Evaluating Safe Yield for Supply Wells in an Aquifer with Fresh Water / Salt Water Interface

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ABSTRACT

Coastal communities often rely on groundwater resources for water supply. Ensuring a safe and adequate supply requires a balance that meets community demands while preventing deleterious hydrologic and environmental impacts. In coastal aquifer settings where supply wells are in proximity to a salt water front (lateral encroachment of a salt water wedge or vertical upconing of an underlying salt water interface) a determination of safe yield must account for the potential for groundwater withdrawals to introduce saline water into the well field, resulting in unacceptable water quality in the short term and a fouling of the aquifer near the well field for a longer period of time.

In this paper we examine factors affecting the safe yield of a well pumping above the salt water transition zone in a fresh water lens aquifer similar to those found on Cape Cod, Massachusetts. We begin with a discussion of traditional methods for determining safe yield and compare these preliminary estimates with the more refined and restrictive estimates produced using a sophisticated density-dependent salt water flow model. A simple example demonstrates that proper consideration of potential salinity impacts for a typical supply well may decrease the feasible safe yield by 30 percent or more.

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INTRODUCTION

Communities for which groundwater is a major source of water supply must carefully manage the resource by striking a balance between meeting community water demands while avoiding deleterious hydrologic and environmental impacts. In certain coastal aquifers, water supply wells are located in proximity to a zone of laterally encroaching salt water or are screened a short distance above a fresh water / salt water interface. A determination of safe yield must account for the potential for groundwater withdrawals to introduce saline water into the well field, resulting in unacceptable water quality in the short term and a fouling of the aquifer in the vicinity of the well field for a much longer period of time.

Traditional methods of determining safe yield or sustainable yield for a water supply well can include estimates based on specific capacity; a long term (e.g. 5-day) aquifer test (as some states require); or the requirement not to exceed a certain drawdown limit near a protected wetland or not to decrease discharges to a sensitive surface water body by more than a certain amount (Kalf and Woolley, 2005). Such methods, which do not explicitly consider potential salinity impacts at the wellhead, may overestimate safe yield when compared with more refined estimates produced using an analytical salt water interface model (which can provide some information regarding the likelihood of salinity impacts) or a more sophisticated density-dependent salt water numerical flow and transport model capable of simulating the drinking water quality for the well field.

AQUIFER CHARACTERIZATION FOR SAFE YIELD ANALYSIS

A number of aquifer parameters in a coastal setting affect the movement of the saline transition zone toward an operating supply well. These parameters, which should be characterized as part of the pre-permitting aquifer test, include:

Proper Delineation of the Fresh Water / Salt Water Interface

The accurate, before pumping, spatial definition of the interface and transition zone will provide an initial location of the interface and transition zone for modeling and for comparison with changes caused by pumping. The monitoring of changes to the interface and transition zone will provide data useful in model calibration and ultimately in safe yield determination. A protective safe yield value depends on how the interface reacts to pumping stresses, thus the design of a pumping test and monitoring of the test should be planned to define the interface and transition zone before and during the pumping test.

Characterization of the Fresh Water and the Salt Water Density Distributions

Density differences will not only influence groundwater flow in a coastal aquifer but can affect measurements of hydraulic head collected from piezometers or monitoring wells. A correction must be applied to measured groundwater elevations to account for density effects at measuring points in the salt water transition zone. These corrections can be significant (on the order of several feet) in determining groundwater flow and in analyzing potentiometric surfaces. A proper modeling code, such as SEAWAT (Gou and Langevin, 2002) which accounts for variable density flow, should be selected so that density dependent groundwater flow can be accurately modeled.

Characterization of the Horizontal and Vertical Hydraulic Conductivity

Safe yield for a well in a coastal aquifer near a potentially encroaching salt water zone is sensitive to the horizontal and vertical hydraulic conductivity of the aquifer material. Low values of vertical conductivity (i.e. strong vertical anisotropy) in the area surrounding the well, or locally beneath the well screen, will dampen salt water upconing and increase estimated safe yield (Ma et al., 1997; van Dam, 1999). Therefore, the hydrogeology and inclusion of the hydrogeology in the model below the pumping well is important in determining safe yield. A concurrent study (Cecan et al., this conference), describes a method of characterizing the hydraulic conductivity and vertical anisotropy in a fresh water lens aquifer through modeling of a pumping test.

Through characterization of the interface, density contrasts and distributions, and hydrogeology of the study area, an understanding of the interface can be incorporated into a salt water flow and transport model to better estimate the safe yield.

SALINITY IMPACT SAFE YIELD ANALYSES

Effect of Considering Potential Salinity Impacts

Water supply for the outer portions of Cape Cod, Massachusetts is derived primarily from pumping of fresh water lenses that range up to approximately 250 feet thick near their centers. Over-pumping of a well has been observed to result in salt water fouling. To augment the current water supply, a new well is proposed. Traditional safe yield analysis testing (based on the state of Massachusetts well permitting requirements) results in a specific capacity of 35 gpm/ft of drawdown and an available drawdown of 20 ft; yielding a safe yield estimate of approximately 1.0 million gallons per day (MGD). This estimate does not consider salt water upconing.

