# Anticipating Growth in the Texas Hill Country: Exploration of Potential for Land Application of Treated Wastewater

Report: 2019-09
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The Meadows Center
for Water and the Environment
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MEMBER **THE TEXAS STATE UNIVERSITY SYSTEM**

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THE MEADOWS CENTER
FOR WATER AND THE ENVIRONMENT
TEXAS STATE UNIVERSITY

601 University Drive, San Marcos Texas 78666
512.245.9200 | MeadowsCenter@txstate.edu | www.MeadowsWater.org

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# Executive Summary

The Texas Hill Country is an iconic landscape known for its unique beauty, including clear-running rivers and streams, and numerous springs both large and small. Given the rapid population growth along the I-35 corridor and west into the Hill Country, water-resource planning and management challenges are emerging that provide opportunity for an integrated or "One Water" approach to problem solving.

First, there is growing demand for drinking water in a region that is also known to be drought-prone and home to many threatened or endangered species that need water too. Secondly, with increased water use comes a proportional increase in treated wastewater effluent production. Absent strong nutrient standards in permitted discharges to prevent cultural eutrophication of Hill Country streams, alternative uses of treated wastewater effluent are available that can reduce withdrawals of surface and groundwater and create new economic opportunities by using wastewater effluent as a resource rather than disposing it as a waste product.

From a larger set of Texas Hill Country cities that were based on their location relative to the Edwards Aquifer, nine were selected in a first phase analysis using a geographic information system and based on weighted criteria including population growth rate, potential site distance from a wastewater treatment plant (WWTP), and a set of land uses deemed suitable for land application of treated wastewater. These nine cities were then evaluated based on their ability to meet four criteria: 1) the target city's WWTP is located within or upstream of either the contributing or recharge zones of the Edwards Aquifer regulatory boundary, 2) the city's WTTP has a current or near future need to expand their WWTP based on reported average daily discharge being 75 percent or more of permitted maximum daily discharge, 3) it being early enough in their planning development cycle, either hypothetically or in actual practice, that reuse infrastructure can be carefully examined and planned for at the most efficient time, and 4) having land-use scenarios suitable for land application that are within a 3-mile (maximum) radius of the WWTP. From this analysis, three cities emerged for study: Blanco, Boerne, and Leander.

A second phase of site analysis given to the three study cities is based on weighted criteria that include land use, location relative to the Edwards Aquifer regulatory boundary, distance from WWTP, and percent slope. Among results, the City of Blanco can meet 100 percent of both current and future needs for land application of TWW effluent on highest-quality sites (scores of ten) within a one-mile radius of its WWTP. The City of Boerne, can also meet both current and future needs for land application within a one-mile radius, but will need to include some sites with scores less than a ten and act with a greater sense of urgency given the current/projected growth rate. The City of Leander presents a particular challenge given its current/projected growth rate, large effluent volume expected in the future, and location and will require other reuse strategies to ensure efficient use of water and protection of local/regional water quality.

By applying a replicable methodology using publicly available data, this study shows promise for land application of treated wastewater effluent in the Texas Hill Country. While infrastructure and other cost considerations need to be analyzed in a future study along with refinement of site selection and a collaborative process for its execution, this study highlights the need for community officials and residents to develop a shared vision for their community's water future. The promise of reusing effluent via land application to help solve growing demand for water must also account for an equal need to protect surface and groundwater quality. Thus, an appropriate level of wastewater treatment must be engineered that fully accounts for specific site characteristics such that land application as a reuse strategy fulfills its promise while avoiding negative impacts on surface and groundwater.

# Introduction

Treated wastewater (TWW) effluent is one of the most common forms of freshwater pollution in the United States (Grantham et al. 2012; EPA 2019). This effluent is considered a pollutant, despite being treated to relatively high standards, because it has the ability to oversaturate receiving streams and lakes with major nutrients that are typically limiting in aquatic ecosystems: Phosphorus (P) and Nitrogen (N). Unless tertiary wastewater treatment procedures are implemented to reduce nutrient levels in TWW effluent, high P & N loading can lead to cultural or artificial eutrophication in the receiving waterbody (Horne and Goldman 1994).

Eutrophication describes the trophic status of an enriched waterbody where high nutrient concentrations result in a level of productivity that leads to overabundant plant life (e.g., algal blooms), subsequent die-off that results in a drastic reduction of dissolved oxygen, and negative impacts on other aquatic life (e.g. fish, shellfish, invertebrates) in the affected body of water (Chrislock et al. 2013). Eutrophication can result from natural processes but is deemed artificial or cultural when it is the result of human-related activities (Horne and Goldman 1994).

Texas Hill Country streams are particularly vulnerable to eutrophication because they tend to have low ambient nutrient concentrations, streambeds that support relatively few plants, low turbidity, and high benthic light availability (*personal communication,* Raymond Slade, Jr., Surface Water Specialist, Texas Office of the United States Geological Survey, retired, June 9th, 2019, conversation). Another factor that makes these iconic waterways even more vulnerable is the drought-prone nature of the region. Periods of drought can lead to decreased base and spring flows and leave less water in rivers and streams to dilute instream-nutrient concentrations from wastewater effluent.

Population growth in the Texas Hill Country is increasing water demand. If the most common wastewater treatment and disposal paradigm is followed, secondary treatment and discharge of TWW effluent into a local waterbody, then the population growth creates a positive feedback loop where increasing groundwater and surface water withdrawals leave less water available in streams to dilute high nutrient concentrations in effluent; which when paired with increased discharges of treated wastewater effluent into waterways results in increased instream nutrient levels. These factors combine to increase the likelihood of eutrophication. It is imperative, therefore, that new alternative uses for TWW effluent are found that can both prevent the discharge of nutrient-rich effluent into Hill Country streams and help mitigate the region's potential water scarcity by offsetting demand for surface and groundwater.

Land application of treated effluent has the potential to address these issues and create new economic opportunities for landowners in the region and sources of revenue for water service providers. Land application of treated wastewater, however, is not without challenges and these will be addressed in another section of this report.

Land application of treated wastewater can help address water scarcity by increasing the efficiency of water use and potentially offset existing or new withdrawals from natural water supplies. Land application of TWW turns what would otherwise be a waste product into a resource by taking nutrient-rich wastewater[1] and supplementing or replacing water and fertilizer for crops and other irrigated landscapes. Thus, the opportunities of stream eutrophication from direct discharge are reduced. Here, we assume that both local land-application management is sound and the state regulatory environment is strengthened to protect water quality. Land application of nonpotable water also enables potable water to be reserved for uses that demand higher water quality. The purpose of this research project is to answer the question "What is the potential for land application of treated wastewater for three rapidly growing cities in the Texas Hill Country?"

# Background

The Texas Hill Country (Figure 1) is located approximately in the center of the state. According to the Texas Water Development Board (TWDB) 2012 State Water Plan, the region has a Humid Subtropical/Semi-Arid climate. The region generally receives less than 35 inches of precipitation per year, with most of the rainfall coinciding with seasonal changes in frontal patterns. The area has an average annual temperature between 60 °F and 65 °F. Summer highs can reach into the mid-90s °F, with heat indexes reaching into triple-digit temperatures. This combination of limited precipitation and high summer temperatures causes lake evaporation to

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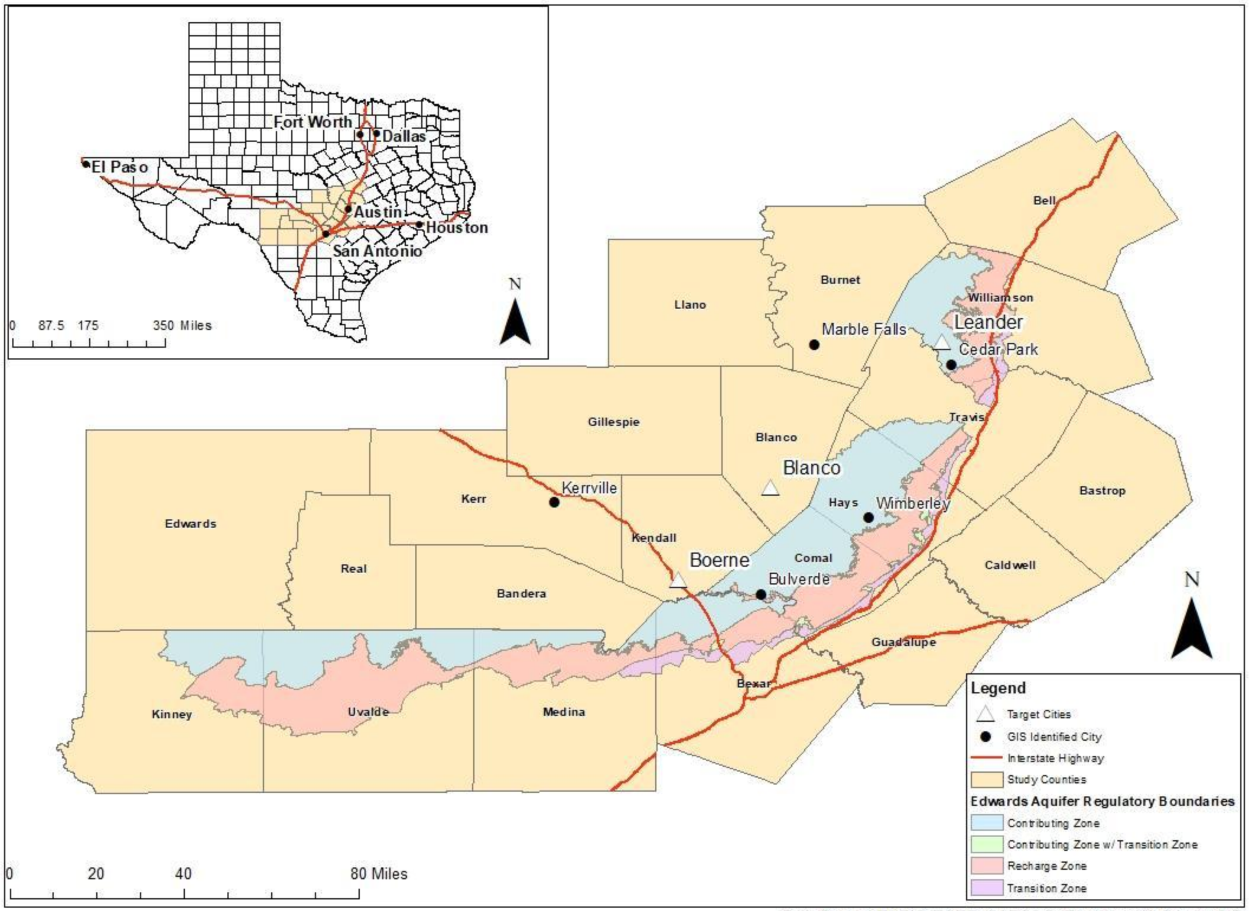
[1] Tertiary treatment, a process that is designed to minimize nutrient concentrations in effluent, will be necessary prior to land application in the study area depending on site characteristics relative to the Edwards Aquifer contributing zone.

