NEAR-SURFACE HYDRAULIC STRATIGRAPHY OF THE CANTERBURY PLAINS BETWEEN ASHBURTON AND RAKAIA RIVERS, NEW ZEALAND

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ABSTRACT

Water wells on the Canterbury Plains between Ashburton and Rakaia Rivers produce mainly from two depth-zones: 0-49 m and 60-75 m. The upper zone can be divided into two on the basis of transmissivities calculated from well-testing records. These three distinct aquifers in the gravel down to 75 m are approximately parallel to the present land surface and are laterally continuous. Transmissivity generally decreases with depth and also decreases inland. Transmissivities within these aquifers are highly variable, but the mean values are significantly greater than in layers above or below.

The new data are consistent with an earlier model for the origin of aquifers, which suggests that they were formed by reworking of glacial outwash from the upper Rakaia fan and deposition near the coast over the lower Rakaia fan during interstadial and interglacial periods. They also are consistent with a model relating sorting, and hence porosity and permeability, to distance of fluvial transport.

Higher yields and transmissivities occur in the gravels near the coast down to 40 m and generally in the younger gravels elsewhere on the Canterbury Plains. It is suggested that these high yielding gravel deposits are interglacial, interstadial, and post-glacial, having been fluvially transported further than their associated glacial gravels.

Most wells with yields sufficient for irrigation occur within thirty kilometres of the coast and produce from less than forty metres beneath present ground level. A few shallow high-yielding wells occur further inland, near the rivers, probably within post-glacial alluvium.

INTRODUCTION

This paper presents an analysis of data extracted predominantly from drillers' logs for domestic and irrigation wells drilled between Ashburton and Rakaia Rivers on the Canterbury Plains, South Island, New Zealand (Fig. 1). The purpose of the analysis is to describe the near-surface stratigraphy, emphasising hydraulic properties of aquifers yielding sufficient quantities of groundwater for irrigation use.

The geology and hydrology of the Canterbury Plains have been described by Suggate (1963) and by Wilson (1973, 1979). The Canterbury Plains consist of a series of coalescing, late Cenozoic, gravel fans, derived by erosion of the rapidly rising Southern Alps. The fans are composed of glacial outwash and inter- and post-glacial alluvium with a discontinuous loess cover on older surfaces. Suggate (1963) described only the Upper Rakaia glacial stratigraphy, without correlating glacial advances and retreats with outwash or interglacial deposits at depth. Wilson (1973) pointed out the distinctly higher permeability of post-glacial alluvium compared with glacial outwash, and suggested reasons for the improved permeability coastward. Subsequently, (1979, p. 411) Wilson postulated that interglacial zones might also constitute zones of high permeability. This paper attempts to recognise such interglacial zones using hydraulic data accumulated by drillers.

DRILLERS' LOGS

Lithological Data

Drillers' logs consist of descriptions of sediment brought to the surface as well drilling proceeds, and sometimes include discharge and drawdown readings taken during pump tests. The well logs show a sequence of "claybound" gravel layers separated by "sandy" gravel layers. The terms in quotation marks are those that are used in the logs by the drillers. About 80 per cent of the water-bearing gravel layers, showing a high

