

Increasing Water Security through Horizontal Wells

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Congressional District of the university where the work is to be conducted: 17th, statewide

Abstract

Access to reliable water supplies is of high priority given the likelihood of drought and growing population in regions such as Texas. Emerging technologies in water resources will provide means for improving water security, especially horizontal wells. During year one, horizontal well costs have been quantified and are modeled deterministically. The first year of study has also been devoted to understanding flow to a horizontal well and associated wellbore energy loss (friction). Our novel treatment of horizontal well flow equations has facilitated a better understanding of flux along the wellbore which is pivotal to horizontal well aquifer storage and recovery (ASR). During year two we will use results from our innovative model to drive specific research goals. Generally, we will be investigating the use of horizontal wells for ASR.

Budget Breakdown

Category	Federal Non-Federal		Total
Salary & Wages			
Grad Student (Blumenthal)	\$ 0	\$20,964	\$20,964
GEOS Professor		\$10,051	\$10,051
TOTAL SALARIES	\$ 0	\$31,015	\$31,015
Fringe	\$ 0	\$ 6,282	\$ 6,282
Supplies	\$ 0		\$ 0
Travel	\$ 825		\$ 825
Other	\$ 8,544		\$ 8,544
Indirect Costs			
Non-Fed & Unrecovered		\$17,346	\$17,346
Total Estimated Cost	\$ 9,369	\$54,643	\$64,012

Budget Justification**Salary & Wages:**

Federal: N/A.

Non-Federal Match: Graduate Student (6 months) @ \$41,928 @ 50% = \$20,964; GEOS Professor (1 month) @ \$120,618/yr = \$10,051. Total = \$31,015.

Fringe:

Federal: N/A.

Non-Federal Match: Graduate Student, Fringe Benefits (10% of salaries + \$236/month medical) = \$3,512. GEOS Professor/Faculty Fringe Benefits (17.7% of salaries + \$591/month medical) = \$2,770. Total = 6,282.

Supplies:

Federal: N/A

Travel:

Federal: Travel to Vancouver, British Columbia, Canada, Oct. 19-22 for the Geological Society of America Conference. Funds will help go toward flight (\$900) and/or four night hotel stay (\$250) = \$825.

Other:

Federal: Tuition @ \$8,544 = \$8,544

Indirect Costs:

Texas AgriLife Research indirect cost rate is 45.5% of Total Direct Costs (\$9,369 Federal, \$37,297 Match). Waived IDC on federal and non-federal funds is \$17,346.

Increasing Water Security through Horizontal Wells

Overall Motivation

Water security is vital to the continued growth and success of the State of Texas. The Texas Water Development Board (TWDB, 2012) has asserted that “unreliable water supplies could have overwhelming negative implications for Texas.” The population of the state is expected to grow 82% by 2060, with a water demand increase of 22% (TWDB, 2012). In the 2012 State Water Plan, planning groups identified a water supply need [demand – supply] of 3.6 million acre feet in 2010 and 8.3 million acre feet by 2060 (TWDB, 2012).

Overall Background on Directional Groundwater Wells

Horizontal wells for groundwater extraction are an attractive new option for water utilities. In low transmissivity (aquifer thickness multiplied by hydraulic conductivity) formations, the cost savings of using horizontally directionally drilled (HDD) wells may be substantial and thus facilitate groundwater development in areas previously deemed unfeasible. The use of HDD would allow greater borehole contact with the target formation and thus allow more water to be extracted from a low permeability and/or thin formation.

While HDD has been used for several groundwater contaminant cleanup projects (Denham and Lombard, 1995; Kaback, 2002; Oakley et al., 1994), only limited use of HDD for conventional groundwater production has occurred (Jehn-Dellaport, 2004; Rash, 2001). Shallow HDD was first used for groundwater production in 1998 near Des Moines, Iowa (Bardsley, 2001). This well has produced at the same rates of nearby Ranney Wells along the Raccoon River (Rash, 2001). Later, deep directional drilling was used to increase yields of an aquifer in the Denver basin near Bennett, Colorado (Jehn-Dellaport, 2004). In the article, it was noted that the cost of HDD was 1.5-3 times more expensive than a vertical well, yet the construction of an HDD well may replace several vertical wells and thus make costs competitive. Shortly after the first deep directional water supply well was installed, another was installed near Castle Pines, Colorado (Jehn-Dellaport, 2013). Similar use of HDD for mine dewatering has also occurred (Struzina et al., 2011).

