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Assessing aquifer storage and recovery feasibility in the Gulf Coastal Plains of Texas

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ABSTRACT

Study region: The Gulf Coast and Carrizo-Wilcox aquifer systems in the Gulf Coastal Plains of Texas.

Study focus: Aquifer storage and recovery is a water storage alternative that is underutilized in Texas, a state with both long periods of drought and high intensity storms. Future water storage plans in Texas almost exclusively rely on surface reservoirs, subject to high evaporative losses. This study seeks to identify sites where aquifer storage and recovery (ASR) may be successful, especially in recovery of injected waters, by analyzing publicly-available hydrogeologic data. Transmissivity, hydraulic gradient, well density, depth to aquifer, and depth to groundwater are used in a GIS-based index to determine feasibility of implementing an ASR system in the Gulf Coast and Carrizo-Wilcox aquifer systems.

New hydrological insights for the region: Large regions of the central and northern Gulf Coast and the central and southern Carrizo-Wilcox aquifer systems are expected to be hydrologically feasible regions for ASR. Corpus Christi, Victoria, San Antonio, Bryan, and College Station are identified as possible cities where ASR would be a useful water storage strategy.

1. Introduction

Aquifer storage and recovery (ASR) is a water storage alternative applicable to a wide range of hydrogeologic conditions and climates. ASR is a subset of managed aquifer recharge (MAR), which sometimes is also termed artificial recharge, artificial aquifer recharge, or artificial recharge and recovery (Dillon, 2005; Sheng and Zhao, 2015). For most purposes, aquifer storage and recovery systems consist of four main subsystems: storage space (aquifer), injection or recharge facilities (wells, infiltration basins, etc.), extraction or recovery facilities (wells), and source water. All four of these subsystems must work in coordination with each other for an ASR system to successfully store water for later use (Sheng, 2005).

ASR has many advantages over surface reservoirs: little to no evaporative losses, minimized environmental disturbances and land consumption, and lower costs (Bouwer, 2002; Khan et al., 2008; Maliva et al., 2006; Maliva and Missimer, 2010; National Research Council, 2008). ASR is highly adaptable and can be used in a variety of aquifer types (e.g., shallow or deep, fresh or saline, thick or thin, sandstone or limestone (Maliva and Missimer, 2010)), in a wide range of climates (e.g., arid deserts (Maliva et al., 2011), temperate grasslands and wetlands (Antoniou et al., 2012), and subtropical wetlands (Jones and Pichler, 2007)), and to provide storage for a range of applications (e.g., drinking water supplies for municipalities, minimum environmental stream flows, and protection against seawater intrusion in freshwater aquifers among other uses (Pyne, 2005)). Two primary methods for determining

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ASR site suitability have been used in recent years. The more common practice is to develop a qualitative suitability index that involves classifying and weighting various factors and evaluating those factors over a spatial area. For instance, CH2MHILL, an engineering consulting firm, created a tool to assess feasibility of ASR in South Florida for the St. John's River Water Management District (CH2MHILL, 1997). The Comprehensive Everglades Restoration Project (CERP) created a site selection suitability index to evaluate feasibility of potential ASR sites to be used in the restoration of the Everglades and implemented the suitability index in GIS (Brown et al., 2005). Eastwood and Stanfield (2001) also employed a qualitative approach when stressing the importance of environmental acceptability as the more important success factor compared to water quality considerations. They argued water quality can be "engineered out" so as to not be an absolute hindrance to ASR like potential environmental damage, noting the economics of water quality mitigation may still eventually render specific ASR projects unfeasible (Eastwood and Stanfield, 2001). Most other published research focuses on estimating suitability for managed aquifer recharge projects, especially those involving surficial infiltration, as opposed to the injection and extraction via wells of aquifer storage and recovery (Fernandez Escalante et al., 2014; Ghayoumian et al., 2007; Malekmohammadi et al., 2012; Pedrero et al., 2011; Rahman et al., 2012; Rahman et al., 2013). Smith and Pollock's (2012) approach is interesting to note, as they applied an analytical model for managed aquifer recharge via infiltration over an area to identify feasible MAR locations in a more quantitative manner than the other multi-criteria decision methods. Bridging the gap between subsurface ASR systems and MAR surficial systems, Russo et al. (2015) estimated the feasibility of managed aquifer recharge sites in California by weighted sum of classified values, accounting for both potential surface infiltration and subsurface injection systems.

