INTERFERENCE EFFECT OF PRODUCING WELLS ON OBSERVATION WELLS IN A GEOTHERMAL FIELD (CERRO PRIETO)

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ABSTRACT

Interference effects of producing wells on an observation well in a geothermal field where the producing formations are porous, naturally fractured, and without much anisotropy can be calculated using the already established pressure-time-mass flow equations for slightly compressible fluids flowing in porous or pseudo-porous formations. When the results are correlated with pressure or water level decline in the observation well, a fundamentally important parameter of the reservoir is obtained. This parameter relates recharge and storativity of the reservoir and can be used in determining the optimum well spacing. The approach is illustrated with an example from Cerro Prieto Geothermal Field, Baja California, Mexico.

INTRODUCTION AND THEORY

Semisteady (pseudosteady) conditions, by their definition,[1,2] represent a major part of the production history of a geothermal field. During these conditions, pressure drop at the center of a closed drainage area, caused by a well at the same point, is given by the following two equations:

$$p_o - p_{r_w} = \frac{Wvrt}{A\phi hc_t} + mr \left(\log \frac{r_e^2}{r_w^2} - D_{SF} + \frac{s}{1.151} \right) \quad (1)$$

Pressure at a distance R from the producing well would be given by:

$$p_o - p_R = \frac{Wvrt}{A\phi hc_t} + mr\ (F)$$

where F is a constant for each well, as seen in the second part of Eq. 1, and would account for the pressure drop occurring before semi-steady conditions are reached.

If one now assumes a recharge into this drainage area, this recharge will be proportional to the pressure drop within the drainage area, and then the well within this drainage area will produce only a fraction of its total production from its drainage volume, but the rest will come from the recharge. If we denote the fraction of the production which comes from the drainage volume as α, the above equations can be modified as follows, taking the recharge effect into account only when the boundary effects are felt (i.e., during semisteady-state conditions):

$$p_o - p_{rw} = \frac{\alpha Wvrt}{A\phi hc_t} + mr \left(\log \frac{r_e^2}{r_w^2} - D_{SF} + \frac{s}{1.151} \right) \tag{3}$$

$$p_o - p_R = \frac{\alpha Wvrt}{A\phi hc_t} + mr\ (F) \tag{4}$$

As pointed out, these equations have two components: the first component gives the linear semisteady pressure decline, and the second accounts for the pressure drop which takes place during the transient conditions.

If the rather temporary transient periods caused by opening and closing wells are neglected, under semisteady-state conditions, the total pressure drop effect of n producing wells (with production rates W_1, W_2, W_3, ..., W_n, and production times t_1, t_2, t_3, ..., t_n) on an observation well which has a distance R_1, R_2, R_3, ..., R_n, from each producing well would be (see Appendix A):

$$\sum_{i=1}^{n} \Delta p_R = \frac{\bar{\alpha}\ \bar{v}r}{A_T(\phi h\bar{c}_t)} \sum_{i=1}^{n} W_i\ t_i + k \tag{5}$$

where k is a constant.

It will be noted from this equation that if:

$$\sum_{i=1}^{n} \Delta p_{R_i}$$

(which is the pressure drop at the observation well) is plotted against:

$$\sum_{i=1}^{n} W_i\ t_i$$

(which is the total cumulative production at the time corresponding to the pressure drop), a straight line should be obtained whose slope will be:

$$\frac{\bar{\alpha}\ \bar{v}r}{A_T(\bar{\phi}h\bar{c}_t)} = E \tag{6}$$

The bar sign on top of the symbols indicates average values within the reservoir drainage volume. It will be noted that the variations in

$\overline{vr}$, $\overline{\alpha}$, $\overline{c}_t$, and $(\overline{\phi h})$ may change the value of E during the lifetime of a reservoir. However, they would remain relatively unchanged during a period of a year or so (especially if the total production rate is maintained constant), and would give an almost constant value for E.

It will be noted that E would be a very important parameter of the exploited field as it would relate recharge, storativity (ϕhc_t) and the total drainage area of the reservoir.

APPLICATION

Cerro Prieto Geothermal Field was chosen for the application of the above conclusions not only for the reason that the required data exist, but also for the fact that the producing formations in this field can be considered as pseudo-porous.

