Increasing Water Security through Horizontal Wells

Project Type: Research
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Research Category: Ground-water Flow and Transport
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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. The first year of purposed research will investigate the use of horizontal wells to extend the applicability of subsurface storage (aquifer storage and recovery) in low transmissivity formations. A literature review will be completed to facilitate said goal along with modeling and a cost/benefit analysis. The second year of research will focus on horizontal wells to increase surface reservoir water supply capacity. A literature review will be completed in addition to modeling and cost/benefit analysis.

Budget Breakdown

Category	*Federal*	*Non-Federal*	*Total*
Salary & Wages			
Grad Student (Blumenthal)	$10,943	$10,021	$20,964
GEOS Professor		$10,051	$10,051
TOTAL SALARIES	$10,943	$20,072	$31,015
Fringe	$ 2,261	$ 4,840	$ 7,101
Supplies	$ 800		$ 800
Travel	$ 825		$ 825
Other	$ 8,994		$ 8,994
Indirect Costs			
Non-Fed & Unrecovered		$18,488	$18,488
Total Estimated Cost	$23,823	$43,400	$67,223

Budget Justification

Salary & Wages:
Federal: Graduate Student (3.1 months) @ $41,928 @ 50% = $10,943.
Non-Federal Match: Graduate Student (2.9 months) @ $41,928 @ 50% = $10,021; GEOS Professor (1 month) @ 120,618/yr = $10,051. Total = $20,072.

Fringe:
Federal: Graduate Student, Fringe Benefits (9.9% of salaries + $376/month medical) = $2,261.
Non-Federal Match: Fringe Benefits (17.4% of salaries + $474/month medical; grad students @ 9.9% of salaries + $376/month medical) = $4,840.

Supplies:
Federal: General project supplies = $800

Travel:
Federal: Travel for project-related trips. Locations TBD = $825

Other:
Federal: Tuition @ $8,544 and Publications @ $450 = $8,994

Indirect Costs:
Texas AgriLife Research indirect cost rate is 46% of Total Direct Costs ($23,823 Federal, $24,912 Match). Waived IDC on federal and non-federal funds is $18,488.

Increasing Water Security through Horizontal Wells

Background

Water security is vital to the continued growth and success of the State of Texas. The Texas Water Development Board (TWDB, 2012b) 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, 2012b). 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, 2012b).

While additional surface reservoirs are in planning stages, they contain many drawbacks. Annual evaporation of lakes ranges 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 (USGS, 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 of these systems in Texas: El Paso, Kerrville and San Antonio (Malcolm Pirnie Inc et al., 2011; Sheng, 2005). San Antonio's ASR currently (October 2012) has 91,000 acre feet in storage, with a maximum capacity of 120,000 acre feet (SAWS, 2012). ASR systems have been identified in the 2012 State Water Plan as a water management strategy to provide 81,000 acre feet per year by 2060 (TWDB, 2012b). 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."

Research Aims

Horizontal Wells in ASR Systems

The first research goal is to investigate optimization of ASR systems through the use of horizontal directional drilling (HDD). In low transmissivity formations, the cost savings of using HDD may be substantial and thus facilitate ASR development in areas previously deemed infeasible. The use of HDD would allow greater borehole contact with the target formation thus increasing the 'radius' of influence and allow more water to be stored in a low permeability/thin formation.

The TWDB's feasibility report on a purposed Laredo ASR system cited transmissivity (both narrow beds and silty substrates) as the chief obstacle to development (CH2MHILL, 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 a Laredo ASR system has been done due to the high costs and low returns.

Another report by CH2MHILL (1998) considered HDD in the San Antonio region for an ASR application 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. When comparing this cost to the $70,000 required for a new well cited in the Laredo report, economics of HDD become interesting.

There has not been any research on HDD in an ASR application and only limited research of HDD in a conventional water extraction well design. HDD was used to increase yields of an aquifer in the Denver basin (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. Similar finding in relation to HDD mine dewatering have also been found (Struzina et al., 2011). While no research to date has been completed on an HDD ASR, the use of HDD in an ASR application has been cited as a research need (JEHN-DELLAPORT, 2004; Segalen et al., 2005).

