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A Landfill Groundwater Study in Christchurch, New Zealand

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SUMMARY A 3 km^2 region in coastal dunes near Christchurch, New Zealand has been chosen as the future site for a landfill scheme that is to begin in 1986. Groundwater levels are very close to ground surface throughout the entire region, which suggests that groundwater pollution might become a problem. Thus, measurements have been taken over a two year period to assess the risk of groundwater pollution. These measurements and the resulting calculations indicate that pollutants are likely to remain in the upper, unconfined aquifer and move seaward with a maximum velocity of about 6.71 metres/month. Furthermore, water table levels are influenced by local rainfall but seem to be largely controlled by leakage from deeper; confined aquifers, which suggests that rubbish should be buried above the present location of this fairly stable groundwater table. All of these results suggest that there will be little danger of polluting the deeper, confined aquifers from which Christchurch obtains its water supplies.

LIST OF SYMBOLS

- h piezometric head
- K permeability
- Q volumetric flow rate
- R observation well pipe radius
- t time
- v pore velocity
- x horizontal coordinate
- σ porosity

1 INTRODUCTION

A 3 km^2 region in coastal dunes near Christchurch, New Zealand has been chosen as the future site for a landfill scheme that is to begin in 1986. Groundwater levels are very close to ground surface throughout the entire region, which suggests that groundwater pollution might become a problem. Thus, measurements have been taken over a two year period to assess the risk of groundwater pollution. The following shows how these measurements and the resulting calculations were used to estimate the direction and speed of groundwater movement and to assess the risk of polluting deeper, confined aquifers from which Christchurch obtains its water supplies.

2 WATER TABLE GEOMETRY

Darcy's law states that groundwater velocities have a magnitude that is proportional to the water table slope and a direction that is perpendicular to the water table contours. Thus, an understanding of the water table geometry is essential for this investigation. Water table measurements have been taken regularly since May 1977 in 11 observation wells at the proposed landfill site. A description of some of these earlier measurements has been given by Young and Hunt (1977), and the results of this earlier investigation that are most pertinent to this discussion are summarised in Figs. 1 and 2. Figure 1 is an elevation view which shows that the unconfined water table is within one to two metres from the ground surface throughout most of the area. Figure 2 is a plan view of the water table contours with the outer boundary of the landfill area shown as a dashed line. Thus, Fig. 2 shows that any pollutants that enter the water table from the landfill site will be transported eastward toward the sea.

Measurements taken since 1977 show that water table levels in this area are relatively stable with maximum fluctuations of about one metre. For example, Fig. 3 shows a plot of water table variation with time at well No. 5 over the two year period since May 1977. Similar variations were observed at all of the other wells, and probably one of the most interesting aspects of these fluctuations is that they all show a sinusoidal variation with a period of exactly one year. On the other hand, a plot of the monthly rainfall variation in Fig. 4 fails to show the same sinusoidal variation, even though water table levels in the area are known to be very responsive to rainfall. This rather interesting paradox is explained by the presence of at least four or five artesian wells that are connected to deeper, confined aquifers. These wells were drilled to supply water for troops and horses being trained for desert warfare during World War I. Today, most of these wells are unused and are allowed to spill water freely onto the ground. Flow rates in these wells are observed to fluctuate with the tide, which also suggests that they are tapping confined aquifers. Thus, the sinusoidal variations in Fig. 3 are largely a result of seasonal pressure fluctuations in the deeper, confined aquifers, and the smaller-scale scatter about the sinusoidal curve is caused mainly by variations in local rainfall.

The landward slope of the water table west of well No. 11 in Fig. 2 is apparently the result of drainage to both the Styx River and to a ditch that parallels the coast on the western side of well 6. Since the proposed landfill area lies on the seaward side of the resulting groundwater mound, pollutants are unlikely to be carried into either the Styx River or the drainage ditch.

