APPLICATION OF HORIZONTAL DRILLING TECHNOLOGY IN GROUNDWATER PROJECTS

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ABSTRACT
Drilling and production of horizontal wells are the most significant technological breakthrough of the oil and gas industry in the eighties. Since then it has been widely used throughout the world for oil and gas production. When compared to a vertical well, horizontal well proved to be one of the most effective choice in increasing production rates and improving reserves and hence increase the current value of the field under hand. In this paper a theoretical study is presented to study the applicability of this technique by comparing water productivity as a function of pressure drawdown of a Saudi fresh water formation using hypothetical vertical and horizontal wells. The scenario considered shows that productivity is two to six times higher using single horizontal well rather than four vertical wells depending on the drainage radius of the horizontal well. This proves that such drilling application is very promising in water formations. It can boost the production with minimal pressure drawdown and hence save a huge amounts of money and reduce the degree of fluid disturbance (conning and saline water intrusion) that may occur due to high pressure drawdown caused by excessive water production.

KEYWORDS
Groundwater, Wasia, Horizontal well, Drawdown, Fresh water.

INTRODUCTION
Saudi Arabia in general is one of hottest and most arid countries in the world, with summer temperatures reaching 46^{o}C and an average rainfall of 120 mm per year. Saudi Arabia has three primary types of water resources. These are non-renewable groundwater, renewable ground and surface waters, and desalinated seawater. About 88 percent of the water consumption requirements of Saudi Arabia are met by groundwater. The western coastal plain (Tihama) receives 60 percent of the country's total rainfall. Rainfall in this region provides an average supply of approximately 1.85 billion cubic meters of water, accounting for approximately nine percent of the total annual water consumption. Desalinated water production is approximately two million cubic meters per day, constituting approximately 2.5 percent of annual water consumption [1]. Table 1 lists the major ground water formations in Saudi Arabia. All wells drilled in these formations for groundwater production are vertical.

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Table. 1 Major groundwater aquifers in Saudi Arabia [2].

Aquifer	Water depth, m	Thickness, m	Productivity, m^3/day	Location	Rock type
Al-Saq	150 – 1500	650	8640	Central-North	Sandstone
Wajid	150 – 900	600	3456 – 6912	Southern	Sandstone
Tabuk	60 – 2500	1072	1296 – 1728	Central-North	Sandstone and Shale
Minjur	1200 – 2000	315	5184 – 10368	Central	Sandstone
Dhruma	100	375	5184 – 10368	Central	Sandstone and Limestone
Biyadh	30 – 200	425	2160 – 4320	Northern	Sandstone
Wasia	100 – 800	150	7344 – 9504	Central-East	Sandstone and Shale
Umm-Er-Radhuma	100 – 400	330	4320 – 8640	Eastern	Limestone
Dammam	160 – 200	80	605 – 1900	Eastern	Limestone
Neogene	50 - 100	100	4320 - 8640	Eastern	Sandstone and Limestone

High water production rates from vertical wells yield excessive drawdown. When exceeding the critical drawdown value, water quality will be reduced and the stability of the productive formation adjacent to the well is altered. Due to the high demand of fresh water, conservation and development plans must be set to produce fresh water at maximum rates without disturbing the physical and mechanical properties of groundwater aquifers [3] and maintaining the quality of the produced water. The previously mentioned goals can be achieved by applying the technology of horizontal drilling.

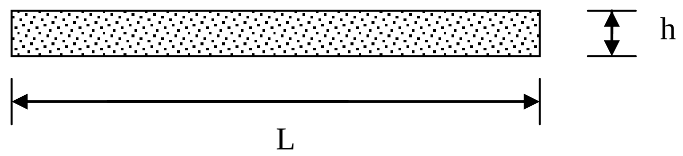
<u>HORIZONTAL WELL TECHNOLOGY</u>

Although directional drilling has been applied in the oil industry for many decades, horizontal well technology has not fully developed until late 1980's. Thousands of horizontal wells have been drilled in the period from 1985 up to date in different parts of the world.

In Saudi Arabia, now there are more than 200 horizontal wells drilled by Saudi Aramco and the Arabian Oil Company Limited (now changed to Saudi Aramco for Overseas Operations). The number of horizontal wells in Saudi Arabia is on the rise and is expected to account for more than 60% of the new planned wells.
Horizontal drilling is practiced in the oil and gas industry to overcome certain problems. Among those applicable to water formations are:

1- Thin pay zone in order to increase the contact between the drilled section and the water bearing formations (see Figure 1).
2- Poor knowledge of the lithology away from the wellbore.
3- Avoiding surface restriction.
4- High-pressure drawdown resulting in conning and formation instability.
5- Increasing recovery with minimal pressure drop.

Horizontal wells proved to be one of the most effective choices in increasing production rates and improving reserves and hence increase the current value of the field under hand. The objective of this study is to compare the productivity of hypothetical vertical and horizontal wells in Wasia groundwater aquifer in the central province of Saudi Arabia.



