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Assessment of well performance criteria and aquifer characteristics using step-drawdown tests and hydrogeochemical data, west of Qena area, Egypt

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A groundwater investigation was performed to characterize hydrogeological conditions and well performance in a shallow alluvial aquifer using well logs, step-drawdown tests, and hydrogeochemical data. Results from three single-well step-drawdown tests conducted in three recently drilled boreholes located west of the Qena area in Upper Egypt and were analyzed by the Rorabaugh (1953) graphical method. A total of 47 groundwater wells were sampled and analyzed to detect the main hydrochemical facies associated geochemical processes. Results of the step-drawdown tests indicated well losses between 1.5% and 27.7% (14.2% avg.) and aquifer losses of between 72.3% and 98.5% (85.8% avg.), reflective of high well efficiencies. Specific capacity values varied from 183.4 m^3/day/m to 278.4 m^3/day/m while well efficiency values varied from 72.3% to 98.5%, indicating that the wells had been properly designed and developed. Estimated aquifer transmissivity ranges from 1103.7 m^2/day to 1459.7 m^2/day (1314.9 m^2/day avg.), indicating high yields and water accessibility to the wells. Results indicated laminar flow at the aquifer/well-face contact with negligible turbulent flow. Gibbs and various scatter ionic ratios plots of the geochemical data indicate that water-rock interaction followed by evaporation are the most dominant processes controlling groundwater composition, while a Piper plot reflects mixing with irrigation-return flows subject to evapotranspiration. The approach demonstrates the practical applications of the single-well step-drawdown tests for estimating of the safe and sustained well yields for future groundwater extraction.

1. Introduction

Over the last four decades, increases in water demand resulting from increasing population, urbanization, land reclamation, and agricultural activities have stressed the resource. This increased stress is particularly acute in a country such as Egypt where the Nile River is the only permanent surface water resource. Therefore, the country has been challenged to develop new water supplies to meet present-day shortages. Groundwater serves as a potential resource needed to support land reclamation projects in desert areas required for new settlements. Fresh groundwater resources represent about 20% of the total potential water resources in Egypt (Allama et al., 2002), and high-quality groundwater is needed by planners and decision makers to develop and manage new settlements west of the Qena region. At present, the Egyptian government considers the area west of the Nile River, between Qena and Naga Hamadi city, as one of the more promising areas for land reclamation, urbanization, and future development. The area is flat with soils that are suitable for varying developmental activities, particularly agricultural (Sultan et al., 2008; Abdelkareem et al., 2012). This area is located near urban areas such as Qena town, Dandara, Naga Hammadi, and El Marashda. Because the availability of groundwater is a key factor in the search for new desert areas needed to provide food and create job opportunities, plans for groundwater resource assessment and development are required. The success of such plans depends on the availability and reliability of hydrogeologic information in the study area. The hydrogeologic characteristics and groundwater potential in the area are controlled by the lithostratigraphy of subsurface deposits, saturated (aquifer)

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thickness, depth to groundwater, aquifer hydraulic properties, and salinity. In order to determine whether there is sufficient groundwater available for different purposes, step-drawdown (aquifer) pumping tests also referred to as well performance tests are essential.

A single-well step-drawdown test quantifies well performance criteria, such as the well-loss coefficient and well efficiency, and provides an estimate of the maximum yield (optimal pumping rate) under varying water-level conditions. Compared to other pumping tests, the step-drawdown test is short and relatively simple and inexpensive. In a step-drawdown test, the abstraction rate from the well is increased in a number of steps (minimum of three) and covers a wide range of flows up to a rate equal to or greater than the required design flow. The process consists of pumping the well at step-wise increasing discharge rates (Q), and then measuring the transient change in water levels (drawdown) at each step until the drawdown stabilizes (Kruseman and de Ridder, 1994).

The test steps should be of sufficient duration to allow the drawdown in the pumping well to stabilize, usually around 30 min to 2 h per step (Kruseman and de Ridder, 1994). The water level decreases (i.e., drawdown increases) with each step-wise increase in the pumping rate Q. Measured drawdown consists of two components — well loss and aquifer (or formation) loss (Fig. 1). Analysis of step-drawdown test data helps to quantify these components and to determine the proportion of laminar versus turbulent flow into the well.

The aquifer (linear) loss parameter is the head loss or drawdown caused as water flows (laminar flow) toward a well screen. It is proportional to the resistance provided by the water-bearing formation, the discharge rate Q, and time. The well (non-linear) loss parameter is the difference between the head in the aquifer immediately outside the screened casing and the head inside the casing during pumping. Well losses are due to turbulent flow that occurs when water passes rapidly through the well screen. It is time-independent and proportional to CQ^2. Turbulent flow and associated well losses can be caused by clogging of the well screen by drilling mud or by head losses that occur through the screen itself and in the gravel filter pack around the screen. A high percentage of well loss reflects an inefficient well.

