Water supplies from Ulster valley gravels

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It may be interesting to note how the wells in the Enler Valley reacted during the dry summer of 1973. The water levels in the gravels fell to about 5–6 m below general ground level, even though the bed of the river is approximately only 2 m below this ground level. Pumping from these wells during autumn 1973 had to be severely curtailed, and a few hours' pumping every second or third day was sufficient over one particular period to drop the water level in the wells to below the bottom cut-out level. Moreover, it was observed that a flow continued in the river, even though I estimated at the time that it was only of the order of some 7 M1/day. I suggest that the low ground water levels combined with a continuing river flow indicate that induced recharge may not be quite as significant as the Authors have indicated. Indeed, I believe that at certain states of the river induced recharge does not occur at all.

53. However, I believe it might be possible to increase the yield from the site considerably by constructing an underground reservoir in the gravels by forming, at some suitable point downstream of the wells, a grout curtain from the surface to and keyed into the bedrock. I would suggest that cleaning of the upper part of the bank would allow flood flows to recharge this reservoir, and that leaving extant the bed of the river (through which, judging by the evidence of 1973, very little if any recharge occurs) would be sufficient to maintain and carry an adequate flow in times of drought to keep alive the fish stocks.

54. Recharge of the wells at the two Kennel Bridge sites may be almost entirely from underflow. It is known that a band of gravel extends for some distance upstream and borings made by my firm, together with various pipelaying operations, have shown clay of various thickness overlying this gravel. However, the gravel may outcrop at the surface in the upper reaches of the river. I suggest that horizontal underflow exists, with vertical recharge from the river at certain limited locations only (as for example at Unicarval), the bulk of the recharge being through the surface outcrop. I also suggest that this hypothesis is consistent with the pattern of draw-down contours, which clearly pass unhindered under the river's bed as indicated on Fig. 4. I believe that the evidence of summer 1973 shows that further drilling would not increase substantially the total yield derived from this aquifer during dry periods unless some means of artificial recharge were employed.

55. Investigations in the Roe Valley certainly revealed heterogeneous conditions. Although the production borehole was drilled into and through a thick glacial outwash, the exact extent of this outwash is unknown, and it may be very limited.

56. Reference is made in the Paper to the possibility of constructing a dual purpose pumping well to abstract water from the upper fine sands as well as from the lower coarse gravel outwash—a possibility which was rejected at the time. The main reason for not proceeding with this well was that it was believed that dewatering of

DISCUSSION

the upper sand layer, which tended to be uniform in grain size, would result in the drawing into the well of sand particles. However, with hindsight, I now think that construction of this dual purpose well should have been attempted using a thicker than normal gravel pack, extending to (say) $1\frac{1}{2}$ m below the base of the upper sand layer, and that such a construction could have increased the potential yield of this site.

57. The Authors suggest that equilibrium was achieved at an abstraction rate of 0.7 M1/day. However, although an apparent equilibrium was achieved in the pumping well, there was no concrete evidence of equilibrium in the observation boreholes. Moreover, I suggest that the equilibrium conditions noted in the borewell were transient, resulting from a flood in the river which, I believe, filled an upper sand layer, and that the pressure of this extra water over the top of the aquifer was transmitted through the clays, causing apparent stability of the water level in the pumping well. This observation underlines the need for a sufficiently long period of test pumping.

58. The Authors indicate that a 24 hour test may be sufficient for hydrological purposes. I would question whether an equilibrium state could be arrived at within this time, even though such a test may yield sufficient information to allow the transmissibility and storage coefficients to be derived for the material of the aquifer. I believe that any equilibrium conditions observed would not be of sufficient duration to ensure that they were not transient and that the water levels could later fall further as, for example, would result from the dewatering of an upper water bearing horizon. It is true that when using the log-time/drawdown plot extended pumping tests lasting for more than about 14 days do not yield a great deal of additional information on the log-time scale unless the duration of pumping is continued for nearly another complete cycle on the log axis—this cycle being 90 000 minutes, whenever minutes are being plotted on the time axis. Under most circumstances an extended test pumping of this duration is not practical under site conditions using temporary power supplies and so on. This underlines the need for the installation of equipment for the continuous monitoring of both flow rates and drawdown levels within the completed well, together with a permanent observation borehole where possible, as aids to further determination of the aquifer's characteristics.

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The Authors have considered the development of induced recharge from a river resulting from pumping a well adjacent to that river. They appear not to have made clear the distinction between induced recharge and total river depletion. In an aquifer with a gradient on the water table, and therefore flow through it, total river flow depletion has two components: the interception of ground water flow which otherwise would have discharged naturally into the river, and induced recharge through the bed and banks of the river. Interception occurs first and will continue throughout pumping (Fig. 7) but induced recharge will not start until the gradient from the well to the river has been reversed (Fig. 8). In the special case where the water table is horizontal and therefore no ground water flow takes place, depletion is entirely induced recharge (Fig. 9). These principles were recognized by Theis²⁰ and Jacob²¹ but have not always been appreciated by other workers.

60. Theis²⁰ and Glover and Balmer²² have given simple graphical methods for determining total depletion from non-steady state theory but only Jacob²¹ appears to have produced a method, albeit from steady state theory, for determining directly the component of induced recharge. The Authors have not used the method derived by Jacob in which he presents a graph of Q_1/Q against $\Delta Q/\pi x v_0$ where Q_1 is the rate of induced recharge, Q the total well discharge, ΔQ the well discharge per unit depth, x the perpendicular distance between well and river and v_0 the velocity of ground water flow. Now $\Delta Q/\pi x v_0 = D\Delta Q/\pi x v_0 D = Q/\pi x T i$, where D is the average depth of saturation and i is the hydraulic gradient. As Q , x , T and i are known, Q_1 can be determined from Jacob's graph.

