APPLICATION OF DERIVATIVE ANALYSIS TECHNIQUE FOR PUMPING TEST INTERPREATION, COASTAL AQUIFER, SHARM EL SHEIKH AREA, EGYPT

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ِABSTRACT

Blind application of Jacob straight line method for the analysis pumping test leads to numerous errors in the estimated aquifer parameters, transmissiivity and storativity. These errors come from overlooking the underlying assumptions of the method. Pumping tests were carried out near shore in four wells installed for desalination unit. They are two pumping well for water pumping from the aquifer and two injection wells to inject back the brine water to the aquifer. This work concerned with examining the importance of derivative analysis technique in the interpretation of pumping tests and investigate the possibility of short circuit of brine water from injection wells to the pumping ones. Diagnostic plot of the drawdown and its derivative of the pumping data were examined and the hydrodynamic parameters of the aquifer estimated by fitting the observed and type curve using the non linear least square method. Also analytical analyses were carried out to investigate the time expected for brine water short circuit. It is found that the most important advantages of derivative analysis is to be used as screening tool for the pumping test data to identify which segment or part of the pumping data satisfy the underlying assumption of Jacob straight line method. This segment called infinite acting radial flow, IARF, especially when u value can't be estimated as Transmissivity and Storativity are not known to check the validity of Jacob method. Derivative analysis in some cases can't help to confirm well-bore storage. Starting aquifer parameters in non linear least square fitting method is crucial in identifying the best type curve which fit the observed pumping data. As a general approach , derivative diagnostic plot, diagnostic plot of original pumping data, aquifer lithology and non-linear least square fitting method with proper starting aquifer parameters all together can help in identifying the aquifer type and the proper interpretation method that yield reliable aquifer parameters. The analytical analysis revealed that there is a high possibility of short circuit of brine water in short time. The limited available space for injection wells location is greatly influence the time expected for short circuit of brine water.

Key words
Derivative analysis, pumping test , groundwater, short circuiting.

تطبيق تقنية التحليل الاشتقاقى لتفسير تجارب الضخ بالخزانات الساحلية بشرم الشيخ - مصر

تم استخدام تقنية التحليل الاشتقاقى لتحليل تجارب ضخ بعدد (اربعة) آبار إنتاجية وصرف والتى تم انشائها بغرض تحليل المياة الجوفية.

وكذلك تحديد زمن وصول مياه صرف الآبار شديده الملوحة الى الآبار الانتاجية. تم تحليل بيانات الانخفاض بالمياة ومشتقاتها. وجد انه يمكن استخدام التحليل الاشتقاقى لتحديد نوع الخزانات الجوفية.

كما تم تحديد زمن وصول مياه الصرف شديدة الملوحة الى الآبار الانتاجية وكان قصير جداً وذلك قد يرجع الى النفاذية العالية للصخور وقرب المسافة بين آبار الصرف والآبار الانتاجية.

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Introduction

Derivative analysis was developed a new technique in petroleum industry by Bourdet et al. (1983) to aid in interpretation of pumping test data. It was first used in hydrogeology field by Karasaki et al. (1988), Spane (1993) and Spane and Wurstner (1993). It is defined by the derivative of the drawdown with respect to log time according to the following simple equation

$\partial S/\partial \ln t = (S_i - S_{i-1})/\log(t_i - t_{i-1})$ (1)

Where S is the drawdown

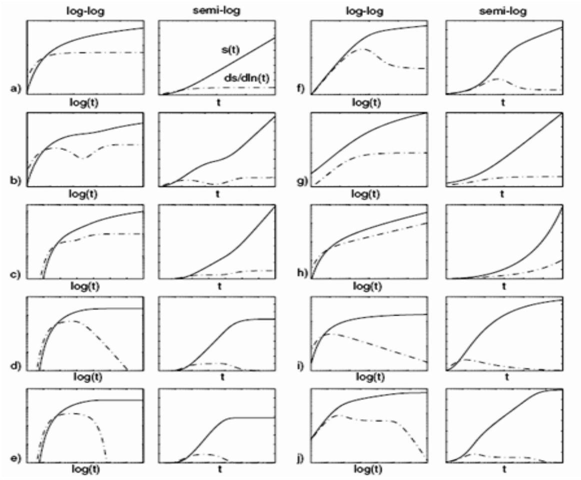
t is the time of drawdown measurements

The derivative diagnostic plot is a plot of measured drawdown with its derivative on log-log graph. The advantage of the derivative is its sensitivity to small change in drawdown during pumping, so it reveals what is hidden in the measured drawdown. Consequently it can help in identifying the aquifer characteristics and type well-bore storage, recharge or barrier boundaries and identifying radial flow conditions using typical diagnostic plots (Fig. 1). Different analytical models for interpreting pumping test data under various conditions were developed. Choosing the best model which could fit the observed pumping data is important process. So it is important to the hydrogeologist to define the type of aquifer and most important is to define which part or segment of the pumping test data that satisfy the assumptions based on which the analytical solution was developed. Derivative diagnostic technique can be used in identify these segments and confirm aquifer type. Derivative diagnostic plot is used to identify of the suitable analytical method that could be used to interpret the pumping test data. One of main disadvantage of derivative diagnostic plot is the noise in data points especially when there are small differences in the measured drawdown. To minimize this high oscillation in the derivative data which reduces or may be cancel the benefit of using this technique in the pumping test data interpretation, numerical differentiation methods have been proposed by many authors such as Bourdet et al. (1989). So the over all trend of drawdown derivative can be used in interpretation not every small change. The assumptions underlying Jacob straight line method Cooper & Jacob(1946) are satisfied when the radial flow component achieved. This radial flow can be inferred when the derivative data *exhibit horizontal line (the drawdown derivative is constant*), the stability of derivative drawdown called infinite radial flow component (*IARF*) (Fig.2). This derivative stabilizes since Theis model (1935) stabilizes at late time according to the following equation:

