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INTERFERENCE TESTS AT OHAAKI

A Search for a Linear Boundary

Mark J. McGuinness and Ken Louie

Applied Mathematics Division
Department of Scientific and Industrial Research
Wellington, New Zealand

ABSTRACT

In this paper an interference test conducted in April 1984 at Ohaaki is analysed, and the presence of a single linear no-flow boundary is investigated. Three wells gave clear responses to the opening and closing of the source well. When each of these three responding wells is dealt with in isolation, and a fit of the infinite reservoir line-source solution is compared 'with a fit that includes a linear no-flow boundary, it is apparent that the fit with a linear boundary is closer. However, there is no location for the linear boundary that is consistent with all three responses. A compromise location for a linear boundary is found by fitting to all three responses at once. When this fit is compared with a compromise fit of the infinite reservoir line-source solution to all three responses, the fit with the boundary included is closer.

THE TEST

In an interference test conducted at the Ohaaki geothermal field in New Zealand (see Figure 1) in April 1984, BR20 was discharged at 237 t/hr for two weeks while the responses at BR13, BR23 and BR34 were monitored. This work was conducted by the Ministry of Works and Development, Wairakei. The responses are plotted in Figure 3. All three wells responded with pressure changes of about 50 kPa, with larger responses in those wells that are closer to BR20, consistent with expectations for a homogeneous reservoir.

SEMILOG PLOTS

Previous studies of pressure responses at Ohaaki have been interpreted as indicating the presence of linear no-flow boundaries. Mention is made in Table 7.2 of Grant et al. (1982) of barrier effects in tests involving BR23, BR13, BR34 and BR31. Grant (1980) observed three semilog straight lines in the response of BR23 to the discharge of BR13, each one with twice the slope of the previous one, and has suggested the barrier locations as indicated in Figure 1 to explain them. Semilog plots for the test studied in this paper are in Figure 2. Possible straight lines are indicated on these plots. These are not inconsistent with the slope-doubling effect expected if barriers are present, but with the gaps present in the data, and the short length of the straight segments of data, we have no confidence in results based on these lines.

LINE-SOURCE FITS

The responses were separately fitted with the line-source or Theis solution, which may be derived for an infinite homogeneous isotropic two-dimensional reservoir (Grant, 1982 or Matthews and Russell, 1967). The fitting was accomplished by a nonlinear regression program which minimises the sum of the squared residuals by adjusting parameters related to the permeability-depth and the storativity of the reservoir. These fits are plotted in Figure 3. The results of these fits are presented in Table 1. The values of permeability-depth and storativity for BR34 are about'half the values for BR23, suggesting that BR34 could lie close to a barrier, as further explained later in this paper.

FITS INCLUDING A BARRIER

A barrier, by which we mean a straight, infinitely long, no-flow boundary in the two-dimensional reservoir, can be imitated by an appropriately placed image well with the same flow history as the source well. Since the diffusion equation for the change in pressure is linear, line-source solutions can be superposed, one for the source well and one for the image well. The nonlinear regression program now also adjusts a parameter that depends on the (unknown) distance from the observation well to the image well. This numerical approach is more accurate than the