Research Aims

Horizontal Well Aquifer Storage and Recovery

While additional surface reservoirs are in planning stages, they contain many drawbacks. Annual evaporation from lakes ranges from 51 cm to 218 cm in the United States (Viessman et al., 1977). Lake seepage may also be of concern, as in the extreme case of Medina and Diversion reservoirs near San Antonio, which lose between 209-326 cm each year this way (Lambert et al., 2000). Other challenges to surface water development are the lack of suitable land/high cost of acquisition, environmental

impacts/permits, disruption of nearby communities, silt deposition and high construction costs (Bouwer, 2002; Malcolm Pirnie Inc et al., 2011). New methods of water storage are necessary to increase the water security of Texas.

Artificial groundwater recharge is not a new concept as the practice was used in Europe before the 1850's (Todd, 1959). Aquifer Storage and Recovery (ASR), also known as Managed Underground Storage (MUS), is a newer concept that combines recharge with extraction. ASR is defined as storing water in aquifers during times of excess (rainy seasons) for use in times of deficient (drought) (Pyne, 1995).

There are currently three ASR systems in Texas: El Paso, Kerrville and San Antonio (Malcolm Pirnie Inc et al., 2011; Sheng, 2005). San Antonio Water System's (SAWS) ASR as of October 2012 had 91,000 acre feet in storage, with a maximum capacity of 120,000 acre feet (SAWS, 2012). ASR systems have been identified in the Texas 2012 State Water Plan as a water management strategy to provide 81,000 acre feet per year by 2060 (TWDB, 2012). The National Research Council (2008) has recommended, "Given the growing complexity of the nation's water management challenges, and the generally successful track record of managed underground storage in a variety of forms and environments, MUS should be seriously considered as a tool in a water manager's arsenal."

The Texas Water Development Board's (TWDB) feasibility report on a purposed Laredo ASR system cited transmissivity (both thin beds and silty substrates) as the chief obstacle to development (Anglea, 1999). The optimal ten million gallon per day ASR could not be built due to low aquifer transmissivity. Therefore a five million gallon per day facility was purposed at a cost of 6.3 million dollars for twenty-eight wells and associated hardware. To date no further planning for the Laredo ASR system has been done due to the high costs and low returns. From my perspective, perhaps horizontal wells could have facilitated an ASR system for Laredo.

Anglea (1998) considered HDD for the San Antonio ASR as it would intersect vertical fractures in the formation and thus increase production. In the report, Halliburton Drilling Systems estimated an additional cost of \$75,000 for 2,000 linear feet of HDD. Despite this option being available, traditional vertical wells were used instead.

It was not until 2004 that a truly horizontal ASR system was proposed for a Texas city (Pyne and Howard, 2004). This system was to be built for Corpus Christi with the motivation of increased well capacity and a minimized subsidence potential. This system has remained in the planning stages and is yet to be constructed.

There is only one known HDD well constructed strictly for an ASR application (Zuurbier et al., 2013). There are, however, several Ranney wells operating in reverse (injection) which mark the first application of horizontal wells for ASR (Pyne, 2013). No research has been conducted on these Ranney wells, but the well strictly constructed for HDD ASR was done so for research purposes. Zuurbier et al. (2013) constructed a small HDD well to study freshwater-saltwater interaction during ASR injection/extraction cycles. To facilitate recovery estimates before well construction, a two dimensional SEAWAT model was created. This first prototype of saline host aquifer HDD ASR has proven effective at storing a target freshwater volume (Zuurbier et al., 2013).

The use of horizontal wells for ASR is a new technology with promise to increase water supply and possibly reduce costs (Pyne, 2005). Because of these possibilities, the use of HDD for ASR has been cited as a research need (Jehn-Dellaport, 2004; Maliva and Missimer, 2010; Segalen et al., 2005). Given proposals for horizontal well ASR in Corpus Christi and San Antonio, in addition to low transmissivity formations negatively affecting ASR in Laredo, this component of the research project is an important step to increasing the water security of Texas.

