Report

METHODOLOGY FOR CALCULATING SPECIFIC-STORAGE VALUES IN THE EDWARDS (BALCONES FAULT ZONE) AQUIFER, CENTRAL TEXAS, USING SEISMIC EFFICIENCIES

Prepared for:

Edwards Aquifer Authority

San Antonio, Texas

by

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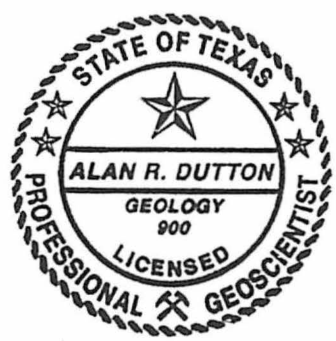

September 2006

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CONTENTS

Summary..1

Introduction..1

Theory..3

Geologic Setting..5

Methodology...6

References..7

SUMMARY

Specific storage in confined aquifers is usually found from either paired-well field tests or calculated estimates for barometric or tidal efficiency. However, the paired wells required for a drawdown or recovery test are generally sparse in any aquifer, including the Edwards aquifer, so this method does not yield much data. Calculating barometric efficiency requires at least several months of detailed records on water levels and atmospheric pressure. Tidal efficiency calculations also require months of water level records as well as access to geodetic data. An additional issue that needs to be addressed is the heterogeneous nature of karst aquifers, where specific storage estimates derived from one well location may not represent the aquifer as a whole.

Thus a method is needed that can quantify specific storage regionally, without the problems of the previous methods. Seismic efficiency calculations provide an approach for estimating aquifer compressibility. Pressure waves generated by seismic events can cause a rapid water-level response in confined aquifers as the surface wave passes. The water-level response lasts <1 hour, so detrending is not needed.

The Edwards aquifer is a logical choice as a study area for this research because seismic events have been shown to produce sizable signals in several of the wells that are equipped with analog or chart recorders. Also, the Edwards aquifer is a known karst aquifer, and therefore a heterogeneous system, with potentially varying storativity.

INTRODUCTION

Storativity (S) is an important input into aquifer models for predicting the amount of water that can be taken into or released from storage with a change in fluid pressure. It can be related to specific storage (S_s) as first shown by Jacob in 1939,

$$S = S_s \times b \qquad (1)$$

where **b** is the saturated thickness of the aquifer. These values are traditionally determined by using a distance drawdown test with paired production and observation wells. However, paired wells are not usually available in most aquifers, and in a heterogeneous system, many pairs would be required to characterize the variations in storativity within the system.

Measurable changes in fluid pressure have led to calculations of specific storage using barometric pressures and earth-tide forces. Specific storage values for confined aquifers have been determined using a simplified barometric-efficiency approach for the Edwards Aquifer described in Hovorka (1993). Tidal efficiencies have been used to determine storativity by Hobbs (2000) for a dolomite aquifer in South Africa, and by Merritt (2004) for the Floridian aquifer system. These methods are based on work by Jacob (1939), where the barometric and tidal efficiencies are shown to be controlled by the ratio of water compressibility to aquifer matrix compressibility. Although these methods can produce the required data, they require at least several months of water-level data as well as corresponding barometric pressure or geodetic data. Removing the influence of local pumping and recharge events from water-level trends is also necessary with these methods.

Seismic events produce a pressure wave that moves quickly though an aquifer system, and produce an easily detectable water level change in well hydrographs. Using the information from this pressure wave, a seismic efficiency can be established in a manner similar to the establishment of the tidal efficiency. The seismic efficiency value for an individual well can then be used to calculate a specific storage value. Calculations for multiple wells can then be compiled to explore the spatial variation of storativity in an aquifer.