$\text{Lim } s(t) = Q/4 \prod T \text{ Ln } (2.25tT / r^2S)$ when t goes to infinity (2)

Where Q, discharges (m^3/d), s drawdown (m), T (m^2/d) transmissivity, S (dimentioless) storativity, r (m) distance of observation point from pumping well. In this case Jacob straight line can be used for this part of pumping data. In this case some authors such as (Renard et al, 2009) suggest that the following equation can be used to estimate transmisivity :

$\partial S/\text{Ln } t = Q/4\pi T$ (3) Where $\partial S/\text{Ln } t$ is the slope of drawdown derivative line. (After Renard et al, 2009)



____ Drawdown

------- Derivative

Figure. 1 Typical diagnostic plots in hydrogeology field : a Theis model: infinite two-dimensional confined aquifer; b double porosity or unconfined aquifer; c infinite linear no-flow boundary; d infinite linear constant head boundary; e leaky aquifer; f well-bore storage and skin effect; g infinite conductivity vertical fracture.; h general radial flow—non-integer flow dimension smaller than 2; i general radial flow model—non-integer flow dimension larger than 2; j combined effect of well bore storage and infinite linear constant head boundary (After Renard , 2005b)

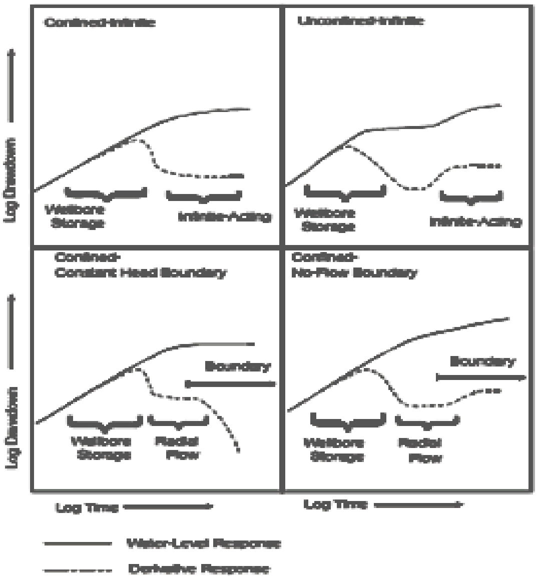


Figure 2 Typical characteristic log-log drawdown and drawdown plots for various aquifer types and boundary conditions (after Spane and Wurstner, 1993).

The studied location lies in Sham El Sheikh area and the four drilled wells lies near shore at Nama Bay (Fig 3). Drilling cuttings from the four wells (two pumping wells 1&2 and two injection wells 1&2) indicate that the water bearing rock in the area are made of limestone and dolomitic limestone with intercalated gravel, sand and silt clay . From the geologic and geophysical logs, the most permeable sections which should be screened of the wells were identified with blank casing in between. The injection wells were drilled to depths greater than the production wells to inject the brines into deeper parts. This work explores the importance of derivative analysis in interpretation pumping test data from wells near shore and investigate the possibility of short circuit of brine water injected bye the injection wells (injection wells 1&2) to be pumped back by pumping well (1 &2).

