Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects or Aquifer Recharge Projects [Abridged]

87th Texas Legislative Session

Texas Water Development Board

Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects or Aquifer Recharge Projects [Abridged]

Report to the 87th Texas Legislature

December 15, 2020

Texas Water Development Board

Errata – January 22, 2021

The contractor provided updated versions of the following pages for this report:

- 67
- 73
- 82
- 85
- 90

On pages 67, 73, 85, and 90, updates correct the threshold values used for excess water and water supply needs classified as "low," "medium," and "high" suitability as follows:

Replace:

- Low– Water Supply Needs Score < 0.5
- Medium– Water Supply Needs Score 0.5 to 0.7
- High– Water Supply Needs Score > 0.7

With:

- Low– Water Supply Needs Score < 0.34
- Medium– Water Supply Needs Score 0.34 to 0.67
- High– Water Supply Needs Score > 0.67

The update to page 82 is as follows:

Replace:

"Scores and weights to be assigned and verified in TWDB workshop"

With:

"Scores and weights were assigned and verified in TWDB workshop"

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Preface

Texas is blessed with both abundant surface and groundwater supplies. Surface water reservoirs have allowed water to be stored when abundant and then utilized in dry times. However, while the population of Texas has continued to grow, the availability of water storage to meet the needs of Texans in times of drought has not. The number of potential reservoir sites has dwindled, and the time that it takes to permit and construct a reservoir has increased, prompting considerations of a new type of water storage to meet the needs of the people and the environment of Texas.

In 2019, the 86th Texas Legislature passed House Bill 721 that directed the Texas Water Development Board (TWDB) to conduct a statewide survey of various major and minor aquifers to identify their relative suitability for use in aquifer storage and recovery (ASR) projects and aquifer recharge (AR) projects and to submit a report that summarizes the statewide survey to the Governor, Lieutenant Governor, and Speaker of the House of Representatives.

The statute further specifies that the survey identify the suitability of ASR or AR projects based upon consideration of hydrogeological characteristics of the aquifer, the location and potential abundance of excess water for injection or infiltration, and current and future water supply needs identified in the state water plan.

To fulfill this legislative directive, the TWDB contracted with a team led by HDR Engineering, Inc. (HDR) to develop and utilize an evaluation framework to measure the relative suitability of major and minor aquifers of Texas for ASR and AR projects. The framework for screening hydrogeological parameters, excess water, and water supply needs is described in the final contract report. In addition, the team also developed an ArcGIS StoryMap and an interactive web map application that allows stakeholders and the public to better understand the process and to geographically view areas within the aquifers of the state that might be suitable for ASR or AR projects. The TWDB wishes to thank and credit the members of the contract team for this work, including Kristi Shaw, P.E., HDR Engineering; Zach Stein, P.E., HDR Engineering; Neil Deeds, Ph.D., P.E., INTERA; Peter George, Ph.D., P.G., Collier Consulting; Mike Milczarek, GeoSystems Analysis, Inc.; and Qian Yan, Ph.D., Bureau of Economic Geology at the University of Texas at Austin.

This summary report to the 87th Texas Legislature is an abridged version of the contracted HDR report. To view the full contracted report, the StoryMap, the web map application, and additional supporting information, please refer to the web links below:

- HDR Engineering Inc., 2020, Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects or Aquifer Recharge Projects, contract report to the Texas Water

Development Board, 115 p. TWDB Contract Information – http://www.twdb.texas.gov/innovativewater/asr/projects/Statewide/index.asp

- Final Report - http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/2000012405.pdf
- Literature review tables - http://www.twdb.texas.gov/innovativewater/asr/projects/Statewide/docs/Table_of_recent_ASR_and_AR_studies.pdf
- Geodatabases and supporting geographic information system (GIS) files –http://www.twdb.texas.gov/innovativewater/asr/projects/Statewide/docs/GIS_StatewideSurvey_ASR_AR_Suitability.zip
- Generalized aquifer characteristics related to ASR table - http://www.twdb.texas.gov/innovativewater/asr/projects/Statewide/docs/Table_of_generalized_aquifer_characteristics_related_to_ASR.pdf
- Step-Wise User Manual to Support Future State Water Plan Updates for the Water Supply Screening Needs - http://www.twdb.texas.gov/innovativewater/asr/projects/Statewide/docs/StepWiseManual_WaterNeedsScreeningTool.xlsx

- StoryMap of the Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects or Aquifer Recharge projects – https://twdb-wsc.maps.arcgis.com/apps/MapSeries/index.html?appid=75313de26daf4994bcb590fdb8846b80
- Web map application of aquifer suitability – https://twdb-wsc.maps.arcgis.com/apps/webappviewer/index.html?id=50d9b795672243d387cef438f7c62311

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Figures

Tables

List of Acronyms

acft	acre foot
AR	aquifer recharge
ASR	aquifer storage and recovery
BFZ	Balcones Fault Zone
BRACS	Brackish Resources Aquifer Characterization System
CCEFN	Consensus Criteria for Environmental Flow Needs
DEM	digital elevation model
DFC	desired future conditions
DO	dissolved oxygen
ECHO	Enforcement and Compliance History Online database
EPA	U.S. Environmental Protection Agency
FWI	Freshwater Inflows
GAM	groundwater available model
GMA	groundwater management area
GCD	groundwater conservation districts
HB 720	House Bill 720
HB 721	House Bill 721
MAG	modeled available groundwater
MANU	manufacturing
MAUT	multi-attribute utility theory
MUN	municipal
RCID	row and column id for grid cells
RWPG	regional water planning group
SE	Steam-electric
SSURGO	Soil Survey Geographic Database
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TIFP	Texas Instream Flow Program
TSS	total suspended solids
TWDB	Texas Water Development Board
draft DB22	TWDB Draft State Water Planning Database
WAM	water availability model
WMS	water management strategy
WUG	water user group

List of Aquifer Abbreviations

BLIN	Blaine
BLSM	Blossom
BSRV	Brazos River Alluvium
BSVP	Bone Spring-Victorio Peak
CRCX	Capitan Reef Complex
CSTB	Cross Timbers
CZWX	Carrizo-Wilcox
DCKM	Dockum
EBFZ	Edwards (Balcones Fault Zone)
EBSS	Ellenburger-San Saba
ETHP	Edwards-Trinity (High Plains)
ETPT	Edwards-Trinity (Plateau)
GLFC	Gulf Coast
HCKR	Hickory
HMBL	Hueco-Mesilla Bolsons
IGBL	Igneous
LIPN	Lipan
MBLF	Marble Falls
MRTN	Marathon
NCTC	Nacatoch
OGLL	Ogallala
PECS	Pecos Valley
QNCT	Queen City
RSLR	Rustler
RTBC	Rita Blanca
SPRT	Sparta
SYMR	Seymour
TRNT	Trinity
WDBN	Woodbine
WXBL	West Texas Bolsons
YGJK	Yegua-Jackson

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Executive Summary

Background

In 2019, the 86th Texas Legislature passed House Bill (HB) 721 directing the Texas Water Development Board (TWDB) to conduct a statewide survey of Texas' major and minor aquifers to determine their relative suitability for use in aquifer storage and recovery (ASR) projects or aquifer recharge projects (AR). Aquifer storage and recovery is defined by Section 27.151 of the Texas Water Code as "the injection of water into a geologic formation for the purpose of subsequent recovery and beneficial use by the project operator." Aquifer recharge, as defined by HB 721 and amended Section 11.155 of the Texas Water Code, "involves the intentional recharge of an aquifer by means of an injection well authorized under Chapter 27 of the Texas Water Code or other means of infiltration, including actions designed to (a) reduce declines in the water level of the aquifer; (b) supplement the quantity of groundwater available; (c) improve water quality in an aquifer; (d) improve spring flows and other interactions between groundwater and surface water; and (e) mitigate subsidence."

The legislation requires that the relative suitability consider hydrogeological characteristics, the availability of excess water for potential storage, and the current and future water supply needs as documented in the state water plan. To accomplish this, three stand-alone screenings were developed:

- Hydrogeological parameters: The first screening focused on hydrogeological characteristics, such as storage potential, transmissivity, infiltration characteristics, storativity, recoverability, and water quality.
- Excess water: The second screening focused on excess water that could be available for storage and recharge from surface, reclaimed water, or groundwater sources based on frequency, volume, and other factors affecting reliability.
- Water supply needs: The third screening focused on identifying current and future water supply needs. To use the most current information available, the water supply needs were based on the draft State Water Planning Database (draft DB22) (submitted March 2020).

Together these three screenings are combined into a Final Suitability Rating to help identify areas where suitable hydrogeology, excess water, and water needs exist for further consideration for ASR or AR project potential. This report documents the approach, methodology, analysis, results completed at each screening level, and summary-level findings to determine the relative suitability of the major and minor aquifers to support ASR or AR in Texas.

Results

Texas has numerous areas suitable for ASR or AR. Hydrogeological parameter screening results for ASR or AR are categorized as “low,” “medium,” or “high” suitability. However, a low suitability score does not necessarily mean that the aquifer is not suitable for ASR or AR, but rather that it is less preferred relative to other areas that may score as medium or high. Similarly, the screenings for excess water and water supply needs categorize results as “low,” “medium,” or “high,” according to parameters and methods described in the report. The Final Suitability Rating, which integrates the three screenings, presents relative suitability by grid cell as “less,” “moderately,” and “most” suitable.

Hydrogeological parameter screening

The results of hydrogeological parameter screening for ASR were scored on a scale of zero to one. Scores above 0.7 are considered “high”; scores equal to or less than 0.7 and greater than 0.5 are considered “medium”; and scores equal to or less than 0.5 are considered “low.” The scores indicate eight of the nine major aquifers have at least some grid cells that are rated “high,” with the Seymour being the only major aquifer with a highest rated cell in the “moderate” suitability category. This suggests that nearly all of the major aquifers have some portions that may be highly suitable for an ASR facility. Four of the nine major aquifers have a median score that is in the “high” category (>0.7). These aquifers are the Carrizo-Wilcox, Edwards (Balcones Fault Zone), Gulf Coast, and Hueco-Mesilla Bolsons. The Trinity Aquifer narrowly missed the median “high” category score cutoff with a median score of 0.69. These aquifers all have either operating ASR wells or pilot studies in San Antonio, New Braunfels (saline portion of the Edwards (Balcones Fault Zone) Aquifer), Victoria, El Paso, and Kerrville, respectively.

Seven of the 22 minor aquifers have at least some grid cells that are rated “high” in terms of hydrogeological suitability for ASR. One of the 22 minor aquifers has a median hydrogeological suitability score that is rated in the “high” category, the Sparta Aquifer. As expected, while many of the minor aquifers contain portions that are hydrogeologically suitable for ASR, this condition is not nearly as common or pervasive as with the major aquifers.

The results of hydrogeological screening for AR were also scored on a zero to one scale. Scores greater than 0.8 are “high”; scores equal to or less than 0.8 and greater than 0.7 are “medium”; and scores less than or equal to 0.7 are “low.” The scores indicate seven of the nine major aquifers have at least some grid cells that are rated “high,” and five of the nine major aquifers have median score rated “high.” One notable exception is the Edwards (Balcones Fault Zone)

Aquifer, which just missed a median "high" score at 0.79, although it has enhanced recharge features currently operating within it. The Edwards (Balcones Fault Zone) Aquifer is rated slightly lower primarily due to its lower score in storage, as seen in its median storage score of 0.5. This low storage score is due to a low effective porosity and limited depths to the water table. In reality, the lack of storage does not affect the current enhanced recharge projects in the aquifer, because the objective of those projects is not necessarily long-term storage, but general augmentation (i.e., keeping water levels and spring flow at desirable levels). So the Edwards (Balcones Fault Zone) Aquifer AR hydrogeologic suitability score should not be considered to be contrary to the objectives of current operations. The Hueco-Mesilla Bolsons Aquifer, where El Paso has performed AR using infiltration basins with reclaimed water, has a median rating of "high."

Four of the 22 minor aquifers have a least some grid cells with a "high" rating. One of the 22 aquifers, the Brazos River Alluvium, has a median value that qualifies for the "high" rating. Similar to the ASR scores, there will be areas in many of the minor aquifers that may be suitable for AR, but those areas are not as common or pervasive as for the major aquifers.

Excess water screening

The screening for excess water considered surface water, reclaimed water, and groundwater that could be available for ASR or AR projects. The surface water evaluation considered the following sources:

- Surplus appropriated surface water—run-of-river and reservoir waters that are permitted but not currently utilized, identified in the draft DB22
- Unappropriated streamflow—surface water not assigned to water rights, from the Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM) analyses
- Existing reservoir locations that could be used in conjunction with ASR or AR operations

Surplus appropriated surface water from run-of-river and reservoirs was obtained from the draft DB22. Because most of the appropriated surface water is already dedicated to meeting existing water use demands or reserved for future water management strategies, surplus water is not widely available throughout the state. However, where available, the surplus appropriated surface water received higher scores due to the higher frequency and duration scores attributed to reliability during drought, which is a requirement for supply evaluations for regional water planning.

Unappropriated streamflow considers historical flows representative of all climatological conditions included in WAM data files. The scoring of unappropriated streamflow generally reflects the climatological conditions observed across the state, with wetter conditions in the eastern portion of the state resulting in higher scores and drier conditions in the western portion of the state resulting in no availability.

Similar to surplus appropriated surface water, the availability of existing reservoir storage receives high scores where available due to high frequency and duration.

In addition to evaluating surface water surpluses, reclaimed water and groundwater were also assessed for excess water supplies. Excess reclaimed water was evaluated using recently reported effluent discharge volumes recorded in the U.S. Environmental Protection Agency (EPA) Enforcement and Compliance History Online (ECHO) database for TCEQ Texas Pollutant Discharge Elimination System program discharge locations. Higher scores are focused near the larger metropolitan areas where larger wastewater effluent discharges are present. The scores also reflect the reliability of the excess reclaimed water source by receiving a generally high score if wastewater discharges are present.

Excess groundwater supplies were based on data from the TWDB Draft State Water Planning Database (draft DB22), which was used to quantify excess groundwater supplies for major and minor aquifers after current use and future water management strategies from the regional water plans were considered. Relative to other major aquifers, excess groundwater from certain areas of the Ogallala and Seymour in the Panhandle area, Hueco-Mesilla Bolsons and Edwards Trinity-Plateau in West Texas, and the Gulf Coast in East Texas received the highest scores after evaluating the frequency, volume, duration, and estimated water quality. Relative to other minor aquifers, the highest scoring aquifers and areas for excess groundwater supplies include the Rita Blanca and Dockum aquifers in the Panhandle, Queen City in East Texas, and Yegua Jackson in South Texas. When excess water supplies from major and minor aquifers are combined to identify opportunities in areas with coinciding aquifers, the greatest opportunities for excess groundwater occurs in the Panhandle, West Texas, and the East Texas area north of Houston.

In general, results of the evaluation indicate excess surface water is the most widely available source for potential use in ASR and AR projects. However, if excess reclaimed water and groundwater sources are available, they generally receive a higher score compared to the excess surface water sources.

Water supply needs screening

Water supply need scores were prepared for municipal, manufacturing, and steam-electric categories and range from zero to one. Scores were based on defined service areas for municipal needs and historical water use data recorded with the TWDB for manufacturing and steam-electric needs. Only water supply needs that exceeded 500 acre-feet per year were scored. The screening does not score county-wide needs for irrigation, mining, or municipal county-other where spatial data is unavailable at a higher resolution than at a county level. The draft DB22 was used as the data source for this information.

The results of the water needs supply screening showed municipal needs throughout Texas; however, the greatest needs generally are along the Interstate Highway 35 (IH 35) corridor from the Dallas-Fort Worth Metroplex south toward San Antonio and affect water supply utilities serving those areas. Significant municipal needs are also evident near Houston and in South Texas, including Hidalgo, Willacy, and Cameron counties.

Manufacturing needs were identified for about 200 grid cells across Texas. Of these, roughly one-quarter received scores because their needs exceeded 500 acre-feet per year. Dividing the greater that 500 acre-feet per year grid cell scores into quarters (<0.25, 0.25-0.5, 0.5-0.75, >0.75) for review revealed that about 60 percent had scores in the top quarter of the range (exceeding 0.75). These top quarter scores were scattered throughout Texas with no discernible trend observed. A few clustered areas are located in the Beaumont/Port Arthur and Corpus Christi areas. Several manufacturing needs exceeding 10,000 acre-feet per year were located along the Gulf of Mexico coastline.

Steam-electric needs were identified for about 50 grid cells across Texas. Of these, about 72 percent received scores based on needs exceeding 500 acre-feet per year. The same quartile data review revealed that about half of these areas with qualifying steam-electric needs had scores in the top quarter of the range (exceeding 0.75). Similar to the manufacturing needs, these are scattered throughout Texas with no discernible trend observed.

Final Suitability Rating

The Final Suitability Rating screen integrates results from the three individual suitability screenings related to hydrogeological parameters, excess water, and water supply needs to identify potential projects based on the relative suitability of Texas' aquifers for ASR or AR.

Final Suitability Ratings were evaluated and assigned for grid cells that previously received an ASR or AR hydrogeological parameter screening score. The hydrogeological parameter score for each grid cell was combined with an excess water and a water supply needs score. The excess water and water supply needs scores could come from grid cells coinciding with or no more than two grid spaces away from the hydrogeological parameter grid cell. This "buffer" was assigned to recognize that supplies and needs located within 20 miles of a suitable ASR or AR aquifer area are likely feasible for an ASR or AR project. The Final Suitability Rating screen includes conjunctive use opportunities by identifying multiple supplies that could be combined to achieve operational, reliability, and redundancy benefits for ASR or AR. The screening takes into account individual water needs, as well as identifying potential opportunities for regional partnership in ASR or AR projects in areas where multiple water needs are in close proximity.

For the ASR Final Suitability Rating, nearly 65 percent of the total statewide grid cells identified in the ASR hydrogeological screening were in close proximity (approximately 20 miles) to excess water and water need grids and received a Final Suitability Rating (Figure 1). Of the cells that were scored, 19 percent reported highly suitable scores for ASR (>0.7), and 51 percent reported moderately suitable ASR scores (0.5–0.7).

Final ASR suitability scores were assigned to all 9 major aquifers and 15 of the minor aquifers. Seven minor aquifers did not receive a score either because the locations overlapped with another aquifer that scored more favorably or because they occurred in areas without excess water and/or needs. The four aquifers with the most widespread coverage included the Carrizo-Wilcox, Gulf Coast, Ogallala, and Trinity aquifers, which accounted for nearly 70 percent of the scored cells. The highest ASR Final Suitability Ratings (>0.85) were found in the Carrizo-Wilcox, Trinity, Gulf Coast, Sparta, and Edwards (Balcones Fault Zone) aquifers.

For the AR Final Suitability Rating, nearly 67 percent of the total statewide grid cells identified in the AR hydrogeological parameter screening were in close proximity (approximately 20 miles) to excess water and water need grids and received a Final Suitability Rating (Figure 2). Of the cells that were scored, 22 percent reported highly suitable scores for AR (>0.7), and 53 percent reported moderately suitable AR scores (0.5–0.7).

Final AR suitability scores were assigned to all 9 major aquifers and 15 of the minor aquifers. The four aquifers with the most widespread coverage included the Gulf Coast, Ogallala, Cross Timbers and Carrizo-Wilcox aquifers, which accounted for 57 percent of the scored cells. The highest AR Final Suitability Ratings (>0.85) were found in the Brazos Valley Alluvium, Gulf Coast, Carrizo-Wilcox, and Hueco-Mesilla Bolsons Aquifer outcrops.

Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects
or Aquifer Recharge Projects

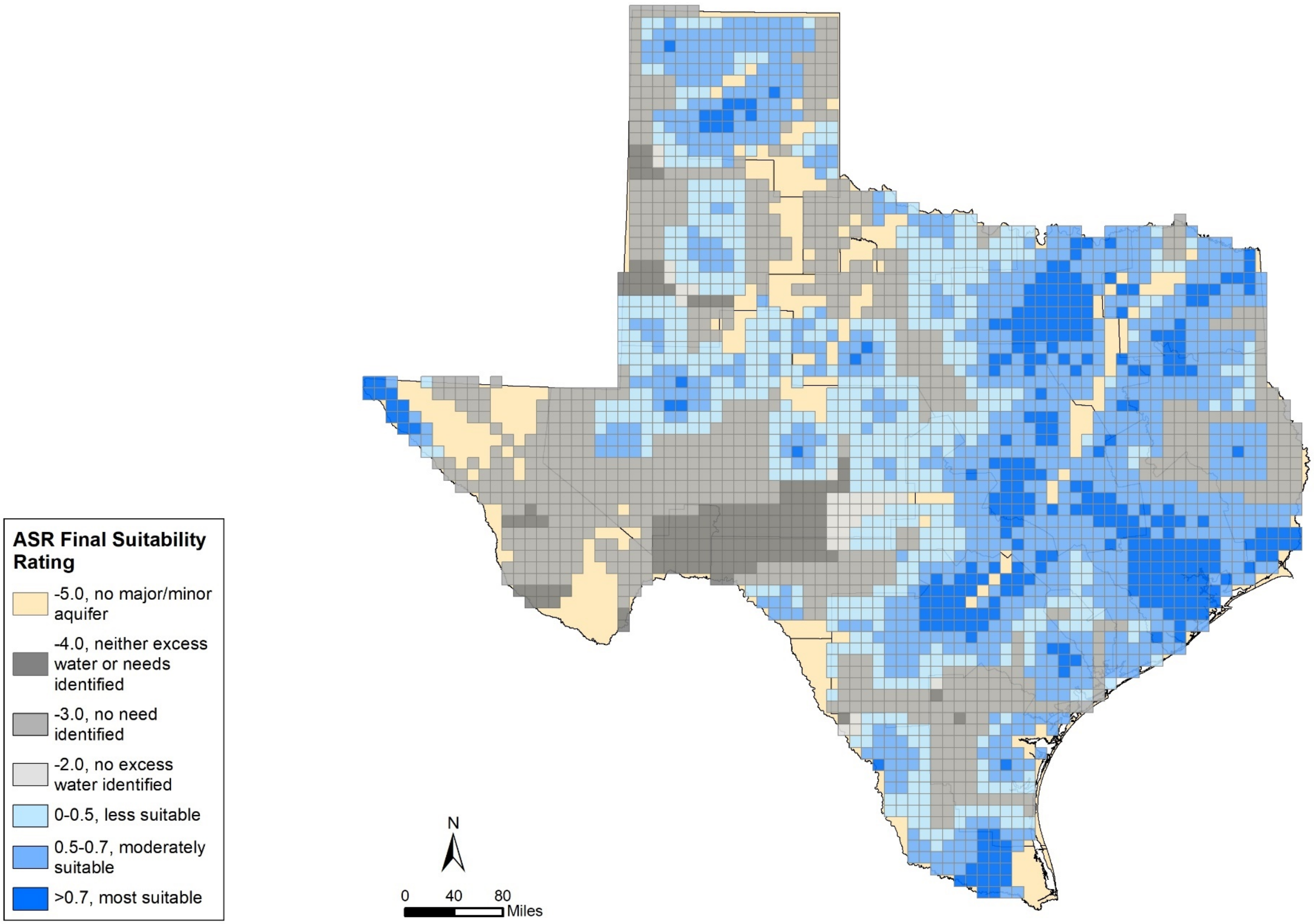

Figure 1. ASR Final Suitability Rating

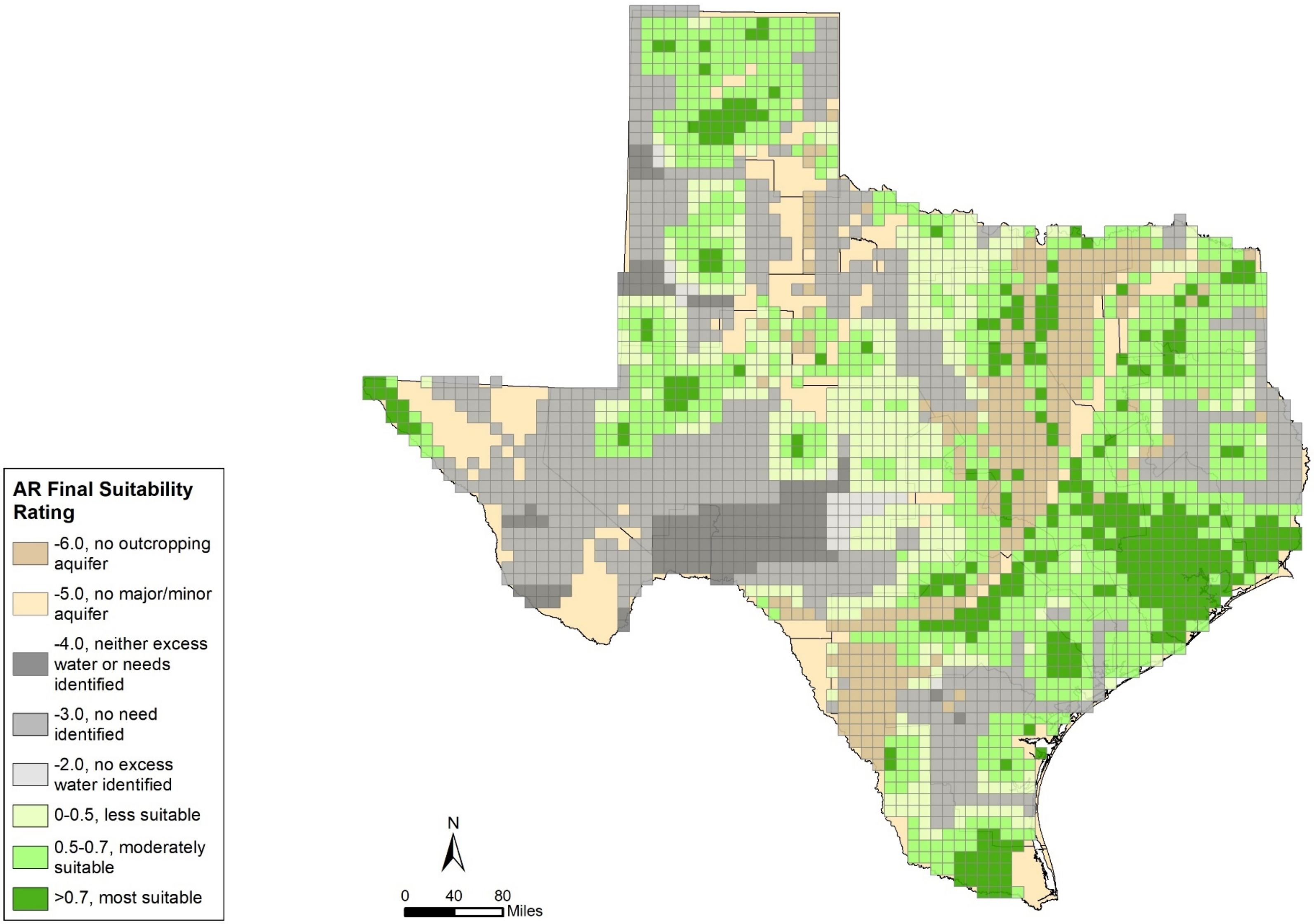

Figure 2. AR Final Suitability Rating

Conclusions

The screenings developed in this statewide survey of aquifer suitability for ASR or AR projects provide support to stakeholders such as water utilities, water planners, and government officials. The screenings are meant to provide regional guidance on ASR or AR development, while at the same time addressing HB 721 legislative requirements by surveying hydrogeological parameters important for assessing ASR and AR on a statewide level.

This statewide survey has many strengths, including giving stakeholders the versatility to use the source data as needed to customize scoring according to parameters they deem most relevant. The Final Suitability Rating includes conjunctive use opportunities by identifying multiple supplies that could be combined in a synergistic way to achieve operational, reliability, and redundancy benefits for ASR or AR. The screening takes into account individual water needs, as well as identifying potential opportunities for regional partnerships in ASR or AR projects in areas where multiple water needs are in close proximity. All four screenings provide a strong foundation that can be built upon with future data sets as the new data becomes available.

The primary limitation for the survey is the natural tension between evaluation of ASR and AR on a statewide basis and the site-specific nature of ASR and AR projects. The results of the screening can be used as an indicator of the probability of finding suitable sites, and site scores should not be considered absolute with respect to the potential success of a project. For example, local and seasonal surplus water supplies could not be mapped at this statewide scale, and county-wide water user groups (like mining and irrigation) lack specific location information to map where water supply needs exist.

A grid size at a resolution of 50,000 feet x 50,000 feet (or 89.5 miles) is considered appropriate for the scale at which data is available while providing sufficient detail. This survey seeks to identify viable areas based on hydrogeological parameters, excess water, and water supply needs, as these are key components that shape the feasibility of ASR and AR projects. A high suitability score from this survey, however, is not required for a given area to have a successful ASR or AR project. There are aquifers other than the major and minor aquifers that could host viable projects.

The results show that the state has numerous areas suitable for ASR or AR. The Final Suitability Rating scores for ASR or AR are categorized as “less,” “moderately,” and “most suitable,” providing a relative indicator of statewide favorability. The purpose of these screenings is not to replace the need for field and site-specific studies but instead to serve as a guide and preliminary screening for stakeholders.

Introduction

Aquifer storage and recovery (ASR) utilizes injection wells for the local storage and recovery of water within an aquifer for later beneficial use. Aquifer recharge (AR) is the intentional recharge of an aquifer by means of injection well or other means of infiltration.

In 2015, the 84th Texas Legislature appropriated funds and directed the TWDB through House Bill 1 (General Appropriations Bill), Rider 25, to provide grant support through groundwater conservation districts for demonstration projects or feasibility studies that would create new water supplies or increase water availability through innovative storage approaches. This grant funding supported three recently completed ASR demonstration projects for Corpus Christi, New Braunfels, and Victoria.

In 2019, the 86th Texas Legislature through House Bill 721 tasked the TWDB with determining the feasibility of using Texas aquifers for ASR and AR. The legislation outlined specific analyses to be included in the statewide survey of relative suitability, including considerations for hydrogeological characteristics, the availability of excess water for potential storage, and the current and future water supply needs as documented in the state water plan. This report summarizes the results from the survey, including three stand-alone screenings in accordance with the three statutory criteria and a combined screening that were developed to address relative ASR or AR suitability.

This summary report is an abridged version of the report delivered for TWDB contract #2000012405 (Shaw and others, 2020). The contract team conducted a literature review to identify recent demonstration projects related to ASR nationally and within Texas, evaluate methodologies from these studies and their application to Texas aquifers, and summarize how existing work could inform the evaluation of relative suitability of ASR and AR. The literature review, including an overall summary of Texas aquifer characteristics and identification of recent ASR studies nationally and in Texas is provided in Appendix A of the contracted report (Shaw and others, 2020). Appendix B of the contracted report includes a description of GIS files developed for this survey. Websites to download and review the contracted report and data are provided in the Preface.

Hydrogeological Parameter Screening

Objective

The objective of hydrogeological parameter screening is to identify the relative suitability of Texas' aquifers for aquifer storage and recovery (ASR) and aquifer recharge (AR) projects based on hydrogeological characteristics, with a focus on storage potential, transmissivity, infiltration characteristics, storativity, recoverability, and water quality.

Approach

The general approach to estimating hydrogeological parameter screening for ASR or AR was as follows:

1. Consider hydrogeological parameters that are important to the probable success of an ASR or AR project, including those identified in House Bill 721 (HB 721).
2. Estimate those hydrogeological parameters for each of the major and minor aquifers in Texas. When possible, consider how these parameters vary spatially for a given aquifer.
3. Develop separate strategies for ASR and AR in scoring these parameters on their relative potential impact on the viability of a project.
4. Combine the parameter scores to create a final hydrogeological parameter screening score for ASR and AR.
5. Use the magnitude of the hydrogeological parameter screening score to rank regions of each aquifer according to ASR or AR suitability according to three general categories of relative suitability to identify those that are more suitable than others. The three categories are "low," "medium," or "high" suitability.

Hydrogeological Parameter Methodology

The design and overall suitability of an ASR or AR project depends on many factors. These can generally be divided into operational considerations and factors associated with the hydrogeological characteristics at the location where the project will be developed. This section of the report only focuses on the suitability as can be determined from hydrogeological characteristics.

To assess hydrogeological parameter screening, a series of metrics were calculated spatially. These metrics are based upon aquifer parameters or other characteristics that are considered important to the suitability of ASR or AR. The reality is that local suitability of ASR and AR are very site-specific. However, both a statewide analysis documented here and a site-specific analysis do share many similar aquifer characteristics that would describe suitability. This survey focuses on regional hydrogeological characteristics that are either quantitative or qualitative and are intended to inform overall suitability. Following is a description of the hydrogeological screening parameters chosen for this analysis.

Methodology for parameter selection

Several fundamental hydrogeological properties or characteristics form the basis for scoring the relative suitability of Texas' aquifers for ASR or AR. Parameters are classified into three suitability categories for ASR: recharge, storage, and recoverability. Similarly, for AR, suitability parameters are classified into two categories: suitability for recharge and suitability for storage. Recoverability was not considered for AR because, while there is an established framework in Texas for how ASR recoverability affects permitting and operations, no such framework exists for AR; thus, it has no demonstrated importance for the success of an AR project. Furthermore, the objective of an AR project is commonly for purposes other than water supply, such as improving local groundwater conditions, improving spring flow and other groundwater-surface water interactions, mitigating subsidence, and others.

HB 721 specified storage potential, transmissivity, infiltration characteristics, storativity, recoverability, and water quality, which are all considered in the screening process either as individual suitability parameters or as scoring categories that depend on multiple suitability parameters. Table 1 shows how each HB 721 focus area is incorporated into the approach.

Table 1. House Bill 721 focus for hydrogeological characterization and how they are addressed in this survey

HB-721 focus area	Description
Storage potential	AR and ASR primary category- *Storage*
Transmissivity	AR and ASR primary category- *Recharge*
Infiltration characteristics	AR primary category- *Recharge*
Storativity	AR and ASR primary category- *Storage*
Recoverability	ASR primary category- *Recoverability*
Water quality	ASR primary category- *Recoverability*

AR = aquifer recharge; ASR = aquifer storage and recovery

Some suitability parameters may have relevance in more than one category. Assigning categories simplifies the task of understanding input/output relationships, because it reduces the number of input variables being considered in a category. The relationship between the weights and scores of the categories can then be analyzed as a separate step before combining into the ASR or AR hydrogeological parameter screening score.

Table 2 includes a list of parameters that are included in the hydrogeological parameter screening for ASR, along with descriptions of the parameter and its scoring category assignment(s). For those parameters that are applicable to more than one category, the primary category is listed first in bold. Table 3 includes a similar list for AR. Each parameter is described in more detail in the Scoring section.

Table 2. Hydrogeological parameter screening for ASR

Parameter name	Category	Notes
Storage zone depth	Recharge	Depth to top of aquifer in a confined system. In an unconfined system, storage zone depth is estimated to be 100 feet below the top of the saturated zone
Horizontal hydraulic conductivity	**Recharge**, Recoverability	Primary factor for rate of recharge or production
Drawup available	Recharge	Distance between hydraulic head and ground surface
Dominant lithology	**Recharge**, Recoverability	Aquifer texture/porosity. Parameter scoring also includes secondary porosity features associated with fractured rock and limestone or karst formations.
Aquifer thickness	**Storage**, Recharge	For unconfined aquifers, this is based on saturated thickness
Aquifer storativity	Storage	Relevant in confined aquifers
Specific yield	Storage	Relevant in unconfined aquifers
Sediment age	Storage	A qualitative indication of aquifer induration
Confinement	Recoverability	Important for control of recharge water
Groundwater quality	Recoverability	Total dissolved solids (TDS)
Drift velocity	Recoverability	Natural drift of recharged water
Drawdown available	Recoverability	Amount of head available above the top of aquifer

Note: Where multiple categories exist, the category for which the parameter contributes to scoring is bolded.

Table 3. Hydrogeological parameter screening for AR

Parameter name	Category	Notes
Vertical hydraulic conductivity	Recharge	Proxy for infiltration rate
Horizontal hydraulic conductivity	Recharge	Primary factor for rate of recharge or production
Topographic slope	Recharge	High slope areas limit above ground ponding potential
Sediment age	Recharge	A qualitative indication of aquifer induration
Aquifer dominant lithology	Recharge	Accounts for aquifer texture/porosity. Parameter scoring also includes secondary porosity features associated with fractured rock and limestone or karst formations.
Specific yield	Storage	Relevant in unconfined portion of the aquifer
Depth to water table	**Storage**, Recharge	Defines potential storage volume and recharge delay

Note: Where multiple categories exist, the category for which the parameter contributes to scoring is bolded.

Assumptions, challenges, and limitations

Several assumptions had to be made to make the analysis reproducible. The following key assumptions were used in developing the hydrogeological parameter screening:

- To address the challenge of regionally estimating continuous distributions of hydrogeological properties, this survey relied heavily upon the TWDB groundwater availability models (GAMs). Parameter values from the published numerical GAMs are currently the best and most readily available estimates. The values in a numerical model may differ from those values proposed in the conceptual model. However, because the numerical model has been calibrated, the additional constraint imposed by calibration should improve the parameter estimates.
- When a major or minor aquifer had multiple hydrogeologic units with varying parameter values, the parameters were averaged to one value to represent the aquifer for that grid cell.
- To address upscaling of hydrogeological parameters, the following assumptions were made:
    - A reasonable scaling approach to move from a finer resolution spatial coverage to the coarser resolution statewide grid used the arithmetic average of cells or pixels that intersect each coarse grid cell.
    - For asymmetrically distributed values, the arithmetic mean tended to emphasize higher values over lower ones. Given how the values are eventually converted to suitability scores, considering alternate summary statistics provided limited value. As long as a consistent approach is applied to all of the aquifers, the relative suitability scores should not be affected.

The following are some of the key challenges in developing the hydrogeological parameter screening:

- Texas is a large state with aquifers that cover very large areas. A key challenge for this analysis was the efficient estimation of hydrogeological parameters and other aquifer characteristics continuously across entire aquifers.
- Many areas of the state have multiple stacked aquifers potentially available at one geographic location.
- In this analysis, suitability is estimated on a discrete spatial grid. A challenge associated with any spatial analysis performed at a fixed spatial resolution is the issue of upscaling

parameters that may be at a smaller spatial scale than the suitability assessment grid scale.

The primary limitation for the hydrogeological parameter screening is the natural tension between evaluating ASR and AR on a statewide basis and the site-specific nature of ASR and AR projects. While the screening can act as a high-level indicator of suitability, a given statewide grid cell with a "high" suitability rating may not actually be suitable throughout. Similarly, if a statewide grid cell is given a "low" suitability rating, that does not necessarily preclude the chance of a successful project being developed in the area encompassed by that cell, depending on the project need. The screening can be used as an indicator of the probability of finding suitable sites in a county or portion of a county but cannot be considered the "final answer" with respect to the potential success of a project. This type of limitation exists to some extent for any screening-level approach that is developed over a large area. Since hydrogeological parameters can vary dramatically at local scales and site-specific field testing is essential for successful design and implementation of ASR and AR, this limitation is an especially important consideration with respect to this survey.

Another limitation is the extent of the official TWDB aquifer boundaries, which serve as the basis for this survey. Generally, the boundaries do not include the brackish and saline portions of aquifers, which could host viable ASR projects.

Data sources

Primary data sources

The following primary data sources were used to estimate the hydrogeological screening parameters:

The parameters listed in Table 2 and Table 3 were estimated for each of the 9 major and 22 minor aquifers in Texas (31 total) based on available data. The TWDB GAM and Brackish Resources Aquifer Characterization System (BRACS) programs have created the most comprehensive quantitative datasets for the aquifers in the state. The GAM program, which assigns hydrogeological parameters spatially in a common modeling platform, offers a relatively efficient repository for spatially varying hydrogeological parameters. Similarly, the BRACS program has produced many aquifer studies that offer a variety of spatially varying, quantitative aquifer assessments. Datasets from these two programs form most of the hydrogeological data sources used in this assessment. When spatially varying data is available and upscaling was relevant, this data was used directly for clipping to the grid cell. When spatially varying data is not available, the aquifer is assigned a single value that may occur over multiple grid cells.

Additional details on the data sources used to develop suitability parameters for all 31 major and minor aquifers is included in Appendix C of the contracted report.

Other sources

Several of the suitability parameters, especially those related to AR, could not be derived from GAMs or BRACS studies; therefore, the following sources were used:

Vertical Hydraulic Conductivity—Vertical hydraulic conductivity was derived from the U.S. Department of Agriculture Soil Survey Geographic Database (SSURGO) dataset. The SSURGO dataset estimates soil types for the first several soil horizons classified spatially throughout Texas and much of the rest of the country. Each soil type has an estimated saturated vertical hydraulic conductivity. The data is assigned to polygons that bound small areas with a consistent soil type. For each of these polygons, a weighted harmonic mean (weighted by the thickness of the soil horizon) was calculated using the hydraulic conductivities for each of the soil horizons. The harmonic mean was used because the direction of flow is orthogonal to the bedding planes of the soil horizons.