Horizontal Wells to Increase Surface Reservoir Water Supply Capacity

As of November 25, 2013, twelve water supply reservoirs in Texas were at less than ten percent capacity (TWDB, 2013). Pumps for surface reservoir extraction usually do not extend all the way to the lake bottom and therefore during drought floating rigs must be employed (Blackburn, 2011; Young, 2011). This means that even with water in the lake, pumps may be unable to access it. Subsurface pumping schemes near water bodies have been used to artificially induce groundwater recharge (Wiese and Nützmann, 2009). By completing horizontal wells beneath a surface reservoir, induced recharge could extract remaining lake waters, and often with a higher quality.

Surface water reservoirs can also cause a rise in the water table over large areas (Winter et al., 2002). Therefore, even though lake levels may be very low or dry, as groundwater is relatively slow moving there is an untapped bubble of water (higher heads) nearby the lake. By installing horizontal wells beneath a reservoir, naturally and induced recharged lake water could be extracted.

As a secondary benefit, many studies have cited the beneficial effects of river bank filtration/lake bank filtration (RBF/LBF) waters in relation to water quality improvement. Removal of dissolved oxygen, metals, organic carbons, pharmaceutically active compounds, and suspended/dissolved solids have been noted (Maeng et al., 2011; Ray et al., 2002; Ray et al., 2011; Stuyfzand, 2011). By installing horizontal wells with a chief purpose of increased water quantity, utilities will also have an added value of improved quality.

MODFLOW computer codes are in existence to simulate groundwater-lake interaction (Cheng and Anderson, 1993; Council, 1999; Fenske et al., 1997) and several studies have utilized said models (Hunt et al., 2003). However, no known studies or projects to date are directly comparable to the 'hybrid-lake' envisioned whereby horizontal wells would increase water supply capacity.

Of interest to note, RBF/LBF pretreatment processes have been suitable for ASR as a means of matching injection/aquifer water chemistries and water quality requirements. By matching water chemistries there will be a reduction in clogging and mineral precipitation/mobilization in ASR injection schemes (Herczeg et al., 2004; Mirecki et al., 2012; Rinck-Pfeiffer et al., 2000). To date there are two known applications of such a pretreatment chain for injection into an ASR system. The first study removed 91% of particles, but few dissolved constituents due to the short travel time of one to three hours (Cushing et al., 2003). The second study modeled a coupled RBF/ASR system and showed favorable results for natural RBF pretreatment of injected ASR waters (Sharma and Ray, 2011). Research to be completed

will not attempt to quantify such a pretreatment chain, but will surely benefit projects considering such an option.

Cost and Benefits of Horizontal Wells

No studies to date have specifically investigated the cost of a directionally drilled horizontal well for groundwater applications. It should be noted, however, that Jehn-Dellaport (2004) mentioned directional well costs 1.5-2 times greater than vertical wells which was based on actual cost data (Jehn-Dellaport, 2013). Similar statements on cost differences between vertical and horizontal wells have also been made in the petroleum industry (Joshi, 2003). Without an economic perspective, groundwater professionals will be unable to quantitatively judge the benefit of new well designs.

Year One Progress

Aquifer Modelling

The overall goal of this project is to investigate horizontal well cost, the use of horizontal wells for ASR, and the use of horizontal wells for surface water body extraction. When determining first year project goals submitted a year ago, the state of the science was not as well understood as it is now upon completion of an exhaustive literature review. After extensive literature review, it was determined that horizontal well energy loss (frictional head loss) must be understood before attempting to model horizontal well ASR. As noted by Maliva and Missimer (2010), modelling head (energy) loss along the wellbore is a significant technical issue to overcome. Due to friction effects, more aquifer drawdown will occur near the pump which is likely placed at the heel of the well, see Figure 1. This then causes non-uniform flux along the wellbore which negates all of the uniform flux assumptions used to date to model horizontal well groundwater extraction both numerically and analytically. The only exception to the previous statement is MODFLOW's Conduit Flow Process (CFP) which numerically models friction effects in the horizontal wellbore (Shoemaker et al., 2007).