The observations made in this section lead to three very important conclusions. First, since the underlying artesian aquifers have greater heads than the upper, unconfined aquifer, pollutants entering the water table will stay in the unconfined aquifer rather than penetrate to deeper confined aquifers that are of economic importance to Christchurch. Second, since water table gradients beneath the proposed landfill area are seaward, pollutants will be convected seaward. Third, since water table elevations and gradients are mainly controlled by artesian wells tapping deeper aquifers, changes in local rainfall drainage

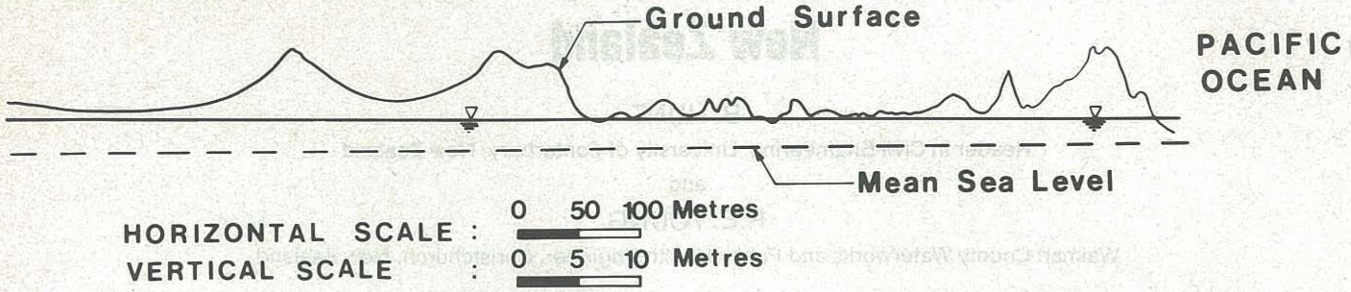

Figure 1 An elevation view of the water table and ground surface

caused by the landfill scheme are unlikely to cause major changes in the water table elevations.

3 GROUNDWATER VELOCITIES

Water table gradients, permeabilities and porosities can be used in Darcy's law to calculate pore velocities. Thus, a field trip was made to the site for the purpose of measuring permeabilities and porosities. The soil appeared to be a very homogeneous mixture of sand, and two field samples, one near well No. 5 and one midway between well Nos. 3 and 4, were collected and analyzed at the University of Canterbury to obtain permeability and porosity values. In situ permeability measurements were also made at well Nos. 2, 3, 4, 5, 7 and 11 by filling the observation well pipes with water and measuring the time required for the free surface in the wells to drop measured distances.

Permeabilities were measured in the laboratory for the two field samples by using a standard, falling-head permeameter (as described, for example, by Taylor (1948)). Then porosities were measured by weighing known volumes of the oven-dried samples. Tests were run on both loosely-packed and densely-packed samples, and the results are shown in the following table:

Sample Location	Packing	Permeability	Porosity
Between wells 3 & 4	loose	.0259 mm s^{-1}	43%
" " " " "	dense	.0265 "	41%
Near well 5	loose	.0170 "	44%
" " "	dense	.00378 "	-