be approximately 60" a year and makes the area prone to moderate to severe drought (TWDB 2012).

*Figure 1. Study area location map.*



Data Source: TNRIS, TCEQ, CAPCOG, EAA, Kendall County GIS
Author: Ty Stonecipher
Date: 9/10/19

Physiographically, the Texas Hill Country is dominated by a karst landscape composed of various limestones (Edwards Aquifer Authority 2019a). The region is named for the valleys that have been eroded out of the Edwards Plateau and is known for its unique water features. The Edwards Aquifer (Figure 2) has an extensive presence on the Hill Country landscape. This aquifer system, as delineated by the Edwards Aquifer Authority (2019b), includes or underlies

12 counties with a total surface area of over 3,000 square miles.[2] Almost all of the precipitation that falls on the Edwards Plateau will interact with the Edwards Aquifer in some form or fashion. Many of the region's streams will lose some of their water to the Edwards via percolation through limestone and serve as recharge (Edwards Aquifer Authority 2019a). Overland flow of precipitation can also be intercepted by the region's numerous caves, sinkholes, and other recharge features.

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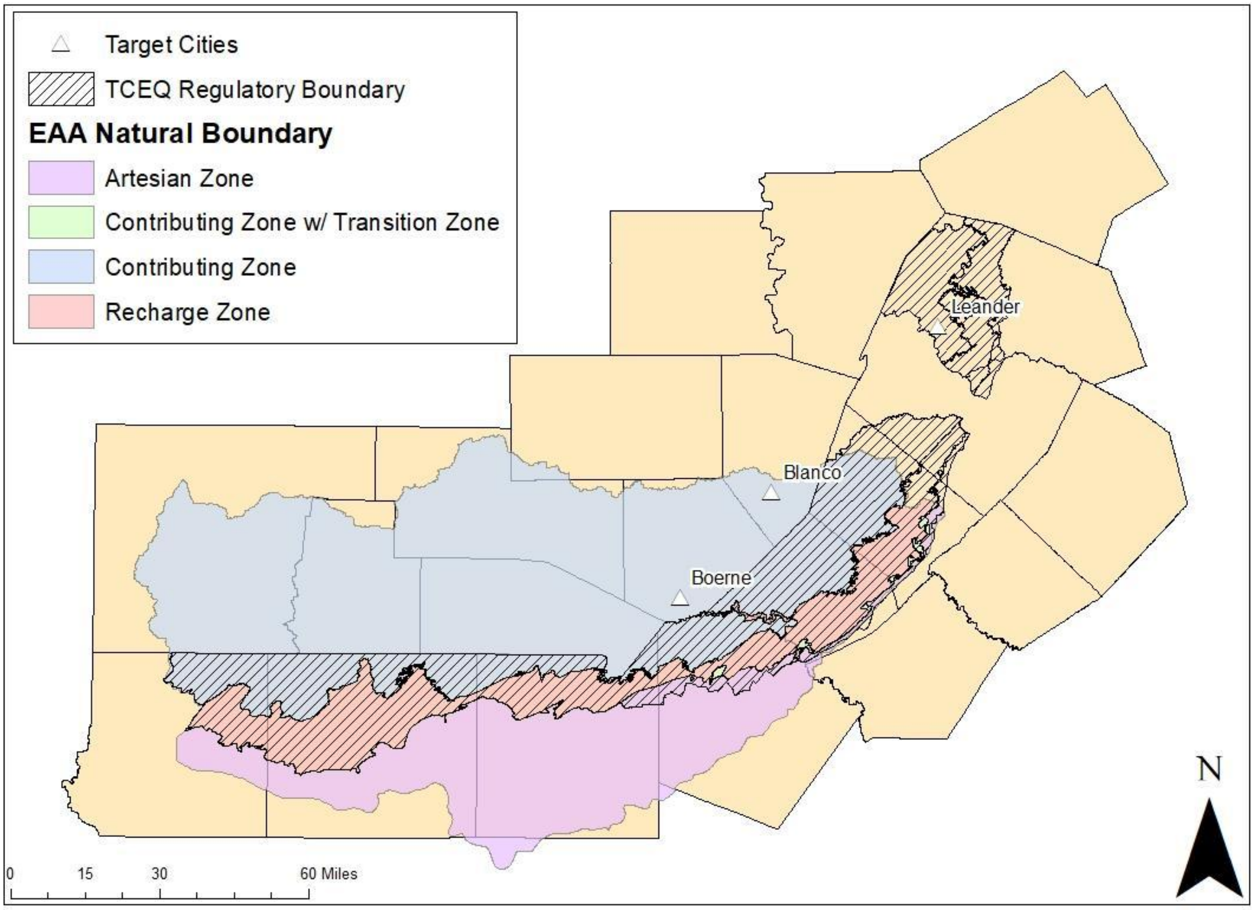
[2] The 12 counties delineated by the Edwards Aquifer Authority do not include the Barton Springs and Northern segments of the Edwards Aquifer that would add Travis, Williamson, and Bell counties.

*Figure 2. Regulatory vs. natural boundary of the Edwards Aquifer System.*[3]



TCEQ Regulatory Boundaries were chosen for analysis since they are more relevant to WWTP operations.
Natural boundaries are shown purely for reference purposes.

Source: EAA, TCEQ, TNRIS
Author: Ty Stonecipher
Date: 9/27/19

The Edwards Aquifer is also a primary source of drinking water for the two million people who live in the greater San Antonio metropolitan region and others situated along the I-35 corridor north to Austin. Most of the region's high-profile and crystal-clear springs, such as the San Marcos, Comal, and Barton springs, are also fed by the aquifer. The Edwards Aquifer's combination of high permeability and porosity, use as a significant water supply, and unique assemblage of threatened and endangered species make it particularly vulnerable to pollution.

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[3] The area referred to as the Edwards Aquifer Regulatory Boundary is defined in 30 TAC §213.3 and includes eight counties. The Edwards Aquifer Authority has jurisdiction over some or all of a somewhat different set of eight counties.

The high degree of hydraulic connectivity in the Edwards Aquifer system means that any pollution in the streams of the Hill Country can be reasonably assumed to have a negative impact on the aquifer itself (Einsiedl, Radke, and Maloszewski 2010). In Texas, 30 TAC §213.6 prohibits land application systems on the on the Edwards Aquifer recharge zone, but is otherwise silent about land application relative to the contributing zone.[4] The rules in Texas for Land Disposal of Sewage Effluent are found in 30 Texas Administrative Code (TAC) §309.20, §309.3, and §309.4. These latter two rules also address effluent limitations for domestic WWTPs as they pertain to discharges and more. Other rules governing Use of Reclaimed Water and most pertinent to this project are found in 30 TAC §210.3, §210.22, §210.24, and §210.32. Additionally, 30 TAC §222.81 addresses Buffer Zone Requirements associated with subsurface area drip dispersal systems. For this project, site identification does not differentiate between types of land application: subsurface area drip dispersal systems vs. irrigation disposal systems.