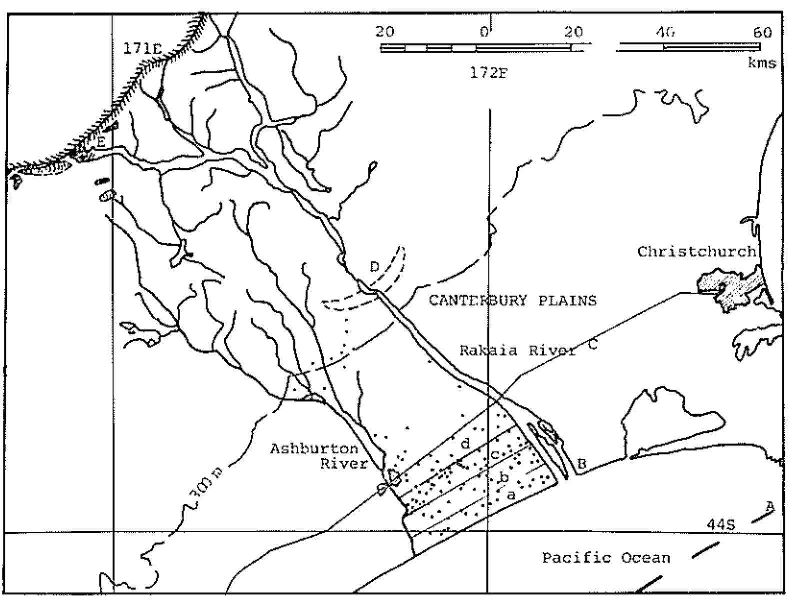

FIG. 1—Map of Rakaia and Ashburton Rivers showing locations of wells whose pump test results are indicated in table 1 and figure 2: a, b, c, d are zones in table 1.

A Pleistocene Shoreline.
B Present Shoreline.
C State Highway 1.
D Pleistocene glacier terrain.
E Present glaciers and main divide.

rate of recovery of water upon bailing, are described as open or "sandy" rather than "claybound".

Hydraulic Data

Hydraulic data for only 122 of the 360 wells between Ashburton and Rakaia Rivers are available and have been analysed. The hydraulic data presented on the drillers' logs consist of discharge (the rate at which water can be pumped from the well in m^3/day), drawdown (the drop in water level in the well during pumping), and the static water level. Separate observation wells were not used during these tests, apart from two tests conducted by the South Canterbury Catchment Board near Pendarves.

TRANSMISSIVITY

From the pump test data, the approximate transmissivity (T) of the tapped aquifer can be calculated using Logan's method (Kruseman and De Ridder, 1970). Transmissivity is the rate at which groundwater flows through the entire thickness (D) of the aquifer, and is measured in m^2/day so that T =KD. Hydraulic conductivity (K) is measured in m/day. Logan's method for steady flow in confined aquifers has been used to calculate transmissivity:

$$T = 1.22\, Q / S_{max}$$

where Q is discharge (m^3/day)

S_{max} is maximum drawdown (m).

The conditions assumed in this formula are:

1. the aquifer is homogeneous, isotropic and of uniform thickness, with infinite areal extent;
2. prior to pumping, the piezometric surface and/or phreatic surfaces are near horizontal;
3. discharge is constant; and
4. the aquifer is fully penetrated.

Inaccurate discharge and drawdown readings, combined with variations in screen types and well construction and inefficiency of well development, can introduce errors of up to 50% (Kruseman and De Ridder, 1970). These approximate methods, however, applied to a large number of pump test data, give clear indication of the magnitude of hydraulic properties of the aquifers. In general, transmissivity decreases inland and with depth (Table 1 and Fig. 2).

This trend is noted by Oborn (1955) and by Wilson (1976) for wells

TABLE 1—Transmissivity, variation with distance from the sea in each aquifer, with mean values ± s.e. of means.

Aquifer Number	Depth Range from ground surface (m)	Transmissivity (m^2/day) Zone on Fig. 1: a	b	c	d
1	0-15		2190 ± 660	4000	980 ± 440
2	25-40	2725 ± 1360	1710 ± 680	1200 ± 840	640 ± 260
3	60-72	1025 ± 470	280 ± 100	280 ± 80	285 ± 200

