Title:

Breaking the 30 Feet Barrier – Exploring the use of Horizontal Wells to Sustain the Ogallala Aquifer

Investigators:

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Summary/Abstract:

Irrigated agriculture is considered not possible when the saturated thickness of the Ogallala Aquifer drops below 30 ft. Typical responses to-date have been to switch to rain-fed farming, slowing down the rate of depletion through technological and cropping changes and identifying alternative sources of water. This proposal seeks to understand whether horizontal wells, can be used to improve well yields in depleted regions of the Ogallala aquifer (i.e., areas where the saturated thickness is below 30 ft.) While horizontal wells have become standard practice in oil and gas industry and have also widely been used to treat groundwater contamination, there has been limited use of this technology in water supply applications particularly for agricultural production. While horizontal wells are known to offer several advantages, they are costlier than traditional vertical wells. It is important to understand how this technology compares to other water augmentation strategies such as the use of the deeper Dockum aquifer. Therefore the overall goal of the proposed study is to perform a comprehensive feasibility evaluation of using horizontal wells to prolonging the useful life of the Ogallala aquifer. More specifically, the research seeks to address the following questions – 1) Can horizontal well extraction provide sufficient water to sustain irrigated agriculture over a growing season and for how long? 2) What hydrogeological (storage, transmissivity) and horizontal well characteristics (length and direction) limit the use of this technology? And as a corollary how can this technology be improved and adapted to the High Plains region? 3) What are the practical challenges in installing and retrofitting existing vertical wells as horizontal wells? 4) What are the costs associated with implementation of this technology? 5) How do the capital, operation and maintenance costs of this technology compare with the retrieval of water from deeper brackish aquifers?

Project Narrative:

Objectives

Water is the critical limiting factor for sustaining agricultural productivity in the High Plains region. As the proposed project seeks to augment water supplies through evaluation of new and innovative technologies it directly addresses the overall OAP Goal of "Developing and evaluating water management strategies and technologies for maintaining and/or enhancing the economic viability of the agriculture industry and the vitality of the Southern Ogallala Aquifer Region." More specifically, the project directly addresses sub-objective 4 as it determines the impacts of alternative water withdrawal/use policies on the economic viability of the agriculture industry and the vitality of the Southern Ogallala Aquifer Region. In addition, the data compilation and modeling efforts also help improve our understanding of the hydrologic impacts of water use and economic profitability (sub-objective 3). The comparison of horizontal drilling against the use of deeper brackish groundwater use helps evaluate the role of brackish groundwater development as a strategy for reducing water extractions from the Ogallala aquifer while maintaining the economic productivity of the region and this pre-plan therefore also addresses sub-objective 1 of the OAP.

Rationale/Literature Review

It is generally recognized that groundwater production for irrigation is not viable when the saturated thickness drops below 30 ft (Ng et al., 2010). However, large volumes of water is still available when this limit is reached. For example, if the saturated thickness were to drop to 30 ft, over the Ogallala Aquifer in Texas, 102 million acre-feet of recoverable water would still be available in the aquifer, which is enough to supply water for over 20 years at the current (and very high) extraction rates. Efforts must therefore be made to overcome the 30 feet barrier that is currently being posed by vertical well technology.

The depletion of oil and gas reservoirs and the inability of vertical wells to capture entrapped fossil fuels resulted in the creation of horizontal drilling technologies in the 1960s (Borisov, 1964). The use of horizontal collector wells to extract groundwater also dates back to 1960s (Hantush and Papadopulos, 1962). Horizontal wells have also been used in the subsurface remediation industry at least since the late 1980s (Dickenson et al., 1987). In recent times, horizontal wells are increasingly being explored in municipal water supply projects (Jehn-Dellaport, 2004; Bennett and Ariaratnam, 2008).

Horizontal wells have greater contact with the aquifer and as such have a much larger zone of influence, higher specific capacity and unlike vertical wells do not create localized regions of excessively large drawdowns. While installation of horizontal wells is 1.5 -3 times more expensive than vertical wells (Joshi, 2003), they could potentially be competitive against the option of exploring deeper brackish aquifers which are not only expensive to drill but also require treatment of water to avoid salinization and sodium toxicity risks. Most studies to date have focused on the use of horizontal wells for environmental or municipal water supply purposes. Agriculture use of water is different from these applications in that the production is intermittent but relatively large volumes of water have to be extracted over a shorter period of time. Analytical and numerical solutions focused on flow to horizontal wells have been developed in the literature (Zhan and Zlotnik, 2002; Mohamed and Rushton, 2006; Bashulto and Uddameri, 2011). However, the aquifer-horizontal well interactions and drawdown and recovery characteristics exhibited by these wells under agricultural production is largely undocumented in the literature.