Another important test parameter is the specific capacity (S_c), or the specific pumping rate, of a well (Jacob, 1947). This parameter, equal to the discharge rate divided by the drawdown, is used to determine if the production well can provide an adequate long-term supply of water in the absence of recharge (BCMELP, 1999). Specific capacity measures the yield (or productivity) of the well and aquifer characteristics such as transmissivity (Fetter, 1994; Dubey et al., 2014). The parameter is not a constant but decreases with continued pumping.

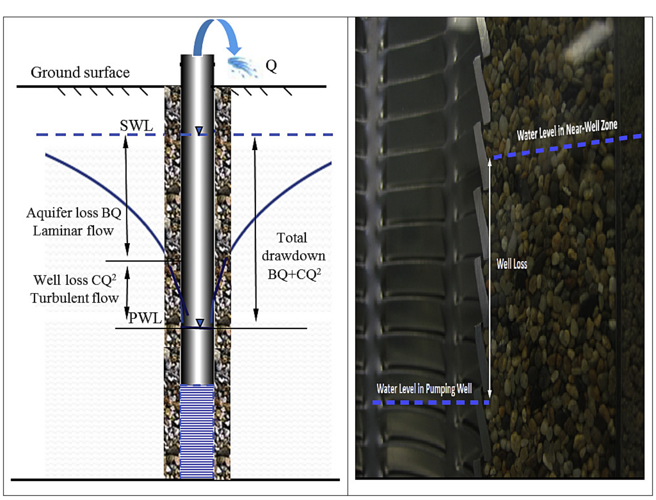

Fig. 1. Single-well step-drawdown test-left: test schematic sketch. right: field Photograph showing the screen part of the well modified after (ACDC, 2013).

One of the main purposes of the step-drawdown test is to estimate the well efficiency in an actual field situation. The actual pumping water level inside the casing is rarely equal to the theoretical value immediately outside the casing, due to head losses through screens and gravel packs around the casing. A well having zero well losses ($CQ^n = 0$) is considered to be 100% efficient.

The study area is located along the western bank of the River Nile in Qena Governorate (Fig. 2) and extends between latitudes 25° 55′ 00″ N and 26° 10′ 00″ N and longitudes 32° 35′ 00″ E and 32° 42′ 00″ E.

The area extends from west of the Nile River to the limestone plateau covering approximately 1432 km^2. It is in an arid to hyper-arid zone characterized by desert climate which are dominated by long hot, rainless summers and arid warm winters. The daily air temperatures range from as high as 45 °C in summer to as low as 14 °C in winter. Rainfall rarely occurs (average annual rainfall is < 4 mm/yr), except for a few showers during summer. Therefore, the existence of groundwater can be attributed mainly to paleoclimatic conditions and/or recharge from the River Nile itself (Geriesh, 1998). The study area is one that is most readily available for agricultural development in the western zone of the Qena Governorate in southern Egypt. The area comprises a part of the Western Desert that has both old cultivated and new reclaimed lands. Therefore, there is an urgent need to evaluate the groundwater availability of this area for multiple purposes.

Several scattered studies conducted in the study area discussed the groundwater resources and groundwater quality (Farrag, 2005; Youssef and Ghallab, 2007; Abdalla et al., 2009) However, a detailed study that discussed the well performance criteria and step-drawdown tests in the study area has not been hitherto reported. Hence, the objectives of this study were twofold: first, to evaluate the well and aquifer response to various pumping rates by estimating well performance and aquifer characteristics in which well performance criteria were used to estimate well loss and efficiency, specific capacity, and an optimal pumping rate under various water-level conditions; and second, to identify the primary process influencing groundwater geochemistry in the area. The above-mentioned objectives were achieved through a hydrogeologic investigation which included three single-well pumping tests that produced data that were graphically analyzed. Logging data, groundwater levels and field conditions were also examined.

2. Geologic and hydrogeologic setting

The regional surface geologic map of Egypt (Conoco, 1987) shows that the study area is comprised of different rock types with ages ranging from the Late Cretaceous/Lower Eocene to the Pliocene and Quaternary (recent Wadi deposits) (Fig. 3). In physiographic terms, the study area can be divided into four geomorphic units: the Upper Cretaceous sedimentary sequence, Paleocene-Eocene sediments, Pliocene-Pleistocene sediments, and Holocene deposits. Therefore, the rock units can be categorized from the oldest (bottom) to the youngest (top) as follows: Upper Cretaceous sediments including the Dakhla Formation; Paleocene/Eocene sediments including the Tarawan Formation, Esna shale, and the Thebes Formation; Pliocene and Pleistocene sand and gravel; and Holocene sediments (silty clay) which comprise the formations that represent the Nile Valley deposits. Geomorphologically, the area is composed of four geomorphologic units which, from north to south, include the young alluvial plains of the Nile, the old