Vertical well:	h = Maximum layer thickness. Maximum flow surface area = 2 л r h
Horizontal well:	L = Maximum layer length. Maximum flow surface area = 2 л r L
Ratio of fluid flow surface area:	Horizontal / Vertical = L/h

Figure 1. Available flow surface areas for vertical and horizontal wells drilled in the same formation.

MODELLING OF FLUID PRODCTION

Radial fluid flow into a vertical wellbore in a homogeneous and isotropic formation is calculated using Darcy equation governing fluid flow in porous media:

$$Q_V = \frac{7.081 * k * h * \Delta P}{\mu * \beta * \ln\left(\frac{r_d}{r_w}\right)} \quad \ldots\ldots(1)$$

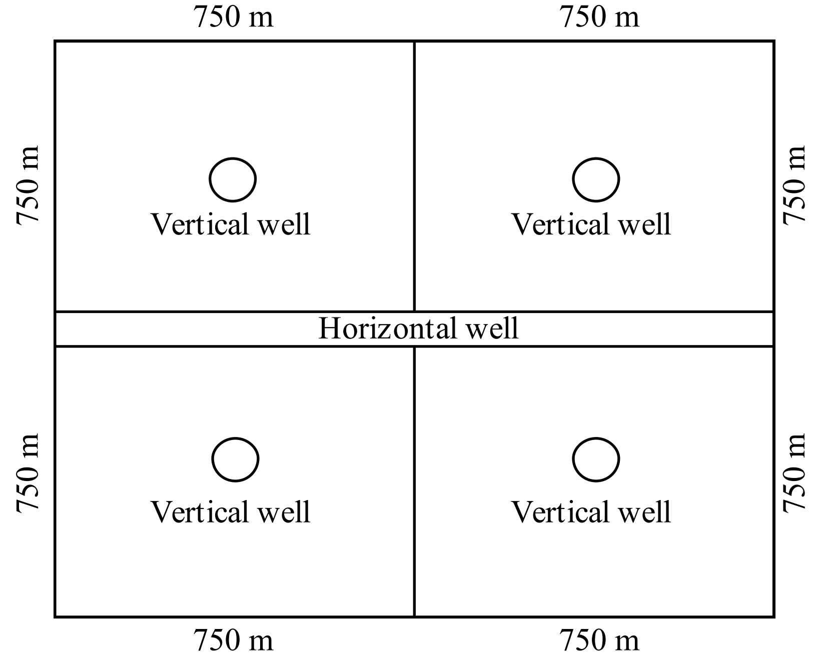
Under similar conditions mentioned above, fluid flow into a horizontal wellbore is calculated using the following formula [6]:

$$Q_V = \frac{7.081 * k * h * \Delta P}{\mu * \beta * \left\{ \ln\left(\frac{1 + \sqrt{1 - \left(L / 2 * r_d \right)^2}}{\left(L / 2 * r_d \right)} \right) + \frac{h}{L} * \ln\left(\frac{h}{2 * \pi * r_w} \right) \right\}} \quad \ldots\ldots(2)$$

From the above equations, it is noticed that pressure drawdown in vertical well is proportional to (Q/h) whereas in horizontal well it is proportional to (Q/L). As a result pressure looses for a given flow rate is a considerably less in horizontal well.

COMPARISON STUDY

Wasia ground water aquifer data was chosen to conduct the comparison analysis between vertical and horizontal wells. Wasia water field is one of the biggest water projects in Saudi Arabia that was constructed to meet water demand of Riyadh city. The well field is designed to supply more than 220,000 m^3/day. The well field is located 110 kilometers northeast of Riyadh. It consists of 62 vertical production wells and three vertical observation wells. The wells are located in four parallel rows extending northwest-southwest and both of the rows and wells are 750 meters apart [7]. The layout map of four wells of Wasia well filed and a single hypothetical horizontal well is shown in Figure 2.



Case 1: 4 vertical wells. Drainage area = 750 X 750 X 4 = 2250000 m^3.

Case 2: a single horizontal well. Drainage area = 1500 X 1500 = 2250000 m^3.

Figure 2. Drainage areas for hypothetical vertical and horizontal wells used in the comparison study.

Equations 1 and 2 have been used to calculate pressure drop (drawdown) for various production rates of water from firstly four vertical wells and secondly form a single horizontal well from an equivalent drainage area. Ground water aquifer rock and fluid properties as well as wells dimensions are shown in Table. 2.

Table 2. Rock, fluid and wells properties of the groundwater aquifer used in the comparison study.

r_d = 423 m (1388 ft) for a single vertical well.		
r_d = 846 m (2776ft) for a single horizontal well.		
L = 1500 m (4922 ft).	h = 150 m (492 ft).	r_w = 0.20 m (0.66 ft).
k = 400 md.	μ = 1 cp, for water.	β = 1, for water
Aquifer depth = 1312 m (4305 ft).		
Aquifer water pressure = 144 atm (2115 psi).		

