Title:

Evaluation of Dockum as an Alternative Source to Reduce the Freshwater Footprint of the Ogallala Aquifer.

Personnel:

Investigators

Venki Uddameri, Ph.D., P.E.; Water Resources Center, Texas Tech University, Lubbock, TX 79409-41023

Nathan Howell, Ph.D., School of Engineering and Computer Science, West Texas A&M University, Canyon, TX 79015

Cooperator

Jason Coleman, P.E., General Manager, High Plains Water District, Lubbock, TX 79411

Summary/Abstract:

The problem of Ogallala Aquifer conservation and preservation is as much related to water supply as water demand. The Dockum Formation is co-located with the Ogallala Aquifer in many places, and this placement provides an opportunity for agricultural producers and water planners to tap into this formation in order to alleviate water demands on the Ogallala. Such a strategy is in direct alignment with the overall Ogallala Aquifer Program's primary goal of providing a means to sustain the rural economies.

The potential for alternative water use via the Dockum Formation is viewed favorably by many regional water users, but several technical challenges and data gaps exist. This project seeks to address these critical needs in three primary areas—(1) Spatial variation in water quantity, quality, and yield through the Dockum that speak to its utility, (2) temporal groundwater quality issues related to local-scale pumping dynamics, and (3) vertical variations in Dockum water salinity which could lead to unwanted salinization of water withdrawals if pumping enhances mass transport of dissolved solids (saltwater upconing). Methods for addressing these research inquiries are to characterize Dockum water quality both regionally and locally using existing data and through data to be collected in the project. Additionally, representative Dockum wells will be chosen to measure salinity changes with depth. Those measurements will be used to model the effects of pumping on extracted water salinities to provide recommendations on reasonable use. Specific deliverables of the project will include a comprehensive, spatially-explicit, time-coded geodatabase of hydrogeological and geochemical data obtained from the study and augmented with other public domain information. A spreadsheet based tool to evaluate the pumping effects on upconing and a rigorous numerical model to understand the role of geologic heterogeneity and pumping intermittency on vertical mixing and its effects on water quality. The results of the study will be condensed into a set of guidelines and tools that will help agricultural producers, local officials, and groundwater districts ensure the wisest use of Dockum formation water.

Project Narrative:

Rationale/Literature Review

There has been a growing interest in recent times to explore the use of alternative water resources to augment dwindling freshwater supplies in agricultural regions (Bouksila et al., 2013). Not surprisingly, many producers in the southern High Plains are increasingly looking at using aquifers underlying the Ogallala formation to supplement their water needs. In particular, there has been a growing interest in utilizing water from the Dockum group of sediments (referred to as the Dockum formation here for brevity) in West Texas. For example, the High Plains Underground Water Conservation District (HPWD) has received nearly 30 permits for drilling wells in the Dockum formation in the year 2014 (Coleman, 2015).

Supplementing irrigation water needs from the deeper Dockum formation certainly has the positive benefit of reducing the freshwater withdrawals from the Ogallala aquifer and as such help prolong its useful life, and thereby enhance the economic vitality of the Southern Ogallala region.

Extracting groundwater resources from the deeper Dockum formation is challenging on several fronts – 1) The costs of drilling such wells is sufficiently high given the depths of the water-bearing sediments; 2) The groundwater in the aquifer generally tends to be brackish and enriched with sodium and other minerals that pose salinity hazards to crops; 3) Vertical salinity gradients exist within the aquifer which essentially implies the water quality will likely deteriorate further over time; 4) As the aquifer has not been used extensively, its hydrogeological properties are poorly characterized (Bradley and Kalaswad, 2001). Overcoming these significant data gaps is critical to evaluate whether the Dockum formation can be used as a supplemental source that can ameliorate freshwater demands on the Ogallala formation. If it can be used, to what extent can this resource complement agricultural water needs in the region? There clearly is no single easy answer to these questions and as such they need to be addressed in a geospatial context within the region.