Production data of the active Cerro Prieto wells (see Fig. 1) covering the period 1973-1977 have been obtained from the internal reports,[3] and the cumulative production of each well and the total cumulative production of the field at the end of each month have been calculated using these data.

The values obtained were plotted against time in Fig. 2. In the same figure, the standing water level variations of the two observation wells, M-6 and M-10,[4] were also plotted. As can be seen from Fig. 1, M-6 is to the west of the main production area, relatively cold, and is considered by many to be at or near the western boundary of the field.

On the other hand, M-10 is within the main production area, near the Cerro Prieto fault, which seems to separate the relatively deeper and higher temperature production area to the east (M-53) from the exploited field to the west.

The total cumulative production is plotted against the static water levels of wells M-6 and M-10 in Figs. 3 and 4. It should be noted that for both wells, graphs with straight-line portions are obtained. The straight-line portions are displaced by effects caused by transient pressure change periods resulting from well openings and shut-downs (especially when the plant shuts down for annual maintenance). The following slopes can be obtained from these graphs:

M-6 Initial part: $E = 0.560\text{x}10^{-6}$ m/t
Subsequent part: $E = 0.435\text{x}10^{-6}$ m/t

M-10 Initial part (short): $E = 1.00\text{x}10^{-6}$ m/t
Subsequent part: $E = 0.536\text{x}10^{-6}$ m/t

Both wells seem to have the same slope ($E = 0.560\text{x}10^{-6}$ m/t) for the major part of their response, which is approximately between total cumulative productions of $23\text{x}10^6$ tons and $68\text{x}10^6$ tons. This would be expected as the wells are within the same reservoir.

Small discrepancies would be caused by the local variations in the average parameters ($\overline{vr}$, $\overline{c}_t$, and $\overline{\phi h}$). Assuming average water density at 100°C:

$$E = 0.560x10^{-6} \text{ m/t} = 0.0538x10^{-6} \text{ kg/cm}^2/t$$

Therefore, knowing ϕ and $v_D = A_T h$, recharge fraction of production $(1 - \alpha)$ can be calculated.

$$\overline{\alpha} = 0.0538x10^{-6} \frac{\overline{c}_t}{\overline{vr}} \overline{\phi} v_D \qquad (7)$$

Assuming $\overline{vr} = 1.14 \text{ m}^3/t$ (water at 300°C) } for reservoir conditions
$\overline{c}_t = 1.991x10^{-4} \ (\text{kg/cm}^2)^{-1}$

$$\overline{\alpha} = 7.7x10^{-12} \ (\phi v_D) \qquad (8)$$

CONCLUSIONS

Standing water level or pressure changes in an observation well can be related to cumulative fluid production in a geothermal field using the already established pressure-time-mass flow equations for slightly compressible fluids flowing in porous or naturally fractured formations which can be considered as pseudo-porous. By doing this, one can obtain a fundamental parameter of the reservoir, which in turn relates recharge, storativity, and total reservoir drainage area. Therefore, it would not only be an important factor in evaluating the recharge, but also, by being used in an equation such as Eq. 3, it would aid in determining the optimum well spacing between wells.[5]

NOMENCLATURE

p_D = initial reservoir pressure, at reference level near well bottom, kg/cm^2

p_{wr} = pressure at reference level near well bottom, kg/cm^2

p_R = pressure at a distance R from the producing well , at the ref- ference level near well bottom, kg/cm^2

W = well production rate, tons/hour

W_T = field production rate, tons/hour

v_r = specific volume at reservoir conditions, m^3/t

t = production time in semisteady-state consitions, hours

mr = $\frac{0.0526 \ Wvr\mu}{kh}$

μ = viscosity, cp

k = absolute permeability, darcy

h = effective production thickness, m

s = skin effect

α = fraction of production coming from drainage volume

ϕ = effective porosity

c_t = total isothermal compressibility, $(kg/cm^2)^{-1}$

r_e = effective drainage radius, m

A = drainage area, m^2

A_T = total drainage area of the field, m^2

n = number of wells

Δp_R = $p_o - p_R$

D_{SF} = shape factor

r_w = well radius, m

R = distance from production well, m

F = a constant for each well accounting for the pressure drop during transient conditions; taking into account also the shape factor