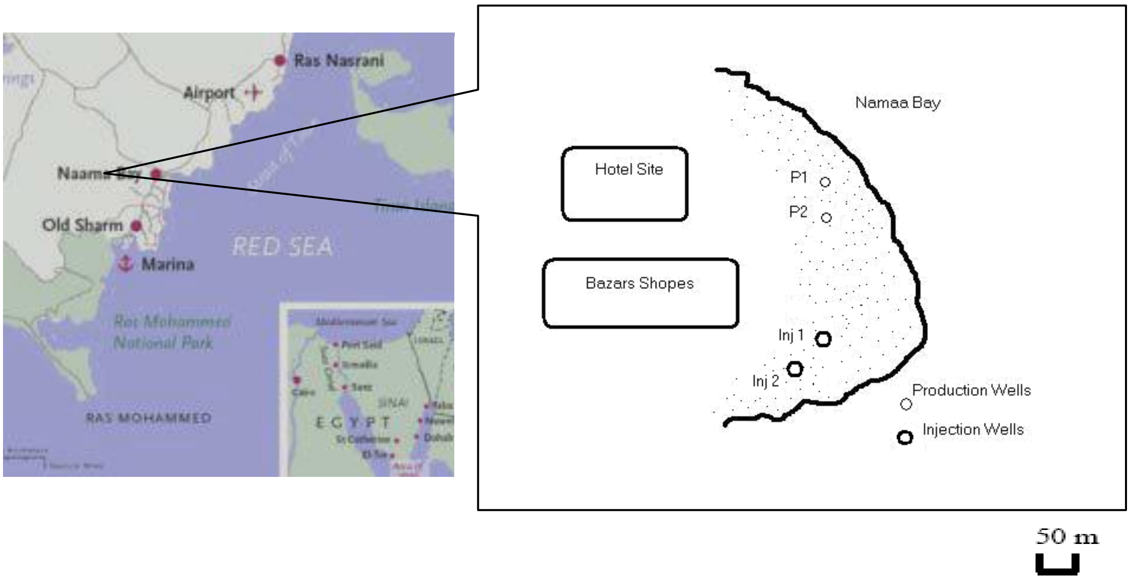
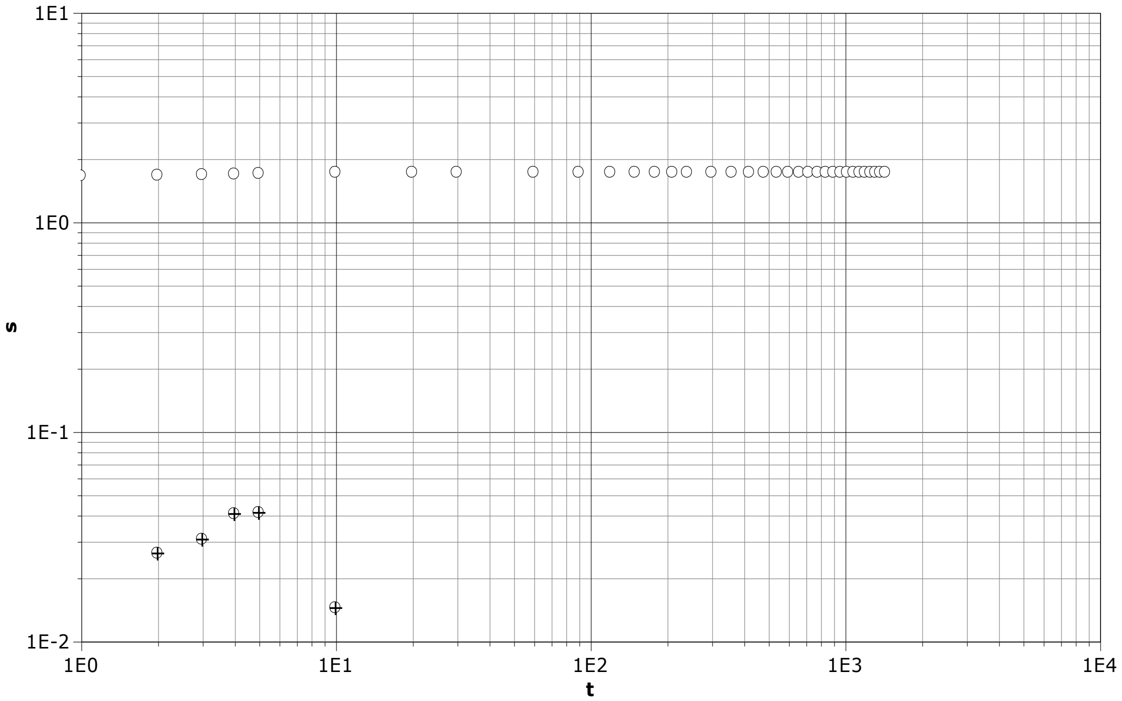


Figure 3 Location map of Sharm El Sheikh area and Sketch diagram for pumping and injection wells