Horizontal Wells to Increase Surface Reservoir Water Supply Capacity

The second research aim is to investigate horizontal well completion beneath water supply reservoirs. As of November 15, 2012, sixteen water supply reservoirs in Texas were at less than ten percent capacity (TWDB, 2012a). 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; Pickle, 2012; 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) underneath the lake. By installing horizontal wells beneath a reservoir, naturally and induced recharged lake water could be extracted.

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.

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.

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 application 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.

Research Objectives

1. Year One
    a. Complete a literature review.
    b. Create a MODFLOW model and compare horizontal vs. vertical wells when varying different parameters (k, thickness, etc.) in an ASR application.
    c. Complete a cost benefit analysis, noting if/when it becomes cost effective to horizontally drill an ASR system.
        i. Revisit the Laredo transmissivity issues and compare modeling vertical vs. horizontal wells in a cost benefit analysis.
    d. Write first half of report.
2. Year Two
    a. Complete a literature review.
    b. Create a MODFLOW model and investigate horizontal well completion beneath surface water reservoirs to increase extractable volumes.
    c. Complete a cost benefit analysis, noting if/when it becomes cost effective to horizontally drill beneath a water supply reservoir.
    d. Write second half of report.

References

Blackburn, E., 2011, Lubbock water supplier switches off pumps at Lake Meredith to preserve what's left, Lubbock Avalance-Journal: Lubbock Texas.

Bouwer, H., 2002, Artificial recharge of groundwater: hydrogeology and engineering: Hydrogeology Journal, v. 10, no. 1, p. 121-142.

CH2MHILL, 1998, Preliminary Investigation and Feasibility Analysis, Step 1, San Antonio Water System and Bexar Metropolitan Water District, San Antonio, Texas.

-, 1999, Aquifer Storage Recovery Feasibility Investigation, Step 2, City of Laredo, Texas.

Cheng, X., and Anderson, M. P., 1993, Numerical Simulation of Ground-Water Interaction with Lakes Allowing for Fluctuating Lake Levels: Ground Water, v. 31, no. 6, p. 929-933.

Council, G., 1999, A Lake Package for MODFLOW (LAK2), HSI Geotrans A Tetra Tech Company.

Cushing, R. S., Pyne, R. D. G., and Wilkes, D. R., 2003, Aquifer Storage and Recovery Pretreatment: Synergies of Bank Filtration, Ozonation, and Ultraviolet Disinfection, *in* MELIN, G., ed., Riverbank Filtration Conference: Cincinnati, Ohio, National Water Research Institute, p. 23-27.

Fenske, J. P., Leake, S. A., and Prudic, D. E., 1997, Simulating Reservoir Leakage in Ground-Water Models: Ground Water, v. 35, no. 5, p. 895-897.

Herczeg, A. L., Rattray, K. J., Dillon, P. J., Pavelic, P., and Barry, K. E., 2004, Geochemical Processes During Five Years of Aquifer Storage Recovery: Ground Water, v. 42, no. 3, p. 438-445.

Hunt, R. J., Haitjema, H. M., Krohelski, J. T., and Feinstein, D. T., 2003, Simulating Ground Water-Lake Interactions: Approaches and Insights: Ground Water, v. 41, no. 2, p. 227-237.

JEHN-DELLAPORT, T., 2004, Innovative Water Well Completion In The Denver Basin, Colorado: The Mountain Geologist

Maeng, S. K., Sharma, S. K., Lekkerkerker-Teunissen, K., and Amy, G. L., 2011, Occurrence and fate of bulk organic matter and pharmaceutically active compounds in managed aquifer recharge: A review: Water Research, v. 45, no. 10, p. 3015-3033.

Malcolm Pirnie Inc, ASR Systems LLC, and Jackson, S., McCarthy & Wilson LLP,, 2011, An Assessment of Aquifer Storage and Recovery in Texas: Texas Water Development Board.