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APPENDIX A

Contributions of different producing wells on the pressure drop observed at the observation well can be written as follows:

Well 1 at R_1:

$$\Delta p_{R_i} = \frac{W_1 vrt_1}{A_1 \phi hc_t} + mr(F_1)$$

Well 2 at R_2:

$$\Delta p_{R_2} = \frac{W_2 vrt_2}{A_2 \phi hc_t} + mr(F_2)$$

Well n at R_n:

$$\Delta p_{R_n} = \frac{W_n vrt_n}{A_n \phi hc_t} + mr(F_n)$$

where F_1, F_2, ... F_n are constants for each well. Assuming all the producing wells are influencing the observation well, and using average values for vr, c_t, ϕ, and mr:

$$\sum_{i=1}^{n} \Delta p_{R_i} = \frac{\overline{\alpha}\overline{vr}}{(\phi h\overline{c}_t)} \left[\frac{W_1 t_1}{1} + \frac{W_2 t_2}{A_2} + \ldots + \frac{W_n t_n}{A_n} \right] + \overline{mr}\ [F_1 + F_2 + \ldots F_n] \qquad \text{(A-1)}$$

or:

$$\sum_{i=1}^{n} \Delta p_{R_i} = \frac{\overline{\alpha}\overline{vr}}{(\phi h\overline{c}_t)} \sum_{i=1}^{n} \frac{W_i t_i}{A_i} + \overline{mr} \sum_{i=1}^{n} F_i \qquad \text{(A-2)}$$

The second part of the right-hand side of this equation is constant for semisteady-state conditions for a particular configuration of wells:

$$\overline{mr} \sum_{i=1}^{n} F_i = k \qquad \text{A-3)}$$

and:

$$\sum_{i=1}^{n} \Delta p_{R_i} = \frac{\overline{vr}}{(\phi h\overline{c}_t)} \sum_{i=1}^{n} \frac{W_i t_i}{A_i} + k \qquad \text{(A-4)}$$

But normally, for semisteady-state conditions, one can write:

(1):
$$\frac{W_i}{A_i} = \frac{W_T}{A_T} \qquad \text{(A-5)}$$

Then Eq. A-4 becomes:

$$\sum_{i=1}^{n} \Delta p_{R_i} = \frac{\overline{\alpha}\overline{v}r}{(\phi h\overline{c}_t)} \sum_{i=1}^{n} \frac{W_T t_i}{A_i} + k \qquad \text{(A-6)}$$

where $W_T t_i$ is the cumulative production of the field at any time t_i, and A_T is constant for any particular field.

But:

$$W_T = \frac{W_1 t_1 + W_2 t_2 + \ldots + W_n t_n}{t_1 + t_2 \ldots + t_n} = \frac{\sum_{i=1}^{n} W_i t_i}{\sum_{i=1}^{n} t_i}$$

also for a field where W_T has been kept relatively constant, as it appears from Fig. 2:

$$\sum_{i=1}^{n} = W_T t_i = W_T \sum_{i=1}^{n} t_i = \sum_{i=1}^{n} W_i t_i$$

Therefore, Eq. A-6 becomes:

$$\sum_{i=1}^{n} \Delta p_{R_i} = \frac{\overline{\alpha}\overline{v}r}{A_T(\phi h\overline{c}_t)} \sum_{i=1}^{n} W_i t_i + k \qquad \text{(A-7)}$$

Equation A-7 can also be obtained by considering each well producing from a total reservoir drainage area of A_T, and superimposing the pressure drops at a fixed point at a distance R, as follows:

Well 1 at R_1:

$$\Delta p_{R_1} = \frac{\alpha W_1 v r t_1}{A_T \phi h c_t} + mr(F_1)$$

Well 2 at R_2:

$$\Delta p_{R_2} = \frac{\alpha W_2 v r t_2}{A_T \phi h c_t} + mr(F_2)$$

Well n at R_n:

$$\Delta p_{R_n} = \frac{\alpha W_2 v r t_2}{A_T \phi h c_t} + mr(F_n)$$

$$\sum_{i=1}^{n} \Delta p_{R_i} = \frac{\bar{\alpha}\bar{v}r}{A_T(\phi h \bar{c}_t)} \sum_{i=1}^{n} W_i t_i + k \qquad \text{(A-7)}$$