As the result of a 1993 lawsuit (*Sierra Club v. United States Fish and Wildlife Service*), the Edwards Aquifer has become one of the most heavily regulated aquifers in Texas (Patoski 2012). The Edwards Aquifer Authority (EAA) was chartered in 1993 by the 73rd Texas Legislature (SB 1477) to study and protect the Edwards Aquifer by establishing pumping limits to maintain base spring flows required to support the aquifer’s 11 endemic endangered or threatened species (Blanton & Associates 2016). The EAA works together with stakeholders in the region in an attempt to protect these species from threats that include: over-pumping and water level

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[4] 30 TAC §213.6 does make reference to areas that are zero to five and more than five miles upstream from the recharge zone. In some or many cases, these areas will coincide with the regulated contributing zone.

drawdown of the aquifer, increased pollution from rapid urbanization, and climate change that could lead to their functional extinction in the next century (Devitt et al. 2019).

The Texas Hill Country, positioned along and west of the I-35 Corridor between Austin and San Antonio, is one of the fastest-growing regions in the United States (US Census Bureau 2019). Texas Water Development Board projections show municipal water demand in the three study cities increasing by 35 percent in Blanco, 154 percent in Boerne, and 562 percent in Leander in the years from 2020 to 2070 (TWDB 2016). This increase in water demand will continue to stress the region's already scarce water resources while leading to a proportional increase in production of wastewater effluent. Furthermore, these cities are upstream of the Edwards Aquifer regulated recharge zone and will need to expand their wastewater treatment plants in the near future.

# Literature Review

Every year, approximately 1.2 billion acre-feet of wastewater is produced globally (Nath and Sengupta 2016). In Texas, when wastewater is produced, it is generally sent to a wastewater treatment plant (WWTP). At the WTTP, the influent will go through various processes intended to remove organic solids (i.e., primary treatment) and more (e.g., biological oxygen demand or BOD with secondary treatment) and eliminate pathogens per 30 TAC §309.3 (g). After the treatment process has concluded, most plants will discharge the treated effluent into a nearby watercourse according to limits defined by a permit issued by a state regulatory agency (e.g., Texas Commission on Environmental Quality (TCEQ)) under the federal National Pollutant

Discharge Elimination System Program created in 1972 by the Clean Water Act (P.L. 92-500; EPA 2019).

Despite often being properly treated to higher standards than drinking water from natural sources (Asano and Cotruvo 2004), relatively high nutrient concentrations in treated effluent can negatively impact water quality (Liu et al. 2011; Harry et al. 2016), making it one of the most common forms of water pollution in the US (Grantham et al. 2012). When considering only direct financial inputs and minimum safety standards, the model of primary treatment and stream discharge is the least-cost solution for disposing of wastewater (Hardsity, Sivapalan, and Humphries 2013). When factoring in ecosystem health and services, however, advanced secondary treatment (which includes nutrient removal) and disposal can lead to improved stream health and more overall benefits when properly implemented (Plumlee, Gurd, and Reinhard 2012; Hardisty, Sivapalan, and Humphries 2013). But secondary treated effluent will still have higher nutrient concentrations than effluent that receives tertiary treatment.

Municipal wastewater in the US can be thought of as having gone through either primary, secondary, or tertiary (sometimes referred to as advanced treatment) treatment (EPA 2019). As of the 1972 Clean Water Act, the Environmental Protection Agency (EPA) only sets minimum standards of secondary treatment of wastewater quality in the US. Individual plants or states can decide to pursue tertiary treatment at their discretion (EPA 2019). Primary treatment of wastewater is the first step in treating wastewater. Primary Treatment consist of removing unprocessable solids from incoming wastewater either by skimming floating solids from the top or by letting the solids settle out of suspension. Once these solids have been removed the wastewater is then sent to secondary treatment, which is designed to remove organic material from the water via organic decomposers (i.e., bacteria, algae, and fungus). Secondary treatment systems generally attempt to create an environment in which wastewater mixes with oxygen to allow the growth of a biofilm that will process out organic materials. The discharge of secondary TWW can still degrade water quality and inhibit aquatic life in the receiving water body since secondary treatment does not typically remove nutrients or pathogens (EPA 2019).[5]

Any process beyond primary or secondary treatment is considered advanced wastewater treatment that can be segmented in three categories: tertiary treatment, physical-chemical treatment, and combined biological-physical treatment (Brillyant 2009). Another way to classify advanced wastewater treatment types is to differentiate based on treatment goals. Tertiary treatment can be defined as any treatment process in which unit operations are added to the flow scheme following secondary treatment (Brillyant 2009). Tertiary treatment can include microbial disinfection, constructed wetlands (aka, polishing wetlands), or nutrient removal (see also, Mareddy 2017, chapter 12). For the purposes of this study, however, tertiary treatment will be used in reference to nutrient removal. Secondary treatment does not typically remove nutrients (phosphorus and nitrogen) below levels that cause eutrophication (EPA 2019).

Tertiary treatment for the removal of nitrogen compounds is very similar to secondary treatment in that it relies on bacteria to extract nitrogen from the water. The difference between tertiary and secondary treatments is that the latter purposely adds oxygen, while tertiary treatment purposely creates an anoxic environment so that the bacteria process the nitrate ($NO_3$)

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[5] Disinfection of domestic wastewater which discharges into waters of the State of Texas is required per 30 TAC §309.3 (g).

into oxygen ($O_2$) and inert nitrogen gas ($N_2$) via a technique called biological nitrogen removal. The Biological Nitrogen Removal process can also be combined with phosphorus removal to save time, space, and money (EPA 2019). Organic phosphorus in wastewater is a dissolved solid that is not captured by filters. The Organic Phosphorus Coagulation-Sedimentation processes relies on the fact that objects heavier than water sink to the bottom via gravity, and that certain chemicals (Alum, Lime, Iron Salts) can make suspended solids heavier than water or cause dissolved solids to precipitate out of solution. The phosphorus clumps together and is then strained out to be processed into fertilizer or otherwise disposed of. Adding alum, lime, or iron salts to the biological nitrogen removal tank allows both nitrate and organic phosphorus to be extracted without compromising the effectiveness of either process (EPA 2019). Tertiary treatment of wastewater effluent may be required for land application in the study area depending on site characteristics and location relative to the Edwards Aquifer contributing zone.

Even at contributions of just five percent treated wastewater effluent of total stream flow, there is a measurable effect on macroinvertebrate diversity and populations (Grantham et al. 2012). Treated effluent discharge can also change the types and amount of plankton and bacteria in a receiving water body (Masserat et al. 2000). Streams are especially vulnerable to nutrient pollution during times of low flow since there is a lack of water to dilute TWW effluent (Rice and Westerhoff 2017). Discharge into ephemeral streams (streams that only flow during and immediately after a significant rain event), has been shown to greatly alter their plant populations, stream width, sedimentation patterns, and overall channel geomorphology (Hassan and Egozi 2001).

Improperly treated wastewater also has the potential to pollute groundwater resources (Tang et al. 2004; Karnjanapiboonwong et al. 2010; Ackerman et al. 2015) and can travel quickly given the right conditions (Donahue et al. 2015; Hubbard et al. 2016). The rapid infiltration of water into a karstic aquifer makes such systems extremely vulnerable to pollution (Katz, Griffin, and Davis 2009: Kelly et al. 2009; Einsiedl, Redke, and Maloszewski 2010), especially those found in semi-arid environments like the Texas Hill Country (Schmidt et al. 2013). This situation makes for a potential challenge to manage when seeking sites for land application in the study area.

Sewer and septic system seepage can raise aquifer levels while lowering water quality (Chamtouri et al. 2007), as can irrigation using TWW effluent with high nutrient concentrations, but TWW Irrigation has the potential to offset future groundwater withdrawals (Yin et al. 2017) and can be less threatening to groundwater if the effluent has undergone tertiary treatment. One study on an aquifer in Jordan, similar to the Edwards Aquifer, found that up to 20 percent of springflow in dry periods could be traced back to wastewater, treated or otherwise (Schmidt et al. 2013).

The relatively high nutrient loads of TWW that has only undergone secondary treatment generally make it useful for agriculture by helping to mitigate the need for fertilizers and acting as a water source for crops (Huertas, Folch, and Salgot 2007; Mahesh, Amerasinghe, and Pavelic 2015; Morretti et al. 2019). Treated wastewater irrigation, however, can increase the amount of salts and metals in soils over time (Tang et al. 2004; Campi et al. 2016; Kaboosi 2016; Li et al. 2019) unless appropriate measures are taken to mitigate long-term soil degradation (Licata et al. 2017; Ganjegunte et al. 2018).

Irrigation with TWW in Texas has been studied since at least the 1970's (Day et al. 1974). Several studies of TWW irrigation in arid and semi-arid environments show that cotton (Day et al. 1981), haylage (Day et al. 1974; Day and Tucker 1977; Day et al. 1982), and forage (Alkhamisi et al. 2011) provide better yields compared to the same crops and conditions using traditional fertilizer and well water. Sorghum seems to be an ideal candidate for TWW irrigation in the study area since it has a high salt tolerance and is drought resistant (Campi et al. 2016; Ganjegunte et al. 2018).

Determining the best reuse of treated wastewater involves a number of different complex factors such as cost, water quality, technology, infrastructure, and existing conditions (Chen et al 2014; Kunz et al 2015; Nath and Sengupta 2016; Cossio et al 2017; Akhoundi and Nazif 2018; Wongburi and Park 2018). But whenever there is limited access to water, TWW irrigation becomes an attractive option (Mahesh, Amerasinghe, and Pavelic 2015). As climate change and population growth increase the potential for water scarcity, wastewater reuse will become a necessity in arid and semi-arid environments (Akhoundi and Nazif 2018; Moretti et al 2019), and efficient wastewater treatment and agricultural practices will become vital to protecting stream ecosystem health (Gücker, Brauns, and Pusch 2006; Banner, Stahl, and Dodds 2009; Grantham et al. 2012).