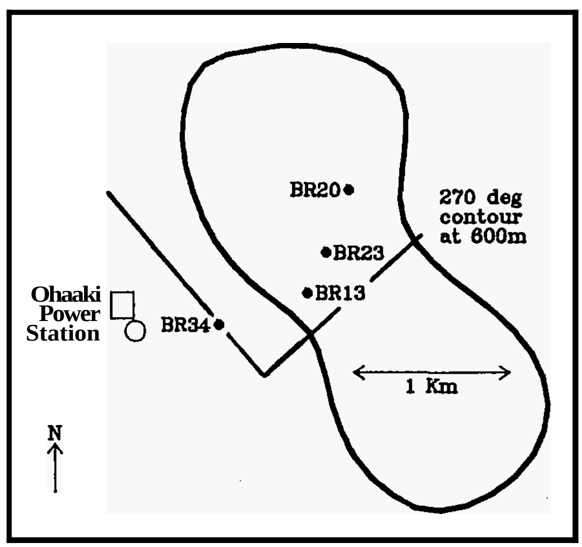
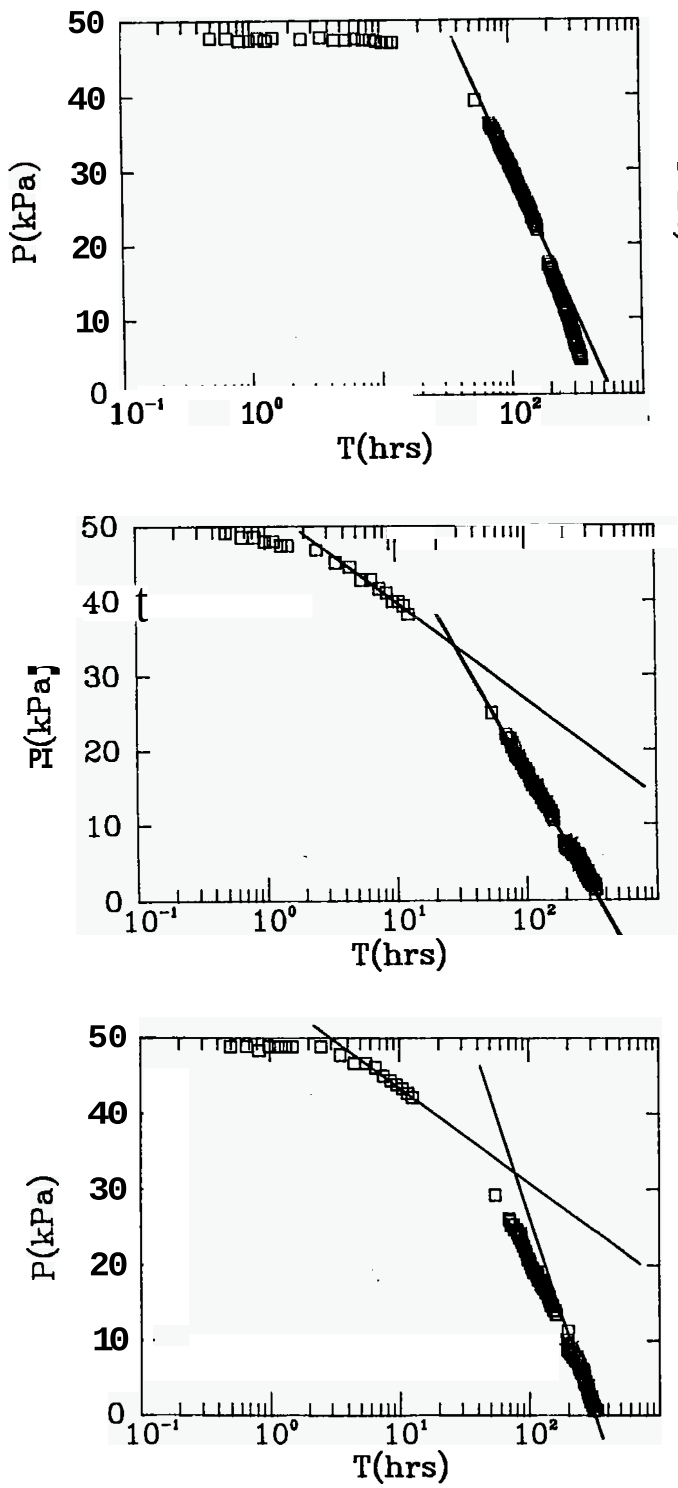


Figure 1. Well locations at Ohaaki geothermal field, New Zealand. The indicated wells participated in a multiple interference test in April 1984. The source well was BR20. The two heavy straight lines are suggested barrier locations from Grant (1980).