The USGS model of Cape Cod (Masterson, 2004) [23 layers; horizontal grid spacing of 400 ft] developed using SEAWAT (Gou and Langevin, 2002) was used to simulate pumping 1.0 MGD from a single well located near the center of a fresh water flow cell. The vertical anisotropy in the aquifer zone between the well screen and the saltwater transition zone included in the model is 5:1, which is near the lower end of the range for this aquifer. Simulated Total Dissolved Solids (TDS) in the well exceeded the current drinking water MCL of 500 mg/L in approximately 40 years (Figure 1). However, if pumping is reduced to 0.72 MGD (approximate 30 percent reduction) salinity remains below the MCL for greater than 100 years of pumping (Figure 1).

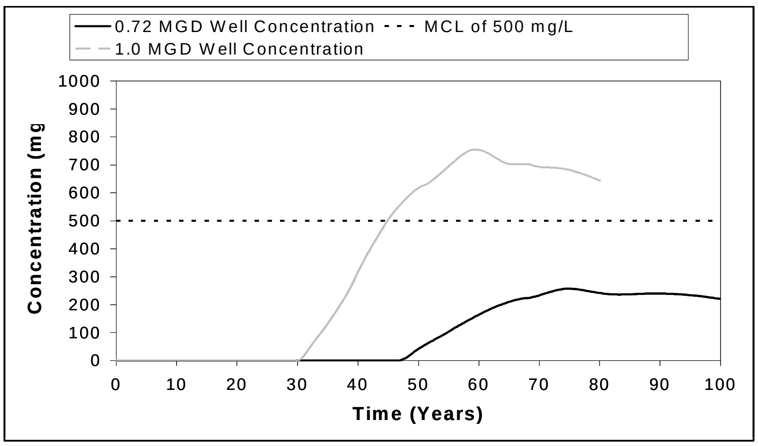

Figure 1 Simulated Total Dissolved Solids breakthrough in a well pumping at 1.0 and at 0.72 MGD from a fresh water lens.

A 30% reduction in pumping results in a well head concentration of 250 mg/L, which is approximately half of the TDS MCL. Depending on what is considered a safe or acceptable well head concentration, the safe yield rate could be adjusted accordingly. Through use of a model that incorporates the interface dynamics and salt water transport, a more protective safe yield estimate is obtained. Further reduction of the pumping rate may be required if water quality requirements are more stringent (e.g. that sodium concentration be less then a given value).

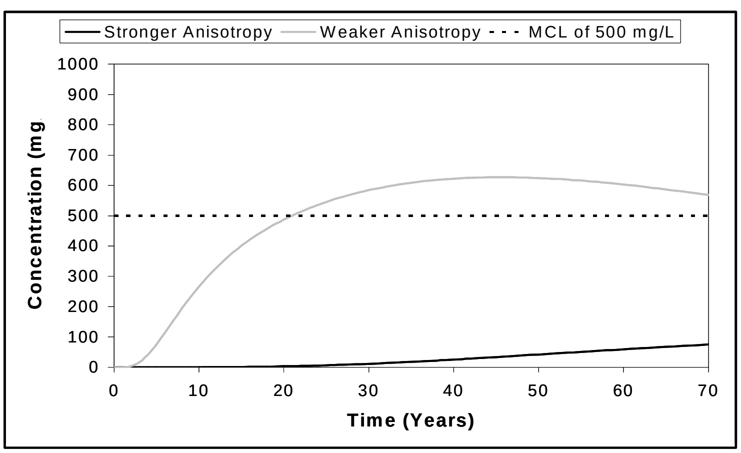

Figure 2 Simulated Total Dissolved Solids breakthrough in a well pumping at 0.6 MGD from a fresh water lens with different anisotropies.

Effect of Vertical Anisotropy

To show the effects of anisotropy on the safe yield, two simulations with different anisotropies were run. In the stronger anisotropy scenario the vertical anisotropy in the area ranged from 6 to 1000, and in the weaker anisotropy scenario the anisotropy ranged from 3 to15. The pumping rate in both scenarios was chosen to be 0.6 MGD.

The concentration-time plots in Figure 2 show clearly the influence of the stronger vertical anisotropy (dark line), which by decreasing the concentrations at the pumping well, allow for an increased safe yield.

DISCUSSION AND CONCLUSIONS

Safe yield estimates for water supply wells in coastal aquifer settings should consider the potential for withdrawals over long periods of time to cause saline water to be drawn toward and adversely impact the well or well field. Such an analysis can be accomplished using a computer model of groundwater flow that accounts for salt water density effects and the transport of salinity from the dilute portion (top) of the transition zone to the well. In this study the Cape Cod SEAWAT model developed by the USGS was used to perform a safe yield analysis based on salinity impacts to a water supply well in a freshwater lens aquifer. Comparison of model results with safe yield estimates derived using commonly applied and accepted methods, demonstrates consideration of potential salinity impacts may reduce estimates by 30 percent or more.

Since salt water intrusion impacts to a well field can render the well field unusable for decades, water managers responsible for the siting and operation of well fields in coastal aquifers should consider potential salinity impacts when establishing safe yield values as part of well field permitting or operational studies. Aquifer anisotropy and the location of, and density distribution surrounding, the transition zone can have a significant impact on the safe yield estimate and should be characterized as part of the well field testing program.

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