Besides the potential benefits of land application and as suggested above, there are legitimate concerns with land application of TWW in the Texas Hill Country. They include level of wastewater treatment applied and resultant nutrient concentrations vis-à-vis application-site characteristics, use of an application rate that doesn't oversaturate soils, and vegetation management that ensures proper harvest of nutrients taken up by plants (*personal* *communication,* Kelly Davis, Staff Attorney, Save our Springs Alliance, November 5, 2019, conversation). Other challenges have to do with the current regulatory environment with regards to inadequate or lack of soil and downgradient water-quality monitoring requirements and other related concerns (Ross 2011; Ross 2019; Porras et al. 2016). Richter and Hiers (2017) have documented elevated concentrations of chloride, nitrate/nitrite, sodium, and strontium isotopes at springs and downgradient streams adjacent to two Texas Land Application Permit (TLAP) facilities. There is room for improvement, therefore, to safeguard local and regional water quality while taking advantage of TWW as a useful source of water.

# Methods

This research project utilizes a geographic information system (GIS) in order to identify the best cities and sites for land application of TWW. A GIS is an important tool in solving spatial problems and has been used before to answer questions related to TWW reuse (Barbagello et al. 2012; Ahmadi and Merkley 2017). A GIS has the ability to analyze disparate pieces of data to identify sites that meet a user's selection criteria (Pedrero et al. 2011; Barbagallo et al. 2012; Ahmadi and Merkley 2017; Viccaro 2017). This research is most similar to Ahmadi and Merkley in theme, and Pedrero et al. (2011) in execution. Ahmadi and Merkley (2017) chose to calculate reuse potential for a single a city in Utah using a water budget, but not to identify individual sites suited to reuse. This research project utilizes a GIS in order to identify the best cities and sites for TWW reuse. Methodologically, this work is similar to Pedrero et al. (2011) where map algebra and Boolean algorithms were used to identify individual sites that would be ideal for aquifer recharge with treated wastewater. Pedrero et al. (2011) chose to conduct their analysis by combining multiple layers into a Boolean grid with simple yes/no criteria then chose the sites that had “yes” where map algebra and Boolean algorithms were used to identify individual sites that would be ideal for aquifer recharge with treated wastewater.

The data used in this study include water use and population from 2010 (TxDOT 2018) and projections out to 2070 (TWDB 2016). This study looked at the areas within one-, two-, and three-mile radii of the WWTPs of three target cities in order to identify sites that meet the selection criteria and could benefit from land application to prevent increased wastewater discharges into Hill Country streams.

The first phase of analysis began with identifying 27 Hill Country cities based on their location relative to the Edwards Aquifer. This phase focused on gathering publicly available data from the TWDB, TCEQ, and the Texas Natural Resource Inventory System (TNRIS) and then analyzing it to winnow down the list to a smaller subset of the best candidate cities. This study used shapefiles available through TNRIS to select cities that were situated in either the contributing zone or the recharge zone of the Edwards Aquifer. It was assumed that increases in these cities stream discharge of treated effluent could potentially degrade the water quality in the aquifer. While the Edwards Natural Boundaries were used for city selection, the Edwards Regulatory Boundaries were chosen for second phase analysis since they are more pertinent to the permits issued by the TCEQ for WWTPs. Just because a part of the Edwards Contributing zone is unregulated, however, does not mean that it is not hydraulically connected to the aquifer and that effluent disposal methods there can't affect the aquifer’s water quality.

Raster data sets were then either found or generated from the available data for projected population growth from 2020 to 2070, land cover data from the National Landcover

Database (NLCD), and Euclidean distance of sites from the cities' WWTP. The raster data were then all reclassified to a standardized 1 to 10 scale so that they could be run through a weighted average tool. The selection criteria and weighting scale is shown (Table 1).

*Table 1. Phase 1 selection criteria and weighting scale applied to initial set of 27 Hill Country cities.*

| Selection Criteria | Assigned Weight |
|---|---|
| Population Growth Rate | 40% |
| Distance from WWTP | 30% |
| Land Use (NLCD) | 30% |

Population growth out to 2070 was given priority in the first-phase analysis since it was used as a proxy to represent a given municipalities need to expand the WWTP and this study wanted to prioritize finding solutions for cities that were expanding the fastest. Land use and Distance from the WWTP were considered equally important in the first-phase selection, but only a little less important than population growth. A 40:30:30 ratio was chosen for weighting these three criteria.

The USGS's National Landcover Database (2016) was also used in the first-phase analysis since it required less resolution and its categories of Hay and Cultivated Crops were considered sufficient for identifying suitable agricultural land for potential land application. The United States Department of Agriculture CropScape (2016) data set was used in the second-phase analysis since it explicitly listed different crop types in a given location but is still derived from the NLCD 2016 LIDAR data.

Scores of 1 in any given category represented the scenarios that were least ideal for each category such as; slowest rates of population growth, land-use designations where reuse was not an option, and sites furthest from WWTPs. Scores of 10 represented the factors that made a site an ideal candidate; fastest rates of population growth, land-use designations traditionally associated with reuse, and sites located nearest to WWTPs. Different raster data values were manually assigned scores within the weighted overlay modelling tool itself. Scores between 1 and 10 represented varying degrees of usefulness for beneficial reuse. A 1 to 10 scale was used because it was something that a casual observer should be generally familiar with and allowed for finer resolution than a scale with fewer designated categories. After the reclassification process the raster data were put through a weighted overlay model. The model calculated a weighted average for each pixel in the study area based on the reclassified 1 to 10 scale raster-data layer generated for population growth, Euclidean distance from WWTPs, and Land Use Designation. The cities in the region that had the most high-scoring pixels within a 3-mile radius were then compiled into a list of the nine top candidates out of the original 27 cities considered.

The top nine cities had their WWTP's most recent average daily discharges compared to their permitted maximum daily discharge to see if they had hit the legally required threshold (75 percent of permitted maximum discharge) for plant expansion. From this group of nine cities, the final three target cities were chosen for study based on meeting the following criteria:

1. The target city's WWTP is located within or upstream of either the contributing or recharge zones of the Edwards Aquifer regulatory boundary,

2. Have a current or near future need to expand their WWTP based on reported average daily discharge being 75 percent or more of permitted maximum daily discharge,
3. Be early enough in their planning development cycle, either hypothetically or in actual practice, that reuse infrastructure could be carefully examined and planned for at the most efficient time, and
4. Have land-use scenarios suitable for land application that were within a 3-mile (maximum) radius of the WWTP.

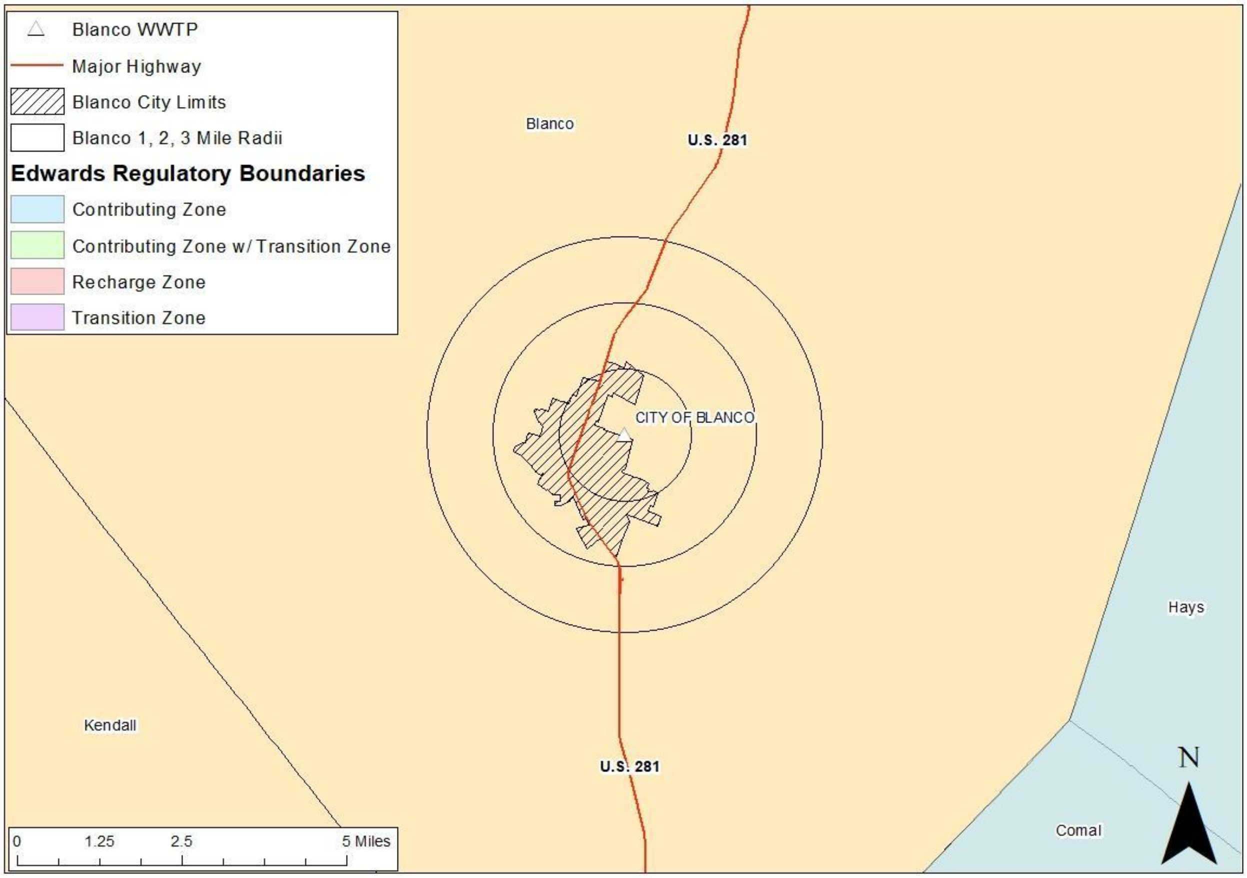
The three cities that met these criteria are Blanco (Figure 3), Boerne (Figure 4), and Leander (Figure 5). These cities were then given a second and more in-depth analysis. Population projections for these three cities are featured in Table 2.