Topographic Slope - Topographic slope is an important consideration for surface AR in the construction of impoundments. Infiltration ponds should be constructed in areas sloping less than 5 percent (Pedrero and others, 2011; Ahmadi and others, 2017). Topographic slope was calculated using the U.S. Geological Survey (USGS) statewide 30-meter digital elevation model (DEM). Because the slope is eventually upscaled to a much coarser grid, the 30-meter DEM was deemed of sufficient resolution for the slope calculation. Topographic slope is a spatially varying coverage, and the gradient intervals are based on an analysis of statewide topography.

Aquifer Age – Aquifer age was determined as a companion parameter to aquifer dominant lithology (described below), from the 2011 TWDB report, *Aquifers of Texas*. Aquifer age is assigned a single value for the unconfined and confined portions of the aquifer. Many of the aquifers had a range of ages. For AR, which only considers the unconfined portion of an aquifer that occurs at surface, two possible ages were assigned. If the aquifer is dipping, it was assigned the midpoint of the age range (since the outcrop likely represents the entire span of age ranges). For non-dipping aquifers, the youngest age was used, since the aquifer material at the surface would trend younger. For ASR, both the unconfined and confined portions were assigned the midpoint of the age range, since the ASR well depth (and thus the age of the sediments it might be completed in) is unknown.

Aquifer Dominant Lithology – Aquifer dominant lithology was derived from a variety of literature sources, such as the *Aquifers of Texas* (TWDB, 2011), smaller reports focused on one or two aquifers, and other studies. A separate list of references for this work is included at the end of Appendix C of the contracted report. Dominant lithology is assigned as a single value for each aquifer.

Groundwater Quality – Groundwater quality for 30 of the 31 aquifers was derived from *Aquifers of Texas* (TWDB, 2011), which includes maps of total dissolved solids (TDS) for all but the Cross Timbers Aquifer, which the TWDB recognized as a minor aquifer of Texas after publication of the 2011 report. These are spatially varying coverages. The water quality of the Cross Timbers Aquifer was estimated from measurements in the TWDB groundwater database. Compatibility of source water for injection and native groundwater quality is critical for ASR project success but is too site-specific to address in a statewide survey.

Integration scale

A statewide grid consisting of cells 50,000 feet by 50,000 feet (or 89.5 square miles) was created to allow a spatially consistent evaluation network for the survey. Given the input datasets, statewide perspective, and timeline of this survey, it was both suitable and relevant. This grid size and extent was used as a template for all screenings and the Final Suitability Rating developed during this survey. This created coinciding datasets for consistency and ease of integration.

Aquifer assignments

For each major and minor aquifer, the aquifer extent was intersected with the 50,000 by 50,000 statewide grid. If the centroid of a grid cell occurred in an aquifer polygon, the aquifer was assigned to that grid cell. Grid cell centroids that did not occur in an aquifer did not receive an aquifer assignment. A manual evaluation was made along the edges of the state, and for those aquifers with small, disconnected regions that made representation with a coarse grid challenging. These grid assignments are shown in Figure 3 and Figure 4, for major and minor aquifers, respectively. In general, an inclusive strategy was used to represent large portions of even the smaller aquifers in the grid. Each aquifer has a grid representation so that overlapping aquifers can share grid locations but have unique suitability parameters at the shared location. Each grid cell for a given aquifer is assigned either an “unconfined” or “confined” attribute, based on the initial intersection and the manual definition of the grid assignments.

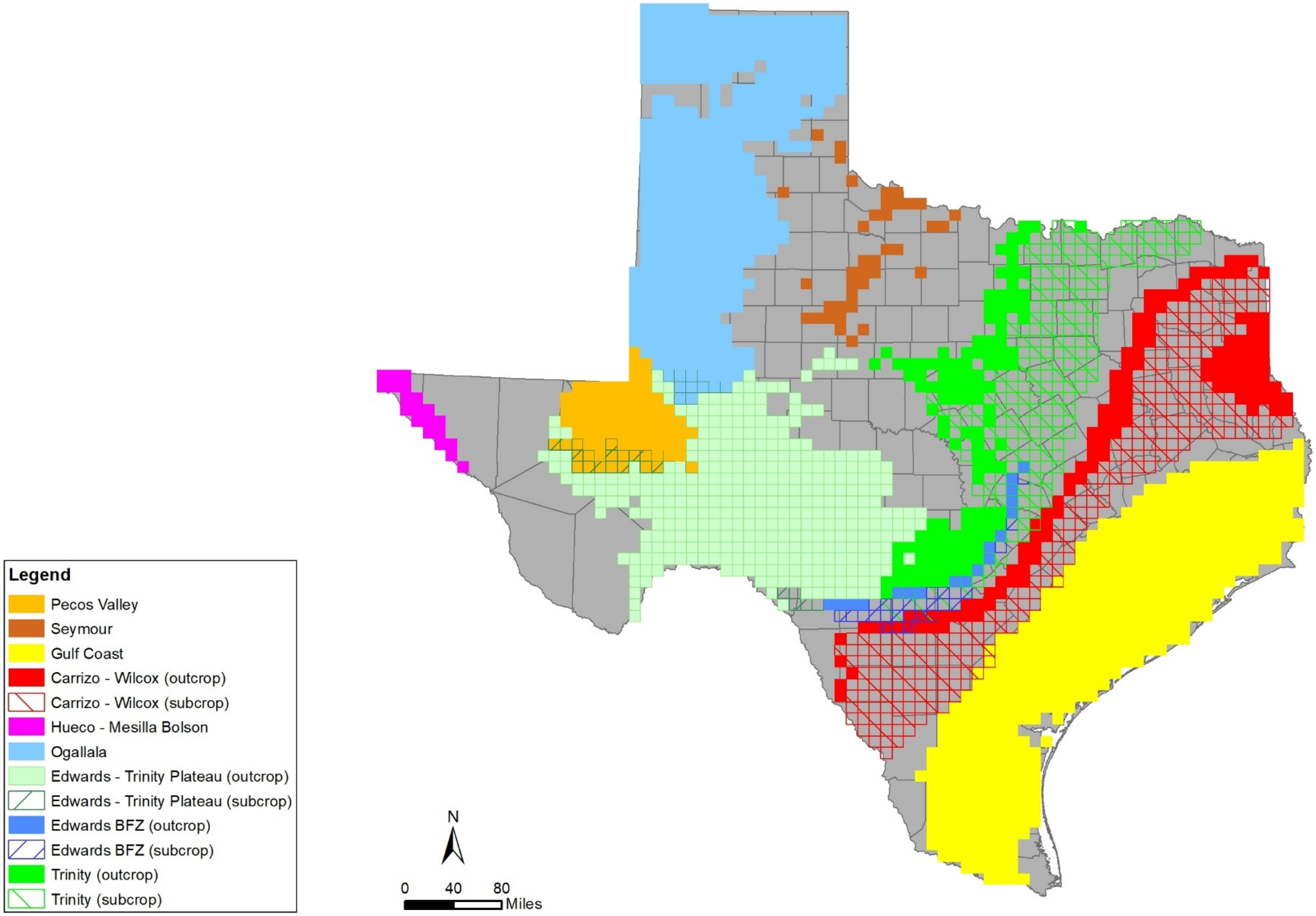

Figure 3. Grid cells for major aquifers

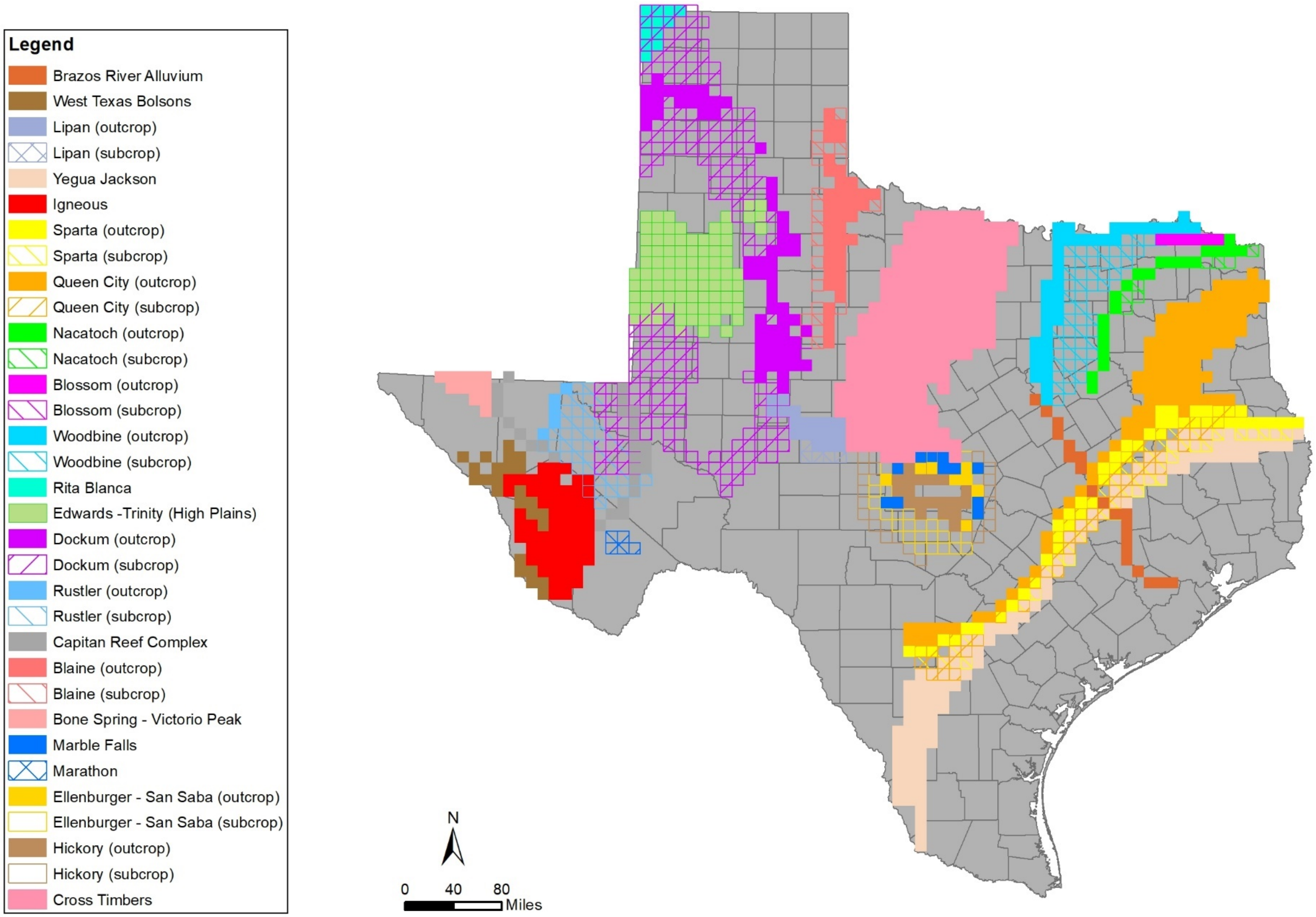

Figure 4. Grid cells for minor aquifers

Scaling source data to the statewide grid

The spatially varying source data, whether it be at a numerical groundwater model grid scale or a raster dataset, exists at a finer resolution than the statewide grid. To scale the parameters to the statewide grid, each input dataset was intersected with the statewide grid, such that the model grid polygons, raster pixels, or other small features were associated on a many-to-one basis with each statewide grid cell based on the centroid location of the higher resolution dataset falling inside a statewide grid cell. The arithmetic average of the values for the finer cells was then calculated and assigned to the statewide grid cell.

The result of this step was a feature class containing the quantitative values of each of the suitability parameters for each aquifer. The suitability parameters shown in Table 2 and Table 3 were identified for all 31 major and minor aquifers to evaluate ASR or AR feasibility.

Data gaps

The following are the key data gaps identified while developing the hydrogeological parameter screening:

- The Cross Timbers Aquifer does not have a conceptual model or numerical model associated with it, as it is currently under development by the TWDB. A numerical model of the Cross Timbers Aquifer (Oliver and Kelley, 2014) was the primary data source. However, the model footprint did not extend as far south or west as the TWDB definition of the aquifer. The parameter values in this southern area were extrapolated along strike, and parameter values in the western area were extrapolated along dip to fill these gaps.
- The Hueco Bolson model, part of the Hueco-Mesilla Bolsons GAM, does not cover the entire area of the Hueco-Mesilla Bolsons Aquifer. Parameter values from adjacent cells were used to fill gaps where coverage was not available.
- Many of the GAMs do not contain estimates of specific yield, because the numerical models were constructed as “confined” models, where transmissivity does not vary with water level. For these cases, the specific yield was estimated from published literature values.

Scoring

In this section, the method of scoring is described for hydrogeological parameters considered most relevant for the relative suitability for ASR and AR projects along with a discussion of the normalized scoring approach for each parameter.

Method

The proposed scoring methodology is based on a multi-attribute utility theory (MAUT), which forms a structure for making decisions when many different variables exist. The suitability parameters discussed in the previous section are integrated into a single hydrogeological parameter screening score for ASR or AR using this approach, with suitability scores and weights for each contributing to the overall score. Some uncertainty in assigning weights to the various factors exists using this approach. A sensitivity analysis provides a method to evaluate weights. The contract team performed this type of analysis in cooperation with the TWDB to review weights and their impacts on the total analysis.

The weighting and scoring process was completed independently for ASR and AR. While the two strategies share some suitability parameters, the scoring and weighting between ASR and AR are not the same, because they are two fundamentally different strategies with different controlling physics.

In accordance with the MAUT approach, each chosen suitability parameter was mapped onto a utility curve so that the highest suitability has a parameter score equal to one and the lowest suitability has a parameter score equal to zero. This process requires normalizing each suitability parameter to a range from zero to one. The benefit of this process of normalization is the ability to combine quantitatively different, and even qualitative and quantitative suitability parameters, into a decision process. Once a suitability parameter is normalized, it is referred to as a suitability parameter normalized score.

For many of the suitability parameters, the normalized score may be assigned categorically (score constant within ranges) or may be linear within a certain range, with a "ceiling" where the score no longer increases with parameter magnitude. A good example of this is aquifer hydraulic conductivity. For aquifer hydraulic conductivities below a certain threshold, ASR is impractical because of low well productivity. Once hydraulic conductivity reaches a certain threshold where good productivity is possible, the normalized score reaches a maximum, and increasing hydraulic conductivity no longer affects the score. Note that low well productivity may still meet specific project needs even if the corresponding hydraulic conductivity scores low in this analysis. This is an example of the need to further refine suitability of a specific project beyond the regional analysis approach from this statewide survey.

The objective in this analysis was not to preclude aquifers that may be adequate under certain project constraints and objectives but rather to provide guidance that the given aquifer is suitable for site/project specific analyses.

Once scores had been developed, the analysis methodology combined the scores for each category into one measure of categorical suitability termed the "categorical score." The process used is a simple summation allowing the decision maker to weight each performance parameter normalized score according to the decision maker's knowledge about the decision problem. The equation for the categorical score is as follows:

$$Categorical\ Score\ (CS) = \frac{\sum_{i=1}^{n} weight_{NS,i}\, NS_i}{\sum_{i=1}^{n} weight_{NS,i}} \qquad \text{(Equation 1)}$$

The categorical scores (suitability for recharge, suitability for storage, and suitability for recoverability) are then combined to create a final hydrogeologic suitability score. The final hydrogeologic suitability score is termed the ASR score (or AR score) and is calculated as follows:

$$Final\ Score = \frac{\sum_{i=1}^{n} weight_{CS,i}\, CS_i}{\sum_{i=1}^{n} weight_{CS,i}} \qquad \text{(Equation 2)}$$

In Equation 2, *Final Score* is the hydrogeologic ASR or AR suitability score (ASR and AR scores will be different for each statewide grid cell). The final hydrogeologic ASR or AR score varies from a minimum of zero to a maximum of one. The ASR score is comparable across aquifers. Similarly, the AR score is comparable across aquifers. However, the ASR and AR scores are not directly comparable, since the weighting approach is applicable only to the strategy (ASR or AR) being considered.

Appendix C of the contracted report includes additional details on the scoring method process used to calculate a categorical score and combine to create a hydrogeological parameter suitability score.

To simplify the display of the ASR or AR score for an end-user, two threshold values were used for ASR and two threshold values for AR, which divide suitability into classes of "low," "medium," and "high". The ASR scores were categorized as follows:

- Low: ASR Score < 0.5
- Medium: ASR Score 0.5 to 0.7
- High: ASR Score > 0.7

These thresholds were primarily based on inspection of the scoring distributions and consideration of where current ASR projects and pilot studies have been successful in Texas.

Threshold values were also considered for AR. The thresholds are not consistent between ASR and AR, again because of the unique weighting scheme for each strategy. The AR scores were categorized as follows:

- Low: AR Score < 0.7
- Medium: AR Score 0.7 to 0.8
- High: AR Score > 0.8

These thresholds are proposed to allow high-level categorization of hydrogeological scores, but the "low," "medium," and "high" hydrogeological parameter screening categories themselves are not carried through to the Final Suitability Rating. Rather, the actual hydrogeological parameter screening score value (ranging between 0 and 1) is carried through to the Final Suitability Rating calculation to keep calculations intact through the entire scoring process.

ASR hydrogeological parameter scores

Table 4 lists the proposed hydrogeological parameters for ASR, the related numerical or categorical values, and the associated scoring. Scores are normalized from zero to one, with one being the highest suitability and zero being the least suitable. A brief description of these parameters is provided in Appendix C of the contracted report.

AR hydrogeological parameter scores

Table 5 lists the proposed hydrogeological parameters for AR, the related numerical or categorical values, and the associated scoring. Scores range from zero to one with zero having low suitability and one having high suitability. A brief description of these parameters is provided in Appendix C of the contracted report**.**

Table 4. Hydrogeological parameter scoring for ASR screening

Storage zone depth	**Depth (ft bgs)**	<200	200–1000	1000–2000	2000–2500	> 2500	
	Score	*0.1*	*1*	*0.75*	*0.5*	*0.1*	
Horizontal hydraulic conductivity	**K (ft/d)**	< 1	1 to 3	3 to 10	10 to 30	> 30	
	Score	*0.2*	*0.3*	*0.5*	*0.8*	*1*	
Drawup available	**Drawup (ft)**	<50	50–100	100–400	> 400		
	Score	*0.1*	*0.2*	*0.2 – 0.9*	*1*		
Dominant lithology	**Dominant lithology**	Clay/Silt	Rock[1]	Limestone	Sandstone	Sand	Gravel
	Score	*0.1*	*0.2*	*0.5*	*0.5*	*1*	*1*
	Lithology modifier		Fractured	Karst			
	Added score		*0.4*	*0.5*			
Aquifer thickness	**Thickness (ft)**	<100	100–300	> 300			
	Score	*0.1*	*0.5*	*1*			
Aquifer storativity	**S (dimensionless)**	< 1e-5	1e-5 to 1e-4	1e-4 to 1e-3	1e-3 to 1e-2	> 1e-2	
	Score	*0.2*	*0.4*	*0.6*	*0.8*	*1*	
Specific yield	**S (dimensionless)**	< 0.01	0.01 to 0.05	0.05 to 0.1	0.1 to 0.15	0.15 to 0.2	> 0.2
	Score	*0.1*	*0.25*	*0.5*	*0.8*	*0.9*	*1*
Sediment age	**Aquifer age (mya)**	< 56	56–541	> 541			
	Score	1	1–0.1	0.1			
Groundwater quality	**TDS (mg/L)**	< 300	300–1000	1000–1500	1500–3000	> 3000	
	Score	*1*	*0.9*	*0.8*	*0.6*	*0.5*	
Confinement	**Unc/Conf (-)**	*Unconfined*	*Confined*				
	Score	0.1	1.0				
Drift velocity	**Drift velocity (ft/y)**	< 20	20–100	100–1000	>1,000		
	Score	*1*	*0.75*	*0.5*	*0.1*		
Drawdown available	**Drawup (ft)**	<50	50–100	100–400	> 400		
	Score	*0.1*	*0.2*	*0.2–0.9*	*1*		

[1]Assumed to be indurated.

