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Design of interacting wells for optimization of investments and operating costs while constructing water-diverting structures

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Abstract. Constructions for water withdrawal are the constitutive building industry component. The cost of these constructions is rather high. That is why while designing it is necessary to choose optimal design model and operating conditions during design life. Operation experience showed that the wells are desirably placed along one line to provide the most optimal conditions for water withdrawal. While designing the wells interaction is considered as a group operation if the distance between them is less than two radiuses of influence. Such wells disposition allows reducing the area and cutting down the investments for water withdrawal construction and also creating the better conditions for equipment and mains operation. Design of interacting wells consists of finding the tube well number, the distance between them, the discharge and levels (static and dynamic). At operating condition determination, it is necessary to consider the combined action of pure water reservoirs and tube well.

1 Introduction

Water withdrawal wells consisting of several tube wells are used for settlements with a great amount of drinking water discharge consumption.

Operation experience showed that it is desirable to place the wells along one line to provide the most optimal conditions for water withdrawal [1,2,6,10,16]. The wells interaction is designed if the distance between the wells is less than 2R that is they work as group ones. Such wells disposition allows reducing the area and cutting down the investments for water wells construction and creating the better conditions for equipment and mains operation. However, because of their influence on each other the wells discharge comes down.

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2 Methods

The design of the interacting wells is in determining the number of tube wells, the distance between them, water discharge and levels (static and dynamic).

The design is done in the following order [3,7,8,12,17]:

1) determine the water discharge for one well Q_w;

2) determine the well radius of influence R (the distance from the center to the point of static level recovery according to the formula

$$R = 1.5\sqrt{at}\ ; \qquad (1)$$

w – pressure conductivity factor m^2/day.

Suitable for:

- confined water strata

$$a = k_f \frac{M}{\mu}; \qquad (2)$$

- free flow strata

$$a = k_f \frac{h_{av}}{\mu}; \qquad (3)$$

h –mean power of waterbearing stratum during the period of pumping, m. h_{av}= 0,8H;

μ –water yield factor;

t – standard time of well operation, years (25 years = 9125 days).

3) interacting well discharge is designed by formula

$$Q_{in} = \alpha_{in} \cdot Q_w; \qquad (4)$$

where α_{in} – interaction factor, for practical calculation is taken according to the table1.

Table 1. Value of interaction factor.

Distance between wells l , m	2 R	R	0,5 R	0,2 R	0,02 R	0,002 R
α	1	0,97	0,9	0,81	0,64	0,53

4) distance between wells is determined according to the table 2.

Table 2. Distance between water wells.

Water-bearing rock	Well productivity, m^3/hour		
	Up to 20	20-100	100-500
Fine sand	50	50-70	70-100
Medium sand	70-100	100-150	120-150
Coarse-grained sand	100-120	120-150	150-200
Gravel and fractured ground	120-150	150-200	200-250

5) the number of operating wells is determined by the formula

$$n = \frac{Q}{Q_{in}}; \qquad (5)$$

where Q– the necessary discharge of water intake, m^3/day.

The number of redundant wells is determined according to the table 3.

6) actual discharge (m^3/day) interacting wells is determined according to the number of workers and needed discharge

$$Q_{in.ac} = \frac{Q}{n}; \qquad (6)$$

7) level lowing, m

- lowing level in each well:

$$S = \frac{0.37\,Q_w}{kf} lg\,\frac{R}{r}; \qquad (7)$$

Table 3. The number of redundant wells.

Number of operating wells	The number of redundant wells on water intake of category		
	I	II	III
From 1 to 4	1	1	1
From 5 to 12	2	1	-
13 and more	20%	10%	-

Maximal lowing level:

$$S = \frac{0.37}{k_f M}\left(Q_{w1} lg\,\frac{R}{r_0} + Q_{w2} lg\,\frac{R}{r_{2-1}} + Q_{w3} lg\,\frac{R}{r_{3-1}} + \cdots + Q_{wi} lg\,\frac{R}{r_{i-1}}\right. ; \qquad (8)$$

where r_0 – well radius, in which the lowing is determined, м;
r_{2-1}, r_{3-1}… r_{i-1}– distance from well № 1 up to the following wells, m.

Thus, the power of water bearing strata and filtration factor are the same on the whole water intake, the productivity of the pump equipment assembled in every tube wells is equal that is well discharges are equal.

8) then the designed maximal lowing is compared
$S_{max}$with allowable lowing $S_{val.}$ At $S_{max} > S_{val}$,
widen the distance between wells and repeat the calculations.