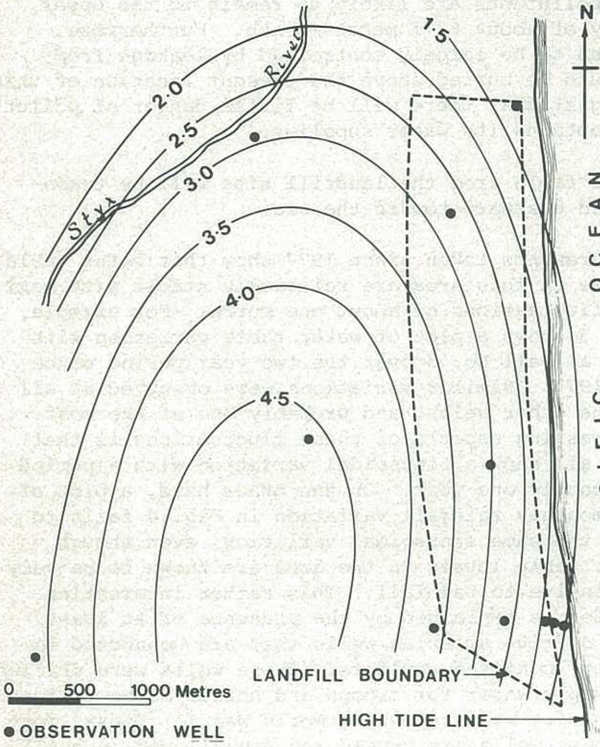

Figure 2 Water table contours in metres above mean sea level

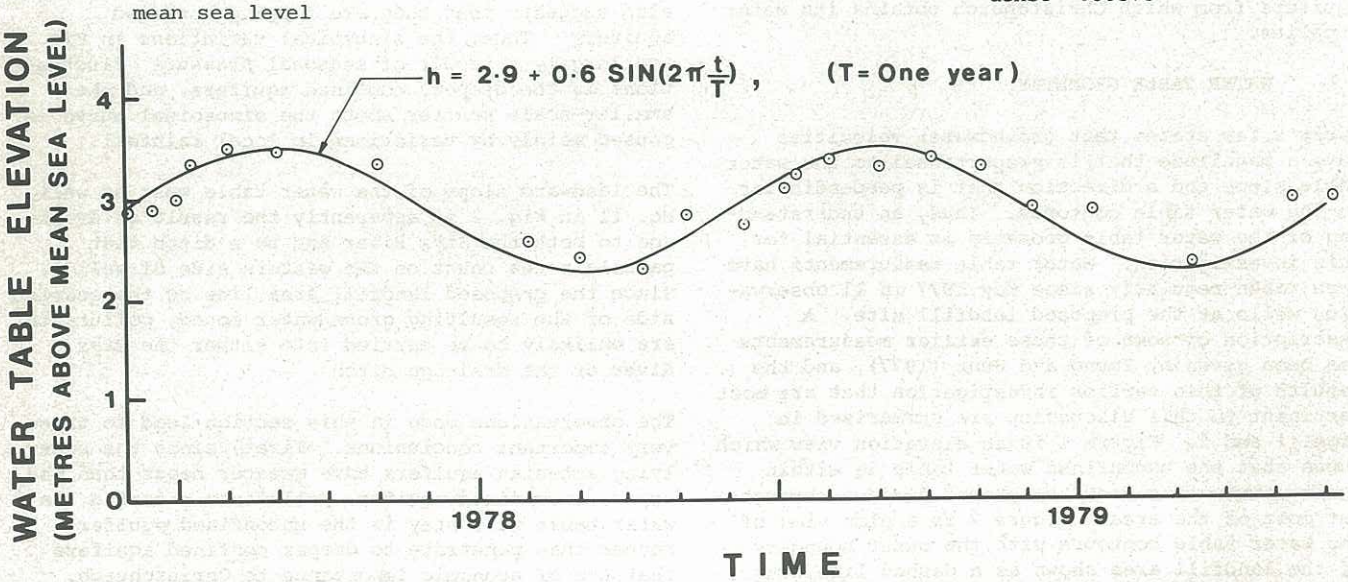

Figure 3 Water table levels in observation well 5 from June 1977 through May 1979