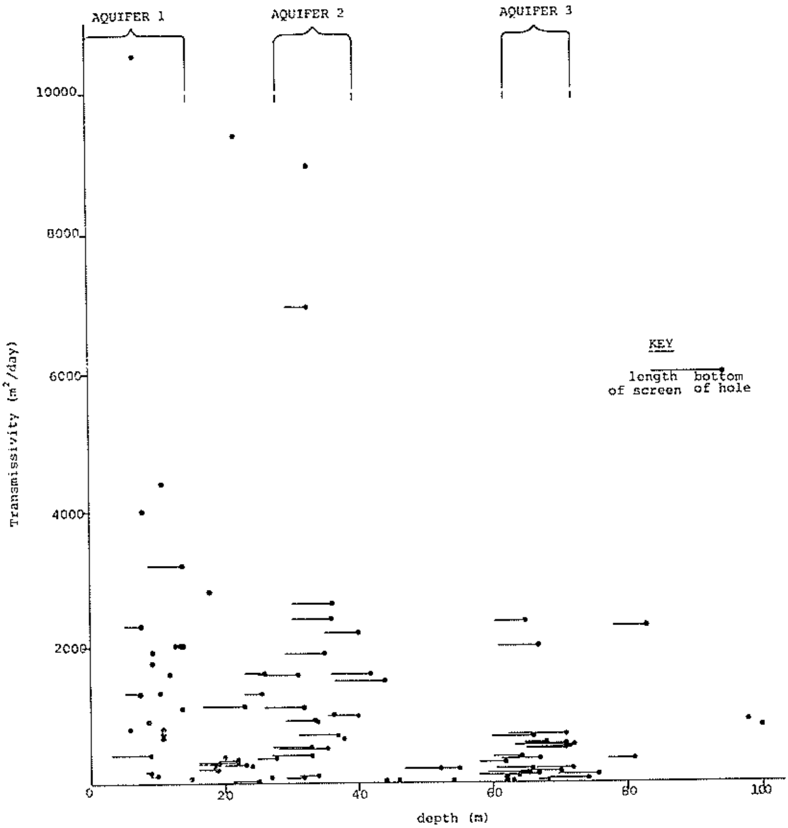

FIG. 2—The variation of transmissivity with depth beneath the Canterbury Plains between the Ashburton and Rakaia Rivers.

in the North Canterbury region. District zones of relatively high transmissivity appear at different depths; the higher transmissivities are found within the upper 40 m of the gravels. These zones are interpreted as associations of broad, thin, ribbonlike aquifers following infilled channels. Wells tapping a specific depth range or zone of thin aquifers are widely scattered across the lower plains, and a simple plot of transmissivity against absolute level of the well collar did not reveal any obvious pattern.

The data suggest that the aquifers are subparallel to the present-day land surface and are laterally continuous, at least near the coast. The former is as expected as the gradient of the land surface near the coast has changed little during the late Pleistocene. The lateral continuity of the aquifers also is not unexpected as the Rakaia River has the capacity to spread gravel across the entire lower fan when in flood and probably did so during late Quaternary times. Deep wells are most common mid-way between the two rivers because the water-table is deeper there. Wells tapping shallow high-yielding aquifers are restricted to the coastal region, confirming the suggestion of Wilson (1973) that the aquifers are more permeable near the coast.

STATIC WATER LEVELS

Isobath maps were drawn for aquifers two and three. Wells tapping aquifer one occur close to the rivers and have not been plotted. Superficial porous gravels laterally equivalent to aquifer one may lie above the water table between the rivers near the coast, but they could not be detected in this analysis. Comparison of the isobath maps shows that the static water levels of the aquifers at the same locality can differ by as much as 20 m. In the remaining areas, the water levels are the same in nearby wells drilled to different depths, indicating that impervious layers are not laterally continuous, and that there is vertical hydraulic connection between aquifers. A discontinuous loess cover lies on the land surface in mid-Canterbury, and similar discontinuous loess horizons at depth could be possible causes of such large differences in static water level. Since the water tables dip away from the rivers, obvious sources of recharge of the aquifers are the Ashburton and Rakaia Rivers. Rainfall is another source of recharge, but the relative proportions of recharge from the rivers and from rainfall are not known accurately.

A few wells near the coast are sub-artesian; water levels have risen up to twenty metres upon penetration of an aquifer. Free flowing wells such as those that occur near Christchurch City are not known to exist in mid-Canterbury.

Large seasonal fluctuations (up to 50 m) of water levels in some deep inland wells (depth ca. 60 cm), are perhaps due to the much lower storage capacity of the deep aquifers relative to shallow ones, and their isolation from recharge zones by intervening aquicludes and by their own low transmissivities.

DISCUSSION

The processes that led to the deposition of the gravel layers of the Canterbury Plains affect the direction of groundwater movement and the hydraulic properties of the gravels. Since about late Wanganui times (Pliocene), rivers draining the Southern Alps have delivered gravel to the region of the Canterbury Plains (Oborn and Suggate, 1959) at greater and lesser rates. By far the greatest changes in river regime have been between glacial and interglacial periods.