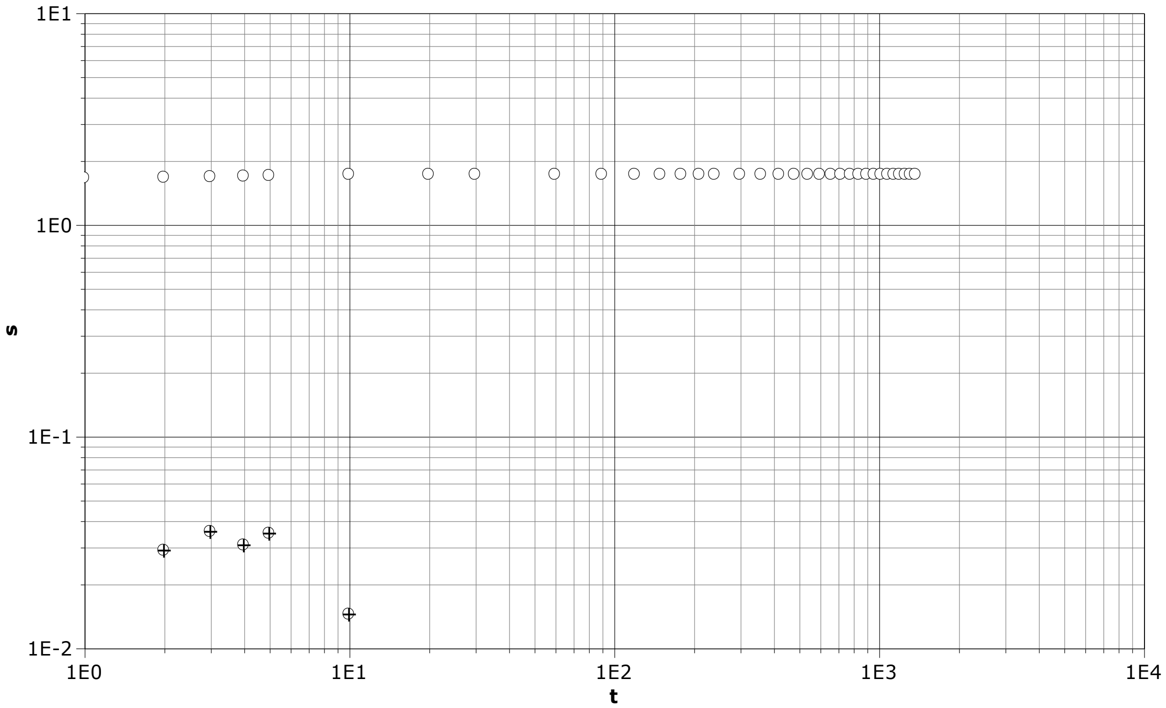
Derivative analysis as screening tool

Diagnostic log-log plots of the measured drawdown and its derivative in the four wells (Fig.4&5) don't exhibit unit slop in the early data. Early pumping data gives very small slope which may be due to pumping near shore, recharge boundary, and high transmisivity. In addition the log derivative doesn't follow log drawdown in the early data. It may be means the log derivative not equal the log drawdown. This is may agree with the view of Renard et al (2009) that in the case of an effective well-bore storage the log drawdown in the well equal to log derivative of the drawdown. Consequently it may be concluded that there's no well bore storage in the four pumping wells. Derivative analysis can ***spot*** and confirm the radial flow segment in the pumping data when drawdown derivative becomes constant (horizontal line), so the frequently mistake committed by hydogeologist once they observe line with constant slope in lat pumping data can be avoided. In this case Jacob straight line method can be applied, and this is the great role for derivative analysis. Comparing the diagnostic plot with the standard one it suggest that the aquifer could be leaky or unconfined with recharge boundary. This is confirmed from inspection of semi-log plot of original pumping data (Fig.6) the late origin drawdown indicating the existence of recharge boundary, Namaa Gulf, at the same time the drawdown derivative declining which indicates existence of recharge boundary and **No** Theisian infinite radial flow component (IARF component). Until this stage the diagnostic derivative plot suggested that the aquifer could be leaky or unconfined aquifer with recharge boundary.