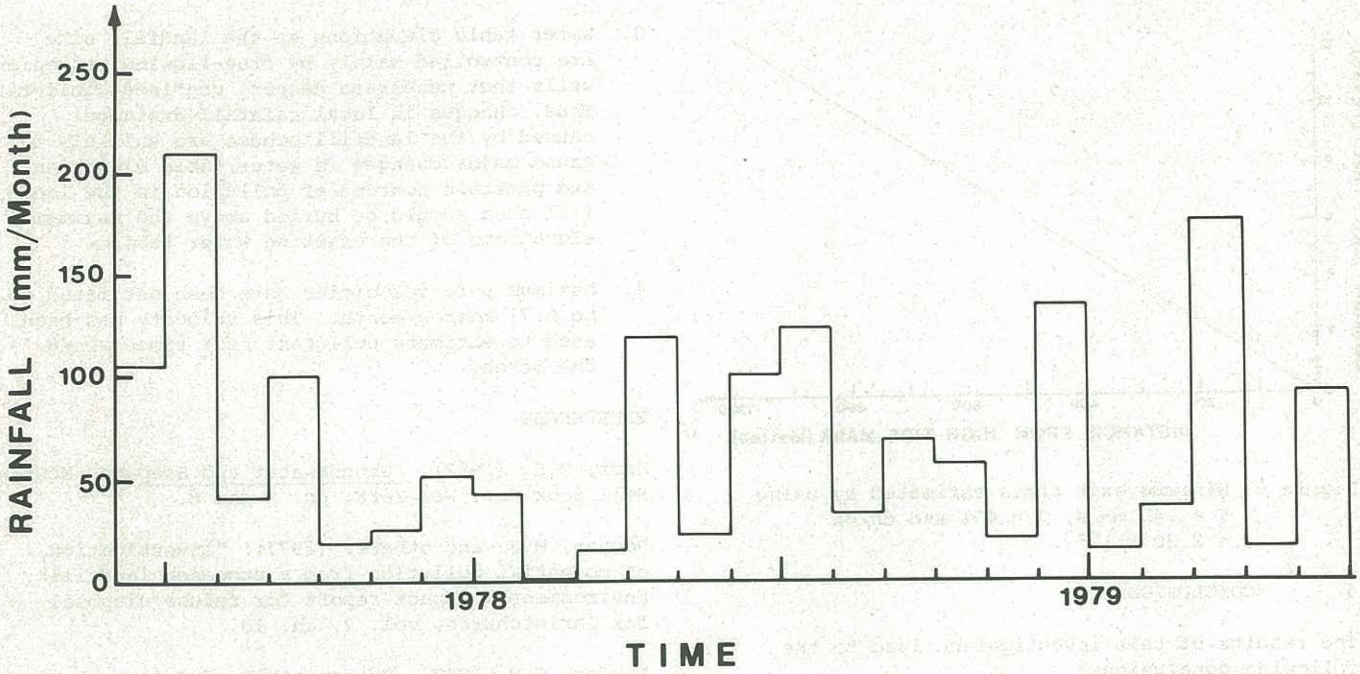

Figure 4 Monthly rainfall at Bromley, Christchurch from June 1977 through May 1979

Harr (1962) gives a range for typical permeabilities and porosities of sand of .001-10 mm s^{-1} and 34-46%, respectively, which suggests that the experimental values are reasonable.

Calculations for the in situ permeability tests were made by using the equation for flow from a three-dimensional, point source

$$h(t) = \frac{Q(t)}{4\pi K} \frac{1}{R} \qquad (1)$$

in which h(t) = elevation of the free surface inside the well above the local water table, Q(t) = flow rate from the source, K = permeability, R = radius of the well pipe and t = time. The flow rate out of the pipe end can be calculated from

$$Q(t) = -\pi R^2 \frac{dh(t)}{dt} \qquad (2)$$

Thus, Q(t) can be eliminated from Eqs. 1 and 2 and the resulting equation can be integrated once to obtain an expression for the permeability:

$$K = \frac{R}{4t} \ln \frac{h(0)}{h(t)} \qquad (3)$$

Permeabilities calculated from Eq. 3 are given in the following table:

Location	Permeability
Well No. 2A	.0754 mm s^{-1}
" " 2B	.0379 "
" " 3	.260 "
" " 4	.0138 "
" " 5	.287 "
" " 7	.0661 "
" " 11	.448 "

These permeabilities have a range of about one order of magnitude, which is not an overly large variation when one considers the size of the area over which the experiments were conducted.