Ice advances have been accompanied by deposition of outwash fans that have coalesced to form the Canterbury Plains. Each advance has been followed by a retreat phase when the previous outwash deposits were dissected in the upper reaches of the fans (Soons and Gullentops, 1973; Wilson, 1973, 1976). During interglacial periods when sea levels were high and glaciers, if present, were mere vestiges near the Main Divide as today, outwash deposits near river gorges were dissected, reworked and redeposited downstream on the lower fan.

River gaugings and longitudinal profiles have been used to identify the apex of the postglacial Rakaia fan (that is, the place where aggradation of postglacial sediments begins) near State Highway 1. Water loss during low flow from the river to groundwater increases abruptly at this locality.

On several occasions, a lake (e.g., Lake Cleardale) ponded behind terminal moraine after glacier retreat at the Rakaia Gorge (Soons and Gullentops, 1973) restricted gravel transport from the Upper Rakaia catchment to the plains. The source of the earlier deposits of some of the interglacial sediments on the lower fan would thus be confined to reworking of glacial outwash from terrace edges at the Rakaia River. Reworked sediment from the entrenched upper fan (Rakaia Gorge) has been redeposited downstream from the intersection of the steeper glacial fan with the gently sloping interglacial or postglacial fan (cf. Fig. 4, Wilson, 1979). Wilson (1973) suggested that the gradual improvement of sorting of the gravels with increase in distance from the source, and ancient buried river channels of high transmissivity, might explain the remarkable eastward increase in aquifer yield within the Springston Formation and the underlying glacial outwash. An alternative model is that the higher yields occur in post-glacial sediments which are better sorted out because they have been transported from a more distant source than those of the glacial epochs.

In general, the grain size of the bed material in braided rivers decreases, and the sorting increases, with distance from the sediment source (Bradley *et al.*, 1972). Since the length of the interglacial and postglacial Rakaia River is about twice the length of the glacial Rakaia River, the sorting of interglacial sediments will be higher than that of glacial sediments for any given distance from the present-day coast, assuming that a glacier delivers unsorted material to the river source.

This model suggests that the better sorted and hence more permeable interglacial gravels serve as aquifers near the present coast. During the longer interglacial, alluvial deposits from adjacent river valleys in the Alps might have coalesced (or interdigitated) on the lower portions of the fans, ultimately forming a laterally continuous gravel veneer near the present coast. As sea level rose, the changing base level would have had the effect of increasing the thickness of the aquifers as the rivers adjusted to the new grade induced by the shifting storm beach.

SUMMARY AND CONCLUSIONS

1. Near the surface of the Canterbury Plains between the Rakaia and Ashburton Rivers, three laterally continuous aquifers that approximately parallel (with $\pm$ 7 m) the present-day land surface can be identified from well records. These aquifers have been tentatively correlated with periods of major glacier recession, when gravels were generally better sorted as a result of their greater distance of transport from their source. Transmissivities within these aquifers are highly variable but the mean value is significantly greater than in layers above and below; hence the term aquifer is justified.
2. Hydraulic data calculated from drillers' pump tests indicate that transmissivity and hydraulic conductivity decrease with depth and laterally inland within each aquifer.
3. Very large seasonal fluctuations observed in some inland wells can

be explained if the aquifers are highly permeable but very thin and confined, thus having low storage capacity and no more than medium transmissivity.

4. Wells with highest groundwater yields on the Canterbury Plains between Ashburton and Rakaia Rivers are generally less than 30 km from the coast, within one of the shallower aquifers and near one of the major rivers which are probably the sources of most of the groundwater recharge in the area.

ACKNOWLEDGEMENTS

The writer is very much indebted to Dr H. R. Thorpe, Water and Soil Division, MWD, for providing support and assistance; to Mr D. H. Bell, Senior Lecturer in Engineering Geology, University of Canterbury; Dr E. R. McSaveney, Assistant Editor of New Zealand Journal of Hydrology; and Dr M. J. McSaveney, MWD, for criticism of the manuscript; and to other members of the Groundwater Section, MWD, for their interest in this study.

Permission to publish this paper has been given by the Commissioner of Works.

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