WATER INTAKES BY WELLS AND INFILTRATION GALLERIES

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Contents

Summary

Infiltration galleries or wells can be used in order to withdraw sea water. Their proper design requires the knowledge of the fundamentals of well hydraulic. The principles of well and infiltration gallery design are developed and illustrated by examples. Maintenance requirements and costs assessments are given.

1. Introduction

Sea water as well as fresh water can be withdrawn from wells or infiltration galleries. In the case of sea water, the wells are located close to the beach.

A well is a hydraulic structure which:

- When hydrogeological conditions are favourable,
- When properly designed and constructed,

permits the economical withdrawal of water free or nearly free of suspended matter. Depending upon the required water quantity, one or more wells are used.

For some geological conditions, particularly when the aquifer thickness is not sufficient to supply a sufficient volume of water from vertical wells or when the aquifer is hydraulically connected to the sea, infiltration galleries can provide the required water volume. Infiltration galleries are placed adjacent or under the surface water body.

In order to determine the number of wells, to design and construct the wells or to dimension the length and layout of the infiltration galleries, an understanding of the fundamentals of well hydraulics is required.

Some aspects of well hydraulics are complicated and involve complex mathematical solutions, which are not always applicable when geological conditions are uncertain. Only basic methods are examined. Remarkably, experience shows that in most cases, when properly applied, such basic methods yield accurate results.

2. Well Hydraulics

When a well is pumped, in unconfined conditions the water level in its vicinity is lowered. The greatest drawdown occurs in the well itself.

An area of low pressure is developed near the well, and, since the water level is lower in the well, than at any place in the water-bearing formation surrounding it, water moves from the formation into the well to replace water being withdrawn by the pump.

Under confined conditions, in most circumstances, the saturated thickness of the aquifer is not reduced during pumping but the hydraulic pressure is diminished in the aquifer and the pressure decrease is the greatest at the bore itself. For both confined or unconfined conditions, the resulting difference of pressure, called head, drives the flow of water into the well.

During pumping, water flows towards the well from every direction. As the water moves closer to the well, it moves through cylindrical sections that are successively smaller in area. When approaching the well, the velocity of the water increases.

Darcy's law indicates that the velocity of flow through porous media varies directly with the hydraulic gradient. As the hydraulic gradient increases, velocity increases as flow converges towards a well. As a result, the lowered water surface develops a continually steeper slope toward the well. The form of this surface resembles a cone and is called the cone of depression. When pumped, all wells are surrounded by a cone of depression. Each cone differs in size and shape depending upon the pumping rate, pumping duration, aquifer characteristics, slope of the water table, and recharge within the cone of depression of the well.

The radius of influence is the horizontal distance from the center of a well to the limit of the cone of depression.

When water is pumped from a well, the initial discharge is taken from casing storage and later from the aquifer storage in the immediate surrounding. As pumping continues, additional water is derived from aquifer storage at greater distances from the bore. It implies the cone of depression is expanding and the radius of influence is increasing. The related drawdown is also increasing at any point in order to provide the required additional head to move the water from greater distances to the well.

The cone of depression will continue to enlarge until at least one of the following conditions is met:

- Enough flow of the aquifer is intercepted to equal the pumping rate,
- A surface water body (e.g. the sea) is intercepted,
- Enough vertical recharge or leakage occurs within the radius of influence.

Transmissivity and storage coefficients are the most important hydraulic parameters of a water bearing formation. The coefficient of transmissivity is related to the quantity of water moving through the formation and the storage coefficient to the quantity that can be removed by pumping or draining.

Both coefficients have to be determined in order to be able to make significant predictions such as:

- Drawdown in the aquifer versus distance from pumped well,
- Drawdown in the aquifer in the well, versus time,
- Drawdown in the aquifer, versus pumping rate,
- Well's drawdown interaction, if several wells are used.

In the text below, we shall see how they can be determined and used for water well design.

2.1. Equilibrium Well Equations

Darcy's basic flow equation to groundwater has been adapted to wells. There are two basic equations: one for unconfined and the other for confined conditions.

