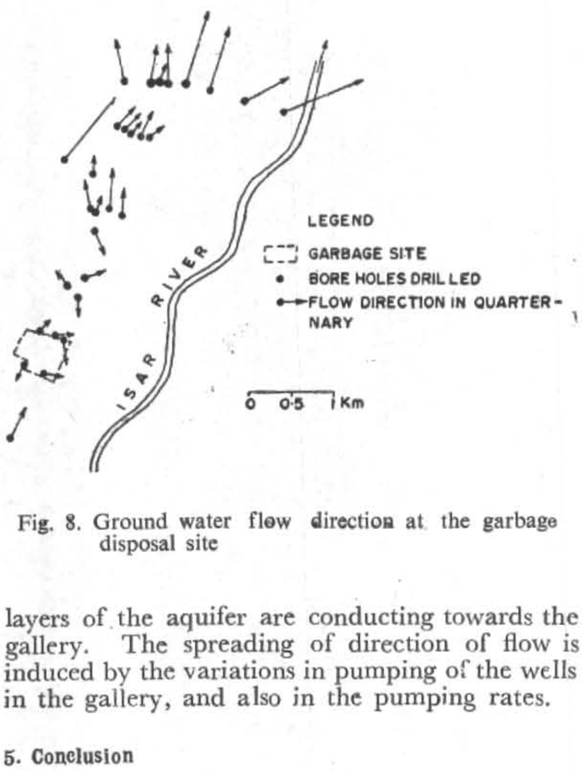

Fig. 8. Ground water flow direction at the garbage disposal site

layers of the aquifer are conducting towards the gallery. The spreading of direction of flow is induced by the variations in pumping of the wells in the gallery, and also in the pumping rates.

5. Conclusion

Detection and measurement of vertical flow in boreholes yields vital hydrological information in an aquifer. It has been possible to study the vertical flow by an electromechanical device. It has also been demonstrated that borehole dilution techniques using radioisotopes and associated nuclear instrumentation can be employed for variety of ground water problems including ground water pollution.

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