*Table 2. Population and projections for three study cities in Texas.*

| **City** | **Population** | **Population Projections** | | | |
|---|---|---|---|---|---|
| | **2010** | **2020** | **2030** | **2050** | **2070** |
| Blanco | 1,739 | 2,156 | 2,563 | 2,927 | 3,060 |
| Boerne | 10,471 | 14,367 | 18,820 | 28,187 | 37,619 |
| Leander | 26,521 | 50,562 | 94,378 | 235,142 | 344,240 |

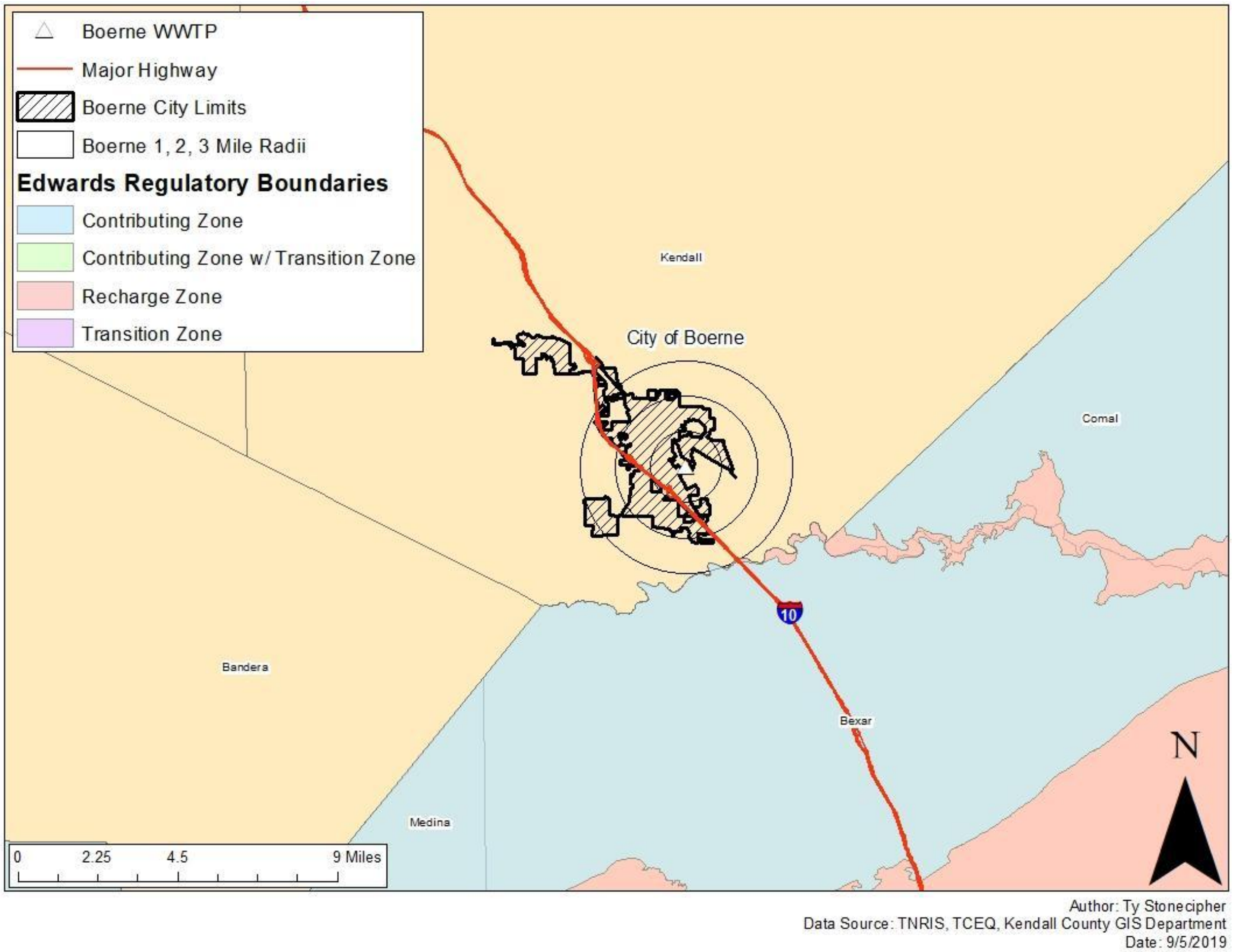
Both Boerne and Leander had two different WWTPs available for analysis. For practical reasons related to project length and budget, this study focuses on one WWTP from each city. Boerne's newer WWTP was chosen since it was closer to reaching its permitted maximum discharge. While Leander's older WWTP was chosen because it was nearing the 75 percent of maximum discharge threshold. The second WWTP serving Leander, the Brushy Creek WWTP, is a regional plant that also serves parts of the City of Round Rock and City of Austin's northern residential districts (K Friese & Associates, Inc. 2008).

*Figure 3. City of Blanco, Texas and relevant spatial features.*



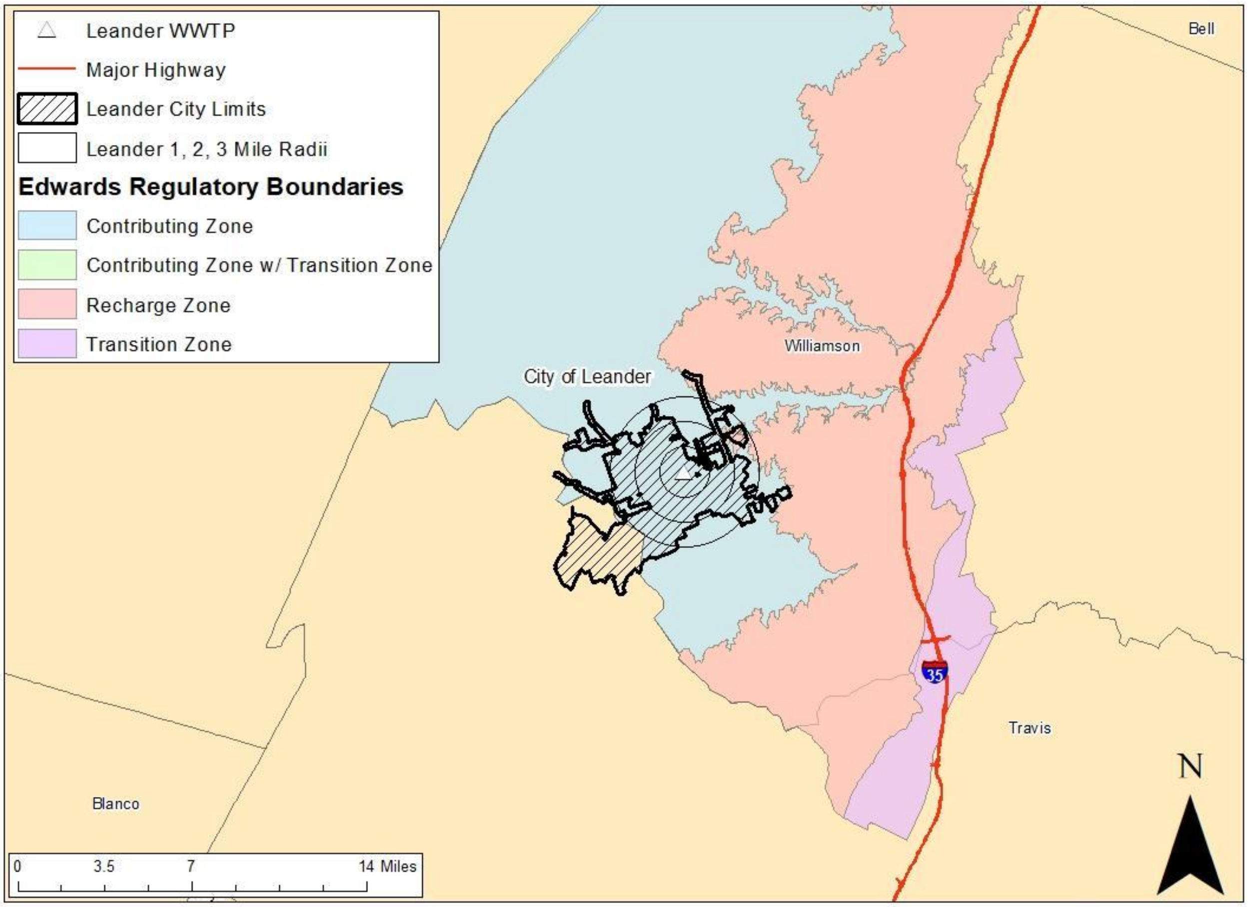
Source: TNRIS, TCEQ, TWDB, USDA
Author: Ty Stonecipher
Date: 9/5/19