K= hydraulic conductivity; ft bgs= feet below ground surface; S = storativity; ft = feet; ft/d = feet per day; mya = million years ago; ft/y = feet per year; mg/L = milligrams per liter; TDS = total dissolved solids; unc = unconfined; conf = confined

Table 5. Hydrogeological parameter scoring for AR screening

Vertical hydraulic conductivity	**K (ft/d)**	<5	5 to 20	> 20			
	Score	*0.1*	*0.1 to 1*	*1*			
Horizontal hydraulic conductivity	**K (ft/d)**	< 1	1 to 3	3 to 10	10 to 30	> 30	
	Score	*0.2*	*0.3*	*0.5*	*0.8*	*1*	
Topographic slope	**Gradient (degrees)**	< 2	2 to 5	> 5			
	Score	*1*	*0.5*	*0.01*			
Lithology type	**Dominant lithology**	Clay/ Silt	Rock[1]	Limestone	Sandstone	Sand	Gravel
	Score	*0.1*	*0.2*	*0.5*	*0.5*	*1*	*1*
			Fractured	Karst			
			0.3	*0.3*			
Sediment age	**Aquifer age (mya)**	< 56	56–541	> 541			
	Score	1	1 - 0.1	0.1			
Specific yield	**Sy (-)**	< 0.01	0.01 to 0.05	0.05 to 0.1	0.1 to 0.15	0.15 to 0.2	> 0.2
	Score	*0.01*	*0.25*	*0.5*	*0.8*	*0.9*	*1*
Depth to water table	**Depth (ft)**	0	1–10	10–30	30–300	> 300	
	Score	*0.01*	*0.2*	*0.5*	*1*	*0.5*	

[1]Assumed to be indurated.

K= hydraulic conductivity; ft/d = feet per day; mya = million years ago; Sy = specific yield; ft = feet;

Weighting

Two sets of weights are needed to complete the scoring, as shown in Equations 1 and 2. In Equation 1, weights are applied to each of the normalized scores of the hydrogeological parameters, resulting in categorical scores for recharge, storage, and recoverability. In Equation 2, weights are applied to each of the categories to calculate a final hydrogeological parameter screening score.

Weights were determined using both a qualitative and qualitative/quantitative hybrid assessment of the parameters and the scoring results. A qualitative assessment is one in which, based on experience and input from the team, one parameter is generally considered more important than another. For example, horizontal hydraulic conductivity is generally considered critical to an effective ASR implementation, so that parameter is weighted with a 1.0. Also, parameters that are considered to be broad discriminators, like lithology, were weighted relatively high. The team performed a qualitative/quantitative hybrid assessment, reviewing the final hydrogeological parameter screening scores and comparing the scores among aquifers against the expectations based on existing ASR operations and pilot studies.

A sensitivity analysis was performed in which weights were set for each parameter at "low" (0.0), "medium" (0.5), and "high" (1.0). In general, a single parameter weight did not have a large effect on the final hydrogeological parameter screening score for a given aquifer. The results of the sensitivity analysis for ASR and AR hydrogeological parameter screening scoring is shown in Appendix C of the contracted report**.** These sensitivities were considered when setting the final weights, but most weights were not changed more than 0.25 from their original estimates.

Table 6 provides the weighting scheme for ASR, along with short descriptor notes. When setting weights, the contract team was careful to balance "conventional wisdom" (i.e., the collective expectations and experience of the team for how the aquifers should be ranked for hydrogeological parameter screening) versus unexpected insights that might appear in the scoring results. All attempts were made to achieve this balance by holding fairly closely to the original weighting scheme and only changing the weight if there was consensus that the original justification was flawed. Table 7 provides the weighting scheme for AR, again with short notes describing the weighting approach.

The categorical weights were estimated using the number of parameters contributing to each of the categories. For ASR, this means that each of the categories (recharge, storage, recoverability) was weighted at approximately 0.33, since each category had four contributing suitability parameters. For AR, recharge had a weight of 5/7 or 0.71, while storage had a weight of 2/7 or 0.29. The higher relative weight on recharge is appropriate for environmental flow applications (such as are performed in the Edwards Aquifer) but would not be as appropriate if the AR application were for long-term storage. Long-term storage AR operations are not currently common in Texas nor are they in the state water plan.

Table 6. Hydrogeological parameter weights for ASR suitability

Parameter name	Weight	Notes
Storage zone depth	0.25	Lower weight because depth generally drives challenges that can be overcome with careful design
Horizontal hydraulic conductivity	1	Key parameter for overall well recharge/production rates
Available drawup	0.5	Can limit recharge rate, but wellheads can be designed to withstand ~70 psi pressure above ground surface, so weighted medium
Aquifer dominant lithology	1	Broad factor separating more suitable from less suitable aquifers, so weighted high
Aquifer thickness	0.5	Very site specific, so weighted medium
Aquifer storativity	0.5	Drives shorter term hydraulic response, but does not typically affect longer term performance, so weighted medium.
Specific yield	0.5	Similar to storativity but for unconfined aquifers
Aquifer age	1	Broad factor separating more suitable from less suitable aquifers, so weighted high
Confinement	1	Broad factor governing hydraulic control challenges, so weighted high
Groundwater quality	0.75	Can be a critical factor for recoverability, but also can be overcome by large buffer zones. Because it is not much of a discriminator among "official" aquifers (which are defined partially by their good water quality), given a medium-high weight.
Drift velocity	0.75	Similar to groundwater quality in terms of recoverability
Drawdown available	0.5	Very site specific, so weighted medium. Can be overcome by increasing local heads through recharge, but this strategy is not possible at all sites.

psi = pounds per square inch

Table 7. Hydrogeological parameter weights for AR suitability

Parameter name	Weight	Notes
Vertical hydraulic conductivity	0.25	While vertical hydraulic conductivity is very important for AR infiltration rates, estimates were limited by a very shallow SSURGO dataset. Because overcoming limited conductivity using excavation or vadose zone wells is very site-specific, this factor was weighted low to offset the overall uncertainty.
Horizontal hydraulic conductivity	1	Key parameter for infiltrating water into the aquifer system.
Slope	0.5	Can often be overcome through engineering, so weighted medium.
Aquifer dominant lithology	1	Broad factor separating more suitable from less suitable aquifers, so weighted high.
Aquifer age	1	Broad factor separating more suitable from less suitable aquifers, so parameter weighted high.
Specific yield	1	Because the unconfined portion of the aquifer is key to AR, parameter weighted high.
Depth to water table	1	Critical for viability of AR and fairly well-known, so weighted high.

SSURGO = U.S. Department of Agriculture (USDA) Soil Survey Geographic Database

Results

About 85 percent of the cells had an ASR score (meaning that a major or minor aquifer was present), so about 15 percent of the cells do not have an ASR score. About 24 percent of the cells do not have an AR score, because AR was not scored where only a confined aquifer was present or where a major or minor aquifer was not present.

The highest-scoring aquifer was assigned to final ASR and AR grids for areas where more than one aquifer was present. When preparing the final score selection for grid cells, multiple input layers and features were assimilated into a single score per grid cell and categories ("low," "medium," and "high") for ASR and AR potential as described previously. These final hydrogeological parameter screening scores are presented in Figures 3 and 4 for ASR and AR, respectively.

ASR scores

Summary statistics for the final hydrogeological parameter screening scores for ASR are shown (Figure 5) for the major and minor aquifers in Table 8 and Table 9, respectively. The statistics are calculated using the individual grid cell scores for each aquifer. Scores above 0.7 are considered to be "high" in terms of suitability, while scores less than 0.7 but greater than 0.5 are considered to be “medium” suitability. Scores below 0.5 are considered to be “low” suitability. About 5 percent of the grid cells (or 158) scored low suitability, 43 percent (or 1,358 cells) scored medium suitability, and 37 percent (or 1,172 cells) scored high suitability for ASR. As mentioned previously, 15 percent of the cells do not have an ASR score.

Eight of the nine major aquifers have at least some grid cells that are rated “high,” with the Seymour being the only major aquifer with a highest rated cell in the “moderate” suitability category. This suggests that nearly all of the major aquifers have some portions that may be highly suitable for an ASR facility. Four of the nine major aquifers have a median score that is in the “high” category (>0.7). These aquifers are the Carrizo-Wilcox, Edwards (Balcones Fault Zone), Gulf Coast, and Hueco-Mesilla Bolsons. The Trinity Aquifer narrowly missed the median “high” category score cutoff with a median score of 0.69. These aquifers all have either operating ASR wells or pilot studies in San Antonio, New Braunfels (saline portion of the Edwards [Balcones Fault Zone] Aquifer), Victoria, El Paso, and Kerrville, respectively.

Seven of the 22 minor aquifers have at least some grid cells that are rated “high” in terms of hydrogeological suitability for ASR, while only 1 of the 22 minor aquifers has a median hydrogeological suitability score that is rated in the “high” category, the Sparta. As expected, while many of the minor aquifers contain portions that are hydrogeologically suitable for ASR, this condition is not nearly as common or pervasive as with the major aquifers.

As was discussed previously, a “low” or “moderate” hydrogeological suitability score at a particular location in an aquifer is not an indication that a successful ASR project cannot be constructed there, since local conditions are key. These regional scores do provide a good indication of areas in aquifers in the state that are more likely to be suitable than others.

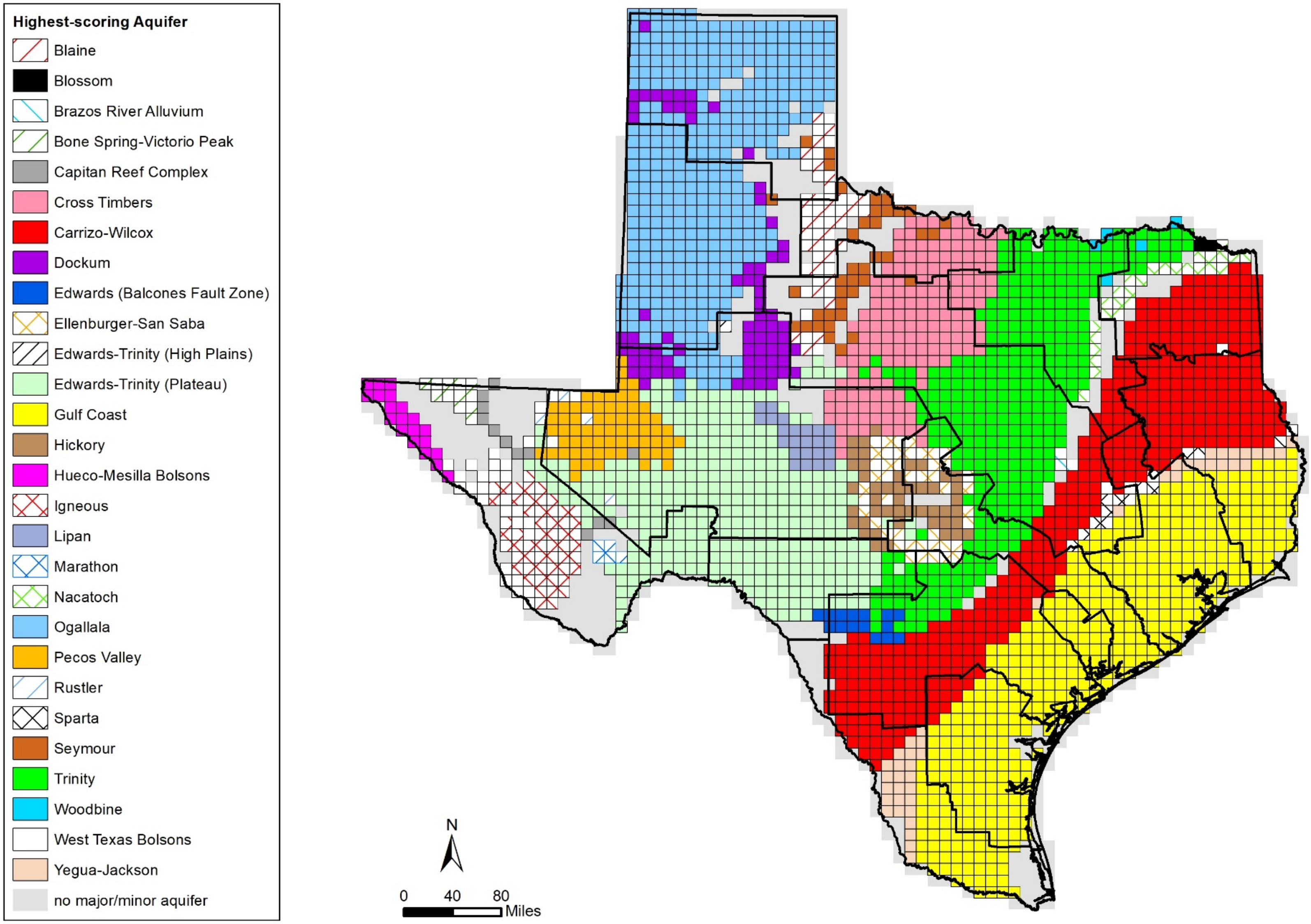

Figure 5. Highest-scoring aquifer for each ASR hydrogeological parameter screening grid cell

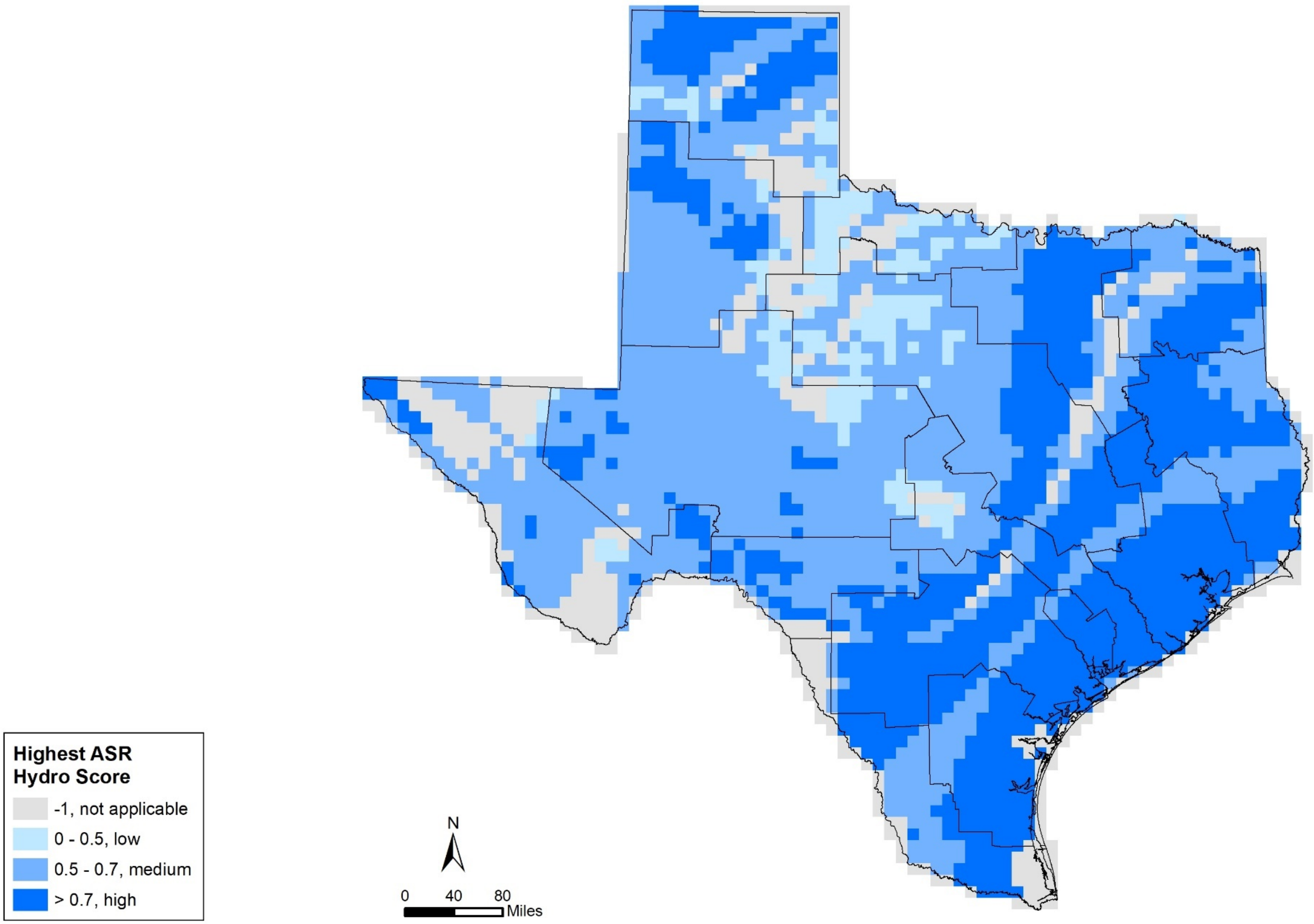

Figure 6. Hydrogeological parameter screening scores for ASR for major and minor aquifers (maximum score)

Table 8. Hydrogeological parameter screening results from ASR screening: Major aquifers

	Final score					Recharge				Storage				Recoverability			
Aquifer*	**min**	**max**	**med**	**med**	**mean**	**min**	**max**	**med**	**mean**	**min**	**max**	**med**	**Mean**	**min**	**max**	**med**	**mean**
CZWX	0.54	0.86	0.77	high	0.74	0.50	0.94	0.70	0.70	0.57	0.79	0.75	0.71	0.30	1.00	0.91	0.81
EBFZ	0.51	0.78	0.71	high	0.67	0.66	0.90	0.82	0.82	0.47	0.75	0.67	0.63	0.30	0.78	0.62	0.57
ETPT	0.52	0.73	0.63	med	0.62	0.40	0.82	0.67	0.66	0.57	0.73	0.73	0.70	0.26	0.88	0.50	0.51
GLFC	0.52	0.78	0.72	high	0.71	0.46	0.93	0.76	0.72	0.62	0.80	0.80	0.79	0.43	0.70	0.61	0.61
HMBL	0.68	0.76	0.71	high	0.71	0.65	0.88	0.76	0.74	0.78	0.78	0.78	0.78	0.54	0.65	0.60	0.60
OGLL	0.50	0.75	0.63	med	0.64	0.50	1.00	0.79	0.78	0.58	0.80	0.68	0.70	0.30	0.51	0.40	0.42
PECS	0.53	0.76	0.58	med	0.61	0.59	0.85	0.74	0.74	0.58	0.78	0.68	0.68	0.30	0.65	0.39	0.42
SYMR	0.53	0.58	0.56	med	0.56	0.68	0.77	0.75	0.74	0.60	0.60	0.60	0.60	0.28	0.40	0.32	0.34
TRNT	0.50	0.80	0.69	med	0.67	0.50	0.88	0.68	0.67	0.45	0.73	0.55	0.58	0.36	0.98	0.83	0.75

*Note: The aquifer codes are included in the List of Aquifer Abbreviations at the beginning of this report.