The allowable level lowing depends on the hydrological conditions of water bearing strata, tube well structure (well), place of pumping aggregate and filter position. This lowing is determined depending on the producing strata pressure by the following formula:

- inpressure water well $S_{val} = H – [(0,3\text{-}0,5)M - \Delta h_p - \Delta h_f]$; (9)
- free flow strata $S_{val.} = (0,5 - 0,8)\ H - \Delta h_p - \Delta h_f$ (10)

where Δh_p – maximal depth of pipe edge immersion under dynamic level in the well, m;
Δh_f – in nonpressure well at inlet through the filter, m.

9) in conclusion, the dynamic level position in the well is determined:

$$Z_d = Z_{st} - S_t \qquad (11)$$

where Z_d – dynamic level, m;
Z_{st} – static level, m;
S_t – accepted value of level lowing, m.

Design of water lifting station consists of some stages:
- substantiation of design model;
- determination of plot size for the water station
- substantiation of rational scheme of well position inside the plot;
- substantiation of well operation during the design working period (discharge and dynamic level lowing).

Linear scheme of well connection to the prefabricated water conduit is the simplest and applied during the water conduit stringing into one line [4,5,9,11,13] (Fig. 1). Prefabricated water conduct diameter can increase, at growing of joined wells number and as a result at the discharge increase.

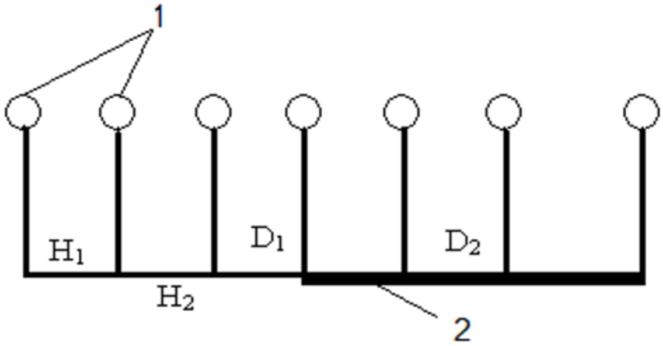

Fig. 1. Linear scheme of well connection to the prefabricated water conduit in one line
1 –water well; 2 –prefabricated water conduit

While determining the prefabricated water conduit operation behavior it is necessary to take into consideration the combined work of pure water tanks and tube wells. Thus, the pressure created by submersible drive pump unit at the point of connection to the prefabricated water conduit H_1 should be greater than in water conduit.

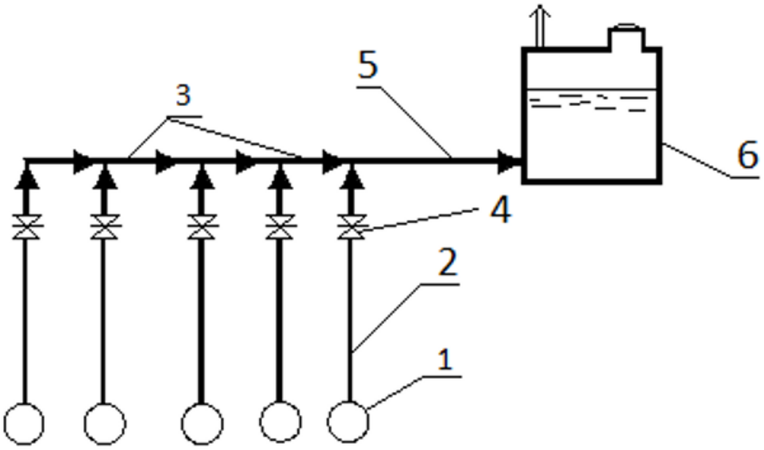

Fig. 2. Linear scheme of wells connection on water diversion work from underground spring
1 – water receiving structures (wells); 2 pressure pipes; 3 – prefabricated water conduit; 4 – stop control valve; 5 – main water conduit; 6 – pure water tank.

In Fig. 2 there is the scheme with well point systems applied as water diversion works. Water derived from water bearing strata by submersible pumps is placed in wells into pressure water conduits delivered into collection water conduit and then comes into pure water tanks.

General scheme of structures disposition on water system presented in draw 2 is the most commonly used in construction practice and underground water-diverting structure operation when wells are used as water receiving structures as the quality of water extracted from water bearing strata before delivery to a consumer needs improving.

If on the water-diverting structure the amount of wells are big and they are located along a river and on the distance L from it, it is possible to use formula admitting the substitution of real well raw, by the galleries with 1m of length discharge [4,14, 15,16]:

$$q = \frac{Q_\Sigma}{2l} = \frac{Q}{2\sigma} \qquad (12)$$

where Q_Σ - total discharge of wells;
Q –one well discharge;
l- half the gallery length;
σ - half the distance between wells; $\sigma = \frac{l}{n-1}$;
n –general number of wells.