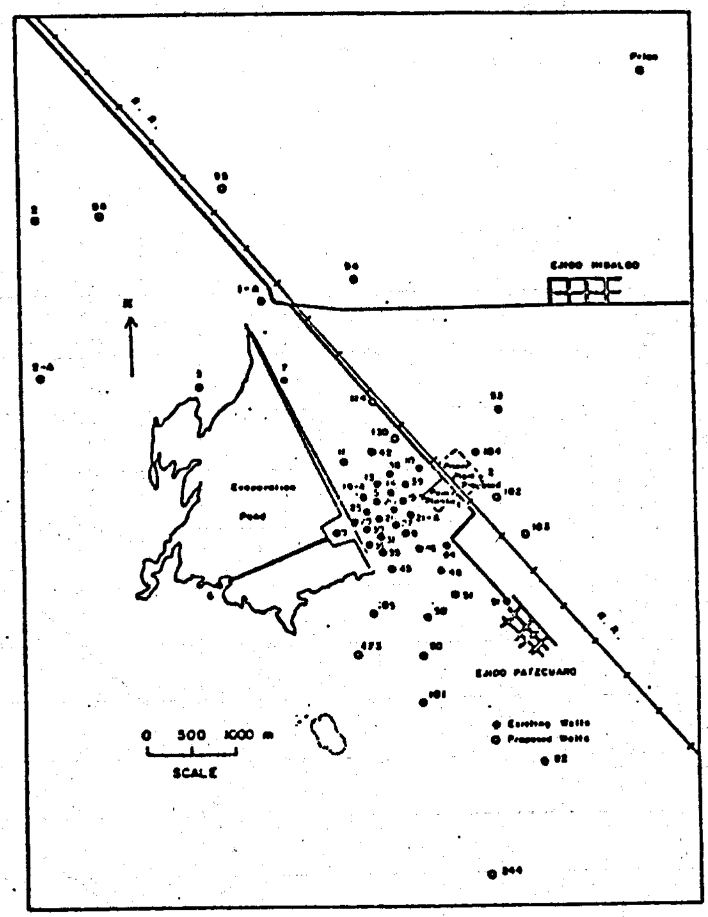

FIG. 1: CERRO PRIETO GEOTHERMAL FIELD WELL LOCATIONS (AS OF 3/78)