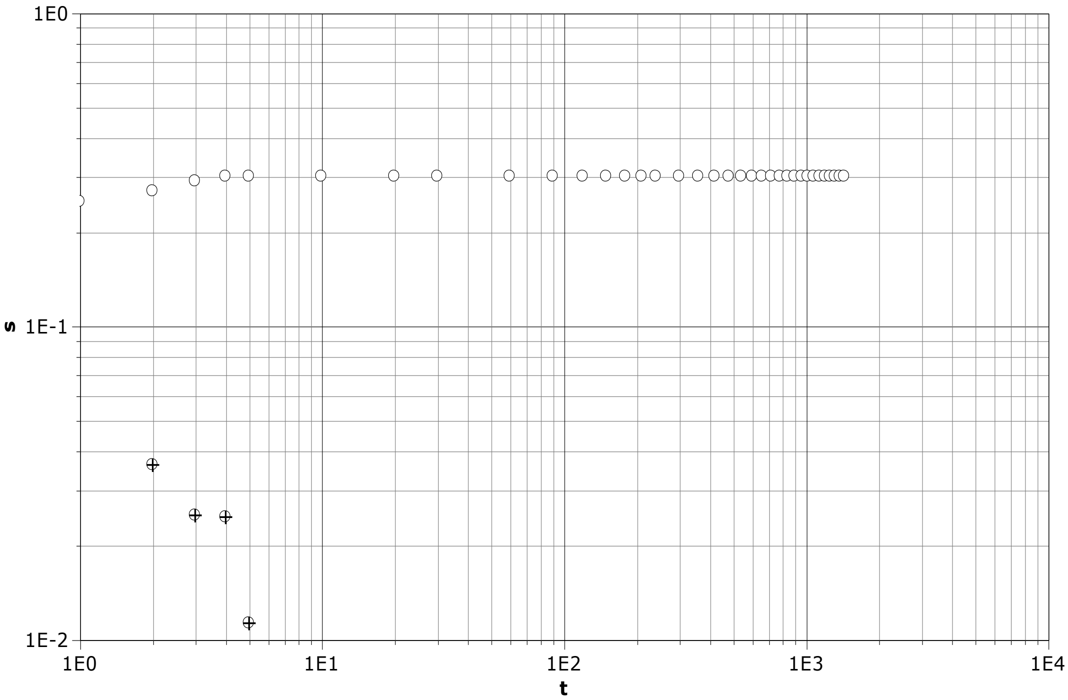
a) Diagnostic plot of pumping well 1

○ Measured Drawdown
⊕ Drawdown derivative



b) Diagnostic plot of pumping well 2

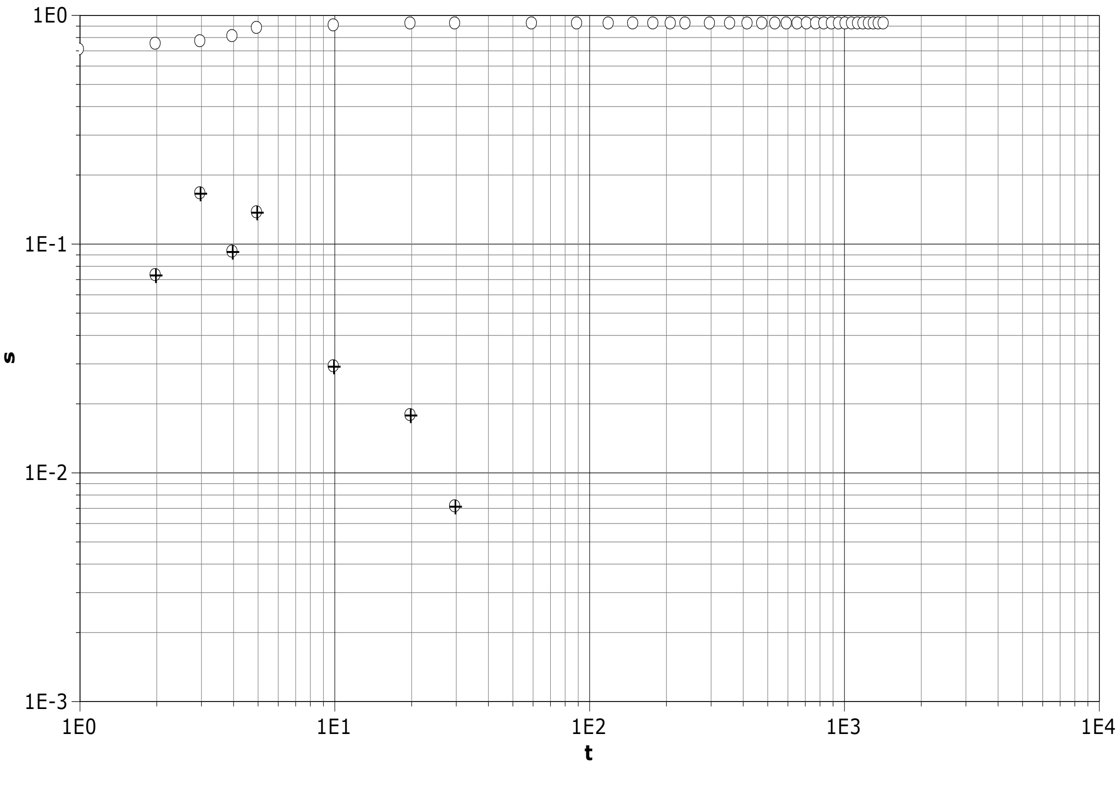
Figure 4 Diagnostic plots of the pumping wells 1& 2



a) Diagnostic plot of injection well 1

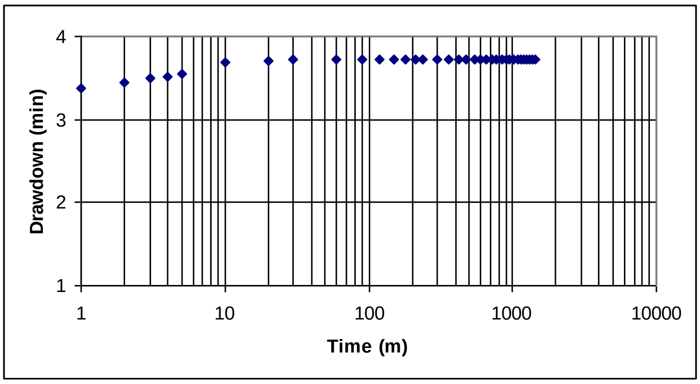
○ Measured Drawdown

⊕ Drawdown derivative

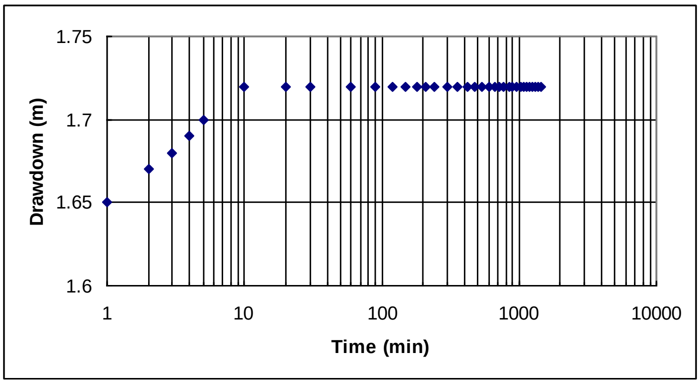


b) Diagnostic plot of injection well 2

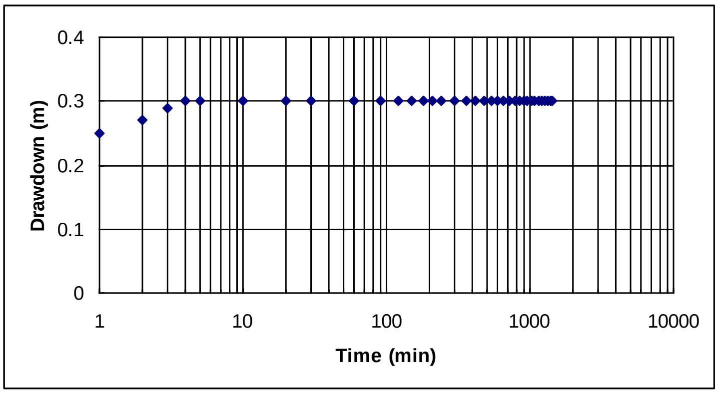
Figure 5 Diagnostic plots of Injection wells 1 & 2