If the linear series of wells has a length commensurate with the distance to the river (that is 2l≈L), the equation for a gallery of finite length is used in the calculations. Then, when using a method of mirror displays, we receive the dependence allowing to define decrease in dynamic level at any time, time at the long periods pumping out to any point of layer M (draw. 3).

If the linear raw has the length commensurable with the distance up to a river (that is 2l≈L), the equations for the galleries of final length are applied [17,18] :

$$S = \frac{Ql}{2\pi km\sigma} R_{lin} \qquad (13)$$

$$R_{lin} = \frac{1}{2}\ln\frac{1+(\bar{y}+\bar{L})^2}{1+(\bar{y}-\bar{L})^2} - \bar{\gamma} arctg\frac{2\bar{L}}{\bar{\gamma}^2 - \bar{L}^2 + 1} + \bar{L} arctg\frac{2\bar{y}}{\bar{\gamma}^2 - \bar{L}^2 - 1} \qquad (14)$$

These formulas give the possibility to determine how the dynamic level falls at points remote from the wells located perpendicularly to it.
If it is demanded to determine the dynamic level lowering in the very tube wells the function R_{lin} is expressed as following:

$$R_{lin} = \frac{1}{2}\ln 1 + (1+2\bar{L}) + 21 + \bar{L} arctg\frac{1}{2\bar{L}} + \frac{\sigma}{L}(\ln\frac{\sigma}{\pi r_0} + \zeta) \qquad (15)$$

Simply transforming the formula (12) and putting formula (14) into it we receive the dependence with the help of which we define the water discharge of one well:

$$Q = \frac{2S\pi km\sigma}{l}\left(\frac{1}{2}\ln 1 + (1+2\bar{L}) + 21 + \bar{L} arctg\frac{1}{2\bar{L}} + \frac{\sigma}{L}(\ln\frac{\sigma}{\pi r_0} + \zeta)\right) \qquad (16)$$

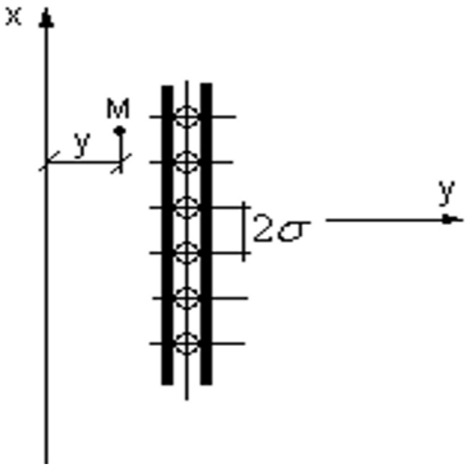

Fig. 3. Scheme of the design of linear row of wells locating near the river.

As a result, we receive the general dependence of discharge for one well:

$$Q = \frac{4\pi k m \sigma S}{\left[-E_i\left(-\frac{r^2}{4at} \right) + \varepsilon \right]} \tag{17}$$

k- filtration factor, m/day;
m–water bearing horizon power, m;
t - duration of water pumping from one well
R – well radius, m;
a – pressure conductivity factor
E_i– integral exponential function;
ε – factor considering filter resistance, considering hydraulic uplift.
If wells give the constant discharge during long period of operation the expression (17) is

$$Q = \frac{2\pi k m \sigma S}{\ln\frac{R}{r} + \varepsilon} \tag{18}$$

R – well radius of influence.
If during the water intake the wells are located in one row and parallel to water body bank the calculation can be done by the expression:

$$Q = \frac{2\pi k m \sigma S}{\ln\sqrt{1+\frac{2L}{l}} + \frac{2L}{l} arctg\frac{l}{2L} + \frac{\sigma}{l}\left(\ln\frac{\sigma}{\pi r_0} + \varepsilon \right)} \tag{19}$$

L – distance between the rows of wells, m.

3 Results

Investments for building and creation of the best conditions for the equipment and mains operation depend on the choice of the scheme of water-diverting structure, its operation performances.

The analysis of optimization of interacting wells operation showed that linear scheme of tube wells connection to the collection water conduit water conduit is the simplest one and is used while water conduit placing in one row.

4 Discussion

The design of interacting wells group consists of defining the tube wells number, distance between them, discharge and levels (static and dynamic). While determining the operation conditions of water collection conduit it is to consider combined work of pure water tanks and tube wells.

The diameter of water collection conduit is to be increased at increasing of connected wells number and consequently the increasing of discharge.

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