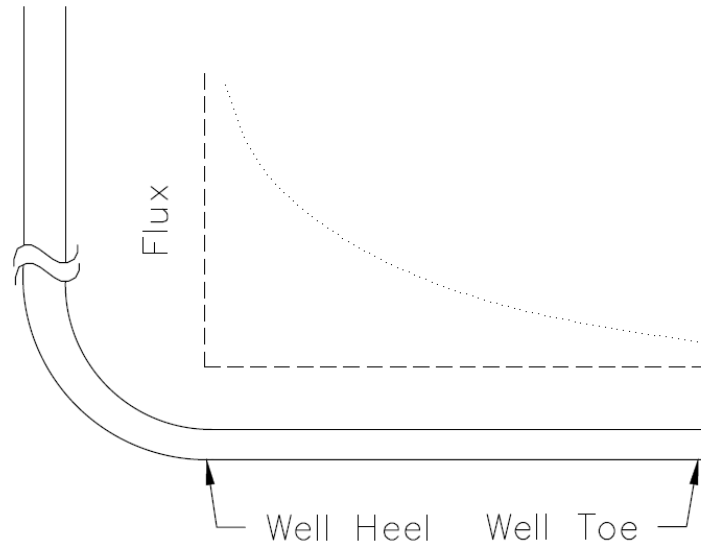


Figure 1. Non-uniform flux along a horizontal wellbore.

While MODFLOW-CFP is an attractive option for modelling horizontal well ASR, there is no graphic user interface for the program and furthermore it is not compatible with SEAWAT which would be used to model density effects of freshwater injection into a saline aquifer. There are versions of the CFP program that can model solute transport and mixing, but to date these are still lacking a buoyancy component (Spiessl et al., 2007). In contrast, MODFLOW Multi-Node-Well Package (MNW) can account for both solute transport and density effects, but is lacking horizontal well head loss (assumes uniform flux).

Given the above problems of modelling horizontal well energy losses, we also completed a literature review in petroleum reservoir engineering. From this review, we found an appropriate method to model horizontal well head losses in a semi-analytical way. We then re-derived the solutions for the groundwater system of units and expanded the boundary conditions. In the petroleum system, no flux boundaries were used which is not particularly useful to groundwater; therefore we re-derived solutions for constant head boundaries and a leaky aquifer in addition to no flux boundaries. Through this work we have created transient solutions for a coupled horizontal well and aquifer, including head loss effects within the wellbore.

As a new model now exists accounting for head loss in the wellbore and is connected to an aquifer with realistic groundwater boundary conditions, we can quantitatively determine groundwater horizontal well production benefits like never before. Determination of optimal horizontal well lengths and operating conditions can now be found relatively quickly and rigorously. In addition, because we solved for a leaky aquifer (constant head boundary separated by a low permeability layer), we can also make quantitative statements about horizontal wells beneath a surface water body. Because we are six months into this project, the remainder of this first year's grant will be spent refining our new model and submitting papers for publication.

Cost Modelling

A MATLAB code has been written to calculate torque and drag forces on the casing. These forces are then used to select appropriate strength casing based on recommendations from petroleum applications. Furthermore, these forces dictate the appropriate rig pullback capacity. With forces calculated, we needed associated costs. We then received information from over 15 companies to get cost parameters and capabilities for our model (contacted 36 companies). Combination of the cost data, forces, and several common simplifying assumptions have led to the creation of a deterministic well cost model for both vertical and directional wells. This model is applicable for only the well (no pump or surface features). As data was collected for a variety of rigs, the model is appropriate for both shallow and deep horizontal wells. Because we are six months into this project, the remainder of this year long grant will be spent refining our new model and submitting a paper for publication.

Year Two Goals

Now that a rigorous horizontal well model has been developed, a rapid, quantitative understanding of the horizontal well can now be achieved. This method is better and faster than the CFP because no finite grid is needed and boundary conditions are easily input into our model. Results from our model will drive specific research activities in year two. Generally we will be investigating the use of horizontal wells for ASR. Our newly developed model will inform us as to when head loss becomes dominant and thus should be considered. Our model will dictate when it is appropriate to use either CFP or MNW.

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Training potential One M.S. student

Investigator's qualifications Resumes follow.