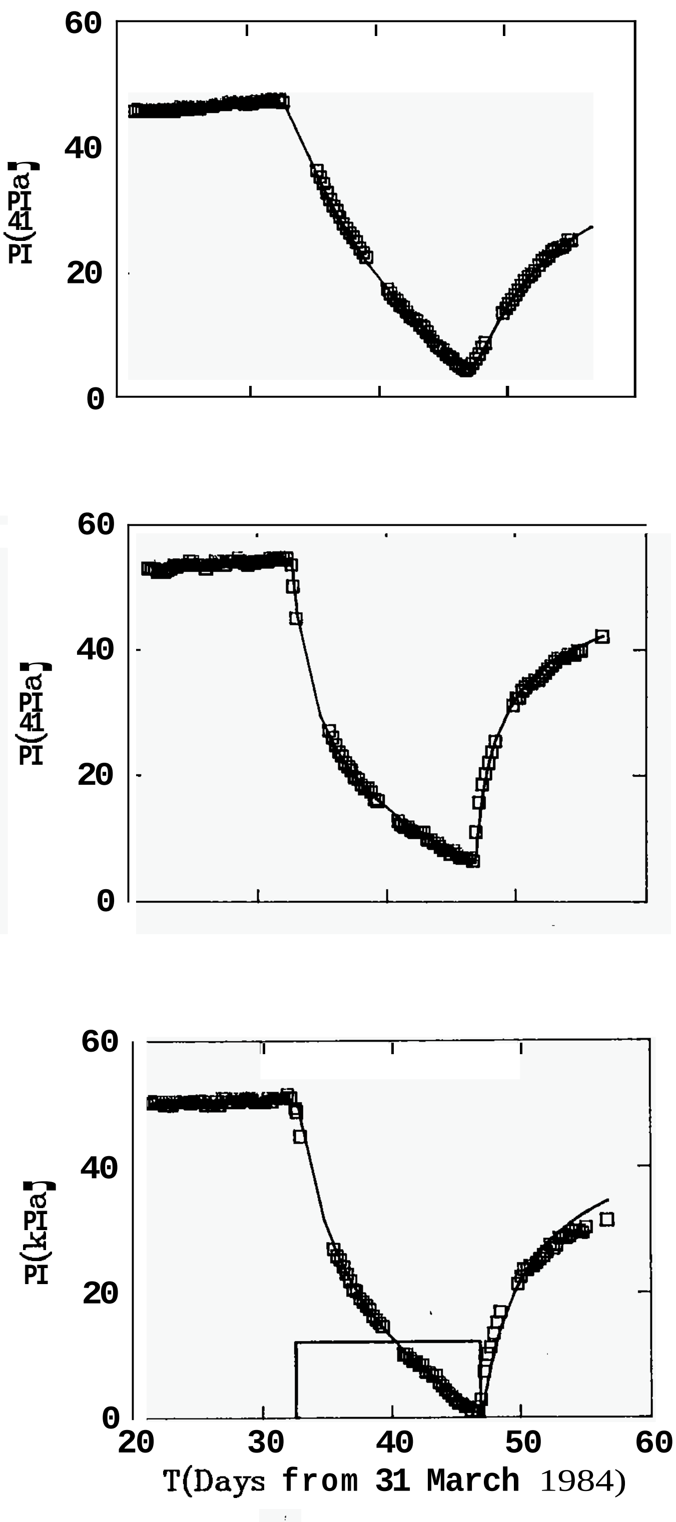


Figure 2. Plots of the pressure changes in BR34, BR23 and BR13 respectively, against the log of the time since production began in BR20. The straight lines are drawn as a guide to the eye, and are not Eitted. The initial pressures have been adjusted to give reasonable numbers on the vertical. axis, and are not the actual initial downhole pressures, as it is the pressure changes that are modelled.

Figure 3. Plots of the responses in BR34, BR23 and BR13 respectively to production and shutting of BR20. The fitted lines are the result of fitting the line source solution to each well separately, superposing for changes in flowrates. The flowrate changes of 237 t/hr in BR20 are indicated on the plot for BR13.