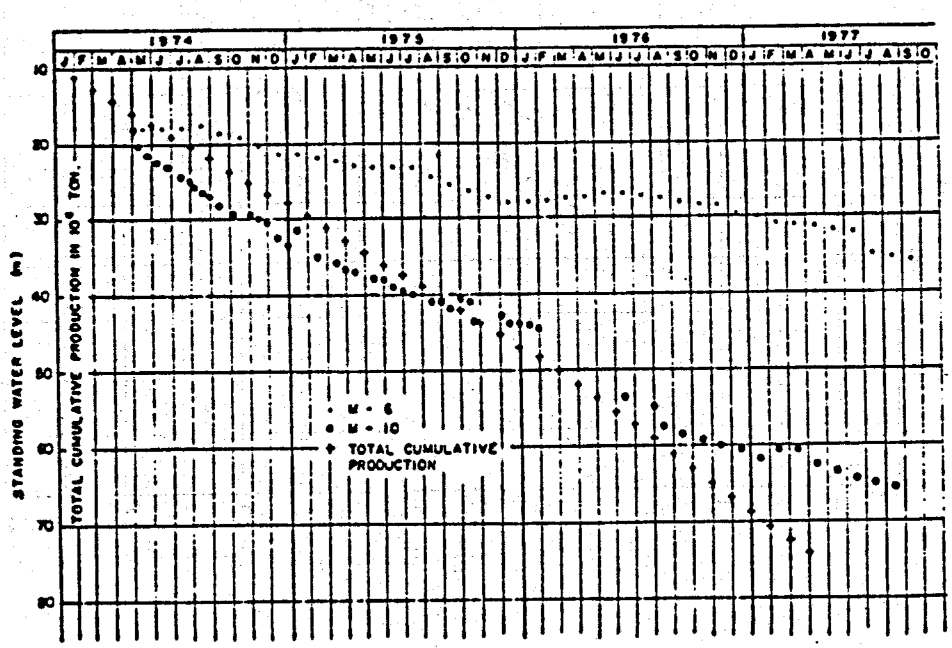

FIG. 2: CERRO PRIETO--STANDING WATER LEVEL CHANGE AND TOTAL CUMULATIVE DISCHARGE AGAINST TIME

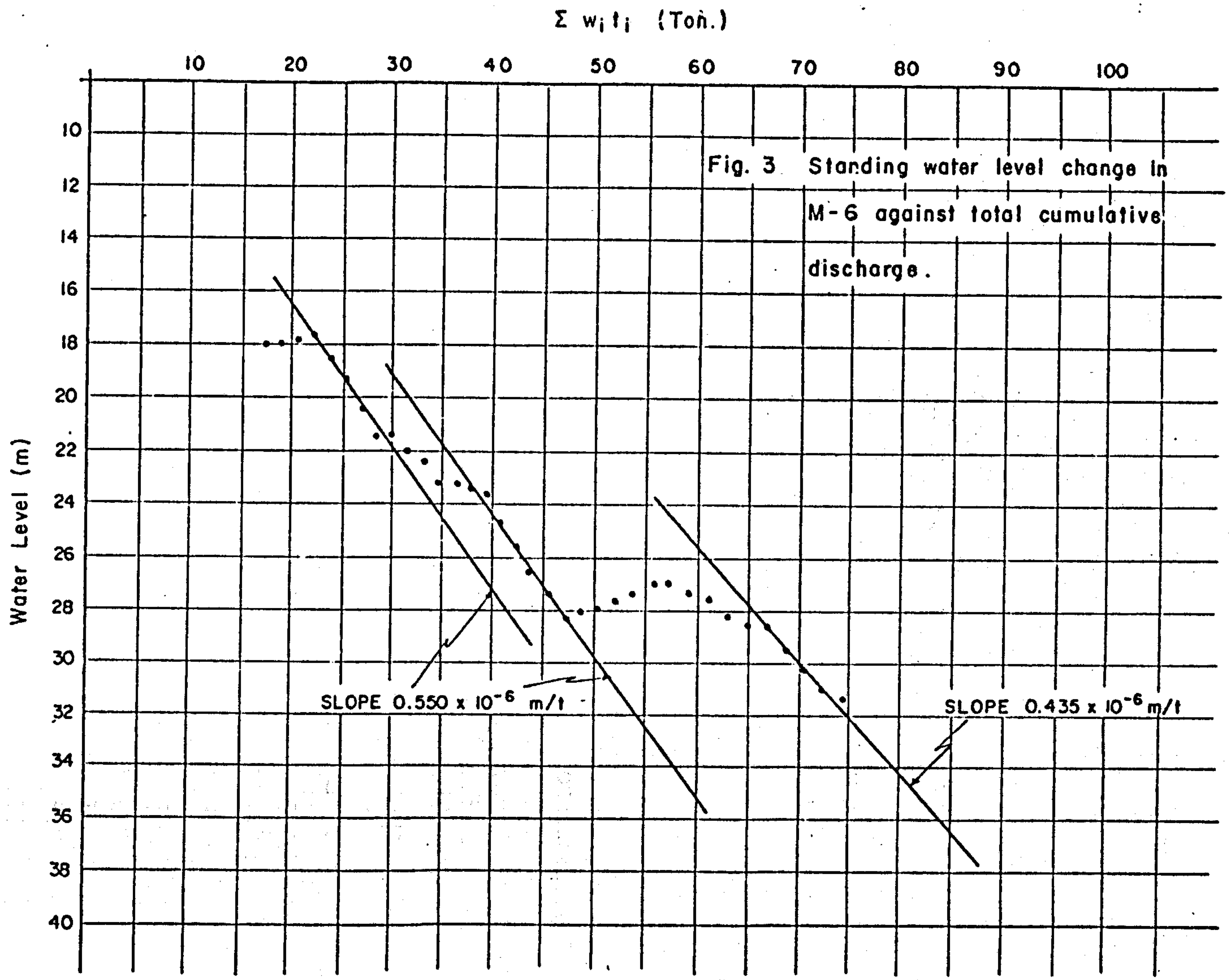

Fig. 3 Standing water level change in M-6 against total cumulative discharge.