Table 9. Hydrogeological parameter screening results from ASR screening: Minor aquifers

	Final score					Recharge				Storage				Recoverability			
Aquifer*	min	max	med	med	mean	min	max	med	mean	min	max	med	mean	Min	max	med	mean
BLIN	0.38	0.50	0.47	low	0.46	0.17	0.35	0.27	0.28	0.51	0.61	0.55	0.57	0.38	0.75	0.49	0.54
BLSM	0.56	0.69	0.58	med	0.60	0.57	0.69	0.58	0.61	0.65	0.75	0.65	0.67	0.45	0.68	0.48	0.51
BSVP	0.53	0.64	0.59	med	0.59	0.67	0.82	0.76	0.76	0.60	0.60	0.60	0.60	0.24	0.54	0.43	0.41
BSRV	0.54	0.61	0.58	med	0.58	0.68	0.75	0.75	0.74	0.60	0.60	0.60	0.60	0.28	0.46	0.40	0.39
CRCX	0.56	0.65	0.60	med	0.60	0.52	0.87	0.70	0.68	0.61	0.61	0.61	0.61	0.40	0.68	0.51	0.52
CSTB	0.44	0.58	0.52	med	0.51	0.45	0.56	0.53	0.53	0.40	0.50	0.40	0.42	0.41	0.68	0.59	0.59
DCKM	0.41	0.65	0.58	med	0.56	0.28	0.56	0.41	0.41	0.41	0.65	0.49	0.53	0.36	0.98	0.82	0.75
ETHP	0.42	0.54	0.48	low	0.48	0.37	0.61	0.50	0.49	0.47	0.61	0.55	0.53	0.30	0.48	0.42	0.42
EBSS	0.44	0.68	0.62	med	0.61	0.55	0.79	0.66	0.67	0.19	0.43	0.37	0.35	0.40	1.00	0.85	0.80
HCKR	0.35	0.67	0.57	med	0.55	0.39	0.66	0.49	0.49	0.18	0.42	0.36	0.32	0.40	0.98	0.91	0.85
IGBL	0.54	0.61	0.58	med	0.58	0.38	0.74	0.52	0.50	0.62	0.62	0.62	0.62	0.45	0.70	0.61	0.62
LIPN	0.54	0.73	0.59	med	0.61	0.57	0.79	0.67	0.70	0.62	0.76	0.65	0.66	0.32	0.70	0.42	0.46
MRTN	0.42	0.42	0.42	low	0.42	0.49	0.49	0.49	0.49	0.35	0.35	0.35	0.35	0.43	0.43	0.43	0.43
MBLF	0.42	0.49	0.45	low	0.45	0.41	0.53	0.46	0.46	0.39	0.47	0.39	0.42	0.40	0.54	0.46	0.47
NCTC	0.47	0.74	0.54	med	0.57	0.50	0.67	0.58	0.60	0.43	0.71	0.51	0.55	0.38	0.91	0.51	0.56
QNCT	0.52	0.80	0.65	med	0.66	0.50	0.68	0.58	0.57	0.58	0.80	0.76	0.72	0.39	1.00	0.59	0.69
RTBC	0.52	0.61	0.55	med	0.55	0.48	0.57	0.53	0.53	0.54	0.62	0.58	0.58	0.52	0.63	0.55	0.55
RSLR	0.43	0.65	0.61	med	0.60	0.28	0.61	0.41	0.42	0.42	0.62	0.56	0.53	0.45	0.90	0.88	0.83
SPRT	0.51	0.79	0.70	med	0.66	0.48	0.68	0.58	0.59	0.58	0.80	0.66	0.66	0.39	1.00	0.80	0.74
WXBL	0.58	0.70	0.65	med	0.66	0.52	0.84	0.71	0.68	0.60	0.70	0.70	0.70	0.32	0.70	0.68	0.61
WDBN	0.44	0.72	0.63	med	0.60	0.28	0.53	0.41	0.40	0.46	0.74	0.68	0.64	0.45	0.98	0.84	0.76
YGJK	0.49	0.71	0.64	med	0.63	0.55	0.80	0.68	0.68	0.47	0.78	0.68	0.67	0.33	0.68	0.53	0.53

*Note: The aquifer codes are included in the List of Aquifer Abbreviations at the beginning of this report.

AR scores

Summary statistics for the final hydrogeologic suitability scores for AR are shown (Figure 8**)** for the major and minor aquifers in Table 10 and Table 11, respectively. The statistics are calculated using the individual grid cell scores for each aquifer. Scores above 0.8 are considered to be "high" in terms of suitability, while scores less than 0.8 but greater than 0.7 are considered to be "medium" suitability. Scores below 0.7 are considered to be "low" suitability. About 27 percent of the grid cells (or 863) scored low suitability, 20 percent (or 623 cells) scored medium suitability, and 29 percent (or 917 cells) scored high suitability for AR. As mentioned previously, 15 percent of the cells are not over major or minor aquifers and therefore do not have a score. An additional 9 percent of cells (about 24 percent) do not have an AR score where no outcrop was present.

Seven of the nine major aquifers have at least some grid cells that are rated "high," and five of the nine major aquifers have a median score rated "high." One notable exception is the Edwards (Balcones Fault Zone) Aquifer, which just missed a median "high" score at 0.79 but has currently operating recharge features. The Edwards (Balcones Fault Zone) Aquifer is rated slightly lower primarily due to its lower score in storage, as seen in its median storage score of 0.5. This low storage score is due to a low effective porosity, and limited depths to water. In reality, the lack of storage does not affect the current recharge projects in the aquifer, because the objective of those projects is not necessarily long-term storage but general augmentation (i.e., keeping water levels and spring flow at desirable levels). So, the Edwards (Balcones Fault Zone) Aquifer AR hydrogeologic suitability score should not be considered to be contrary to the reality of current operations.

The Hueco-Mesilla Bolsons Aquifer, where El Paso has performed AR using infiltration basins with reclaimed water, has a median rating of "high."

Four of the 22 minor aquifers have a least some grid cells with a "high" rating, while only one of the 22 aquifers has a median value that qualifies for the "high" rating. Similar to the ASR scores, there will be areas in many of the minor aquifers that may be suitable for AR, but those areas will not be as common or pervasive as for the major aquifers.

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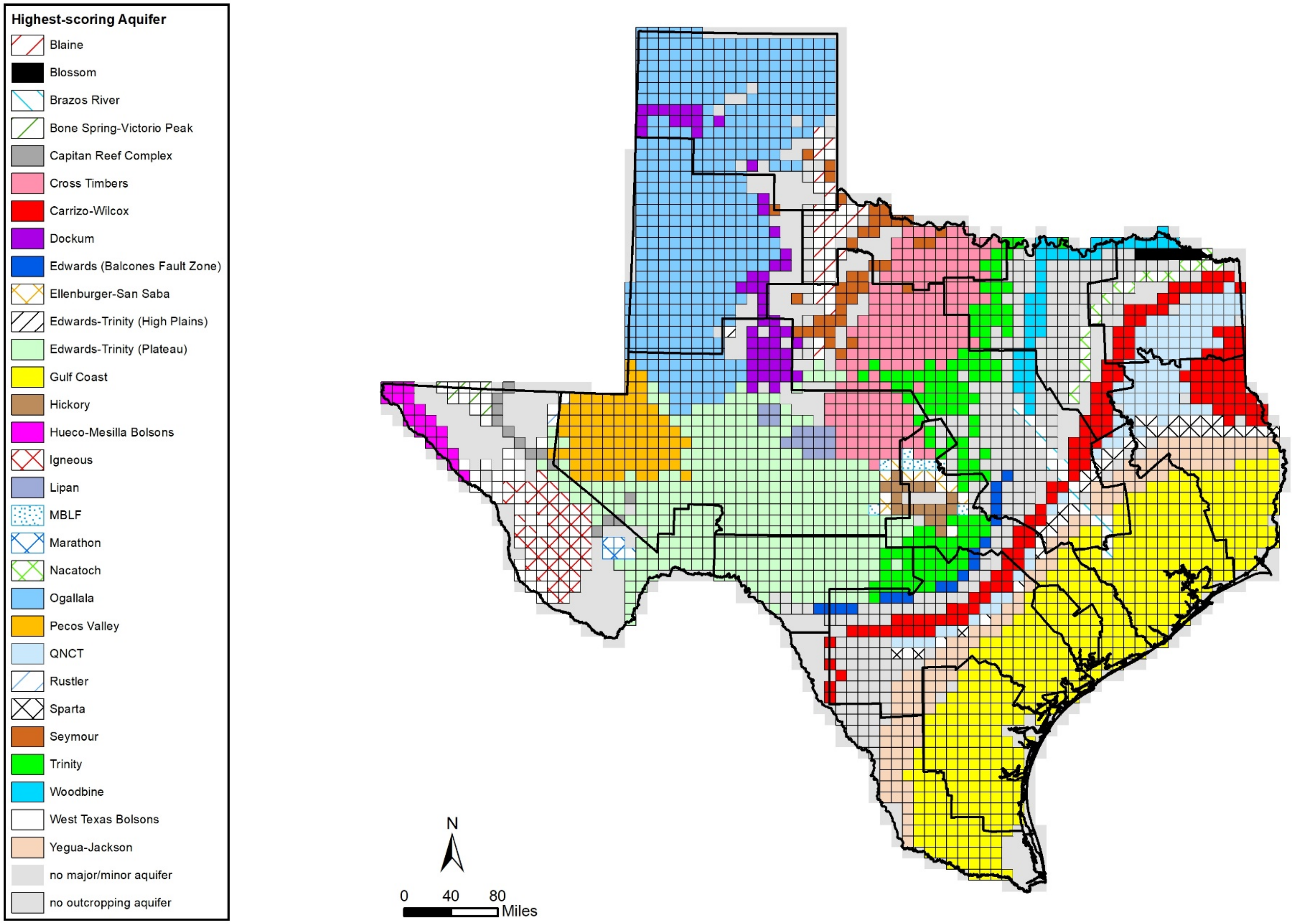


Figure 7. Highest-scoring aquifer for each AR hydrogeological parameter screening grid cell

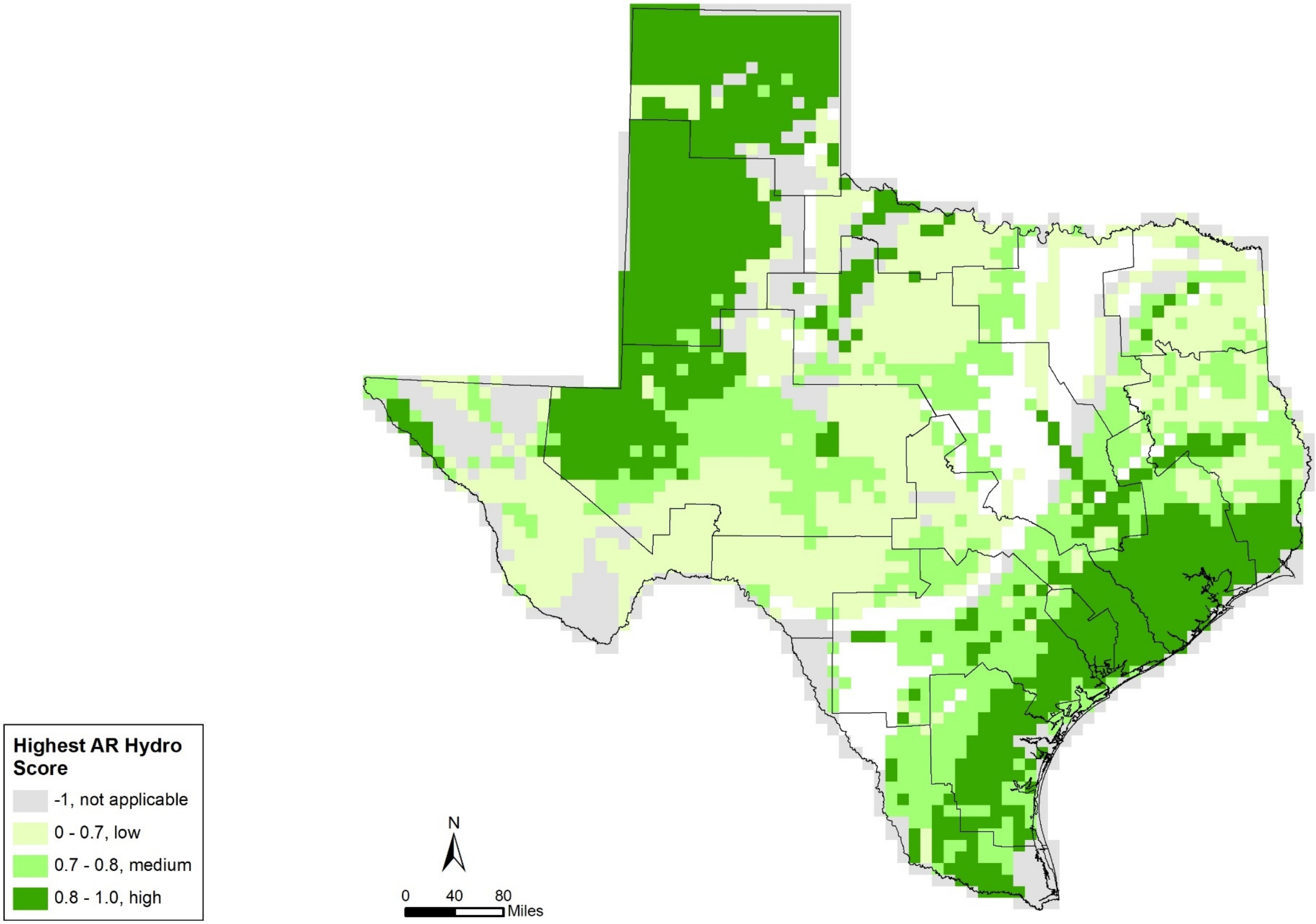


Figure 8. Hydrogeological parameter screening scores for AR for major and minor aquifers (maximum score)

Table 10. Hydrogeological parameter screening results from AR screening: Major aquifers

	Final score					Recharge				Storage			
Aquifer*	min	max	med	med	mean	min	max	med	mean	min	max	med	mean
CZWX	0.60	0.83	0.74	med	0.75	0.55	0.81	0.68	0.69	0.50	1.00	0.88	0.88
EBFZ	0.50	0.79	0.64	low	0.65	0.63	0.71	0.70	0.68	0.01	1.00	0.50	0.56
ETPT	0.44	0.78	0.66	low	0.65	0.31	0.70	0.56	0.55	0.75	1.00	1.00	0.90
GLFC	0.62	0.98	0.84	high	0.83	0.63	0.97	0.86	0.83	0.50	1.00	1.00	0.84
HMBL	0.77	0.89	0.81	high	0.82	0.67	0.85	0.81	0.80	0.75	1.00	0.88	0.88
OGLL	0.72	1.00	0.92	high	0.91	0.75	1.00	0.88	0.89	0.50	1.00	1.00	0.95
PECS	0.78	1.00	0.92	high	0.92	0.82	1.00	0.89	0.91	0.50	1.00	1.00	0.95
SYMR	0.77	0.96	0.84	high	0.86	0.87	1.00	0.94	0.94	0.50	1.00	0.60	0.66
TRNT	0.57	0.80	0.71	med	0.71	0.53	0.72	0.59	0.60	0.50	1.00	1.00	0.99

*Note: The aquifer codes are included in the List of Aquifer Abbreviations at the beginning of this report.

Table 11. Hydrogeological parameter screening results from AR screening: Minor aquifers

	Final score					Recharge				Storage			
Aquifer*	min	max	med	med	mean	min	max	med	mean	min	max	med	mean
BLIN	0.45	0.56	0.51	low	0.52	0.26	0.38	0.32	0.33	0.75	1.00	1.00	0.98
BLSM	0.65	0.76	0.69	low	0.71	0.67	0.67	0.67	0.67	0.60	1.00	0.75	0.81
BSVP	0.57	0.77	0.64	low	0.65	0.50	0.68	0.60	0.59	0.75	1.00	0.75	0.81
BSRV	0.76	0.89	0.89	high	0.87	0.82	0.97	0.94	0.93	0.60	0.75	0.75	0.70
CRCX	0.57	0.77	0.67	low	0.66	0.53	0.74	0.60	0.60	0.50	1.00	1.00	0.80
CSTB	0.35	0.48	0.43	low	0.42	0.30	0.47	0.40	0.39	0.50	0.50	0.50	0.50
DCKM	0.49	0.68	0.59	low	0.58	0.32	0.58	0.44	0.42	0.75	1.00	1.00	0.98
ETHP	0.57	0.68	0.65	low	0.63	0.47	0.63	0.61	0.57	0.48	0.88	0.75	0.78
EBSS	0.58	0.68	0.68	low	0.66	0.41	0.56	0.56	0.52	1.00	1.00	1.00	1.00
HCKR	0.46	0.60	0.55	low	0.56	0.30	0.45	0.37	0.40	0.50	1.00	1.00	0.96
IGBL	0.37	0.64	0.41	low	0.44	0.42	0.70	0.46	0.48	0.26	0.50	0.26	0.33
LIPN	0.67	0.81	0.73	med	0.74	0.74	0.89	0.82	0.82	0.50	0.62	0.50	0.55
MRTN	0.34	0.39	0.39	low	0.37	0.27	0.34	0.34	0.31	0.50	0.50	0.50	0.50
MBLF	0.53	0.64	0.58	low	0.60	0.35	0.49	0.41	0.44	1.00	1.00	1.00	1.00
NCTC	0.47	0.66	0.55	low	0.56	0.59	0.72	0.67	0.66	0.01	0.62	0.26	0.30
QNCT	0.55	0.78	0.69	low	0.68	0.55	0.69	0.57	0.60	0.50	1.00	1.00	0.87
RTBC	0.70	0.73	0.70	low	0.71	0.58	0.62	0.58	0.59	1.00	1.00	1.00	1.00
RSLR	0.39	0.58	0.53	low	0.49	0.35	0.41	0.35	0.37	0.50	1.00	1.00	0.80
SPRT	0.62	0.82	0.76	med	0.74	0.63	0.75	0.69	0.67	0.60	1.00	1.00	0.92
WXBL	0.53	0.76	0.68	low	0.66	0.59	0.98	0.86	0.80	0.13	0.62	0.22	0.30
WDBN	0.46	0.63	0.61	low	0.58	0.38	0.50	0.45	0.44	0.50	1.00	1.00	0.91
YGJK	0.54	0.84	0.77	med	0.77	0.55	0.83	0.78	0.74	0.38	1.00	0.88	0.85

*Note: The aquifer codes are included in the List of Aquifer Abbreviations at the beginning of this report.

Future work

This survey provides a statewide evaluation of hydrogeological parameter screening of the major and minor aquifers for ASR and AR. A natural progression of the analysis would be to increase the resolution of the survey by focusing in particular areas of high interest or to increase the spatial extent of the survey in key areas. Examples include the following:

1. The current major and minor aquifer boundaries generally do not include brackish portions of the aquifer, and this survey was limited to the TWDB official boundaries. There are aquifers, such as the Edwards (Balcones Fault Zone) and the Carrizo-Wilcox, where ASR would clearly be feasible outside of the official aquifer boundaries.

2. Many of the minor aquifers have dated or sparse underlying datasets. For example, the Cross Timbers Aquifer conceptual model is currently in development but was not available for this current survey. As conceptual or numerical models are updated, they could be easily integrated into the existing workflow to update and improve the hydrogeological parameter screening scoring.

3. Some aquifers have multiple formations that can be used independently at nearby locations. The Carrizo-Wilcox Aquifer is a good example of this, where the Carrizo and Simsboro formations may be productive and suitable for ASR at the same location. A future survey could assess these formations independently, rather than as a single aquifer.

Excess Water Screening

Objective

For an ASR or AR project to be considered a viable water management strategy, excess water supplies must be available for recharge and storage. The objective of the excess water screening is to identify and score the potential availability of excess water sources based on frequency, volume, and duration by developing an excess water screening and associated geodatabase.

The excess water screening, designed in accordance with scope and legislation, is a statewide screen with the goal of presenting information for regional water planning and stakeholder consideration and discussion. The screening identifies surplus water that could be developed for ASR or AR projects, which can be leveraged by water users or stakeholders who want to pursue more detailed studies. The screening is not intended to replace or be a substitute for site- and project-specific detailed analyses that are required for permitting, financing, and designing actual projects prior to implementation.

Approach

The general approach to estimating excess water for ASR or AR was as follows:

1. Compile data on excess water sources including surface water, groundwater, and reclaimed water deemed available for potential storage for ASR or AR.
2. Estimate parameters that are important to the probable success of an ASR or AR project consistent with HB 721 provisions. In accordance with HB 721, excess water parameters evaluated included frequency, volume, duration, and distance of water to relatively suitable aquifer storage areas identified in the hydrogeological parameter screening. The distance parameter was included in the final screening and is discussed in the Final Suitability Rating section later in the report.
3. Estimate those parameters for excess water sources identified for screening at a resolution consistent with primary data.
4. Develop strategy for scoring parameters and their relative potential impact (or weighting) on the viability of a project, including how these parameters scale up on the grid cell level for consistency among screenings.
5. Calculate a composite score for each supply source on a 50,000-foot by 50,000-foot (or 89.5 square miles) grid cell basis, coinciding with the hydrogeological parameter screening.
6. Use the magnitude of the excess water screening scores to rank grid cells into three general categories of relative suitability, “low,” “medium,” or “high.”
7. Aggregate overlapping scores into a single scored layer for the screening.

It is generally assumed that water is stored in ASR or AR during times of plenty and used in times of need. For some supplies, such as groundwater and surface water supplies identified through the TWDB draft State Water Planning Database (draft DB22), drought conditions were used to be consistent with regional water planning efforts. Where practical, excess supplies have been identified during non-drought times. Due to data constraints, it is not feasible to address non-drought of record excess supplies for all potential excess water sources. The following sections detail the excess supply sources that were included in the excess water screening evaluation, including methodology, assumptions, data sources, results, and other information.