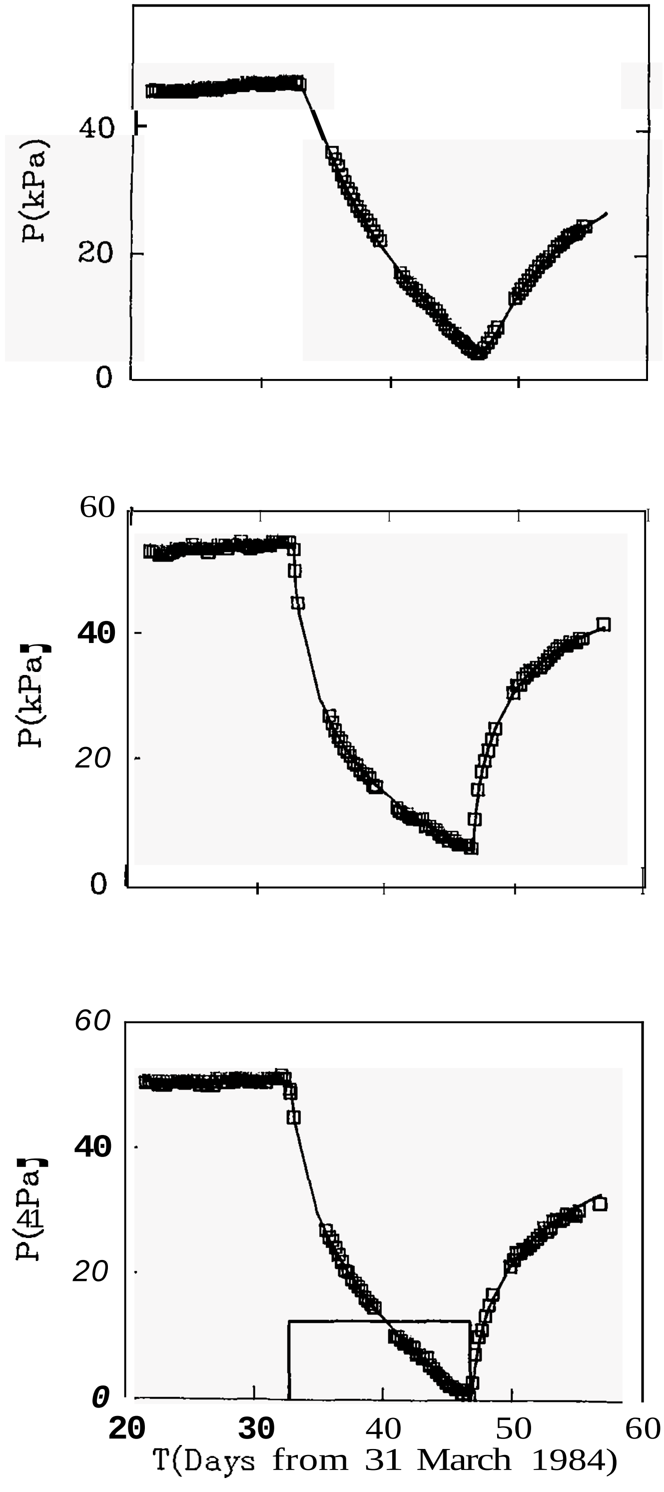


Figure 4. Plots of the responses in BR34, BR23 and BR13 respectively to production and shutting of BR20. The fitted lines are the result of fitting the line source solution for BR20 and an image well to each well separately. The flowrate changes of 237 t/hr in BR20 are indicated on the plot for BR13.

Table 1. Results of the fits in Figures 3, 4. The first set of results is from fitting the line source solution for just the source well. The second set is from fitting the line source solution for the source well and an image well. that is, with a barrier. Fitted values of the permeability-depth (kh) and the storativity (ϕch) are given for both sets of results. The fitted distance L from the observation well to the image well is given in the second set. The root mean squared deviation √MS of the fit from the data is given for both sets as an indication of the closeness of fit obtained. Uncertainties are taken as three times the standard errors. The reservoir fluid is assumed to be liquid at 270 deg C.