THEORY

The effective stress in an aquifer is an important concept for understanding the compressibility of the matrix material and quantifying specific storage. The effective stress (σ_e) (Eq. 2) is the difference between the total stress (σ_T), which is due to the weight of the overlying rock and water, and the fluid pressure (**P**) within the pores of the aquifer matrix material (Fetter 2001).

$$\sigma_e = \sigma_T - \mathbf{P} \qquad (2)$$

For an unconfined aquifer, total stress changes with an increase or decrease of the water level. In the case of a confined aquifer, however, total stress does not change with the raising or lowering of the pressure head, because the system is always saturated and the weight of fluid and rock is constant. The change in effective stress in a confined aquifer is dependant on the change in fluid pressure in the system:

$$\Delta\sigma_e = -\,\Delta \mathbf{P} \qquad (3)$$

Because of this relationship, the compressibility of the aquifer matrix (α), which is usually defined in terms of changes in effective stress (Fetter 2001):

$$\alpha = (-db/b)/d\sigma_e \qquad (4)$$

can be defined in terms of fluid pressure changes:

$$\alpha = (db/b)/dP \qquad (5)$$

Once the aquifer matrix compressibility is defined, the specific storage can be calculated using the equation developed by Jacob (1940):

$$S_S = \gamma(\alpha + n\beta) \qquad (6)$$

Water level changes in hydrographs due to seismic pressures have been previously documented in the Floridan aquifer (Parker 1950) and the Edwards Aquifer of South-Central

Texas (Schindel, 2003). Previous work has shown the relationship of the seismic pressures to the observed water level changes (Cooper 1965) and the relationship of the deformation of the aquifer to Rayleigh wave properties (Liu and others, 1989). At this point in time, however, no one has previously used this information to calculate specific storage values for a confined aquifer.

Cooper (1965) discussed the fact that the hydraulic-head fluctuation (**Δh**) in a well resulting from a seismic event is directly related to the pressure fluctuation (**Δp**) owing to a passing Rayleigh or surface wave:

$$\Delta p_f = \rho g \Delta h_f \qquad (7)$$

The deformation of the material in the aquifer in response to the seismic wave depends on Poisson's ratio (**C**), the angular frequency of the Rayleigh wave (ω), the Rayleigh wave velocity (v_r), and the measured displacement of the Earth's crust (w_o):

$$\Delta b = C(\omega/v_r)w_o \qquad (8)$$

Once the pressure fluctuation and the deformation are determined the seismic efficiency (Σ_E) for the aquifer material can be calculated:

$$\Sigma_E = \Delta p/\beta\Delta b \qquad (9)$$

where β is the compressibility of water.

Seismic efficiency can then be substituted into Jacob's equation (6) for specific storage (1940) and then used to calculate the specific storage for the area around the chosen well:

$$S_S = \gamma(1/\beta b\Sigma_E + n\beta) \qquad (10)$$

GEOLOGIC SETTING

The San Antonio segment of the Edwards Aquifer is a heterogeneous limestone aquifer that is known for its karstic nature. The large demand on the aquifer as a water resource requires a more accurate estimate of storativity to enable management decisions. Obtaining specific storage values for several wells is necessary to understanding regional storativity trends.

