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Journal of Hydrology 326 (2006) 181–198
Journal of Hydrology
www.elsevier.com/locate/jhydrol

Field, laboratory, and modeling investigation of the skin effect at wells with slotted casing, Boise Hydrogeophysical Research Site

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Received 14 February 2005; revised 24 October 2005; accepted 25 October 2005

Abstract

Understanding and quantification of wellbore skin improves our ability to accurately measure or estimate hydrologic parameters with tests at wells such as pumping tests, flowmeter tests, and slug tests. This paper presents observations and results from a series of field, laboratory, and modeling tests which, together, explain the source of wellbore skin at wells at a research wellfield and which support estimation of skin thickness (d_s) and skin hydraulic conductivity (K_s). Positive wellbore skin effects were recognized at wells in the shallow, unconfined, coarse-grained fluvial aquifer at the Boise Hydrogeophysical Research Site (BHRS). Well development efforts at the BHRS removed residual drilling fines but only marginally reduced the skin effect. Likely causes for the remaining wellbore skin effect were examined; partial clogging of screen slots with sand is consistent with field observations and can account for the magnitude of wellbore skin effect observed. We then use the WTAQ code (Barlow and Moench, 1999) with a redefinition of the term for delayed observation well response to include skin effects at observation wells (in addition to pumping wells) in order to analyze aquifer tests at the BHRS for average K_s values at individual wells. Systematic differences in K_s values are recognized in results at pumping (K_{s_Q}) and observation (K_{s_obs}) wells: larger values are seen at observation wells (average $K_{s\_obs}=0.0023$ cm/s) than pumping wells. Two possible causes are recognized for the occurrence of higher K_s values at observation wells than pumping wells: (1) flow diversion between aquifer layers on approach to a pumping well with positive skin; and (2) larger portion of flow passing through lower-K zones in the heterogeneous aquifer near the pumping well than the observation wells due to strongly radially convergent flow near the pumping well. For the well-aquifer system at the BHRS, modeling analyses of drawdown vs time at observation wells provide better K_s estimates than those from pumping wells.

Keywords: Wellbore skin; Well hydraulics; Modeling; Pumping tests

1. Introduction

Wellbore skin is a general term for imperfect hydraulic connection between a wellbore and the well structure and/or formation immediately outside the borehole. The imperfect connection may be due

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0022-1694/$ - see front matter
doi:10.1016/j.jhydrol.2005.10.029

to: drilling, construction, or other effects on the well structure; composition and structure of annular fill; and/or changes in the formation near the well during or following the drilling process. Wellbore skin acts as a filter in series between the borehole and the undisturbed formation. As such, wellbore skin causes either an additional resistance to flow (positive skin) if it has lower hydraulic conductivity (K) than the undisturbed formation (e.g. invasion of drilling mud into the formation; encrustation or sand-clogging of a well screen), or causes a lessened resistance to flow (negative skin) if it has higher K than the undisturbed formation (e.g. sand or gravel pack in annular space).

Depending on the contrast in K between wellbore skin and the formation, the presence of wellbore skin can influence the use of a well, and can cause drawdown measured in a pumping well to give misleading values of K. Examples include lost production or added cost for operation in order to overcome additional head loss to achieve a given flowrate. Understanding the causes and magnitude of wellbore skin permits evaluation of effects and consideration of options to mitigate or quantitatively account for effects. Also, inclusion of values for skin improves our ability to get accurate formation parameters from hydrologic well tests (van Everdingen, 1953; Ramey, 1970; Faust and Mercer, 1984; Moench, 1984; 1997; Dane and Molz, 1991; Molz et al., 1994; Butler, 1998; Young, 1998; Dinwiddie et al., 1999; Rovey and Niemann, 2001).

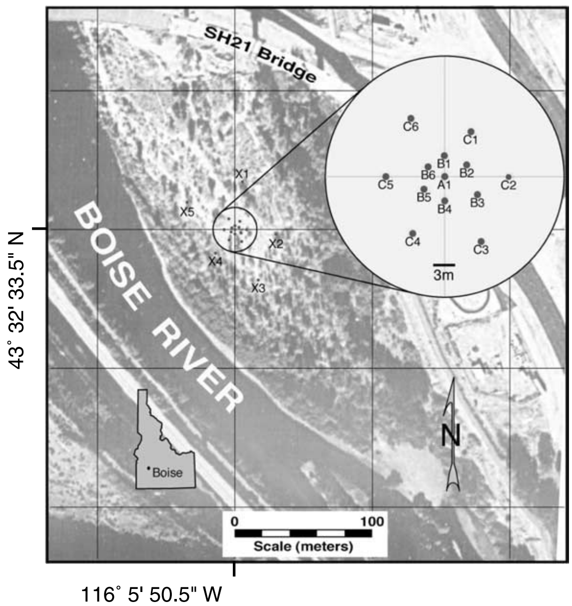

Fig. 1. Photomap showing the location and wellfield design of the Boise Hydrogeophysical Research Site (BHRS).

In this paper, we focus on the estimation of wellbore skin at the Boise Hydrogeophysical Research Site or BHRS (Fig. 1), a research wellfield that has been developed in a shallow, unconsolidated, coarse-grained fluvial aquifer (Barrash et al., 1999). Our interest in understanding and quantifying wellbore skin is to support subsequent investigations of heterogeneity of hydraulic parameters from hydrologic well tests at the BHRS. In this paper we: (a) describe the well construction method used at the BHRS and present evidence for positive wellbore skin; (b) examine causes for skin using field, laboratory, and modeling methods; (c) use our understanding of the cause for skin and a version of the WTAQ model (Barlow and Moench, 1999) that includes skin effects at observation wells, in addition to pumping wells, in order to analyze aquifer tests at the BHRS for skin hydraulic conductivity (K_s) values at individual wells; and (d) examine systematic differences in K_s values at pumping and observation wells and determine that these differences may be due to the conceptual model-error associated with (1) treating the aquifer as a homogeneous (one-layer) system rather than a multi-layered system, and perhaps also with (2) the 'pseudoskin' effect, or lower effective K in the immediate vicinity of a pumping well due to strongly convergent flow in a heterogeneous aquifer (Desbarats, 1992; Neuman and Orr, 1993; Rovey and Niemann, 2001).

2. Hydrogeologic setting and well construction

Field data for this paper are taken from the BHRS, which is located on a gravel bar adjacent to the Boise river 15 km east of downtown Boise, Idaho, USA. Eighteen wells were completed in the same manner (Fig. 2) within an 80 m×60 m area (Fig. 1). General stratigraphy at the site is: coarse-grained unconsolidated fluvial deposits underlain by clay (Barrash and Reboulet, 2004). Wells were designed to: (a) support a wide variety of hydrologic and geophysical testing; (b) provide hydraulic communication to the formation