a. No barrier fitted

WELL	kh(d-m)	ϕch(m/MPa)	√MS(Pa)
BR13	37 ±1	.15 ±.01	1207
BR23	52 ±1	.22 f.O1	744
BR34	27 2.3	.116 ±.003	576

b. Barrier fitted

WELL	kh(d-m)	ϕch(m/MPa)	L(m)	√MS(Pa)
BR13	56 22	.10 ±.007	3500 2150	523
BR23	95 f2	.14 2.007	1700 2120	487
BR34	53 2.4	.23 ±.08	1200 ±400	577

semilog method, since it does not require the Theis solution to reach semilog straight-line behaviour. The fits resulting from including an image well, that is, a barrier, are plotted in Figure 4. The results of these fits are presented in Table 1. These results have been obtained by fitting to each observation well separately. The fits are closer for BR13 and BR23 when the image well is present, as indicated by the mean squared residuals in Table 1. The fit for BR34 is not detectably improved by including an image well, as the minimisation places the image well at the same distance from BR34 as the distance of the source well. This doubles the values of permeability-depth and storativity, bringing them more into line with values for the other wells.

Each nonlinear minimisation gives a distance from the observation well to the image well, or gives a circle centred on the observation well on which the image well lies. Three such circles, centred on three different observation wells, should locate the image well uniquely. Each circle gives an ellipse to which the barrier is tangent (Vela, 1977). The three ellipses, fattened by the uncertainies of the fitted parameters, are indicated in Figure 5. There is clearly no consistent location for a linear boundary.

Another technique €or linear boundary detection, involving semilog type curve matching (Sageev et al., 1985), has been applied to interference tests at Ohaaki with similar results (Leaver et al., 1985a and 1985b, Sageev el al., 1986). That is, each individual response is consistent with the existence of a linear boundary, but the positioning of the boundary is not consistent for different tests or observation wells.

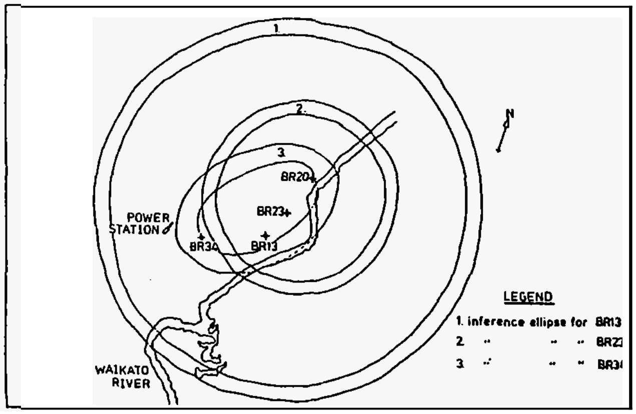


Figure 5. Ellipse locations from the results of the fits in Figure 4. The barrier for each fit is tangent to the ellipse for that fit. uncertainties in fitted parameters mean the ellipses are fattened.

The data that is fitted to in Figure 4 is spaced in one-hourly intervals. The residuals of the fits are highly auto-correlated, violating the assumption of independence that underlies the statistical theory behind the efficacy of regression and the computation of uncertainties. When ten-hourly values of pressure are used instead (E. Bradford, private communication), the residuals have a low auto-correlation. This procedure makes the ellipses even fatter, and does bring them closer together, but not enough to resolve the consistency problem.

FITTING SIMULTANEOUSLY

In an attempt to place the image well (and hence the boundary) in a unique compromise location, the data from the three observation wells was fitted to simultaneously. That is, the sum of the squared residuals for all three responses was minimised. To accomplish this, the three data sets were placed end to end, and the model response set up for the line-source solution and an image well. The image well solution involved the two unknown coordinates of its location in a nonlinear manner. The different initial values of the pressures in each well were accommodated by also fitting three step functions. This was necessary for computational reasons - the changes in pressures are what determine the reservoir parameters. A total of three nonlinear and Eour linear parameters were fitted.