Excess water methodology

Parameters related to excess water and relevant to the probable success of an ASR or AR project were identified by source water category (surface water, reclaimed water, and groundwater).

Stormwater and floodwater were accounted for in the WAM for the surface water evaluation. This allowed for consistency with how water rights are administered in the state. Groundwater produced from oil and gas exploration (produced water) is not explicitly addressed in this screen, and attempts to parse and segregate produced groundwater from individual sources is exceedingly labor intensive. Additionally, challenges associated with water quality and limited volume, frequency, and duration of available excess supplies from these sources make produced groundwater an unlikely feasible supply source for ASR and AR projects at this time. The screening is readily adaptable and capable of receiving additional excess water sources in the future that are deemed practicable and for which data is available.

Table 12 through Table 14 list the parameters included in the excess water screening by source water category, along with descriptions of the attribute table fields, weighting, and data source.

The excess surface water source comprises three components:

- Surplus appropriated surface water—run-of-river and reservoir waters that are appropriated for use but remain unutilized as identified in the draft DB22
- Unappropriated streamflow supply—surface water not assigned to water rights from WAM analyses
- Existing reservoir storage—point-source reservoir locations that could be used in conjunction with ASR or AR operations.

Surplus appropriated surface water and reservoir storage volumes at point locations are summed within a grid cell and scoring is completed at the component grid level at a value between 0 and 1. This approach reflects the ability of an ASR or AR project to use multiple reservoirs or surplus appropriated surface water sources within a grid cell.

Scoring for the unappropriated streamflow supply component is completed at the point level, and the maximum score of individual points is taken as the score at the component grid level at a value between 0 and 1. The highest point score is used as opposed to combining the scores of all points within a grid cell, because available unappropriated streamflow is not independent among point locations. For example, if unappropriated streamflow is diverted and used for ASR or AR at an upstream point, the amount of unappropriated streamflow at a downstream point would be reduced.

The three surface water component scores are then added together and capped at a value of one and reported at the excess surface water source grid level. This approach reflects the ability of an ASR or AR project to use the three surface water components within a grid cell.

For reclaimed water, the 10-mile grid cells report a score based on the frequency, duration, volume, and water quality of the combined reclaimed water points within a grid cell. This approach recognizes that sources of reclaimed water are independent of each other and can be combined to increase the excess reclaimed water supply.

For groundwater, excess water volume is calculated at the county and river basin polygon-level after subtracting current and recommended water strategies from the modeled available groundwater, consistent with the draft DB22 database availability. This excess water volume was divided and distributed equally to all 10-mile grid cells with centroids located within county and river basin polygons. Scoring for the groundwater source was then completed at the grid level.

Table 12. Surface water parameters for excess water screening

Field name ID	Weight	Alias	Notes	Data source
Surface_Frequency	0.3	Excess surface water availability frequency	Score of 0–1 (unappropriated streamflow and surplus appropriated streamflow and reservoir volume. *See text below for details.*)	WAM/draft DB22/TWDB Water Data for Texas website
Surface_Duration	0.3	Excess surface water availability duration	Score of 0–1 (unappropriated streamflow and unutilized appropriated streamflow and reservoir volume) *See text below for details.*	WAM/draft DB22/ TWDB Water Data for Texas website
Surface_Volume	0.3	Excess surface water availability volume	Score of 0–1 (unappropriated streamflow and unutilized appropriated streamflow and reservoir volume) *See text below for details.*	WAM/draft DB22/ TWDB Water Data for Texas website
Surface_WQ	0.1	Water quality	Score of 0.5 (assumes conventional treatment required for surface water)	
Surface_Score	---	Excess surface water supply composite score	Score of 0–1	**See Table 17**

WAM = water availability model; draft DB22 = TWDB draft State Water Planning Database;
TWDB = Texas Water Development Board

Table 13. Reclaimed water parameters for excess water screening

Field name ID	Weight	Alias	Notes	Data source
Reclaimed_Frequency	0.3	Excess reclaimed water availability frequency	Score of 0-1 No excess supply amount – 0; Supply amount available – 1	EPA ECHO
Reclaimed_Duration	0.3	Excess reclaimed water availability duration	Score of 0-1 No excess supply amount – 0; Supply amount available – 1	EPA ECHO
Reclaimed_Volume	0.3	Excess reclaimed water availability volume	Score of 0-1 For projected treated effluent in 2040 Available supply > 35,000 acft/yr – 1 Available supply between 15,000 and 35,000 acft/yr – 0.75 Available supply between 2,500 and 15,000 acft/yr – 0.5 Available supply between 500 and 2,500 acft/yr – 0.25 Available supply < 500 acft/yr – 0	EPA ECHO/draft DB22
Reclaimed_WQ	0.1	Water quality	Score of 0 (assumes high level of treatment required for reclaimed water)	
Reclaimed_Score	---	Excess reclaimed water supply composite score	Score of 0-1	

EPA ECHO = U.S. Environmental Protection Agency Enforcement and Compliance History Online database; draft DB22 = TWDB Draft State Water Planning Database; acft/yr = acre-feet per year

Table 14. Groundwater (GW) parameters for excess water screening

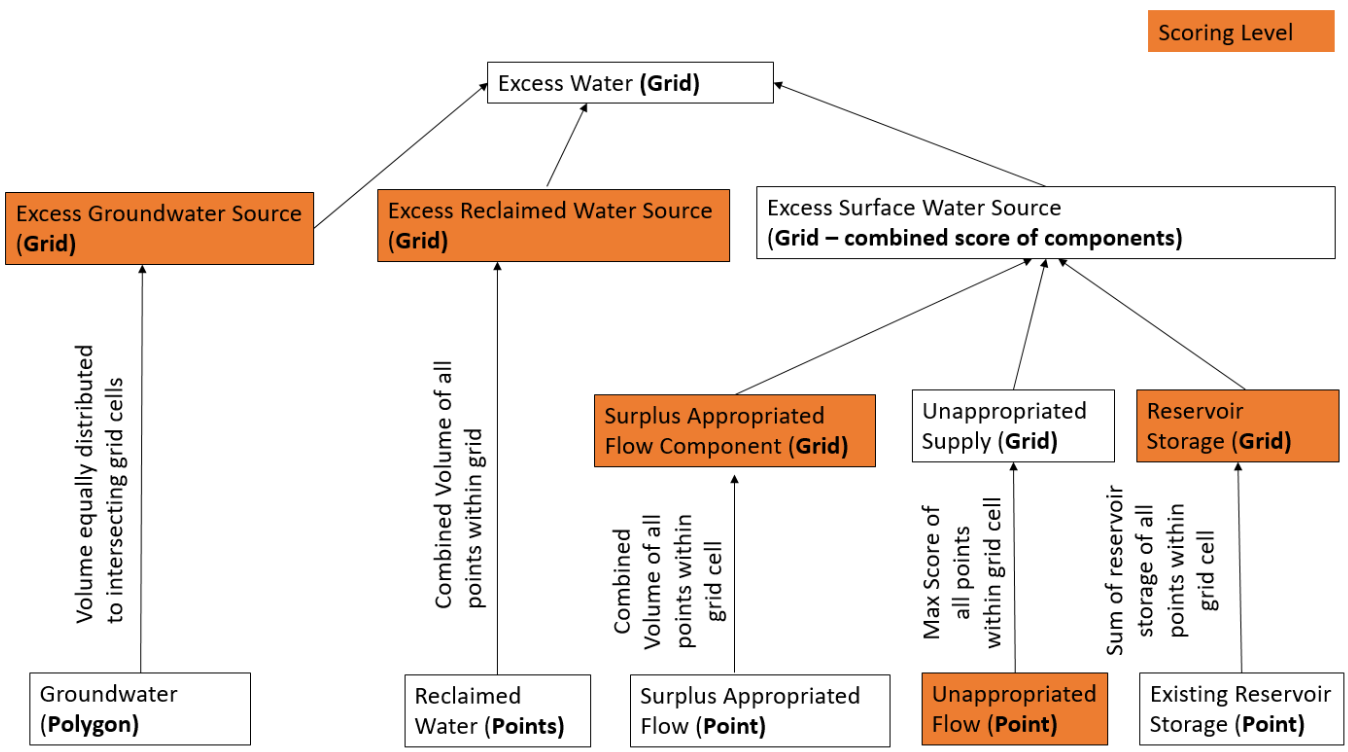
Field name ID	Weight	Alias	Notes	Data source
Ground_Frequency	0.3	Excess GW availability frequency	Score of 0–1 Surplus amount in all 6 decades – 1; Surplus amount in 4 or 5 decades – 0.75; Surplus amount in 2 or 3 decades – 0.50; Surplus amount in 1 decade – 0.25; No surplus amount - 0	Draft DB22
Ground_Duration	0.3	Excess GW availability duration	Score of 0–1 MAG available (after WMS) 2020–2070 period. 5-6 consecutive decades – 1 4 consecutive decades – 0.75 3 consecutive decades – 0.5 2 consecutive decades – 0.25 No consecutive decades – 0	Draft DB22
Ground_Volume	0.3	Excess GW availability volume	Score of 0–1 Minimum MAG (after WMS) over 2020–2070. Available supply > 35,000 acft/yr – 1 Available supply between 15,000 and 35,000 acft/yr – 0.75 Available supply between 2,500 and 15,000 acft/yr – 0.5 Available supply between 500 and 2,500 acft/yr – 0.25 Available supply < 500 acft/yr – 0	Draft DB22
Ground_WQ	0.1	GW_WQ	Score of 1 (assumes low level of treatment required for groundwater)	Draft DB22
Ground_Score	---	Excess GW supply composite score	Score of 0–1	

Draft DB22 = TWDB draft State Water Planning Database; MAG = modeled available groundwater; WMS = water management strategy; acft/yr = acre-feet per year

Three feature classes (one for each excess water source) were compiled into a geodatabase at grid-level resolution coinciding with the hydrogeological parameter screening. For the surface water and reclaimed water sources, point data was used to calculate the availability composite score within a grid cell based on the volume, frequency, and duration parameters of the excess water source. For groundwater sources, polygon data for each major and minor aquifer supply were clipped to grid to calculate grid cell scores.

Figure 9 provides the general framework of the excess water screening and the level in which availability of excess water sources is scored.

The detailed methodology used to identify and score each excess water source is included in Appendix D of the contracted report.



Note: The orange highlights indicate the level at which availability of excess water sources is scored.

Figure 9. Framework of excess water screening

Excess surface water

Methodology

Surface water in Texas is owned by the state and is defined by Texas Water Code Section 11.021 to be the ordinary flow, underflow, and tides of every flowing river, natural stream, and lake and of every bay or arm of the Gulf of Mexico. Surface water also includes the stormwater, floodwater, and rainwater of every river, natural stream, canyon, ravine, depression, and watershed. The TCEQ administers water rights and regulates the use of surface water in Texas. HB 720 of the 86th Texas Legislature recognizes aquifer recharge as a beneficial use of state water and further authorizes the TCEQ to appropriate state water, which includes stormwater and floodwater, for aquifer recharge. The methodology used to identify and score the availability of excess surface water, was developed to be consistent with State law (including HB 720) and with current practices for appropriation of state water in Texas.

The excess water screening considers surface water available for ASR or AR from surplus surface water that is already appropriated to water users under existing water rights and is unutilized. This screening also considers water from unappropriated streamflow (excess streamflow, including stormwater and floodwater, available after all surface water that is appropriated to existing water rights and after downstream TCEQ-adopted environmental flow standards have been satisfied). Additionally, the screening identifies locations of existing reservoir storage that could be used to create excess surface water through reservoir operations, such as by overdrafting a portion of the stored water from conservation or flood storage for aquifer recharge. Although reservoir operations have the potential to create excess surface water supply, explicit accounting of such supply was beyond the scope of the survey.

Surplus appropriated surface water available from reservoir and run-of-river sources is the amount of supply remaining after accounting for current demands and recommended water management strategies from the draft DB22 and is therefore considered unutilized and available. Since these supplies are currently appropriated, it is a challenge to predict how the legal water right user would operate during non-drought of record conditions. A one-size-fits-all assumption for non-drought conditions is not appropriate and prone to error at a statewide screening scale by overestimating supplies that may not be available, especially when supplies are operated as part of a multi-source system. In an absence of this information, drought of record conditions were considered the most appropriate for this excess supply opportunity consistent with regional water planning and the draft DB22 database. Data from the draft DB22 database is available on an annual volume basis and only at the county level. As a result, the county-level data was converted to point locations at the centroid of reservoirs or the centroid of the longest stream reach within a county for run-of-river sources.

The TCEQ evaluates the availability of unappropriated streamflow for water right permit applications using its water availability models (WAMs). To be consistent with current practice for appropriating state water in Texas, the contract team applied the WAMs to estimate the monthly availability of unappropriated streamflow, which includes stormwater and floodwater. This approach considers the availability of excess unappropriated streamflow during non-drought and drought conditions at point locations throughout the state. The method for evaluating unappropriated streamflow is the most complex analysis for excess water in this survey. It involves analyzing water rights and environmental flows at multiple locations within a basin using approved WAMs for consistency with how water rights are administered in Texas. In cases where WAMs have not been updated to reflect adopted instream and freshwater flow standards, the contract team developed a method for this survey to account for environmental flows to avoid overestimating water availability for ASR or AR. Additional detail on the method is included in Appendix D of the contracted report.

Previous excess surface water availability analyses quantified the daily floodwater (≥95th percentile of daily discharge) volume at the outlet of 10 major river basins in Texas and evaluated the availability of streamflow based on the volume, frequency, and duration of the occurrence of flood flows (Yang and Scanlon, 2019). The evaluation of available unappropriated streamflow in this survey builds upon the previous analysis by also considering the availability of unappropriated streamflow outside of flood events and at locations throughout the major river and coastal basins of Texas. In comparing Yang and Scanlon's study with this survey, the following observations were noted:

- The annual floodwater volume aggregated from daily volumes in Yang and Scanlon's study is less than unappropriated streamflow volume simulated during this survey based on TCEQ WAM analyses at 8 out of 10 outlet gages, meaning that most of those floodwaters were not appropriated over the period of 1940 to 1988 (WAM simulation period).
- At the outlets of Nueces, San Antonio, Lavaca, Colorado, and San Jacinto river basins, the annual floodwater volume is close to the annual unappropriated flow volume from WAM simulations, and the total floodwater volume is at least 50 percent of the total unappropriated flow volume, suggesting that the annual volume of unappropriated flow used in this survey is a good proxy for the annual volume of floodwater in these basins.
- At the outlets of other basins, floodwater only represented a small portion of the unappropriated flow. For areas of greater stakeholder interest, a quantification of surface water availability during storms, especially regarding duration and frequency, would require a daily time step WAM, which is beyond the scale of this survey.

The excess water screening identifies existing reservoir storage locations; however, the ability to overdraft the conservation pool and use the flood pool of a reservoir was not explicitly included in the model. Such analysis would need to consider each reservoir individually and the limitations of the existing water rights associated with the reservoir and current demand on it, which may result in excess water that is different from what was calculated as the reservoir supply.

Assumptions, challenges, and limitations

Key assumptions and challenges for the surface water component included in the excess water screening include the following:

- Monthly availability timestep—TCEQ WAM analyses used for permitting are typically performed on a monthly timestep. Analyses could be performed to evaluate excess water availability on a daily timestep; however, such analyses would need to be done at numerous locations within each basin and would require a substantial effort to consider existing water rights and environmental flow standards. Thus, evaluating excess water availability on a daily timestep is impractical on a statewide basis. An example daily streamflow availability assessment could be conducted to provide a framework for water user groups and project sponsors to consider when determining excess water availability for a deeper, site-specific analysis of ASR/AR feasibility. Such daily timestep information would also identify non-drought times when more water could be available. Native data compiled on a monthly basis is aggregated on an annual basis (acre-feet per year) for volume and duration parameters for the screening to be consistent with surplus appropriated surface water and excess groundwater units. This method provides uniformity in evaluating excess supplies.

- Consideration of TCEQ instream flow standards—Most of the WAMs include the TCEQ instream flow standards in the river basins in which they have been adopted. However, a few of the WAMs do not include some or all of the standards (Table 15). For these locations, the adopted base flow requirements were added to the WAMs at gage points in the Colorado, Guadalupe-San Antonio, Nueces, Rio Grande and a few coastal basins (Appendix D of the contracted report). Adding pulse flow requirements would be a substantial effort and is impractical for this application. For river basins where TCEQ standards have not been adopted, the TCEQ determines the instream flow requirements for a new permit on a case-by-case basis, and the default method used by the TCEQ is the Lyons Method (Bounds and Lyons, 1979). For consistency with current TCEQ permitting procedures, the contract team selected the Lyons Method for considering instream flow requirements in river basins without adopted standards as opposed to the Consensus Criteria for Environmental Flow Needs (CCEFN) method used by the TWDB for regional and state water planning. The Lyons Method instream flow criteria was added to the WAMs in 11 locations **(**Appendix D of the contracted report). An additional parameter is included in the unappropriated streamflow point feature as a placeholder to calculate scores in future work considering CCEFN. In all basins, including those with adopted TCEQ standards, instream flow requirements that are included as special conditions in water right certificates of adjudication or permits are in most cases already included in the WAMs.

- Consideration of TCEQ freshwater inflow standards—TCEQ freshwater inflow standards are long-term statistics (as opposed to instream flow standards that are daily average flow criteria). Compliance with these standards is determined by simulating a project in the WAM with specific storage, diversion capacity, and volume, etc. and then determining whether the long-term freshwater inflow statistics were reduced below the criteria or, in some cases, significantly reduced from the baseline simulation without the project. As a result, freshwater inflow standards cannot be modeled in the WAM similar to TCEQ-adopted instream flow standards and must be done through post processing of WAM output for each specific project. It is impractical to simulate every potential project to consider the effect of freshwater inflow standards on surface water availability. To account for these standards, a parameter was included in the scoring screen based on the distance of available unappropriated streamflow from the coast, with the understanding that streamflow locations closer to the coast would most likely be subject to freshwater inflow standards when water rights applications are filed.

- The operation of water treatment facilities to treat available excess surface water for ASR using seasonal excess treatment capacity was considered for the screening but was not included due to the absence of a publicly available database containing such information.

- Water generated as runoff from impervious cover temporarily impounded in stormwater detention facilities and/or permanently impounded in water quality ponds on a site-specific basis is not explicitly addressed in this screening. Attempts to parse and segregate components of runoff based on impervious cover or theoretical interpretations of diffused water definitions is exceedingly labor intensive and does not serve a clear purpose in terms of quantifying excess state water potentially available for appropriation by the TCEQ for aquifer recharge pursuant to HB 720.

- The analyses required to quantify the ability to overdraft and use the flood pool of each reservoir location is not practical for this screening process. Therefore, existing reservoir point locations and storage volume are used to estimate the availability of this potential supply source rather that quantify excess supply opportunities.

- Permits will need to be obtained from TCEQ for surface water supplies identified to be eligible for project use.

Table 15. Summary of basins with TCEQ environmental flow standards

River or coastal basin	Instream flow standards		Freshwater inflow standards	
	Adopted in basin	Included in WAM	Adopted in basin	Included in WAM
River basins				
Brazos	Yes	Yes	Yes	No
Canadian	No	---	No	---
Colorado	Yes	Partial	Yes	No
Cypress	No	---	No	---
Guadalupe-San Antonio	Yes	Partial	Yes	No
Lavaca	Yes	Yes	Yes	No
Neches	Yes	Yes	Yes	No
Nueces	Yes	No	Yes	No
Red	No	---	No	---
Rio Grande	Yes	Partial	Yes	No
Sabine	Yes	Yes	Yes	No
San Jacinto	Yes	Yes	Yes	No
Sulphur	No	---	No	---
Trinity	Yes	Yes	Yes	No
Coastal basins				
Brazos-Colorado	Yes	No	No	---
Colorado-Lavaca	Yes	No	Yes	No
Lavaca-Guadalupe	Yes	Yes	Yes	No
Neches-Trinity	No	---	No	---
Nueces-Rio Grande	Yes	No	No	---
San Antonio-Nueces	Yes	No	Yes	No
San Jacinto-Brazos	No	---	No	---
Trinity-San Jacinto	No	---	No	---

NOTE: TCEQ rules state that the Sabine-Neches, Brazos, and Rio Grande estuaries are sound ecological environments that can best be maintained by a set of flow standards that implement a schedule of flow quantities containing subsistence flow, base flow, and high flow pulses at defined measurement points. Defined measurement points in the rules for these basins do not include the associated estuaries.