More quantitative methods for estimating the feasibility of locations for ASR-specific systems have been developed as well. These methods involve deriving dimensionless parameters that describe a physical process governing the recovery efficiency of an ASR system. Bakker (2010) created a dimensionless parameter based on well discharge, hydraulic conductivity, aquifer thickness, and dimensionless density difference, and used it along with the relative lengths of injection, storage and recovery periods to evaluate potential feasibility of ASR in saltwater aquifers. Ward et al. (2009) developed four additional dimensionless parameters to describe three major governing factors of ASR recovery efficiency: lateral flow, density-driven flow, and dispersive mixing. They proposed that these parameters could be used to help identify suitable ASR sites if sufficient data were available. The dimensionless parameters of Bakker (2010) and Ward et al. (2009) were evaluated separately to assess their effectiveness at predicting ASR site suitability in a coastal area of the Netherlands using GIS, and both were shown to be effective at predicting successful ASR sites (Zuurbier et al., 2013). Characterization of suitable regions by parameters with real physical significance, instead of simple qualitative characterizations like 'very suitable,' 'suitable,' or 'unsuitable' can provide valuable information to water resource managers.

Historically, Texas water utilities have primarily used surface reservoirs to manage temporal differences in water supply and demand, despite significant evaporative losses. The 2012 Texas State Water Plan, published by the Texas Water Development Board (TWDB), primarily prescribes increasing water storage capacity via the construction of additional surface reservoirs throughout the state. Despite the fact that ASR provides additional benefits beyond water storage, including minimized environmental damage and replenished aquifers, it is currently underutilized in Texas, and based on the 2012 water plan, is projected to be in the future as well (Malcolm Pirnie et al., 2011; TWDB, 2012). ASR can never completely replace surface storage, as it cannot match some benefits of surface storage, especially in regards to storm water management. Surface and subsurface storage of freshwater provide complementary benefits to water providers, and both should be considered for future storage needs.

ASR, when implemented as part of a water storage portfolio, can help Texas achieve water security and replenish aquifers that have been depleted and overstressed for more than 100 years. Natural aquifer recharge rates are typically much lower than anthropogenic extraction rates, and without artificial recharge, groundwater as a natural resource in Texas could easily disappear on a relatively short timescale. A 2011 TWDB report on ASR use in Texas found that the biggest concerns of municipalities in regards to ASR were the ability to physically recover stored water and degradation of water quality during storage, both of which highlight the need for additional information on aquifer storage spaces across the state (Malcolm Pirnie et al., 2011).

This work focuses on the potential feasibility of systems that both inject and extract water from an aquifer via wells. Previous ASR feasibility indices have required significant amounts of site-specific data to assess feasibility at specific locations, which make large, regional scale analyses difficult. The objectives of this study are three-fold: 1) to develop a method for rating the feasibility of aquifer storage and recovery at a regional aquifer scales using commonly available data; 2) to compile a geospatial information system (GIS) database for the Gulf Coast and Carrizo-Wilcox aquifer systems of Texas; and 3) use the database to create feasibility maps suitable for use by regional water planners and other government entities. Specifically, we define ASR as both injection into and extraction from the aquifer occurring via wells. We also view ASR feasibility through the lens of a municipality seeking seasonal or long term water storage in an aquifer, such that locations which minimize injected water losses, operational costs, and constructions costs are given the highest ratings. Mapping scales are appropriate for use in selection of sites where pilot studies or more detailed engineering studies will be conducted, rather for the placement of specific facilities.

2. Materials and methods

2.1. Study areas

Both the Gulf Coast and Carrizo-Wilcox aquifer systems in Texas' Gulf Coastal Plains were evaluated for their feasibility of implementing ASR systems. The primary aquifers within the Gulf Coast system are the Chicot, Evangeline, and Jasper aquifers. The primary aquifers in the Carrizo-Wilcox system are the Carrizo, Middle Wilcox, and Simsboro aquifers. The Simsboro aquifer represents the middle unit of the Wilcox group in the central portion of the Carrizo-Wilcox, and is therefore treated as one "Wilcox"