The results of this simultaneous compromise fit are presented in Table 2. The fits are plotted in Figure 6. They are worse than any of the individual fits, as might be expected Eor such a compromise. The permeability-depth, storativity and image well location are the best compromise for all three responses at once. The resulting barrier location, smeared by the uncertainties in the fitted parameters, is shown in Figure 7. When the program is run, the nonlinear regression is supplied with starting guesses for the coordinates locating the image well, from which location it moves the image well in an attempt to get a closer fit. For three of the Eour starting points tried (see Figure 7), the program found the same optimum location for the image well. For the starting point that was furthest from this optimum, the program moved the image well location as far away as possible, suggesting convergence to a no-barrier model.

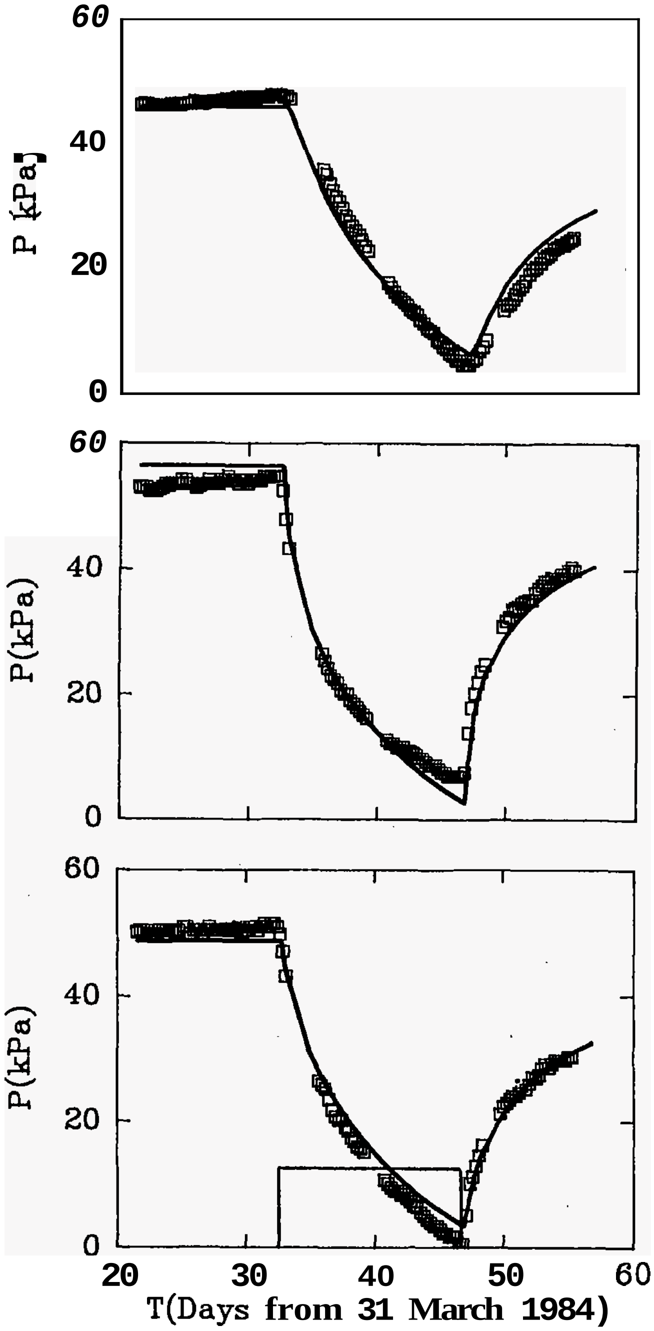


Figure 6. Plots of the responses in BR34, BR23 and BR13 respectively to production and shutting of BR20. The fitted lines in these plots are the result of fitting the line source solution for BR20 and an image well to all three wells simultaneously. The flowrate changes of 237 t/hr in BR20 are indicated on the plot for BR13.