For both equations, all dynamic conditions in the well and ground are assumed to be in equilibrium, that is, the discharge is constant, the drawdown and radius of influence have stabilized, and water enters the well in equal volumes from all directions. Both assume horizontal flow everywhere in the aquifer with recharge occurring at the periphery of the cone of depression. The equation for the yield of an unconfined aquifer is (Fletcher and Driscoll 1986):

$$Q = \frac{2\pi k\left(H^2 - h^2\right)}{2.3\,\log\left(R/r_a\right)}$$

For the well yield of a confined aquifer one has (Fletcher and Driscoll 1986):

$$Q = \frac{2\pi ke\left(H - h\right)}{2.3\,\log\left(R/r_a\right)}$$

Derivations of the foregoing equations are based on simplifying assumptions as:

- The water-bearing materials have a uniform hydraulic conductivity within the radius of influence of the well,
- For an unconfined aquifer, the saturated thickness is constant before pumping starts; for a confined aquifer, the aquifer thickness is constant,
- The pumping well is 100 per cent efficient, that is, the drawdown levels inside and just outside the well bore are at the same elevation (head losses in the vicinity of the well are non-existent),
- The intake portion of the well penetrated the entire aquifer,
- The water table or piezometric surface has no slope,
- Laminar flow exists throughout the aquifer and within the radius of influence.

2.2. Non-equilibrium Well Equation

The non-equilibrium well equation was developed by Theis (1935). The Theis equation was the first to take into account the effect of pumping time on well yield. Its derivation was a major advance in groundwater hydraulics. By use of this equation, one predicts the drawdown at any time after pumping begins. Transmissivity and average hydraulic conductivity are determined during the early stages of a pumping test rather than after water levels in observation wells have virtually stabilized. Aquifer coefficients are determined from the time-drawdown measurements in a single observation well rather than from two observation wells as required in equations based on Darcy's law. The derivation of the Theis equation is based on the following assumptions:

- The water-bearing formation is uniform in character and the hydraulic conductivity is the same in all directions,
- The formation is uniform in thickness and infinite in extent,
- The formation receives no recharge from any source,
- The pumped well penetrates and receives water from the full thickness of water-bearing formation,
- The water removed from storage is discharged instantaneously when the head is lowered,
- The pumping well is 100 per cent efficient,
- All water removed from the well comes from aquifer storage,
- Laminar flow exists throughout the well and aquifer,
- The water table or piezometric surface has no slope.

These assumptions are essentially the same as those for the equilibrium equation, except that the water levels within the cone of depression need not have stabilized or reached equilibrium.

Reworked by Cooper and Jacob (1952), the Theis equation becomes:

$$s = \frac{0.183Q}{T} \log\frac{2.25Tt}{d^2 S}$$

For a particular situation where the pumping rate is held constant, Q, T and S are all constants. The above equation shows, therefore, that the drawdown s varies with log t/d^2. From this relationship, two important relationships are stated:

- For a particular aquifer at any specific point (where d is constant), the terms s and t are the only variables of above equation. Thus, s varies as log αt, where α represents all the constant terms in the equation
- For a particular formation and at given values of t, the terms s and d are the only variables. In this case, s varies as log β/d^2 where β represents all the constant terms in the equation.

Using these simple relationships, it is possible to derive the hydraulic parameters that are characteristic of an aquifer and furthermore, after having performed a pumping test, to properly design a well and to forecast its water withdrawal capacity.

If several wells have to be used in order to reach the required water quantity, it is rather easy to predict their reciprocal influence by mathematical modeling.

Example of determination of hydraulic parameters. At Dekhelia (Von Echelpoel 1993), a field investigation based on five wells along the beach was made. Pumping tests were performed.

The wells were located at 10 m distance from the shore and at a spacing of 30 m. The aquifer is a 31 m thick band of sandstone, underlain by impervious marl. Static levels are found at 5 m depth.

The log time-drawdown graph was linear. For one well, the test has been performed at a pumping yield of 65 $m^3 h^{-1}$. The angular coefficient "a" on the graph is 2.5 m. From the Theis equation, $a = 0.183Q/T$ and one obtains $T = 1.3 \times 10^{-3}$ $m^2 s^{-1}$.

During the pumping test, the water level in the nearest well which was used as an observation well, started to drawdown after 150 min.

Again from Theis equation, since the drawdown $s = 0$ at $t = 150$ minutes and d = the distance from the pumped well to the observation well, one has the storage coefficient

$$\mathrm{S} = \frac{2.25Tt}{d^2} = 2.9\%.$$

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