Pore velocities can be calculated from the following form of Darcy's law:

$$v = -\frac{K}{\sigma} \frac{dh}{dx}$$

in which v = pore velocity, K = permeability, σ = porosity, x = horizontal coordinate and h = water table elevation above a horizontal datum. Water table gradients for wells 1-5 and 7 are shown in Fig. 5 for both high and low water table conditions.

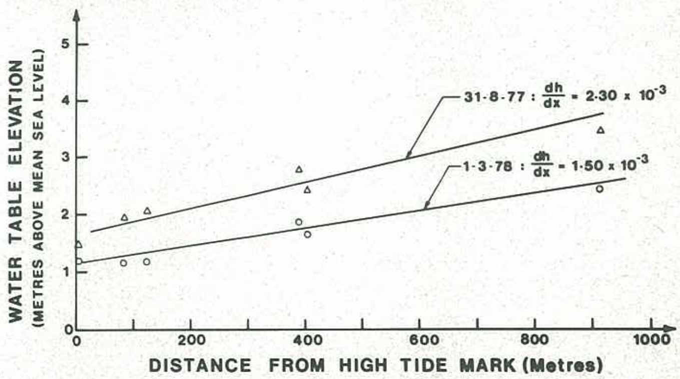

Figure 5 Data plotted from wells 1-5 and 7 under high and low water table conditions.

Use of the average value of K = .115 mm/s, σ = .43 and dh/dx = 1.90 x 10^{-3} in Eq. 4 gives an average velocity magnitude of 1.32 metres/month, which is remarkably close to the value of about 1 metre/month that was estimated earlier by Noonan and others (1977) from in situ tracer tests. However, it is probably more meaningful in this investigation to estimate a maximum velocity magnitude, since this will give minimum pollutant travel times. Thus, use of K = .450 mm/s, σ = .40 and dh/dx = 2.30 x 10^{-3} gives a maximum velocity magnitude of 6.71 metres/month. This maximum velocity has been used in Fig. 6 to show the time required for a conservative (zero decay rate) tracer to exist at the high tide mark for different starting positions inland from the beach.

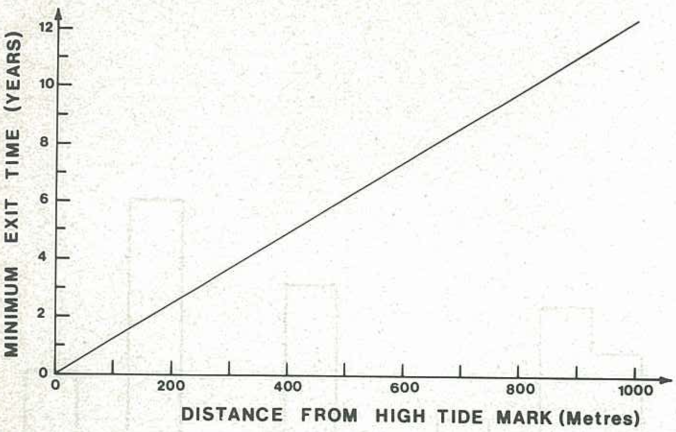

Figure 6 Minimum exit times estimated by using $K = .45$ mm/s, $\sigma = 40\%$ and $dh/dx = 2.30 \times 10^{-3}$.

4 CONCLUSIONS

The results of this investigation lead to the following conclusions:

1. Vertical piezometric head gradients will prevent pollutants from moving downward to the deeper, confined aquifers that are of economic importance to Christchurch.

2. Horizontal piezometric head gradients insure that pollutants from the landfill will be carried seaward rather than inland.

3. Water table elevations at the landfill site are controlled mainly by free-flowing, artesian wells that penetrate deeper, confined aquifers. Thus, changes in local rainfall drainage caused by the landfill scheme are unlikely to cause major changes in water table elevations, and possible sources of pollution in the landfill area should be buried above the maximum elevations of the existing water table.

4. Maximum pore velocities have been estimated to be 6.71 metres/month. This velocity has been used to estimate pollutant exit times along the beach.

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