This compromise fit was then oompared with one which has no image well, that is, with a compromise simultaneous fit of the infinite reservoir line-source solution. The fits resulting from such a regression are plotted in Figure 8. The fitted parameters are indicated in Table 2. Close inspection of the fits confirms the implication of the mean

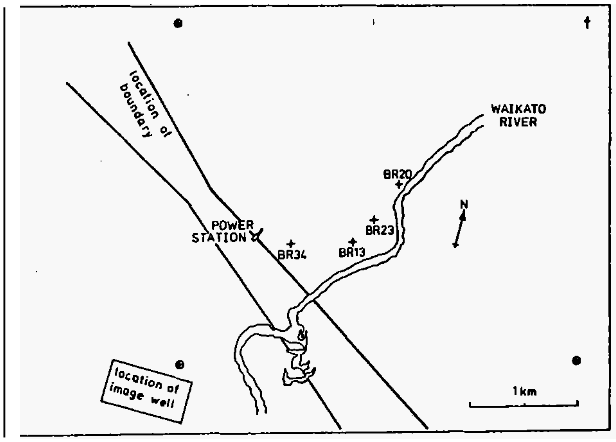


Figure 7. The heavy lines indicate possible harrier locations, given by the fit plotted in Figure 6. The range of possible locations arises from the uncertainties in the fitted image well location. The three locations marked with a crosshair indicate the four different starting points tried for the image well in the regression program, from which it converged to the present location. The regression did not converge from the location marked with a dagger.

Table 2. Results of the fits in Figures 6. 8. The first results are from fitting the line source solution for the source well and an image well, that is, with a barrier. The second results are from fitting the line source solution for just the source well. Compromise fitted values of the permeability-depth (kh) and the storativity (ϕch) are given for both sets of results. The fitted location coordinates in meters south (U) and west (V) from the source well BR20 to the image well are given in the first set. The root mean squared deviation JMS of the fit from the data is given for both sets as an indication of the closeness of fit obtained. Uncertainties are taken as three times the standard errors. The reservoir fluid is assumed to be liquid at 270 deg C.

a. Barrier fitted to all three observation wells simultaneously

kh(d-m)	ϕch(m/MPa)	U(m)	V(m)	JMS(Pa
66 ±1	.14 ±.01	1700 ±400	2400 ±200	2084

b. Simultaneous fit, no barrier.