Pressure drawdown for a single vertical well is calculated using Eq. 1 and multiplied by four assuming the existence of four vertical wells in the drainage area. This calculation was repeated at different production rate. For comparison, a single horizontal well replaced the four vertical wells using the same drainage area. The same values of the production rates used in the case of vertical wells were used in Eq. 2 to calculate the drop in the aquifer pressure (drawdown). The resulted drawdown data was plotted versus the production rates as shown in Figure 3. It can be seen that a production rate of 180 MM m^3/day using the four vertical wells requires a drawdown four times greater than that required to produce the same quantity from a single horizontal well.

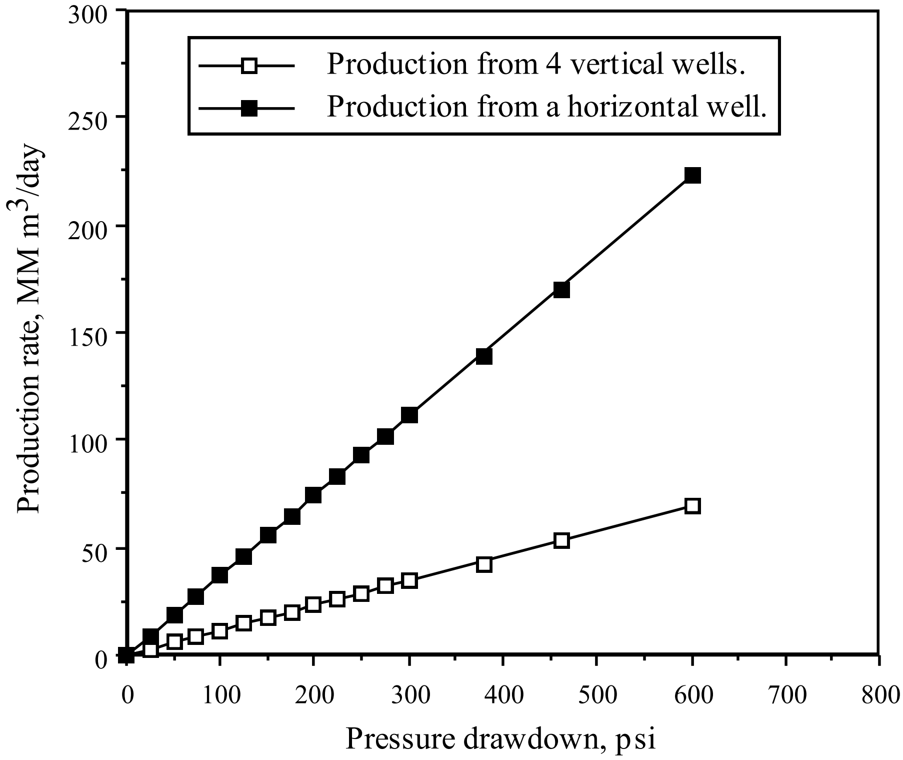


Figure 3. Relationship between pressure drawdown and water production rate for vertical and horizontal wells.

ECONOMICAL FACTOR

Early in the horizontal drilling practice, cost was high when compared to vertical wells in addition to loss of time due to hazards and lack of experience in this new technology. Nowadays, drilling and completion of horizontal and vertical wells are relatively similar due to the huge technological development in drilling tools manufacturing and the huge experience gained throughout the years. The marginal cost ratio between a horizontal to vertical wells is reduced to a ratio of 1.5. In Saudi Arabia cost was reduced by 40 % in four years time between 1990 and 1993 without scarifying the productivity. The difference in drilling and completion cost can be overcome by reducing the number of wells drilled to drain a certain area and the increase in reserves and production rates.

CONCLUSIONS

Based on the analysis conducted in this study, the following conclusions are obtained:

- For the same pressure drawdown in the same formation and drainage area, a single horizontal well yields four times higher fluid production than that obtained by four vertical wells

- The utilization of horizontal wells reduces the cost of maintenance and observation.

- The utilization of horizontal wells provides higher fluid production at minimal disturbance of fluids and formation properties.

- The application of horizontal drilling technology is therefore highly recommended in groundwater projects.

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NOMENCLATURE

r_d = Radius of the drainage area, ft.

r_w = Wellbore radius, ft.

h = Formation thickness, ft.

k = Formation permeability, md.

μ = Fluid viscosity, cp.

β = Formation volume factor, bbl/STB.

ΔP = Pressure drawdown, psi.

L = Length of the horizontal section, ft.

Q_v = Fluid flow (production) rate from a vertical wellbore, bbl/day.

Q_h = Fluid flow (production) rate from a horizontal wellbore, bbl/day.