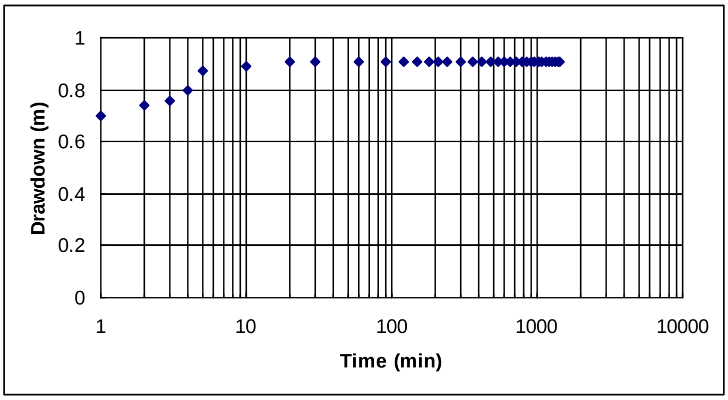
Semi-log plot of pumping well 1



Semi-log plot of pumping well 2



Semi-log plot of injection well 1



Semi-log plot of injection well 1

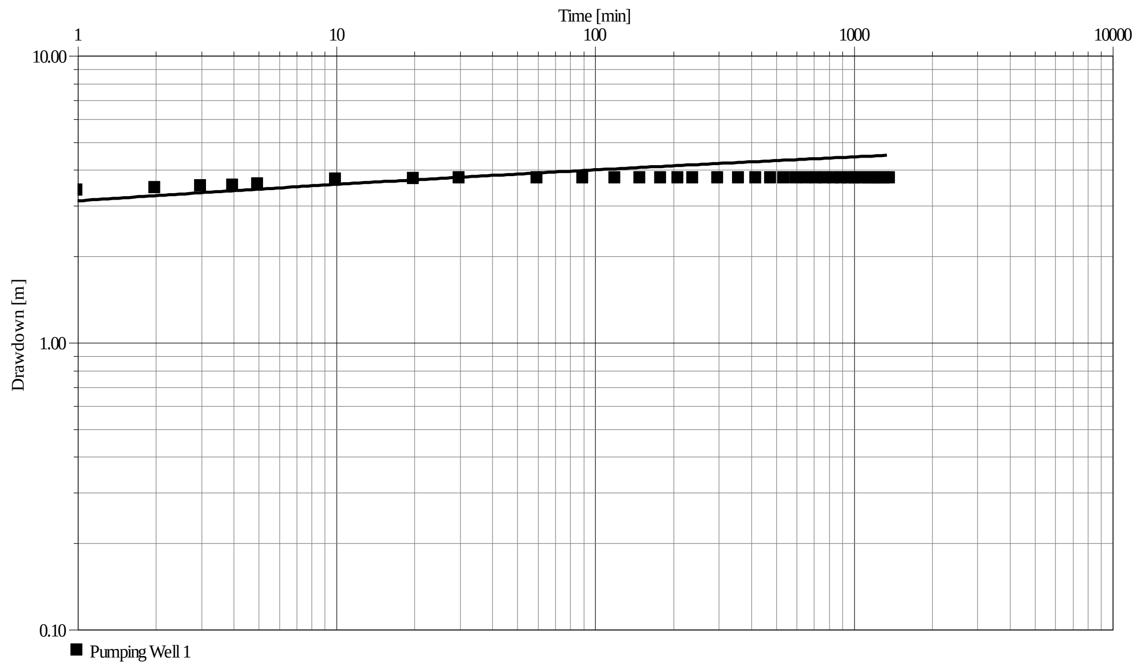
Figure 6 Semi-log plot of pumping wells

Aquifer Type and Parameters Estimation

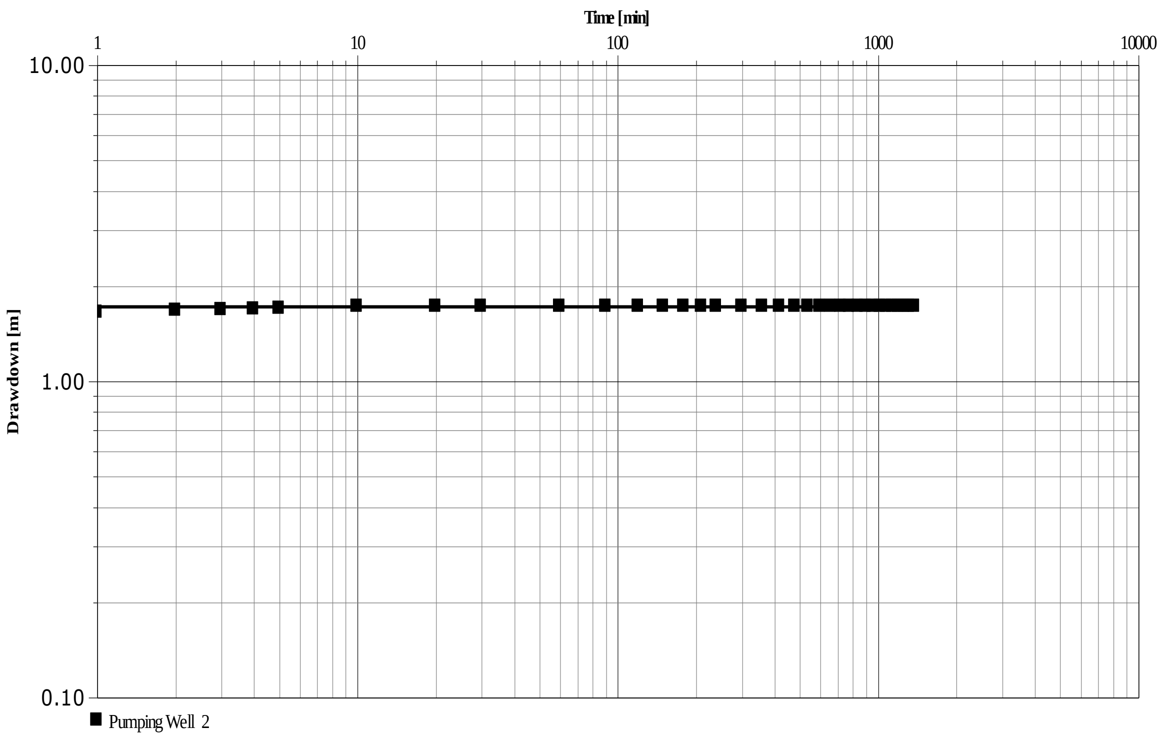
Derivative diagnostic plot of the four wells indicate that infinite radial flow component which satisfies the assumption under Jacob straight line method are not achieved at any one of the pumping wells. So Jacob straight line can't be applied and the type curve matching process is considered the best approach to interpret pumping data in this case. Derivative diagnostic plot couldn't confirm existence of well-bore storage in all wells this may be due to the noisy of the derivative points which result from the small differences in the measured drawdown as the pumping carried out near the shore. Type curve matching process with non-linear least square fitting method (Gorm, 2006) in (Aquifer test pro software) was used to fit different type curves to the measured drawdown searching for the best model match the observed data. From derivative analysis it was concluded that, the aquifer could be leaky or unconfined and no well-bore storage , so Neuman (1975) and Hantush(1955) methods were suggested as they are deal with no well-bore storage. However, good fitting to the above suggested methods requires proper starting parameters for least square fitting process. Matching process started with manual fitting to have proper start parameters for non- linear least square fitting process. Neuman(1975) method gives good match to the observed data at pumping well 1 & 2 (Fig.7) and Hantush (1955) method could gives good match to the observed data in injection well 1 and injection well 2 (Fig.8). Results indicated in table (1). The matching process indicating that the aquifer reflects the response of leaky and unconfined at different places. This discrepancy may be due to the presence of separate silt intercalation .