While the limited literature on horizontal wells appears to suggest their utility in prolonging the life of the Ogallala aquifer, additional research is required to fully understand their benefits and evaluate if they can be part of the solution set. Therefore the overall goal of the proposed study is to perform a comprehensive feasibility evaluation of the use of horizontal wells for prolonging the life of the Ogallala aquifer. More specifically, the research seeks to address the following questions – 1) What hydrogeological (storage, transmissivity) and horizontal well characteristics (length and direction) limit the use of this technology? And as a corollary how can this technology be improved and adapted to the High Plains region 2) Can horizontal well extraction provide sufficient water to sustain irrigated agriculture over a growing season and for how long? 3) What are the practical challenges in installing and retrofitting existing vertical wells as horizontal wells? 4) What are the costs associated with implementation of this technology? 5) How do the capital, operation and maintenance costs of this technology compare with obtaining water from deeper brackish aquifers?

How the Objective will be met?

The above objectives will be met using a combination of methods including review of documented literature, discussions with industry personnel and experts, using existing hydrogeological information in conjunction with the development and application of mathematical models and using scenario analysis and sensitivity analysis.

Research Objective 1 Production from Depleted Aquifers and Hydrogeological Impacts: The production from a horizontal well will result in an ellipsoid zone of influence constrained along the end-points of the lateral. A variety of factors including screening length, orientation, saturated thickness, aquifer storage and transmissivity, anisotropy, well bore storage, formation damage during well construction (skin effect) and delayed drainage from the overlying vadose zone affect the pumping-drawdown behavior of horizontal wells (Park and Zhan, 2003). Analytical solutions have been proposed in the literature (Zhan and Zlotnik, 2002; Park and Zhan, 2003; Langseth et al., 2004) and will be used in conjunction with the principle of superposition to develop preliminary insights into the behavior of groundwater production from a horizontal well. Pumping test data available in the region along with estimated crop water requirements and water level measurements will be used to parameterize these solutions to conditions in the Southern High Plains region. The principle of superposition will be used to simulate intermittent pumping. The analytical solutions are useful to provide initial insights with regards to whether horizontal wells can be used to either fully provide or supplement other sources of water for irrigation.

While analytical methods are useful to obtain initial insights into production characteristics from depleted aquifers, they are incapable of addressing important issues such as the placement of the horizontal laterals in the context of aquifer anisotropy. Furthermore, regional gradients cause differential movement of water into horizontal wells and can play a critical role in controlling their production characteristics (Rushton and Brassington, 2013). A field-scale numerical model will be developed using USGS MODFLOW software to understand these impacts. The horizontal well will be simulated using a thin layer of high permeability following the approach developed by Bashulto and Uddameri (2011) and using the conduit flow process (CFP) package (Shoemaker et al., 2008). The boundaries of this field-scale model will be constrained using information obtained from regional-scale groundwater availability models (TWDB, 2015). Sensitivity analysis using the numerical model will shed light on the importance of aquifer heterogeneity and regional hydrogeology on the performance of horizontal wells.

Research Objective 2 Evaluation of Horizontal Wells for Agriculture Production: The analytical and numerical models developed as part of Research Objective 1 will be used to evaluate the feasibility of horizontal well technology for agriculture water production. Irrigation scheduling patterns for commonly grown crops such as cotton and sorghum will be developed in consultation with USDA scientists and other experts. Model sensitivity analysis will be used to evaluate how these production patterns will affect the drawdown behavior at the field. While analytical solutions can be used for long-term simulations, the convolution solution schemes quickly become cumbersome. As such, numerical models will be used to understand the long-term impacts of agricultural water production. Cross-sectional hydraulic head plots will be used to evaluate whether pumping results in excessive drawdowns that essentially render the horizontal well useless. Conditions leading to the failure of the horizontal wells (i.e., creation of dry cells) will be evaluated by sequentially increasing pumping and performing long-term (decadal scales) simulations.

Research Objectives 3 and 4 Practical Installation Challenges and Costs: Research objectives 1 & 2 focus on developing theoretical insights pertaining to the feasibility of horizontal well technology. However, practical considerations play a critical role in whether this technology will be adapted in the field. The important practical questions surrounding this technology include – 1) How much will this technology cost? 2) Are local drillers capable of installing such wells? 3) How disruptive is the construction and can an existing vertical well be converted into a horizontal well? Literature based estimates indicate that horizontal wells are typically 1.5 – 3 times more expensive than equivalent vertical wells (Langseth et al., 1990; Joshi, 2003). Several water drilling companies and consultants have experience installing Ranney wells. Oil and gas service companies such as Schlumberger Drilling who also operate in the water sector will be contacted to obtain reliable cost estimates for constructing such wells and identify the feasibility of converting existing vertical wells and the extent of trenching necessary to accomplish this task.

Research Objective 5 – Comparison with Deeper Brackish Groundwater Extraction: In addition to the construction costs, the energy required for groundwater production as well as for treatment and storage of water will be estimated using information obtained from steps 1 – 4. The PI currently has funding from the OAP program to evaluate the feasibility of using the brackish Dockum aquifer. He has also has other ongoing projects funded by the High Plains Water District, Texas Department of Agriculture and previous funding from the Oil and Gas industry which have focused on the water quality of the Dockum aquifer. The PI and his research team have participated in the construction of a new Dockum well in Abernathy, TX. These projects have enabled the PI to understand the costs of installation of Dockum wells and the quality of water produced by them. The PI has also carried out preliminary calculations on energy requirements for water production and water treatment to convert brackish groundwater. The data obtained from these previous endeavors will be leveraged to compare the options of horizontal drilling and brackish groundwater production.