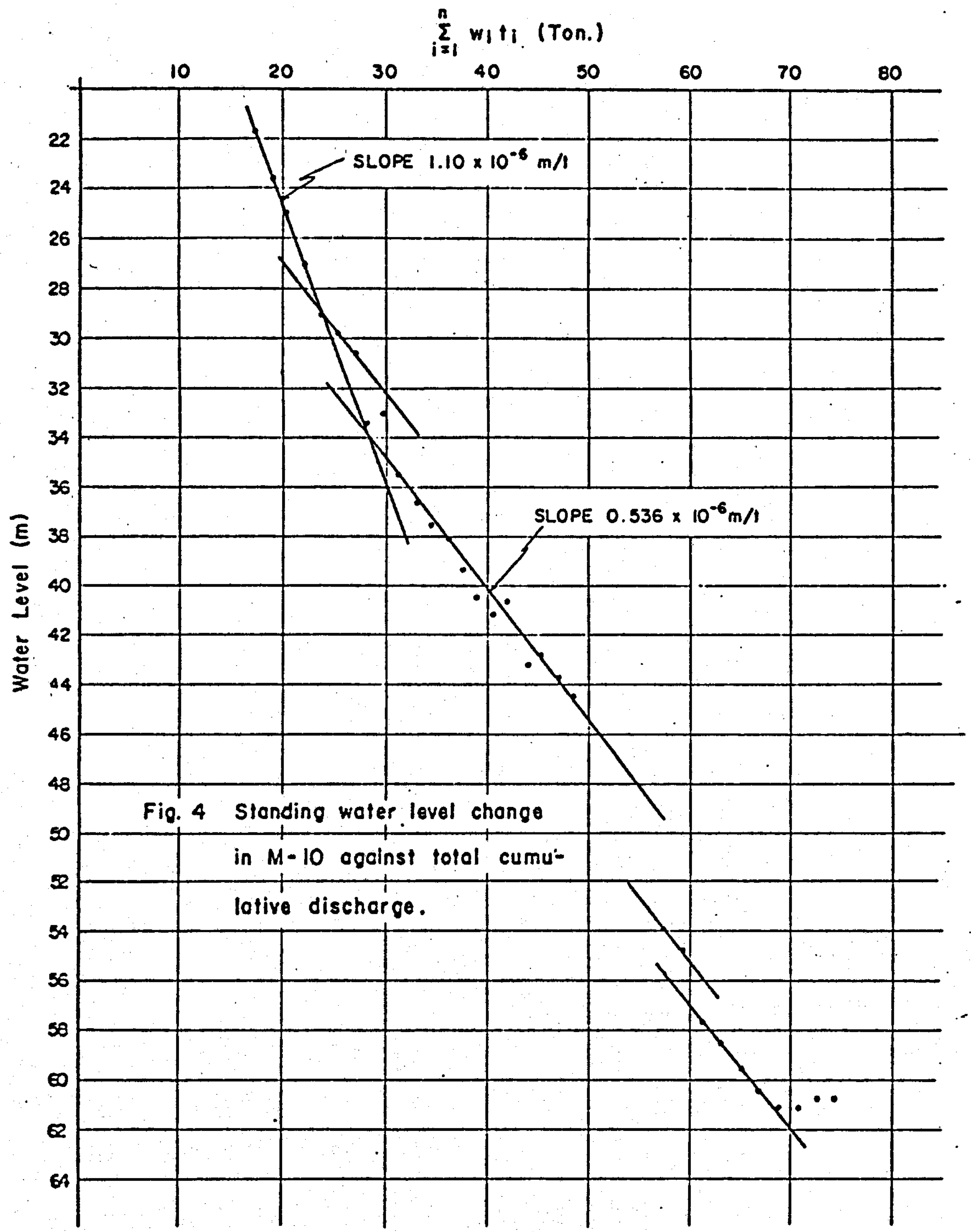

Fig. 4 Standing water level change in M-10 against total cumulative discharge.