Mirecki, J. E., Bennett, M. W., and López-Baláez, M. C., 2012, Arsenic Control During Aquifer Storage Recovery Cycle Tests in the Floridan Aquifer: Ground Water, p. no-no.

National Research Council, C. o. S. U. S. o. R. W., 2008, Prospects for Managed Underground Storage of Recoverable Water: Washington, D.C., The National Academic Press.

Pickle, J., 2012, Colorado River Municipal Water District, Texas State Historical Association Handbook of Texas Online.

Pyne, R., 1995, Groundwater recharge and wells: a guide to aquifer storage recovery: Boca Raton, Florida, Lewis Publishers.

Ray, C., Grischek, T., Schubert, J., Wang, J. Z., and Speth, T. F., 2002, A perspective of riverbank filtration: American Water Works Association. Journal, v. 94, no. 4, p. 149-149.

Ray, C., Jasperse, J., and Grischek, T., 2011, Bank Filtration as Natural Filtration

Drinking Water Treatment, *in* Ray, C., and Jain, R., eds., Springer Netherlands, p. 93-158.

Rinck-Pfeiffer, S., Ragusa, S., Sztajnbok, P., and Vandevelde, T., 2000, Interrelationships between biological, chemical, and physical processes as an analog to clogging in aquifer storage and recovery (ASR) wells: Water Research, v. 34, no. 7, p. 2110-2118.

SAWS, 2012, Twin Oaks - Aquifer Storage & Recovery, San Antonio Water System.

Segalen, A.-S., Pavelic, P., and Dillon, P., 2005, Review of Drilling, Completion and Remediation Methods for ASR Wells in Unconsolidated Aquifers: CSIRO Land and Water, Technical Report No. 04/05.

Sharma, L., and Ray, C., 2011, A Combined RBF and ASR System for Providing Drinking Water in Water Scarce Areas

Riverbank Filtration for Water Security in Desert Countries, *in* Shamrukh, M., ed., Springer Netherlands, p. 29-49.

Sheng, Z., 2005, An aquifer storage and recovery system with reclaimed wastewater to preserve native groundwater resources in El Paso, Texas: Journal of Environmental Management, v. 75, no. 4, p. 367-377.

Struzina, M., Müller, M., Drebenstedt, C., Mansel, H., and Jolas, P., 2011, Dewatering of Multi-aquifer Unconsolidated Rock Opencast Mines: Alternative Solutions with Horizontal Wells Mine Water and the Environment.

Stuyfzand, P. J., 2011, Hydrogeochemical Processes During Riverbank Filtration and Artificial Recharge of Polluted Surface Waters: Zonation, Identification, and Quantification

Riverbank Filtration for Water Security in Desert Countries, *in* Shamrukh, M., ed., Springer Netherlands, p. 97-128.

Todd, D. K., 1959, Annotated bibliography on artificial recharge of ground water through 1954, U. S. Geological Survey Water-supply paper 1477: Washington, DC, U.S. Government Printing Office.

TWDB, 2012a, Water Data for Texas -- Texas Reservoirs: Austin, TX.

-, 2012b, Water for Texas 2012 State Water Plan.

USGS, 2000, Hydrogeology, Hydrologic Budget and Water Chemistry of the Medina Lake Area, Texas, Water-Resources Investigations Report 00–4148, USGS.

Viessman, W., Klapp, J. W., Lewis, G. L., and Harbaugh, T. E., 1977, Introduction to Hydrology: New York, Harper & Row.

Wiese, B., and Nützmann, G., 2009, Transient Leakance and Infiltration Characteristics during Lake Bank Filtration: Ground Water, v. 47, no. 1, p. 57-68.

Winter, T., Harvey, J., Franke, O. L., and Alley, W., 2002, Ground Water and Surface Water A Single Resource, Denver, U.S. Geological Survey.

Young, M., 2011, If drought continues, Dallas-Fort Worth faces severe water shortages, higher bills The Dallas Morning News: Dallas.

Training potential One M.S. student

Investigator's qualifications Resumes follow.