*Figure 4. City of Boerne, Texas and relevant spatial features.*



Author: Ty Stonecipher
Data Source: TNRIS, TCEQ, Kendall County GIS Department
Date: 9/5/2019

*Figure 5. City of Leander, Texas and relevant spatial features.*



Source: TNRIS. TCEQ. EAA. CAPCOG
Author: Ty Stonecipher
Date: 9/19/19

The second phase of this study features a more in-depth investigation into specific sites around each of the target cities that would be ideal for TWW reuse. All three cities were analyzed individually. The analysis began by calculating the number of acres required to meet present outflows and future effluent land application needs. Current needs for total land application of effluent were calculated by dividing the most recent average daily discharge as of June 2019 by an application rate based on land application permits issued by the TCEQ to several nearby cities with similar environmental conditions; Kerrville, Marble Falls, and Wimberly. Wimberly's permitted application rate of 4,195 gallons per acre per day was chosen for calculating the required acreage for meeting all effluent allocation needs via land application since it was the most conservative of the three relevant permits.

Future acreage required was calculated by using an estimate of residential indoor water use, expressed as gallons per capita per day (GPCD), of 62 (Loftus and Smith 2018; Hermitte and Mace 2012), then multiplying that number by future population estimates to determine the amount of water that would become treated effluent and thus, potentially discharged to a local stream in the future (Table 3). That number was then divided by the aforementioned application rate to determine the area required to achieve 100 percent land application in the future (Table 4).

*Table 3. WWTP discharge data by city.*

| City | Average Daily Discharge Gallons/Day (6/6/19) | Projected Future Effluent Gallons/Day (2070) |
|---|---|---|
| Blanco | 135,000 | 189,720 |
| Boerne | 1,023,500 | 2,332,378 |
| Leander | 1,196,000 | 21,342,880 |

*Table 4. Acreage requirements for full reuse via land application by city.*

| City | Current Land Application Area Needed for Full Reuse | Future Land Application Area Needed for Full Reuse |
|---|---|---|
| Blanco | 32 acres | 45 acres |
| Boerne | 244 acres | 556 acres |
| Leander | 286 acres | 5,088 acres |

A weighted overlay model was again used to determine sites in proximity to the WWTPs that could benefit from land application of treated effluent. The criteria for this weighted overlay were determined by a combination of the Texas Administrative Code's Title 30, Part 1, Chapter 213 rules for the Edwards Aquifer (specifically §213.6 having to do with wastewater treatment and disposal systems) and a synthesis of information gained from reading relevant literature. The selection criteria weighting scale for the phase 2 analysis is shown in Table 5. Note that the Edwards Aquifer regulatory boundary criterion did not use all scores between 1 and 10.

*Table 5. Phase 2 selection criteria and weighting scale.*

| **Site Selection Criteria** | **Assigned Weight** |
|---|---|
| Land Use (CropScape) | 50% |
| Edwards Aquifer Regulatory Boundary | 25% |
| Distance From WWTP | 15% |
| Percent Slope | 10% |

This analysis prioritized:

1. sites with traditional land use scenarios like parks, school related recreational fields, cemeteries, golf courses, and nonfood crops,
2. sites outside Edwards Aquifer regulatory boundary,
3. sites closer to the WWTP within the radius of interest, and
4. sites with slopes of less than 8 percent.

Some criteria in the Texas Administrative Code that are related to land application not considered as part of this initial study of potential: soil properties, site specific evapotranspiration rates, public and private well locations, and well water quality near application sites. These criteria will be considered by the TCEQ on a case by case basis during the permit application process. Here, land use was considered to be an acceptable proxy for soils, and the area's average net lake evaporation of 60" per year (TWDB 2012) should generally support land application. While well data may be available from local groundwater conservation districts (GCD), not all private wells are known to be registered with the local GCD. Thus, ground truthing and additional data collection may ultimately be necessary to determine the presence of or distance from a well. It should be noted, however, the presence of water wells doesn't automatically disqualify a site from being used for land application and must be reviewed based on the permitting requirements found in 30 TAC Chapter 210 and 30 TAC §309.13, rules defining unsuitable site characteristics for irrigation using wastewater effluent.

Much like in phase 1, a 1 to 10 scale raster data layer was generated for each of the four criteria identified in Table 5. Much like in the first phase analysis, higher scores represented sites with more ideal conditions per the selection criteria while lower scores denoted sites that were less ideal. A few conditions automatically excluded a site from beneficial reuse: sites that had slopes greater than eight percent, sites that were located within the floodway, or were within the Edwards Aquifer recharge zone. Anytime a site met one or more of these three conditions, that cell's score was automatically set to a value of zero, regardless of how well it scored in any other category since it would automatically fail the permitting process

The second weighted-overlay model automatically generated a results raster data layer based on the weighted average of the four new 1 to 10 scale raster data. The results raster data layer was also a 1 to 10 scale raster where pixels with a higher score represent sites that are theoretically more ideal for beneficial reuse. A site with a score of 10, for example, may represent a flat field exceptionally close to the WWTP that is growing a growing a crop that meets the rules outlined in 30 TAC §210.24 (Irrigation Using Reclaimed Water) and §210.32 (Specific Uses of Reclaimed Water.) A site with a score of 8 might be that same agriculture field but further away from the WWTP or be a ballpark that has more restrictions on how to use land application.

# Results

The results section for each city first quantifies the amount of high scoring sites required to meet current and future land application needs. Secondly, the results quantify the percentage of sites required to meet future land application needs that are within the current regulatory boundary of the Edwards Aquifer (other than recharge).

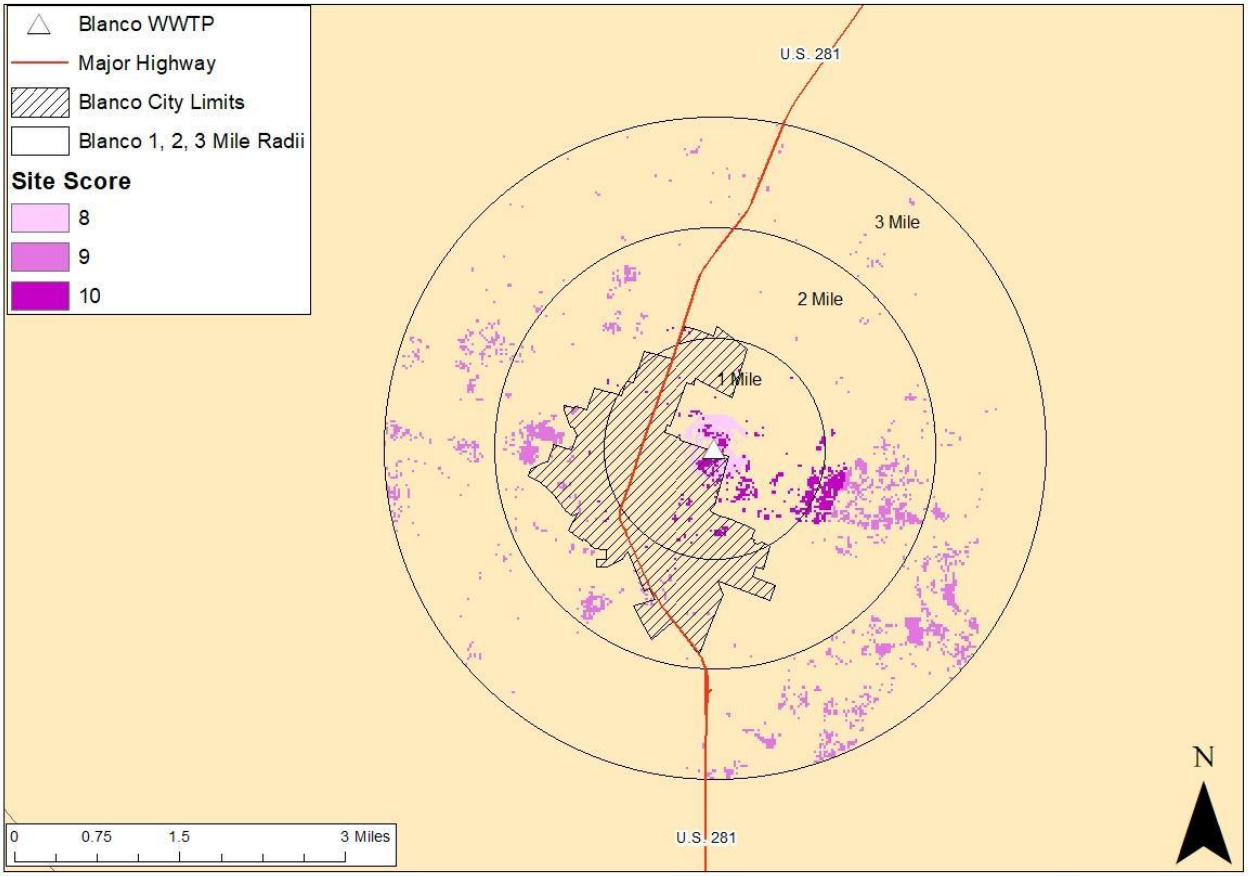
## Blanco, Texas

The City of Blanco (Figure 6) can meet 100 percent of its current (32 acres) and future (45 acres) needs for land application sites within a one-mile radius using only sites with a score of 10 (Table 6). One hundred percent of the highest quality sites identified for Blanco are outside of the regulatory boundary of the Edwards Aquifer.