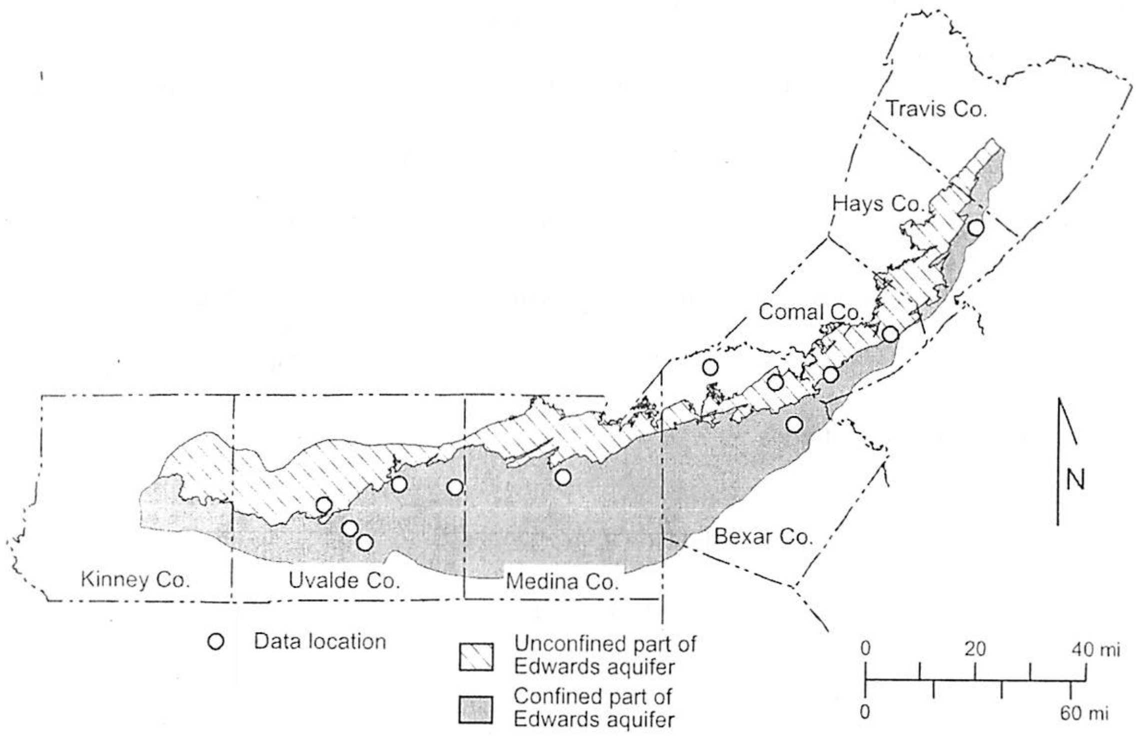

Figure 1 – Position of study wells across the study area.

The up dip part of the Edwards Limestone, where groundwater is under water table conditions, comprises the recharge zone of the aquifer. The aquifer is considered mostly confined where it is overlain by younger shale and clay deposits. Wells monitored for this study will be from the confined part of the aquifer, where the aquifer is bounded at the bottom by the Upper Glen Rose Limestone, and at the top by the Del Rio Clay. The position of the wells across the artesian zone is illustrated in figure 1.

There are three geologic trends within the San Antonio segment of the Edwards aquifer. These trends are known as the Maverick Basin, Devils River Trend, and San Marcos Platform. The Edwards Group in the San Marcos Platform consists of the Kainer Formation, overlain by the Person Formation, and is the descriptor used for defining the geology in Hays, Comal, and Bexar counties, as well as the eastern portion of Medina County (Hansen 1995, Small 1994, Stein 1996, Small 2000). The Devils River Formation is the only defined geologic unit of the Devil's River Trend and is found in the remaining portion of Medina County and parts of Uvalde County (Small 2000, Clark 1997). The remaining portion of Uvalde County, commonly referred to as the Maverick Basin, consists of the Salmon Peak Formation, the McKnight Formation and the West Nueces Formation, here listed in descending order (Clark 1997). Since there are monitoring wells present across the San Antonio segment, the seismic efficiency method can be tested across all three geologic trends.

METHODOLOGY

Multiple sources of information are pulled together to make seismic efficiency calculations:

(1) From a hydrograph, the time of the head fluctuation is checked to confirm that the fluctuation is due to a specific seismic event.

(2) Overall water displacement, or amplitude of the fluctuation, is measured and used to calculate the pressure fluctuation. (Eq. 7)

(3) Seismographs from local seismic stations are evaluated to determine angular frequency (ω) and vertical displacement (w_0) of the Rayleigh waves.

(4) Rayleigh wave arrival times are compared with the initial event time to determine the Rayleigh wave velocity (v_r).

(5) Deformation of the aquifer is calculated from these values (ω, w_o, v_r) (Eq. 8)

(6) Saturated thickness of the aquifer is taken from drillers' reports or structure maps.

(7) Saturated thickness is then used to calculate seismic efficiency (Eq. 9) and specific storage (Eq. 10).

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