Table (1) Results of pumping testes in the four wells

Method Used	**Underlying Assumption**	**Well No**	**T**	**S**	**Anisotropy**
Neuman	No well-bore storage - unconfined-Anisotropic	Pumping Well 1	7000	$4.18\ 10^{-4}$	1*10-2
Neuman	No well-bore storage - unconfined-Anisotropic	Pumping Well 2	6500	$1*10^{-30}$	$1*10^{-3}$
Leaky behaviour					
Hantush	No well-bore storage– Leaky -Anisotropic	Injection Well 1	4000	$1.7*10^{-4}$	.001
Hantush	No well-bore storage – Leaky -Anisotropic	Injection Well 2	1280	.02	.04

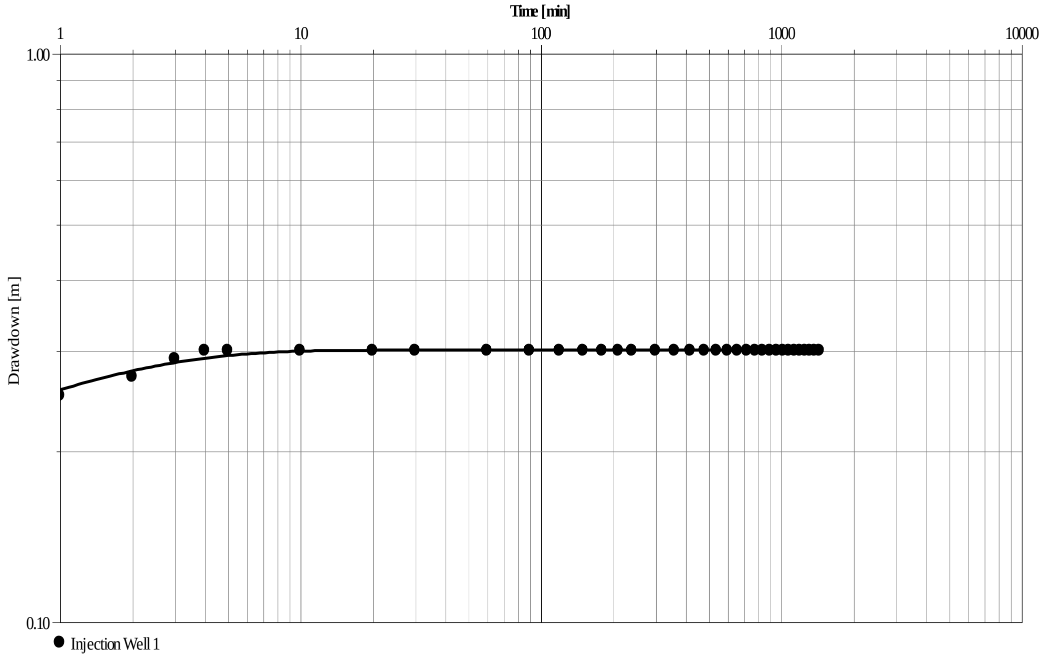


7. a) Neuman method match to observed data at pumping Well 1

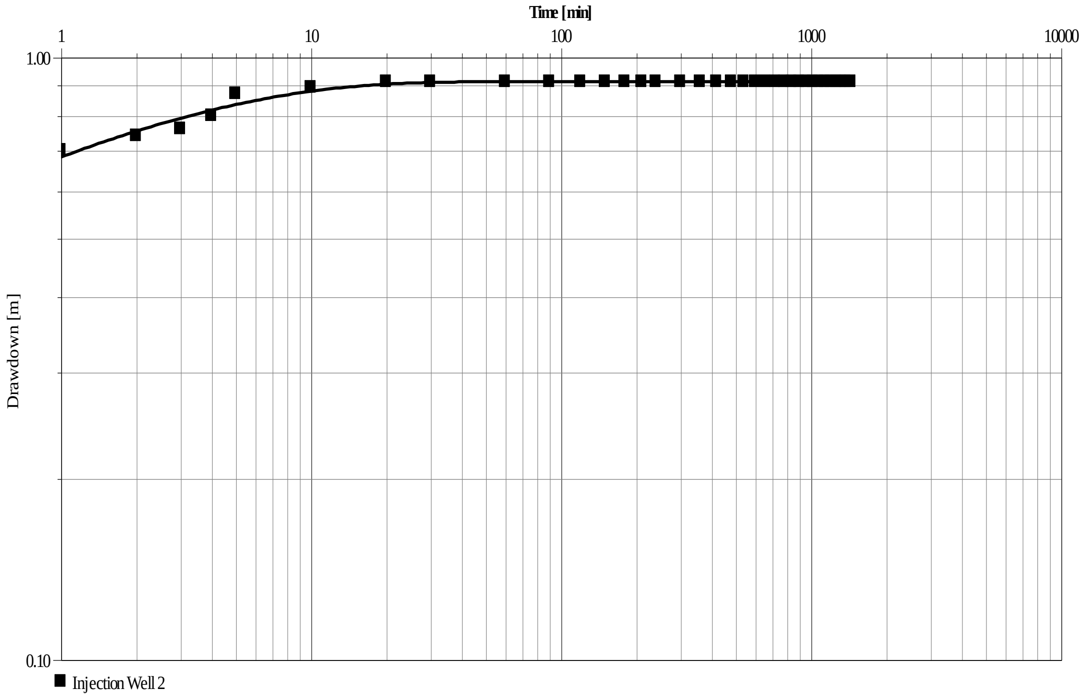


7. b) Neuman method match to observed data at pumping Well 2

Figure **7** Type curve match process for pumping wells 1 & 2



8.a) Hantush curve match the observed data at injection well 1



8.b) Hantush curve match the observed data at injection well 2

Figure 8 Type curve matching for the observed data at injection wells 1&2

Short circuit of Brine water

The most serious problem facing desalination technique is the pumping back of the Injected brine water by the production wells. Analytical solutions were carried to investigate the time required to reach equilibrium conditions at production wells (P1 and P2) due to recharge boundary (injection wells). The distance (X) from the production well (P1) to nearest injection well (1) is 185 m, X, the brine water effective recharge boundary, a, toward P1 is considered to be (185/2) according to image well theory (Fig.9)

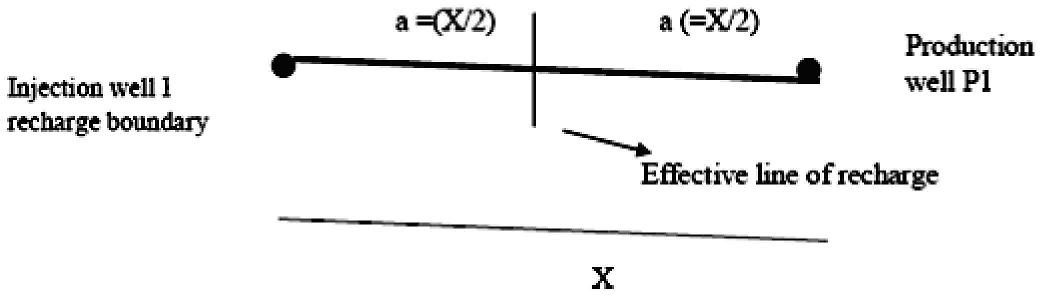


Figure 9 Sketch diagram for recharge well image theory

The radius of influences of production wells P1 and P2 are calculated using the following formula:

$s = 2.3Q/2\Pi T \log (2a-r/r)$ (Raghunath, 1987) where

s Drawdown near recharge boundary (assumed to be 0.01m)
Q Pumping rate
T Transmisivity
a Distance from pumping well to recharge boundary (X/2)
r Radius of influence of pumping well