*Table 6. Breakdown by site scores of acreage needs met within one mile of WWTP for City of Blanco, Texas.*

| Site Scores Within 1-Mile Radius of WWTP | Current Acreage Need Met | Future Acreage Need Met |
|---|---|---|
| Score of 10 | 100% | 100% |
| Score of 9 | N/A | N/A |
| Score of 8 | N/A | N/A |

*Figure 6. Distribution of weighted-site scores for City of Blanco, Texas.*



Blanco can satisfy its current and future need by using only sites with a score of 10 with in 1 mile.

Source: TNRIS, TCEQ, TWDB, USDA
Author: Ty Stonecipher
Date: 9/27/19

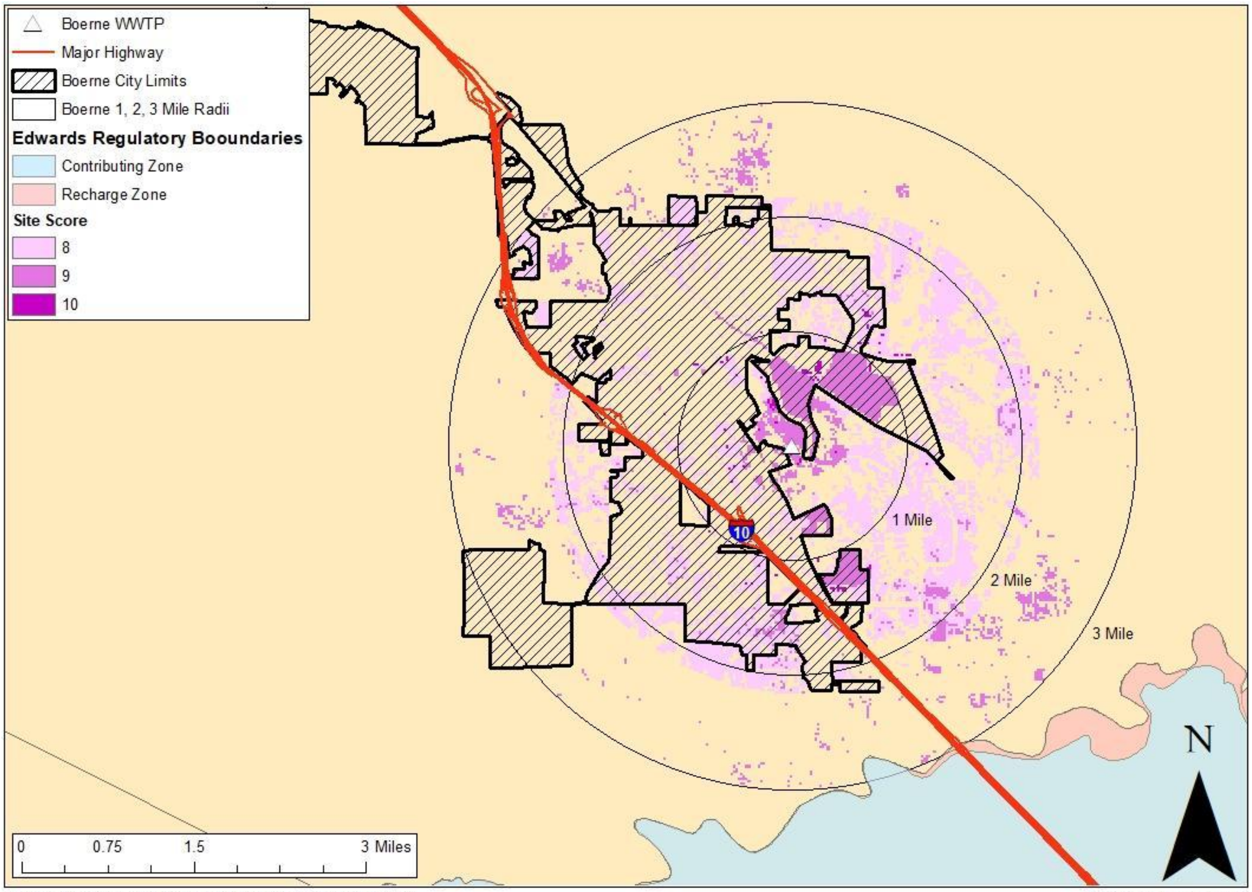
## Boerne, Texas

The City of Boerne (Figure 7) can meet current needs (244 acres) with sites featuring scores of 9 or 10 within a one-mile radius of the WWTP. Ninety-two percent of the sites needed to meet current needs within one mile of the WWTP feature a score of 9 (Table 7). Meeting all of Boerne's future needs (556 acres) within one mile would require that thirteen percent of future effluent would be applied to sites with a score of 8. Given the weighting scale, a lower site score most likely represents a land use category that is less ideal for land application, but could potentially represent a site that is further away (within the radius under study: here, one mile) or within a regulatory boundary (i.e., contributing zone) of the Edwards Aquifer. Table 7 shows how acreage needs are met within the 1-mile radius of the WWTP. Zero percent of sites required to meet either current or future land application needs fall within the Edwards Regulatory Boundary. Extending the radius out to two miles will allow Boerne to meet its future needs entirely with sites featuring a score of 9 or 10 should sites scores of 8 be deemed less feasible.

*Table 7. Breakdown by site scores of acreage needs met within one mile of WWTP for City of Boerne, Texas.*

| Site Scores Within 1-Mile Radius of WWTP | Current Acreage Need Met | Future Acreage Need Met |
|---|---|---|
| **Score of 10** | 8% | 4% |
| **Score of 9** | 92% | 83% |
| **Score of 8** | N/A | 13% |

*Figure 7. Distribution of weighted-site scores for City of Boerne, Texas.*



Boerne can meet current need using sites with a score of 9 or more within 1 mile.
Future need can be met by using all sites with scores of 8 or more with in 1 mile.

Author: Ty Stonecipher
Data Source: TNRIS, TCEQ, Kendall County GIS Department
Date: 9/5/2019

# Leander, Texas

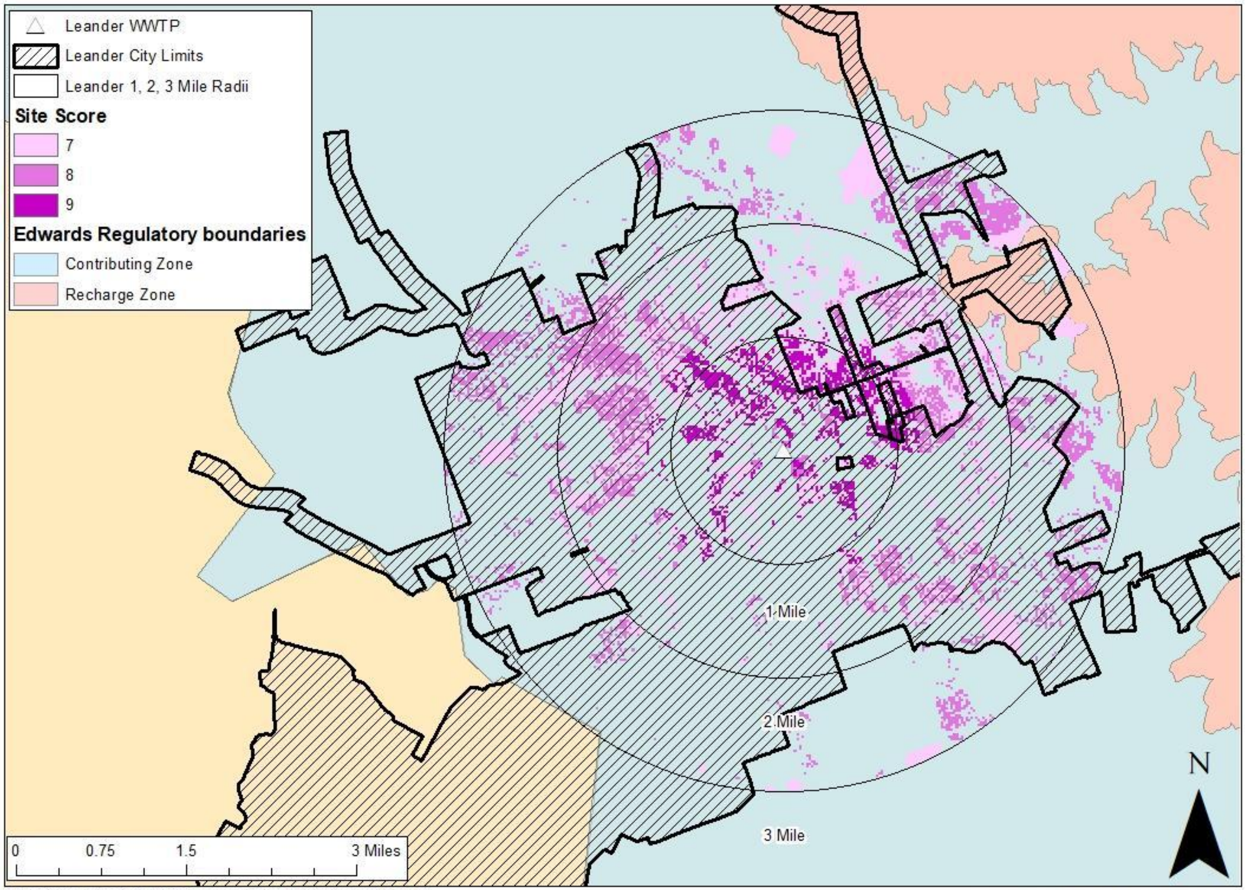
The City of Leander (Figure 8) does not feature any sites with a score of 10 within a three-mile radius of its WWTP. Leander can meet its current need (285 acres) for land application of effluent, however, using sites with a score of 9 within a one-mile radius (Table 8). To meet Leander's future need (5,088 acres), the city will need to irrigate every site with a score of 7 or more and irrigate to meet the last 17 percent of its effluent-allocation needs with sites featuring a score of 6; extending out to a three-mile radius. Meeting Leander's future needs would require using approximately 28 percent of all the land within a three-mile radius of its