Objectives

The primary goal of this study is to build upon the recent efforts of the PIs in understanding the hydrologic and geochemical characteristics of the Dockum formation and build a comprehensive knowledge base that can help producers, land and water planners and policy makers make informed decisions on the most efficient use of this resource to bolster and augment the agricultural based economy of the Southern Ogallala region. Using a combination of field data collection and modeling, the study seeks to address the following research questions:

1. In what areas underlying the Ogallala formation can Dockum be a useful as a stand-alone or supplemental irrigation source? As a corollary, what hydrogeological and geochemical characteristics limit the utility of Dockum formation to serve as a useful resource for meeting or offsetting water stresses on the Ogallala aquifer? Or what are the regional-scale characteristics of the aquifer?

2. What are the temporal characteristics of groundwater quality in the Dockum water? In particular, how does water quality change during production and recovery phases? This issue has particular relevance in understanding the local-scale (near well) characteristics of the aquifer and spacing of irrigation production from the formation during the growing season.

3. How does the salinity change with depth in the Dockum Formation? Production of water from aquifers exhibiting depth-salinity stratification results in a hydrogeological condition referred to as upconing which refers to the mixing of deeper saline waters with shallower better quality (fresher) waters. Uncontrolled upconing results in deterioration of water quality and increases salinization hazards. Upconing along with diminishing well yields therefore places a limit on the amount of groundwater that can be sustainably produced from the aquifer on a long-term basis.

The proposed study is designed to answer fundamental hydrologic and geochemical questions about the Dockum Formation, and these fundamental questions do lead directly to several of the stated objectives of the Ogallala Aquifer Program:

- OAP objective 1 [water management strategies and technologies that reduce irrigation by 20% in 2020 compared to 2012]-The potential use of Dockum Formation water will directly reduce irrigation use of Ogallala Aquifer water once the agro-economic potential and risks of Dockum withdrawals are better characterized.

- OAP objective 3 [Improve understanding of hydrologic and climatic factors that affect water use and profitability both now and in the next 50 years]-This study will better characterize the Dockum Formation as it exists currently and in light of how it could change according to the prevailing trends of well development. Decreases in rainfall and increases in temperature will only increase demand for Dockum Formation waters, and so the proposed work will help many water decision-makers employ Dockum water wisely in light of both climate and hydrology.

How the Objective will be met

The above objectives will be met using a combination of field monitoring and modeling studies over a one and a half year project timeframe.

Research Objective 1 Regional-scale Characterization (Sep 2015-March 2016): PI Uddameri is completing a project focused on evaluating the characteristics of the Dockum formation and its potential for use in hydraulic fracturing operations (Callahan et al., 2014). As part of this study, PI Uddameri has compiled an extensive hydrogeological and geochemical dataset which includes major ions (Ca, Mg, Na, K, Cl, SO_4, HCO_3, CO_3) typically found in groundwater as well as nitrate (NO_3) an indicator of irrigation influences as well as Barium (Ba) and Strontium (Sr) indicators of geological volcanic ash deposits typical of West Texas sediments. Co-PI Howell has also collected groundwater data from several wells using a previous OAP funded project. These studies provide an ideal starting point to identify data gaps that exist spatially that need to be filled to develop a comprehensive picture of the Dockum formation. The data collection efforts will be coordinated with the High Plains Underground Water Conservation District (HPWD) with whom PI Uddameri has an established relationship. In addition, the PI will also work with USGS personnel who will be conducting geophysical logging under contract with the HPWD. The City of Abernathy plans to drill a ~ 1200 feet well in the Dockum Formation in early 2016 which will provide an unique opportunity to collect data during well construction that is otherwise not possible. In particular, the PIs will plan to obtain step-drawdown data during the well development to understand the well construction and development aspects that are so critical for proper functioning of wells (Hunter, 2012) but are very difficult to measure due to fiscal constraints of drilling new wells as part of small-budget research projects. Water quality sampling will be carried out using standard sample collection and preservation procedures (Boghichi, 2003) and analyzed following analytical protocols provided in the Standard Methods for Water and Wastewater Analysis (AHPA, 2007).