kh(d-m)	ϕch(m/MPa)	JMS(Pa)
47 tl	.14 ±.01	4241

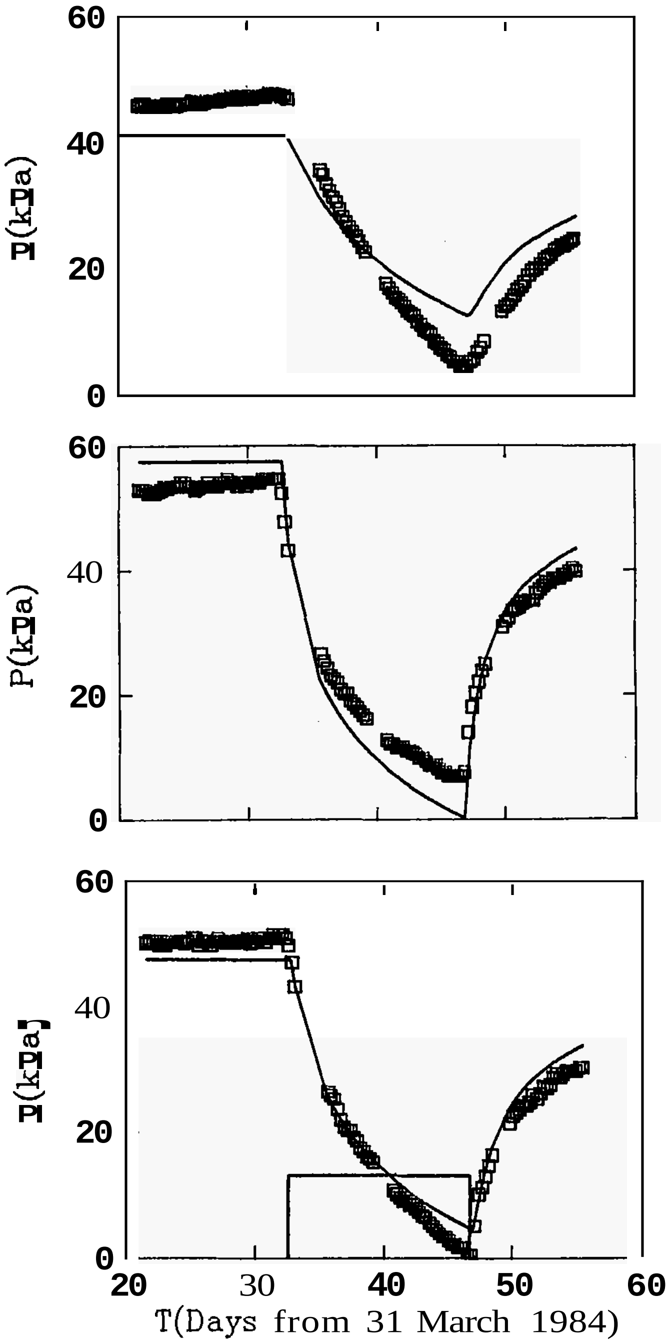


Figure 8. Plots of the responses in BR34, BR23 and BR13 respectively to production and shutting of BR20. The fitted lines in these plots are the result of fitting the line source solution for BR20 as the only source well (no barrier) to all three wells simultaneously. The flowrate changes of 237 t/hr in BR20 are indicated on the plot for BR13.

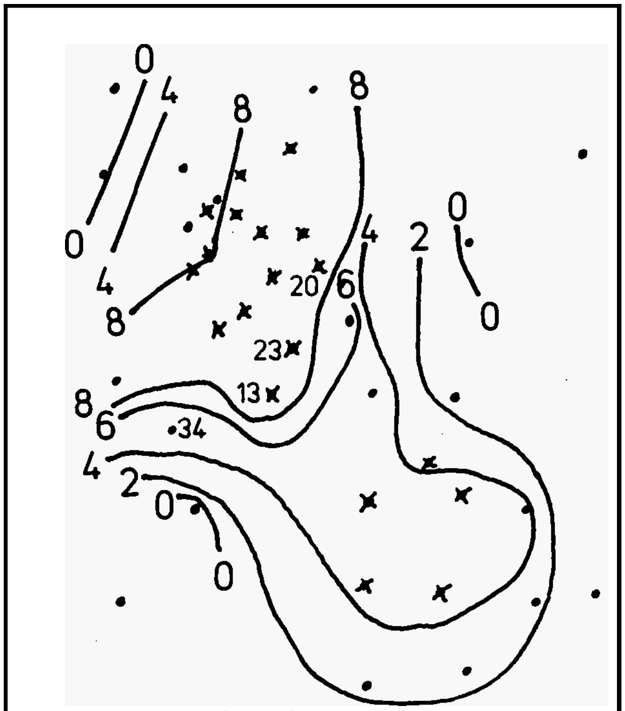


Figure 9. Contours of pressure drawdown in bars from undisturbed values at Ohaaki, resulting from field-wide well discharge. Taken from Grant and Iles (1981).

squared residuals - the three sets of responses taken together are better fitted when there is a linear boundary present. This implies that the values of permeability-depth and storativity obtained with a barrier present are more accurate than those obtained with no barrier.

It is a little surprising that the model with a single linear boundary is so successful at Ohaaki, when it is noticed that contours of the drawdown from the undisturbed reservoir bunch together (Grant and Iles, 1981, and reproduced here in Figure 9), suggesting several not very linear boundaries or regions of reduced permeability. The fitted boundary location displayed in Figure 7 does correspond to one of the indicated regions of bunched contours in Figure 9. Improved fits could be obtained by introducing another linear boundary into the model (and at least another two nonlinear parameters).

CONCLUSIONS

When responses to interference tests at Ohaaki are considered individually, a model of the reservoir as an infinite homogeneous isotropic two-dimensional porous medium with a linear no-flow boundary gives good fits, and the fits are better with the barrier than without it. However, the fits are in conflict over the location of the barrier.

When the three responses of April 1984 to production from BR20 are considered simultaneously, an adequate compromise location for the barrier is found. Single compromise values of reservoir parameters are also obtained. This simultaneous fit is closer than a simultaneous fit without a barrier present.

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