WWTP. About three percent of Leander's three-mile radius is within the recharge zone of the Edwards Aquifer regulatory boundary and 97 percent is within the contributing zone. Thus, 100 percent of sites required to meet future land application needs are located in the contributing zone.

*Table 8. Breakdown by site scores of acreage needs met within one and three miles of WWTP for City of Leander, Texas.*

| Site Scores Within 1- and 3-Mile Radius of WWTP | Current Need – 1-mile radius | Future Need – 3-mile radius |
|---|---|---|
| **Score of 10** | 0% | 0% |
| **Score of 9** | 100% | 10% |
| **Score of 8** | N/A | 32% |
| **Score of 7** | N/A | 41% |
| **Score of 6** | N/A | 17% |

*Figure 8. Distribution of weighted-site scores for City of Leander, Texas*



Leander has no sites with a score of 10. Leander could meet current need using only sites with a score of 9 within 1 mile
Meeting Leanders future need would require using sites with a score of 6 or more and 28% of land within a 3 mile radius of the WWTP.

Source: TNRIS, TCEQ, EAA, CAPCOG
Author: Ty Stonecipher
Date: 9/19/19

# Discussion

This study identified over 800 acres of high-quality sites within three miles of Blanco, and almost 4,000 acres of ideal reuse sites within three miles of Boerne. Both Blanco and Boerne currently have 17 and seven times the amount of land required, within three miles of their WWTPs, to meet their respective effluent allocation needs. This abundance of high-quality sites nearby increases the likelihood of these two cities securing enough land to actually implement 100 percent reuse of TWW via land application.

Of the three cities studied, Blanco appears to be an ideal candidate for land application of TWW effluent given the ample supply of high-quality sites also identified within one mile of their WWTP. Blanco is smaller and growing at a slower rate than the other cities studied. For example, the acreage required for Blanco to land apply all of its treated effluent in the future is only eight percent of Boerne's future need and 0.8 percent of Leander's. Blanco is still relatively undeveloped and has plenty of agriculture fields and pastures that would benefit from TWW reuse in close proximity to their WWTP.

Another benefit that Blanco enjoys is that of being a relatively smaller, less populous city that produces commensurably less effluent requiring less area to achieve one hundred percent land application. Blanco does not have neighboring cities encroaching on its boundaries; another potential limit to land availability for reuse of TWW. If the city plans its growth well, then they should be able to acquire, lease, or contract with enough sites for land application of effluent to ensure total reuse while still having room for their expected future development.

The City of Boerne can potentially benefit from TWW reuse but needs to act quickly on making arrangements with enough high-quality sites to meet both present and future demand. Based on population projections, Boerne will need more area for land application from an increasingly shrinking number of nearby-available sites as the city grows. Boerne's land application future lies in utilizing the parks and open spaces that are already near its WWTP and securing an arrangement for/with the large fields of nearby shrubland before they are developed. If Boerne does not act quickly to secure the best reuse sites, then the large open fields required for 100 percent reuse will likely be developed and become mostly unusable for future land application of TWW effluent. If most of the land around the WWTP were to be developed, Boerne's ability to pursue land application will not necessarily end. The city could establish an ordinance or building code for new subdivisions and developments on the north and west sides of the city to start building decentralized WWTPs that would be closer to other suitable land application sites. Examples of developments that are self-contained in this way can be found elsewhere in the country including the Mill Creek subdivision in Geneva, Illinois (Sheaffer [2004?]).[6]

Considering that Leander is a rapidly urbanizing city with 99.97% of the three-mile radius of its WWTP falling within a Edwards Aquifer regulatory boundary, reuse of treated wastewater from this central location may not be a viable way to deal with the increased volumes of effluent that will result from its future growth. Leander lacks sufficient quantities of agricultural land and open fields that are well suited for land application of TWW effluent within a three-mile radius. Leander does have parks, cemeteries, and ballfields in proximity to the WWTP, but these do not represent a large enough area to meet Leander's future effluent application needs. A series of decentralized WWTPs nearer to land application sites also does not seem to hold the answer for Leander's future needs because Leander abuts three other rapidly growing suburbs of Austin: Cedar Park, Georgetown, and Round Rock and has another neighbor that has the potential to box them in. Development-specific, on-site treatment and reuse capacity can obviate this constraint.

Considering alternatives, Leander might be better served by other a reuse options: direct-potable reuse, dual plumbing in new developments, and industrial reuse that this study

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[6] The Mill Creek Project is designed by Sheaffer and Roland, Inc.

did not consider. A future study can quantify the industrial reuse potential in or near the growing suburbs of Austin and San Antonio, study the cost of direct-potable reuse and/or dual plumbing in new construction, or explore the viability of a residential lawn reuse program. Lastly, the authors would be remiss if we didn’t stress that the pursuit to maximize water-use conservation and efficiency and thus, reduce the production of wastewater effluent, is a cost-effective and first-order strategy for all communities to implement.

# Conclusion

Rapidly growing towns and urbanizing areas face many challenges and achieving efficient water resource management is among them. The Texas Hill Country faces such challenges and is a unique and beautiful landscape where drought is commonplace, scarcity looms large in the face of a growing population, and competition for water is a growing phenomenon. Here, concern for managing water demand and protecting the high-quality streams and the Edwards Aquifer is very high.

This research was conducted because of the opportunity available to anticipate new developments in the region and to help accelerate the transformation of treated wastewater from a pollutant and waste by-product into a resource that protects water quality and extends water supply. Reuse of treated wastewater effluent also has the potential to create new economic opportunities for both city utilities and landowners who receive the resource.

This study applies a replicable methodology that makes use of publicly available data for identifying candidate cities and specific sites that could potentially benefit from land application (i.e., reuse) of TWW. The attributes of readily available technology, social and environmental benefits related to protecting the health of local streams and rivers, and increasing need for water conservation make land application an ideal best management practice for a city and utility to implement. That said, it is acknowledged that tertiary treatment of wastewater may be necessary in certain situations for achieving both land application goals and simultaneously protecting the quality of groundwater and local streams that are closely connected with the Edwards Aquifer.

The results of this study are mixed across the three cities considered, owing to the many factors that constrain decision-making that is centered on land application of TWW. A follow-up feasibility analysis that considers, for example, cost and willingness of neighboring landowners to collaborate as partners is warranted for both Blanco and Boerne. The City of Leander poses additional challenges and warrants discussion among residents and elected officials alike about how and where they plan to treat greatly increasing volumes of wastewater and what they plan to do with the resulting effluent.

In the case of all three cities studied here along with others in the Texas Hill Country, leaders and residents must work together to build a shared vision for their community's water future. A shared vision need not be bound by the predominant 20th Century model for development including the more traditional ways of thinking about wastewater disposal. In the Texas Hill Country, treated effluent is growing in volume in lockstep with population and increasing demand for more water. Here in the Texas Hill Country and elsewhere, development provides an opportunity to manage water in a holistic and integrated fashion; as one water on a watershed basis rather than different kinds of water that each require separate and independent planning and management scenarios.

As noted above, TWW reuse is not without challenges to overcome and costs to be considered. In any event, there is ample reason to pursue alternatives to stream discharge of treated wastewater including land application where possible. Cities that wish to pursue reuse of TWW such as the land application potential explored here, will need to begin discussions and planning now in order to get ahead of inevitable development and reap the full benefits potentially available.

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The Meadows Center
for Water and the Environment
TEXAS STATE UNIVERSITY

601 University Drive, San Marcos Texas 78666
512.245.9200 | MeadowsCenter@txstate.edu | www.MeadowsWater.org