TCEQ = Texas Commission on Environmental Quality; WAM = water availability model

Data sources

The data sources that were used to estimate excess surface water include the following:

- TCEQ WAM Run 3 (full authorization and no return flows)
- TCEQ WAM Control Point Geodatabase
- Draft DB22
- TWDB Water Data for Texas.

Data gaps

The data gaps identified during the excess surface water analysis include the following:

- For surplus appropriated surface water (reservoirs), 55 reservoirs with draft DB22 records did not have a corresponding match in the TWDB reservoir shapefile (online). Of these reservoirs, 15 of the 55 records showed excess water available during the 2020–2070 period. The 15 points were geospatially referenced on Google Earth and points added to the geodatabase.

- For surplus appropriated surface water (run-of-river), draft DB22 records were provided for basin and county only. The longest stream in the respective basin and county was identified and a point was placed at the centroid of the reach. The locations for appropriated surface water (run-of-river) could be refined in the future with additional details beyond the county and river basin level.

Excess reclaimed water

Reclaimed water in the form of treated wastewater effluent discharges is included separately as a potential surface water excess supply source in the screening evaluation, as these return flows are not included in the unappropriated streamflow analysis[1]. Treated wastewater effluent is owned by the entity producing the effluent until it is returned to a state watercourse. Once the treated effluent enters a state watercourse, the effluent becomes state water, is available to existing water rights, and subject to TCEQ-adopted environmental flow standards, unless the entity discharging the treated effluent owns a water use permit to convey the treated effluent using the bed and banks of a state watercourse. A comprehensive database of water use permits for the conveyance of treated effluent does not exist, nor do the TCEQ WAMs calculate excess treated effluent in a state watercourse. As a result, site-specific analyses would need to be performed to account for existing water rights and planned reuse projects, and the level of effort to perform such analyses at every reservoir location throughout the state is not practical for this screening process.

[1] The unappropriated streamflow analysis was based on TCEQ WAM Run 3 (full authorization and no return flows).

Methodology

Historical treated municipal effluent discharge data at point locations from the EPA Enforcement and Compliance History Online (ECHO) database was used to estimate the availability of the reclaimed water source. Discharge data included in the ECHO database is the amount of treated discharge that is returned to a watercourse after other existing uses, including direct reuse programs. The average annual discharge data[2] reported from 2015 to 2019 is considered representative of the current availability of the reclaimed water source. Future increases in treated discharge are projected to 2070 using approved county population estimates from draft DB22. ECHO discharge data for municipal users does not show significant variability throughout the year, as municipal discharges are generally the result of indoor water use. Outdoor irrigation, which results in higher summer water use, is not collected and treated and does not influence municipal discharges. As a result, the excess supply identified for reclaimed water is considered available during drought and non-drought conditions.

Data from the draft DB22 was initially considered for estimating excess reclaimed water used throughout the state. However, after reviewing additional information provided by the TWDB[3], it was determined that the planning data contained a combination of permitted discharge and self-reported used discharge values. Determining the percentage of permitted discharge used across the state would have required assessing monthly operational reports from each permit holder and was considered not feasible for the scale of this study. Future studies will need to investigate planning data from DB22 for site-specific information.

Assumptions, challenges, and limitations

Key assumptions and challenges for the excess reclaimed water component included in the excess water screening include the following:

- Available unappropriated streamflow calculations to estimate excess surface water used TCEQ Run 3 WAMs (no return flows). For this reason, ECHO discharge volumes can be considered available for reclaimed supply and excess water is not double counted.

- All ECHO discharge data from 2015 to 2019 was considered. Discharges associated with power generation and other industrial uses were not included in estimating excess reclaimed water. These discharges were excluded because, in most cases, the source water used for power generation and other industrial applications is surface water that is diverted from a stream or reservoir, used for power generation cooling or mining

[2] Average annual ECHO discharge data over a five-year period (2015–2019) ranged from 0 in Cass County to 700,770,000 acre-feet per year in Harris County.

[3] TWDB presentation by Simon Schmitz, Mickey Leland Intern, entitled "2016/2017 Reuse Data Patterns and Discrepancies, An Analysis of Data Reporting between TCEQ's Monthly Effluent Reports, the TWDB Water Use Survey, and Annual Report".

activities, and then returned to the surface water source. These water management activities are typically simulated in a simplified manner in the WAMs. Considering these discharges in the excess reclaimed water availability category would effectively be double-counting available excess supply for ASR and AR. Additionally, industrial discharge often has lower water quality than desirable for ASR or AR purposes.

- Planning data was ultimately not used as the basis for evaluating excess reclaimed water availability; however, it is recognized that some planning groups have included reclaimed water "reuse" as a future recommended water management strategy.

- Reclaimed water quality is assumed to require more treatment than surface water and groundwater, except for sources noted as brackish in the draft DB22. High total suspended solids (TSS) in reclaimed water is often an indication of the presence of bacteria, which could require advanced treatment for quality to be suitable for ASR. Additional water quality discussion is provided in the Scoring section below.

Data sources

The data sources that were used to estimate excess reclaimed water include the following:

- TCEQ Texas Pollutant Discharge Elimination System (TPDES) Geodatabase
- EPA ECHO database
- TWDB county population projections

Data gaps

The data gaps identified during the excess reclaimed water analysis include the following:

- Basin and/or statewide reclaimed WAMs.

- EPA ECHO database included 108 records that could not be matched to TPDES discharge locations from the TCEQ. These points were excluded from the excess water screen because they could not be readily spatially located.

Excess groundwater

There are 31 major and minor aquifers in Texas. Local groundwater conservation districts and groundwater management areas have been created to manage these aquifer systems. The districts have authority to issue permits to achieve desired future conditions, such as maximum drawdown conditions or maintaining spring flow, which are established within the management areas. These desired future conditions are adopted by the local groundwater conservation districts and groundwater management areas and provided to the TWDB, which in turn simulates desired future conditions in the respective GAM to develop modeled available groundwater estimates.

Modeled available groundwater is an estimate of the groundwater pumping that can be afforded while preserving the aquifer's desired future condition and is used as a proxy for groundwater availability in the state water plan. For water planning purposes, regional water planning groups are required to constrain groundwater availability according to the modeled available groundwater. For areas where desired future conditions have not been adopted and modeled available groundwater has not been developed, planning groups have the discretion to prepare groundwater availability estimates that are not based on modeled available groundwater.

The draft DB22 identifies surplus modeled available groundwater, non-modeled available groundwater, and partial modeled volumes that are considered available from 2020 to 2070 after accounting for current use and future recommended water management strategies. This information is presented on the county-river basin level for each aquifer for which modeled available groundwater was developed or the supply determined by planning group methods.

Methodology

The draft DB22 database identifies groundwater availability (note this term includes modeled available groundwater and region-determined availability) surplus from 2020 to 2070 after accounting for current groundwater use and future recommended water management strategies. To support the regional water planning process and avoid double-counting, excess groundwater for potential ASR and AR projects is estimated to be the amount remaining from modeled available groundwater, non-modeled available groundwater, and partial modeled available groundwater values *after* accounting for recommended water management strategies identified in the draft DB22. The TWDB provided a draft DB22 spreadsheet with this data to the contractor for use in the screening.

Each excess groundwater supply and aquifer and county and river basin combination was clipped to the grid level coinciding with the hydrogeological parameter screening grid for the 31 major and minor aquifers. Several planning groups classified groundwater from non-major or minor aquifers considered "Other Aquifers." However, supplies from Other Aquifers, which amounted to 3 percent of the total excess groundwater identified in the draft DB22, were not included in the screening for two reasons: (1) the TWDB screening focuses on major and minor aquifers, and (2) lack of geographical data regarding the location of these other aquifer units needed to clip to grid cells with accuracy.

Because groundwater conservation districts may manage groundwater production differently based on variable factors, it is challenging to predict how groundwater users would operate during non-drought of record conditions, including seasonal use patterns that may offer excess water opportunities when water use pumping is low. A one-size-fits-all assumption for non-drought conditions is not appropriate and may conflict with district management in addition to being prone to error at a statewide screening scale by overestimating supplies that may not be available, especially when supplies are operated as part of a managed system. In the absence of this information, only drought of record conditions are considered in evaluating this excess supply opportunity consistent with regional water planning and the draft DB22.

Assumptions, challenges, and limitations

The key assumptions and challenges for the excess groundwater component include the following:

- Groundwater surplus identified in the draft DB22 is considered excess water available for ASR or AR. Furthermore, the draft DB22 database categorizes general water quality according to fresh, brackish (some dissolved solids), or saline, which was used by the scoring screen to assess treatment level. This water quality designation is general at the county and river basin level and may vary considerably based on site-specific conditions encountered.

- There may be additional groundwater supply opportunities for ASR beyond those included in modeled available groundwater projections and other groundwater supplies considered during the regional water planning process. Due to the timeline and data gaps in this information, these additional groundwater supplies are not included in the screening. When data becomes available, future versions of the screening can be adapted to include such information.

Data sources

The primary data source used to estimate excess groundwater was the draft DB22 database.

Data gaps

The data gaps identified during the excess groundwater analysis include the following:

- Groundwater availability in areas where no modeled available groundwater was identified during the groundwater conservation district's process nor estimated by regional water planning groups.

- Water supplies from "Other Aquifer" systems identified in the draft DB22 were not included in the excess water evaluation due to the lack of more detailed information at a more refined level than county and river basin.

- Spatial information on "Other Aquifer" systems by which groundwater supplies have been quantified on a county/basin level through the regional water planning process.

Scoring

Table 16 lists the parameters, weighting, and scale included in the excess water screening for surface water, reclaimed water, and groundwater as discussed previously in Table 12 through Table 14. Additional details regarding the scoring of parameters for surface water sources are presented in Table 17. The frequency, volume, and duration parameters each carry an equal weight of 30 percent, with the water quality parameter contributing the remaining 10 percent of the composite score for each surface water source. Each parameter receives a score ranging from 0 to 1 in the screening and is then weighted accordingly. A detailed methodology used for calculating and scoring the availability of excess water for each of the identified surface water sources, reclaimed water, and groundwater is detailed in Appendix D of the contracted report. The data used in calculating the excess water scores was compiled in a separate geodatabase and used as a precursor for developing the grid-level geodatabase to preserve data integrity for future updates. At the grid level, the excess water scores are compiled and normalized to calculate the Final Suitability Rating described later in this report.

Table 16. Weighting of availability parameters

	Frequency	Volume	Duration	Water quality
Weight	0.30	0.30	0.30	0.10
Scale	0 (low) 1 (high)	0 (low) 1 (high)	0 (low) 1 (high)	0 (high TDS, high TSS) 1 (low treatment)

TDS = total dissolved solids; TSS = total suspended solids

The excess water volume parameter was scored consistently amongst all supply categories, with scoring breaks to capture a range of sizes for potential AR and ASR projects. Based on industry experience, water supplies that provide less than 500 acre-feet per year are unlikely to be cost-effective for ASR and AR projects. As a result, if an excess water supply volume did not exceed that amount, the volume, frequency, and duration parameters received a score of zero.

Excess water supplies that ranged between 500 and 2,500 acre-feet per year were assigned a volume score of 0.25; between 2,500 acre-feet per year and 15,000 acre-feet per year a score of 0.5; between 15,000 and 35,000 acre-feet per year a score of 0.75; and supplies exceeding 35,000 acre-feet per year a score of 1. While this screening does not take the place of site-specific evaluations, the above ranges were identified with small- to mid-sized utilities in mind and provides flexibility according to system needs. The above intervals also recognize that if excess supplies are available for multiple years in a row, storage capacity could increase (subject to hydrogeological favorability) to provide prolonged supplies during extreme, multi-year drought conditions. The upper end (35,000 acre-feet per year) is scaled for larger utility projects. For instance, if a utility is primarily considering ASR for drought protection and excess supplies of 35,000 acre-feet per year are available for multiple years during an average or rainy condition, then after 5 years the storage capacity could be nearly 200,000 acre-feet per year. The same scoring intervals are used for screening water supply needs.

Table 17. Scoring matrix for excess surface water

<table>
<tr><th>Weight</th><th colspan="2">---</th><th>0.30</th><th>0.30</th><th>0.30</th><th>0.1</th></tr>
<tr><th>---</th><th colspan="2">Category</th><th>Frequency</th><th>Volume</th><th>Duration</th><th>Water quality indicator</th></tr>
<tr><td>1.00</td><td colspan="2">Surplus appropriated surface water (reservoirs and run-of-river)</td><td>• No surplus amount – 0
• Surplus amount in 1 decade – 0.25
• Surplus amount in 2 or 3 decades – 0.50
• Surplus amount in 4 or 5 decades – 0.75
• Surplus amount in all 6 decades – 1</td><td>• Average decade surplus amount (2020–2070) < 500 acft/yr – 0
• Average decade surplus amount (2020–2070) between 500 and 2,500 acft/yr – 0.25
• Average decade surplus amount (2020–2070) between 2,500 and 15,000 acft/yr – 0.50
• Average decade surplus amount (2020–2070) between 15,000 and 35,000 acft/yr – 0.75
• Average decade surplus amount (2020–2070) > 35,000 acft/yr – 1</td><td>• No consecutive decades – 0
• 2 consecutive decades – 0.25
• 3 consecutive decades – 0.5
• 4 consecutive decades – 0.75
• 5-6 consecutive decades – 1.0</td><td>• High treatment level (bacteria, high TDS, cl, TSS, low DO) – 0
• Conventional treatment (SW) – 0.5 <most likely>
• Low treatment level (low TDS, fresh GW) – 1</td></tr>
<tr><td rowspan="3">1.00</td><td rowspan="3">Available unappropriated streamflow</td><td rowspan="2">WAM unappropriated streamflow weight (0.90)</td><td rowspan="2">Percentage of months with available flow:
*The actual percentage is the score, i.e. if a point has available flow in 36% of the months then the score is 0.36</td><td rowspan="2">• Median annual volume is < 500 acft/yr (30th percentile) - 0
• Median annual volume is between 30th (500 acft/yr) and 45th (2,500 acft/yr) percentile – 0.25
• Median annual volume is between 45th (2,500 acft/yr) and 60th percentile (15,000 acft/yr) – 0.5
• Median annual volume is between 60th (15,000 acft/yr) and 75th percentile (35,000 acft/yr) – 0.75
• Median annual volume is greater than 75th percentile (35,000 acft/yr) – 1</td><td>Max consecutive years with available flow greater than the median
* Less than 5 years – 0
* 5 years or more – 0.5</td><td rowspan="3">• High treatment level (bacteria, high TDS, cl, TSS, low DO) – 0
• Conventional treatment (SW) – 0.5 <most likely>
• Low treatment level (low TDS, fresh GW) – 1</td></tr>
<tr><td>Max consecutive years with available flow less than the median
* More than 8 years – 0
* 8 years or less – 0.5</td></tr>
<tr><td>FWI consideration weight (0.10)</td><td>Straight line distance from coast x2
*Less than 50 miles – 0
*50 miles–100 miles – 0.25
*100 miles–150 miles – 0.5
*150 miles–200 miles – 0.75
*greater than 200 miles – 1</td><td>Straight line distance from coast x2
*Less than 50 miles – 0
*50 miles–100 miles – 0.25
*100 miles–150 miles – 0.5
*150 miles–200 miles – 0.75
*greater than 200 miles – 1</td><td>Straight Line Distance from Coast x2
*Less than 50 miles – 0
*50 miles–100 miles – 0.25
*100 miles–150 miles – 0.5
*150 miles–200 miles – 0.75
*greater than 200 miles – 1</td></tr>
<tr><td>1.00</td><td colspan="2">Existing reservoir storage</td><td>* No storage or storage less than 5,000 acft – 0
*Storage greater than 5,000 acft – 1</td><td>*0-5,000 acft – 0
*5,000–100,000 acft – 0.5
Greater than 100,000 acft – 1</td><td> No storage or storage less than 5,000 acft – 0
*Storage greater than 5,000 acft – 1</td><td>• High treatment level (bacteria, high TDS, cl, TSS, low DO) – 0
• Conventional treatment (SW) – 0.5 <most likely>
• Low treatment level (low TDS, fresh GW) – 1</td></tr>
</table>

WAM = water availability model; FWI = Freshwater Inflows; acft/yr = acre-feet per year; SW = surface water; GW = groundwater; TDS = total dissolved solids; TSS = total suspended solids; DO = dissolved oxygen; cl = chloride

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The frequency and duration parameters were evaluated using specific criteria for each excess supply source to accommodate the varying timestep of source data. For instance, the TCEQ WAMs were applied to calculate the availability of unappropriated surface water on a monthly timestep, while the availability of groundwater is evaluated on an annual timestep. An exception to this is for existing reservoir storage sources, which used frequency and duration parameters to identify reservoirs exceeding 5,000 acre-feet in size. Scoring criteria for the frequency and duration parameters for each excess water category is described in Table 12 through Table 14.

A water quality score is also included in the excess water screening to generally recognize different treatment levels that may be needed to use excess water sources. Water quality was categorized according to three levels of treatment: "high" treatment level (bacteria, high total dissolved solids, chloride, total suspended solids, low dissolved oxygen), "conventional" treatment (most likely treatment for surface water), or "low" treatment level (low total dissolved solids). Reclaimed water typically requires high treatment level, whereas fresh groundwater likely requires much less treatment. The statewide screening presents water quality at a very cursory level, as this survey is not intended to replace site- and system-specific water quality evaluations that are needed to understand source water compatibility, blending, and/or specific water quality parameter interaction before combining with existing supplies or systems (see Final Suitability Rating). As a result, scoring the water quality parameter is based on the source of the excess supply, with groundwater sources receiving a score of 1, surface water sources receiving a score of 0.5, and reclaimed water sources receiving a score of 0. A site- and project-specific feasibility study will incorporate fatal-flaw considerations, like water compatibility, that this survey cannot provide at the statewide level.

A full list of parameters that were considered in the excess water screening, including unappropriated available flow statistics compiled from WAM output but not included in the scoring, are detailed in tables in Appendix D of the contracted report, for use in a future phase of screening.

Results

Results of the excess water screening scores are presented in Figure 10 through Figure 17 for each of the three excess water categories (surface water, reclaimed water, and groundwater). These total scores were calculated from scores and weights according to criteria described above and in Appendix D of the contracted report. In general, results of the evaluation indicate excess surface water is the most widely available source for potential use in ASR and AR projects. However, if excess reclaimed water and groundwater sources are available, they generally receive a higher score compared to the excess surface water sources.

Excess surface water

Figure 10, Figure 11, and Figure 12 show the scoring results for the three excess surface water components (surplus appropriated surface water, unappropriated surface water, and existing reservoir storage). Results of the component scores show that surplus appropriated surface water is not widely available throughout the state, as most of this surface water component is already dedicated to meet existing water use demands or for future water management strategies. However, where available, the surplus appropriated surface water received higher scores due to the higher frequency and duration. Similarly, the availability of existing reservoir storage receives high scores where available due to high frequency and duration.

The scoring of the available unappropriated streamflow component generally reflects climatological conditions observed across the state, with wetter conditions in the eastern portion of the state resulting in higher scores, and drier conditions in the western portion of the state resulting in no availability. Limited availability is present in the Colorado Basin due to high levels of water management and existing appropriations resulting in limited available unappropriated water. The TCEQ Colorado and Sulphur WAMs contain an extended hydrologic period of 1940–2016 and 1940–2017 and include the recent drought conditions experienced across most of the state. Hydrologic periods included in the TCEQ WAMs for other basins do not extend past 1997 and do not include recent extreme droughts. As a result, the extended period of record in the Colorado and Sulphur basins could have lower availability statistics compared to the other basins.

Lower scores are also present in the Upper Trinity River Basin upstream of the reservoirs in the vicinity of the Dallas-Fort Worth Metroplex. Unappropriated streamflow is limited in these areas because most of the surface water is already appropriated for impoundment and use from the reservoirs. The component scores are summed and capped at one to calculate the final excess surface water score that considers all three sources, shown in Figure 13**.**

Similar to surplus appropriated surface water, the availability of existing reservoir storage receives high scores where available due to high frequency and duration.