Research Objective 2 Local Well-Scale Characterization (Sep 2015-Sep 2016): A subset of wells (ideally spread across the southern high plains) will be identified for detailed local scale monitoring. Automated water level loggers will be installed in these wells to monitor the drawdown and recovery characteristics. This data will be used for estimating aquifer transmissivity. Water quality monitoring will be conducted during different times of the year at these wells to understand the temporal variation of water quality. An evaluation of the water quality data available from the Texas Water Development Board (TWDB) indicates that the most sampled well in the Dockum aquifer had six measurements of basic water quality parameters over a period of 1990 – 2014 (Uddameri et al., 2015). Understanding short-term (intra-annual) variability is a significant data gap and particularly useful for assess whether water quality of irrigation production during the latter part of the growing season is the same from that at the early times and how best to schedule irrigation production from this aquifer. As such this objective addresses another important concern of landowners seeking to use Dockum as an alternative source.

Research Objective 3 Depth-Stratified Groundwater Salinity and Upconing Impacts (March 2016-Feb 2017): Progressive salinization of major surficial aquifers in West Texas has been noted due to mixing ensuing from cross-formational flow, seepage from saline plumes and playas, evaporative enrichment, and irrigation return flow (Chaudhary and Ale, 2014). These issues are even more critical in the deeper Dockum

formation which is predominantly brackish. Depth-Salinity profiles will be logged at selected wells using a Temperature, Water level, Conductivity (TLC) meter (SolInst, Inc) which allows for high spatial vertical resolution (centimeter scale) sampling. The measurements will be made under relatively static conditions (post-recovery) and during production to see the vertical mixing during production. The data obtained from the field will then be used to guide the development of upconing models. Modeling will be carried out in two stages - Preliminary insights will be obtained by parameterizing the analytical solution presented by Motz (1992) which is based on the sharp-interface approximation. The modeling will be extended to relax this assumption to account for variable density flow and transport of salt and water and the resulting numerical formation will be solved using the finite-element method using USGS SUTRA software (Voss, 1984). These modeling studies will help establish critical pumping limits in the Dockum aquifer which prevent saltwater upconing. The critical pumping will be mapped spatially (using ArcGIS) and will be another useful tool for stakeholders in their evaluation of the water availability in the Dockum formation.

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

1. A spatially-explicit and temporally-coded geodatabase containing all the geochemical data for the Dockum Aquifer. In addition to regional-scale and local scale monitoring data collected as part of this effort, the database will also contain all other publicly available hydrogeological and geochemical information compiled from other local, state and federal agencies as well from the literature. All data will be in the ESRI Geodatabase and ArcHydro formats as well as shapefiles to allow widespread dissemination.
2. An analytical model for saltwater upconing parameterized using field data from the Dockum formation. The model will be coded in a spreadsheet using Visual Basic for Applications (VBA) to allow stakeholders to interact and make preliminary (tier-1) evaluations of the impacts of their pumping requirements.
3. A numerical model for saltwater upconing parameterized using field data from the Dockum formation. This model will be developed using public domain SUTRA code and made available for all interested stakeholders who choose to perform advanced (tier-2) analysis on the effects of pumping on mixing in the aquifer. The numerical model will be used gain fundamental insights into the effects of geological heterogeneity and intermittent pumping and cross-formational flows on the water quality of the aquifer.

Relevant Publications:

Hernandez, E. A., & Uddameri, V. (2015). Simulation-optimization model for water management in hydraulic fracturing operations. *Hydrogeology Journal*, 1-19. DOI:10.1007/s10040-015-1249-y

C. Callahan, V. Uddameri and D. Reible (2014); Evaluation of Dockum Formation Water Quality for use in Hydraulic Fracturing Processes using Principal Component Analysis; Air and Waste Management Association - Fracturing Impacts and Technology Specialty Conference, Lubbock, TX Sept 4 -5 2014.

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.

Livingston, D.; DeOtte, R. E.; Howell, N. L., Current and historical examination of Dockum and Ogallala Aquifer. In *Ogallala Aquifer Program Annual Meeting 2015*, USDA Agricultural Research Services (USDA-ARS): Manhattan, KS, USA, 2015.

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Voss, C. I. (1984). *SUTRA (Saturated-Unsaturated Transport). A Finite-Element Simulation Model for Saturated-Unsaturated, Fluid-Density-Dependent Ground-Water Flow with Energy Transport or Chemically-Reactive Single-Species Solute Transport* (No. USGS/WRI/84-4369). GEOLOGICAL SURVEY RESTON VA WATER RESOURCES DIV.