61. Assuming a steady state condition obtains, Jacob's method can be applied to the Upper Kennel Bridge site using information either given by the Authors or obtainable from Fig. 4. From this a value of $Q_1 = 0.6Q$ is obtained, i.e. $Q_1 = 610 \text{ m}^3/\text{day}$. By making a crude estimate of 1000 m^2 for the area of the river bed over which the Authors indicate induced recharge takes place, a value of I_r of approximately 0.6 m/day is obtained. Assuming the average depth of the river to be 1.0 m and taking the average drawdown along the river bank to be 0.5 m , (from Fig. 4) the permeability of the stream bed has a value of 1.2 m/day —close to the lower figure quoted by the Authors.

62. In discussing briefly the time-drawdown plots in observation wells during the pumping tests, the Authors have misinterpreted the departure of the observed data from the infinite aquifer case as showing that induced recharge had occurred. The departure actually shows that the distribution of drawdown around the pumped well is being influenced by the line of constant head presented by the recharge boundary of the river. This response can occur without induced recharge where an initial hydraulic gradient between the pumped well and the river is not reversed (Fig. 7); even when the gradient is reversed (Fig. 8) the response is not wholly accounted for by induced recharge. The natural hydraulic gradient at Upper Kennel Bridge produces

a throughput of groundwater flow of $1.5\text{--}2.0\text{ m}^3/\text{day}$ per metre width of aquifer, which is significant compared with the yield of the well.

Mr Price and Mr Foster

We were grateful to receive some news from **Dr Gould** of the performance of the test production wells in the Enler Valley under drought operating conditions but were disappointed that there are clearly not sufficient data (on changes in borehole yield/drawdown characteristics, rest groundwater level trends and stream flow records) to evaluate unequivocally the reasons for the apparent failure. Throughout our work in Ulster we were concerned about the sparseness of low flow data on the rivers concerned (§§ 10, 22, 39). On our interpretation of Dr Gould's comments in § 52 it appears likely that a reduction in river-bed area A_r and probably also river-bed permeability K_r (§ 14) at extreme drought river stage reduced the induced recharge component available to a single well, such as well C in Fig. 4, to much less than the test yield. It would have been interesting if Dr Gould had given his estimate of the width of the river in extreme drought. We assumed from the limited evidence then available that it would not reduce to less than about 4 m.

64. The fact that drawdowns extend beyond a river, in itself does not prove (§ 54) that induced river-bed recharge is not occurring. Indeed it is a necessary part of the process of development of such recharge in naturally effluent rivers (Fig. 5). We believe that induced recharge does occur in these hydrogeological environments in nearly all cases, when groundwater abstraction exceeds aquifer throughflow; the problem is that variations with time in the rate of such recharge are rather unpredictable and constitute a major factor complicating any development (§ 14).

65. The best method of sustaining and increasing the yield from the valley would, we feel, be further exploitation of the bedrock storage (§ 24) rather than the methods suggested by Dr Gould in §§ 53 and 54. We consider that there are insufficient data to substantiate or refute Dr Gould's rather speculative comments on the Roe Valley investigation (§§ 55–57).

66. We agree that the optimum length for pumping tests in this hydrogeological environment is debatable and also that pilot operation of one or two test boreholes for a period of a few years with continuous monitoring of groundwater levels and river stage would be an ideal approach in a staged development (§ 58). However, the normally urgent demand for new supplies coupled with the reluctance of operators to undertake conscientious long-term data collection often preclude this optimum.

67. **Dr Owen** raises discussion on the mechanisms of overall river flow depletion (§ 59). We agree that the distinction between its two components, namely—interception of natural groundwater flow to the river and river-bed recharge of the aquifer induced directly at the expense of river flow—is fundamental and not always recognized (§ 21).

68. There are indeed several graphical methods available, using pump test and associated data, to solve for the theoretical component of induced river-bed recharge Q_r . Most of these assume, as an initial condition, a horizontal water table or pressure surface together with many other simplifications and also do not permit evaluation of the rate of induced recharge I_r , the vertical permeability of the river bed K_r and therefore of the overall potential for inducing recharge. Also given the heterogeneity of most valley fill deposits and the complexity of many river beds, we favour the direct determination of the distribution of groundwater head areally in the aquifer and vertically beneath the river bed as has been used by Walton and Ackroyd.¹⁷ Unfortunately the cost of an adequate number of observation boreholes and piezometers may be prohibitive in small schemes.

69. In the case of the Enler Valley (§§ 21 and 22), the estimation of Q_r for a given equilibrium pumping rate was based, among other considerations, on the fact that the aquifer throughflow intercepted by test well C could not have exceeded about

30% of the pumping rate of 11 l/s (about 1 Ml/d). This was based on a throughflow of about 0.9 m³/d per metre width of aquifer and we find Dr Owen's figure (§ 62) too high. Even taking his figure and assuming that all the throughflow had been tapped by the single shallow test well (a most unlikely situation), only 50% of the test pumping rate would have been accounted for and without another significant source of recharge the observed equilibrium could not have been sustained. This substantiates our interpretation of a positive river recharge boundary from the non-steady state observation well data (Fig. 3) disputed by Dr Owen (§ 62).

References

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