Project Outcomes and Deliverables: The project will result in the following deliverables:

1. Development of analytical and numerical models parameterized to conditions in the Southern Ogallala Aquifer in Texas, OK and Kansas to evaluate the utility of horizontal well technology
2. Spatial maps depicting production potential using horizontal wells under typical configurations.
3. Sensitivity studies highlighting critical well design parameters as well as the effects of hydrogeology on groundwater production using horizontal wells.
4. Documentation of typical construction costs, a listing of corporations capable of drilling these wells.
5. Cost and technology comparisons with groundwater production from brackish groundwater aquifers.

Relevant Publications:

C. Callahan, Uddameri, V., and D. Reible. (2016), Geochemical Characterization of the Dockum Aquifer and the Brackish Unit as an Alternative Source in West Texas; (in Review); Draft available from the lead author.

V. Uddameri and D. Reible (2015); Water Availability in the Permian Basin Region of West Texas; in Hydraulic Fracturing Impacts and Technology – A Multidisciplinary Perspective (V. Uddameri, A. Morse, K Tindle, ed); 133 – 158; Taylor and Francis/CRC Press; ISBN: 978-1-4987-2117-2

Venkataraman, K., and Uddameri, V. (2012). Modeling simultaneous exceedance of drinking-water standards of arsenic and nitrate in the Southern Ogallala aquifer using multinomial logistic regression. *Journal of Hydrology*, *458*, 16-27.

J. De Lara Bashulto and V. Uddameri (2011); A Simulation-Optimization Model for ASR Operational Planning Subject to Probabilistic Supply and Water Quality Constraints; National Groundwater Association Groundwater Summit and Groundwater Protection Council Meeting; Baltimore, MD.

Resources and Budget

The proposed research is a collaboration between Texas Tech University and the USDA ARS Laboratory in Lubbock. In addition, the High Plains Underground Water Conservation District (HPWD) and United States Geological Survey (USGS) will serve as partners and assist with providing necessary contacts and identification of appropriate wells. The PI (Uddameri) will have access to hydrogeological and geophysical data collected by these entities in the Ogallala and Dockum Aquifers.

Literature Cited/References

Bashulto, J. D. and V. Uddameri (2011); A Simulation-Optimization Model for ASR Operational Planning Subject to Probabilistic Supply and Water Quality Constraints; National Groundwater Association Groundwater Summit and Groundwater Protection Council Meeting; Baltimore, MD.

Bennett, D. and Ariaratnam, S.T., 2008. Horizontal Directional Drilling: Good Practices Guidelines. North American Society for Trenchless Technology.

Borisov, J.P., 1964. Oil production using horizontal and multiple deviation wells. *Nedra, Moscow*, p.r4.

Dickenson, W., Dickenson, R. W., Mote, P., Nelson, P. 1987. Horizontal Radials for Hazardous Waste Remediation. NSWMA Waste Tech 87 Conference, San Francisco, CA, October 26-27.

Hantush, M.S. and Papadopulos, I.S., 1962. Flow of ground water to collector wells. *Journal of the Hydraulics Division*, *88*(5), pp.221-244.

Jehn-Dellaport, T., 2004, Innovative Water Well Completion in the Denver Basin, Colorado: The Mountain Geologist, v. 41, no. 4, p. 211-217.

Joshi, S.D., 2003, January. Cost/benefits of horizontal wells. In *SPE Western Regional/AAPG Pacific Section Joint Meeting*. Society of Petroleum Engineers.

Langseth, D.E., Smyth, A.H. and May, J., 2004. A method for evaluating horizontal well pumping tests. *Ground water*, *42*(5), pp.689-699.

Mohamed, A. and Rushton, K., 2006. Horizontal wells in shallow aquifers: field experiment and numerical model. *Journal of Hydrology*, *329*(1), pp.98-109.

Ng, Gene-Hua Crystal, Dennis McLaughlin, Dara Entekhabi, and Bridget R. Scanlon. 2010. "Probabilistic analysis of the effects of climate change on groundwater recharge." *Water Resources Research* 46, no. 7. *W07502, doi:10.1029/2009WR007904.*

Park, E. and Zhan, H., 2003. Hydraulics of horizontal wells in fractured shallow aquifer systems. *Journal of hydrology*, *281*(1), pp.147-158.

Rushton, K.R. and Brassington, F.C., 2013. Significance of hydraulic head gradients within horizontal wells in unconfined aquifers of limited saturated thickness. *Journal of Hydrology*, *492*, pp.281-289.

Shoemaker, W.B., Kuniansky, E.L., Birk, S., Bauer, S. and Swain, E.D., 2008. Documentation of a conduit flow process (CFP) for MODFLOW-2005.

TWDB, 2015. High Plains Aquifer System Groundwater Availability Model. Austin, TX

Zhan, H. and Zlotnik, V.A., 2002. Groundwater flow to a horizontal or slanted well in an unconfined aquifer. *Water Resources Research*, *38*(7).