r Estimated to be 90 m and 60m respectively. The time required to reach approximate equilibrium condition at production wells, P1 and P2, was calculated using the following formula

$t = a_2 S/2.25\ T\ 0.05\log (2a/r)^2$ (Foley et al., 1953),

Where S Storativity
a Distance to recharge boundary
T Transmisivity
r Radius of influence of production well

The estimated equilibrium time is nearly one day. This means that the threat of short circuit is high due to high transmisivity and may be due to the existence of highly fracture and caving in the limestone formation. The approximate percentage of brine water pumped back by production Wells after any time of pumping e.g, 30 days, was estimated by graphical method using the following equation:

$Qs/Q = a/(4Tt/S)^{0.5}$ (Glover and Balmer,1954)

Where Qs volume of water drawn from recharge source (brine water)
Q Total pumped water
T transmisivity at production well
t time of pumping
S Storativity

The percentage is expected to be nearly 75 % for each injection well and this of course high percentage. This is may be due to high transmisivity and the limited between the injection wells and pumping wells in the studied locality

Conclusion

The main advantage of derivative analysis is to define the part or segment of the pumping data that satisfy the assumption based on which the analytical solution was of straight line method was developed to yield reliable aquifer parameters. Derivative plot can spot these segments. In non S curve drawdown derivative couldn't confirm well-bore storage. The other information which can be deduced from derivative diagnostic technique can be extracted from pumping data. Such as flow type and well bore storage can be inferred from the slope of early original pumping data. The aquifer recharge or barrier boundary can be inferred as well from the slope of late data in semi-log plot and no need for derivative diagnostic plot. Least square fitting method with proper starting parameters with derivative gives good approach in identifying aquifer type and the best matching type curve to analysis the data.

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