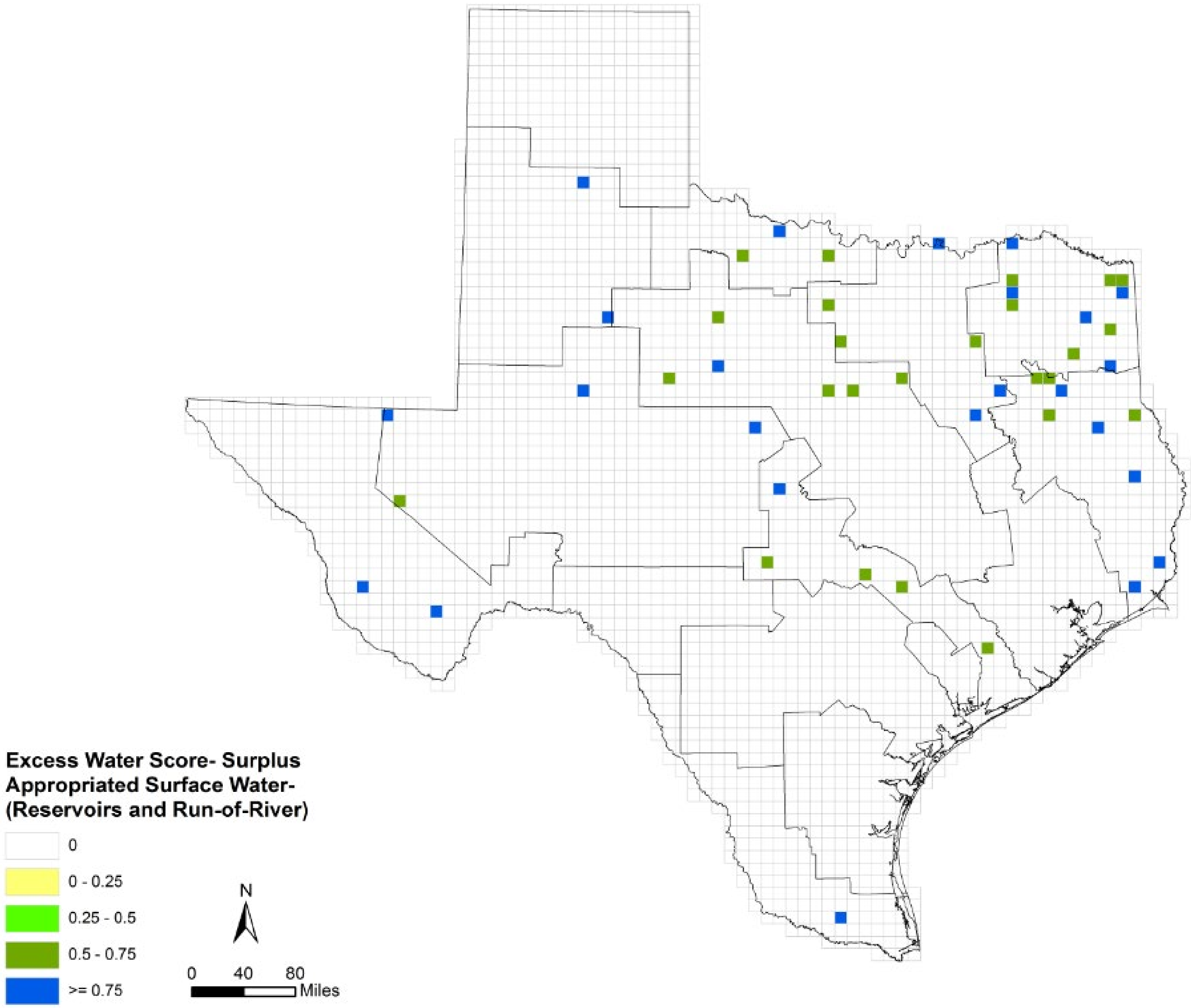

Figure 10. Excess surface water component scoring results: Surplus appropriated surface water

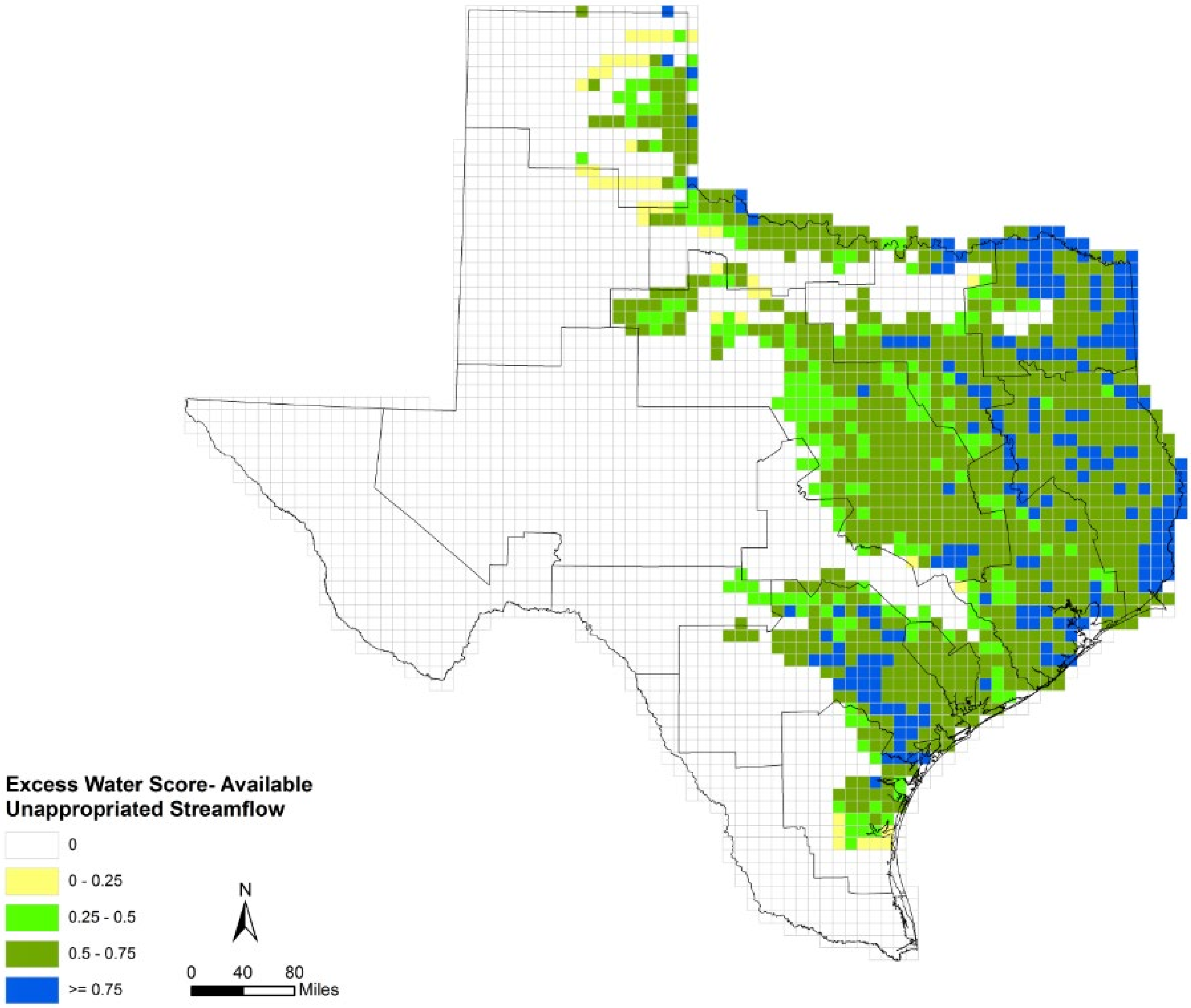

Figure 11. Excess surface water component scoring results: Available unappropriated streamflow

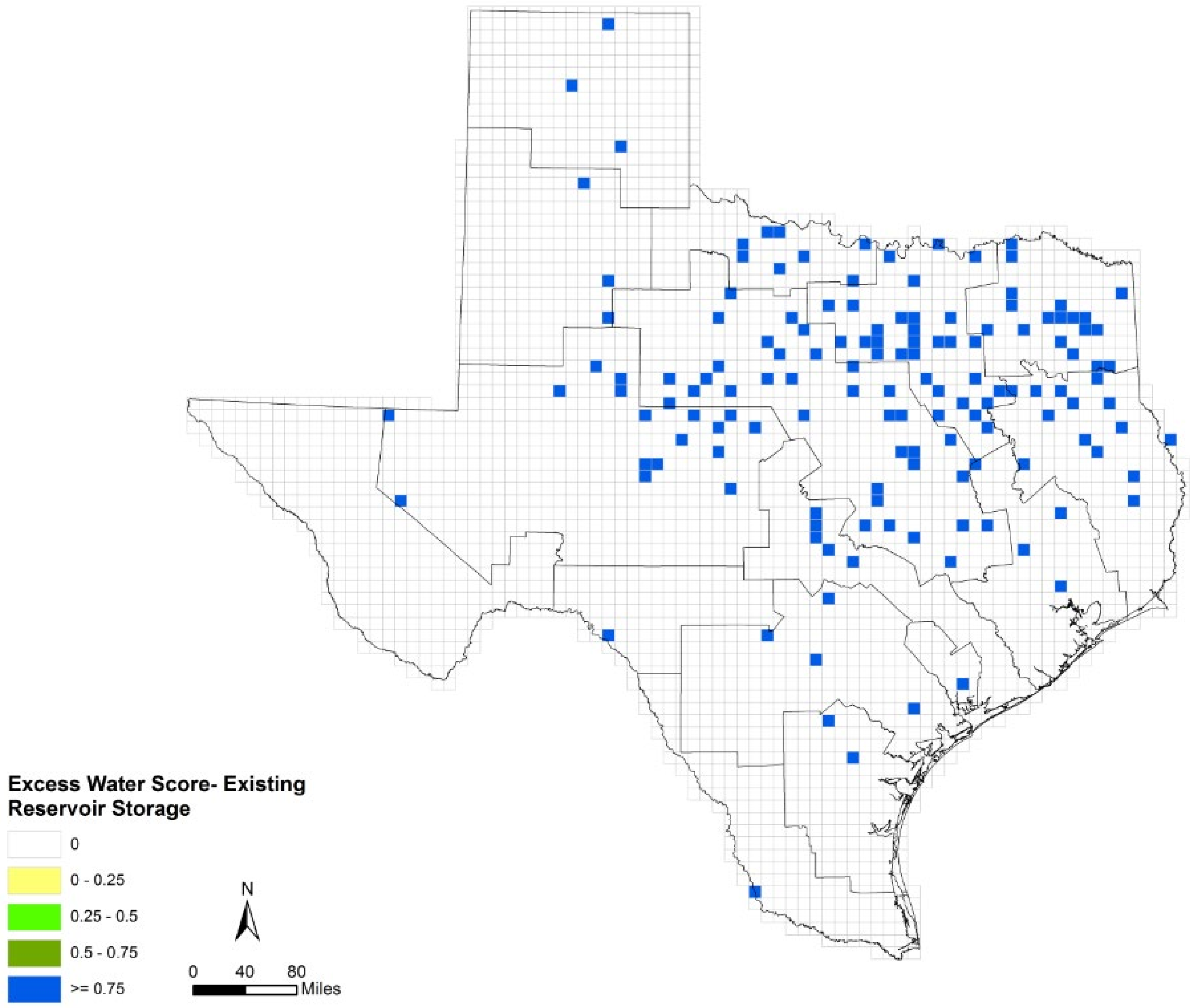

Figure 12. Excess surface water component scoring results: Existing reservoir storage

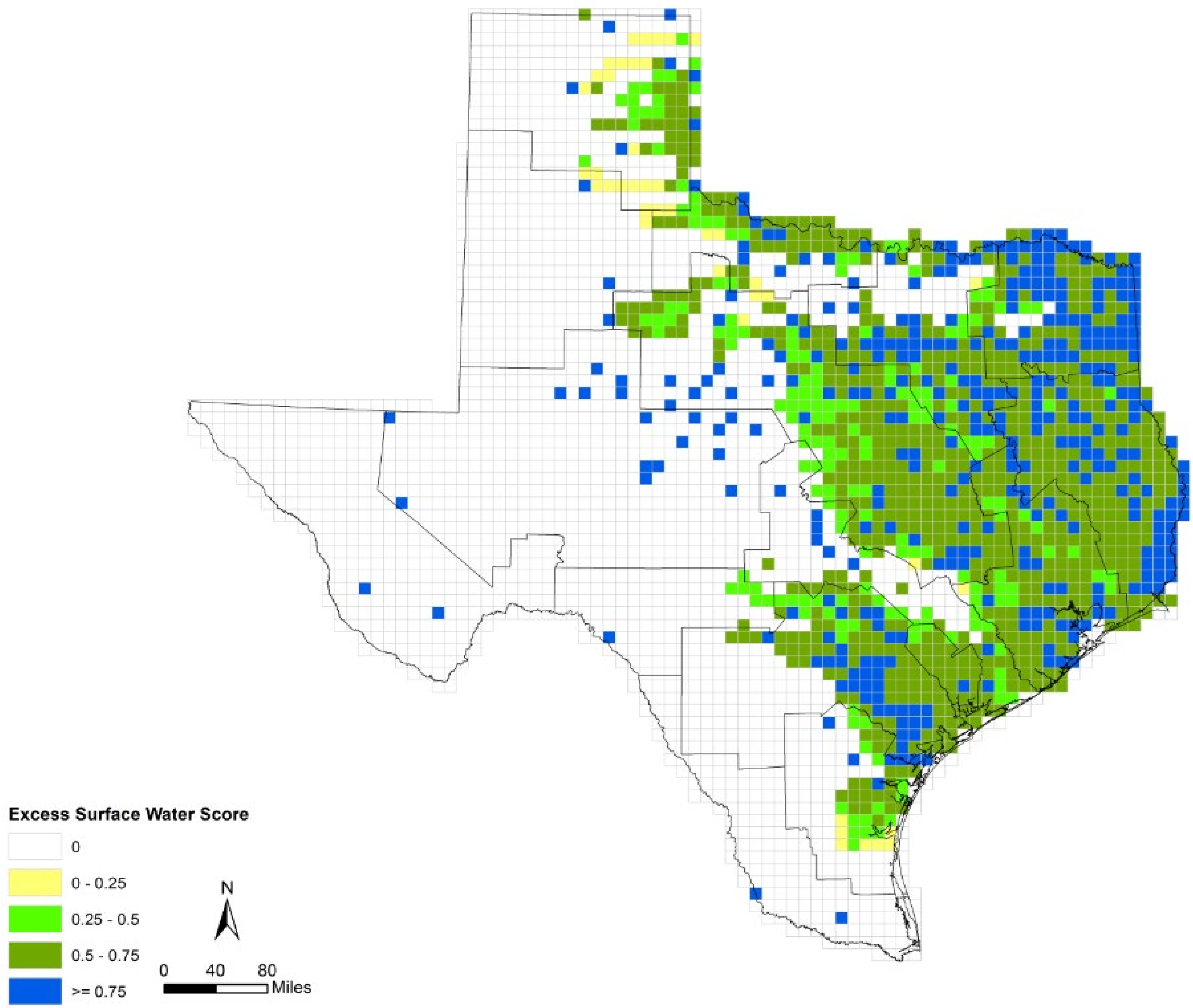

Figure 13. Excess surface water scoring results

Excess reclaimed water

Higher scores for reclaimed water are focused near the larger metropolitan areas where larger wastewater effluent discharges are present (Figure 14). The scores also reflect the high reliability of the excess reclaimed water source by receiving a generally high score if wastewater discharges are present.

Excess groundwater

The largest volume of excess groundwater supplies from major aquifers include the Ogallala and Seymour in the Panhandle area and Hueco-Mesilla Bolsons and Edwards Trinity-Plateau in West Texas, with minimum water balances exceeding 8,000 acre-feet per grid cell (Figure 15). For minor aquifers, the areas showing highest excess supply volumes include the Rita Blanca and Dockum in the Panhandle and the Queen City in East Texas, with water balances exceeding 1,500 acre-ft per grid cell (Figure 16). When excess water supplies from major and minor aquifers are combined to identify opportunities in areas with coinciding aquifers, high scoring areas are shown in the Panhandle, West Texas, and East Texas area north of Houston. Figure 17 shows the maximum excess groundwater score by grid cell.

Summary of excess water

The excess water scores for the three source categories were combined in a final excess water grid in areas where multiple excess water supplies were present.

The excess water screening scores were categorized for each grid cell with excess supplies identified (Figure 18). Threshold values used for excess water divided suitability into classes of "low," "medium," and "high" as follows:

- Low: Excess water score < 0.5
- Medium: Excess water score 0.5 to 0.7
- High: Excess water score > 0.7

About 14 percent of the grid cells (or 448) scored low suitability, 35 percent (or 1,115 cells) scored medium suitability, and 21 percent (or 677 cells) scored high suitability for excess water. The remaining 29 percent (or 920 cells) did not have excess water supplies.

The actual values were used in the Final Suitability Rating to evaluate ASR or AR project suitability.

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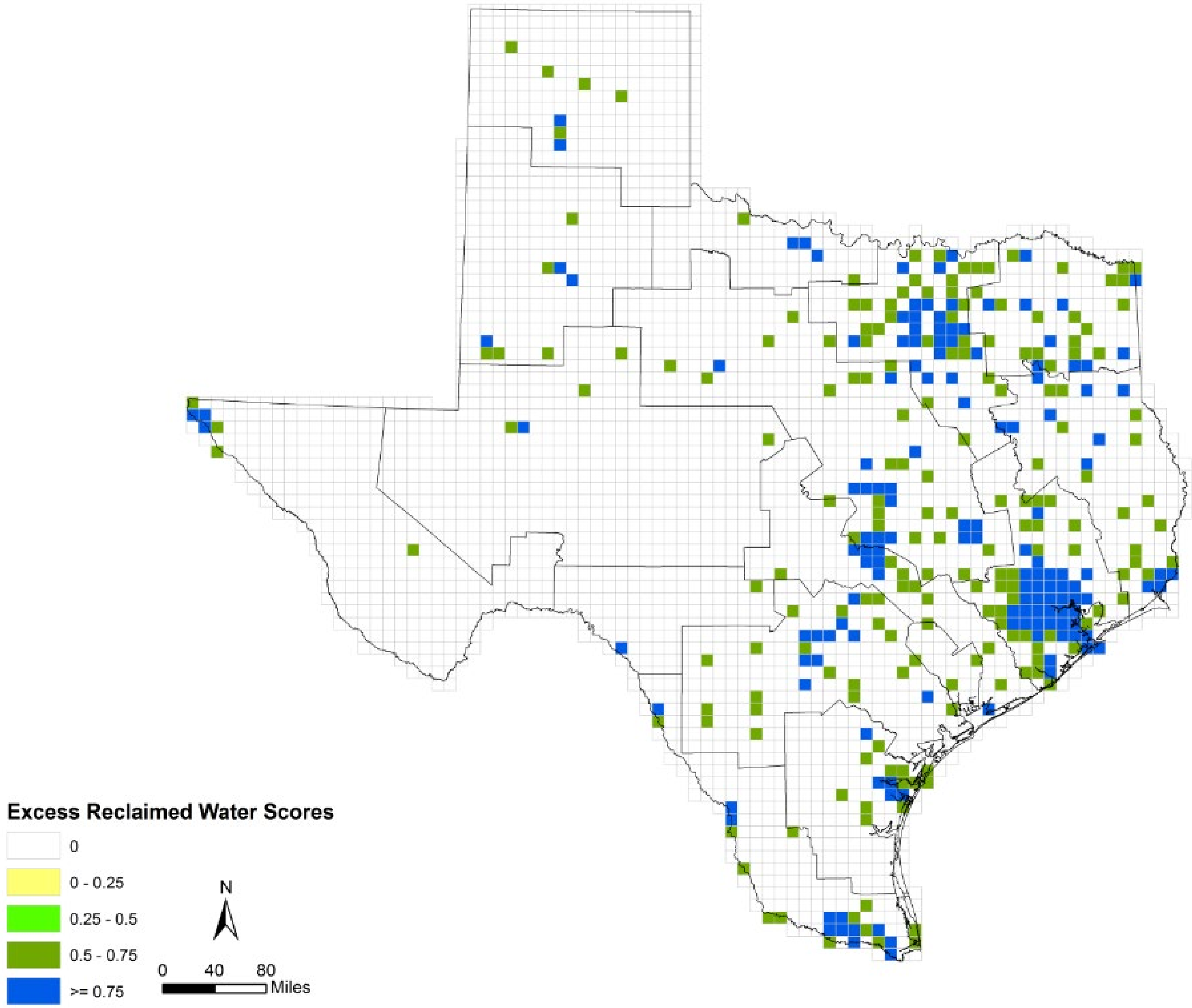

Figure 14. Excess reclaimed water scoring results

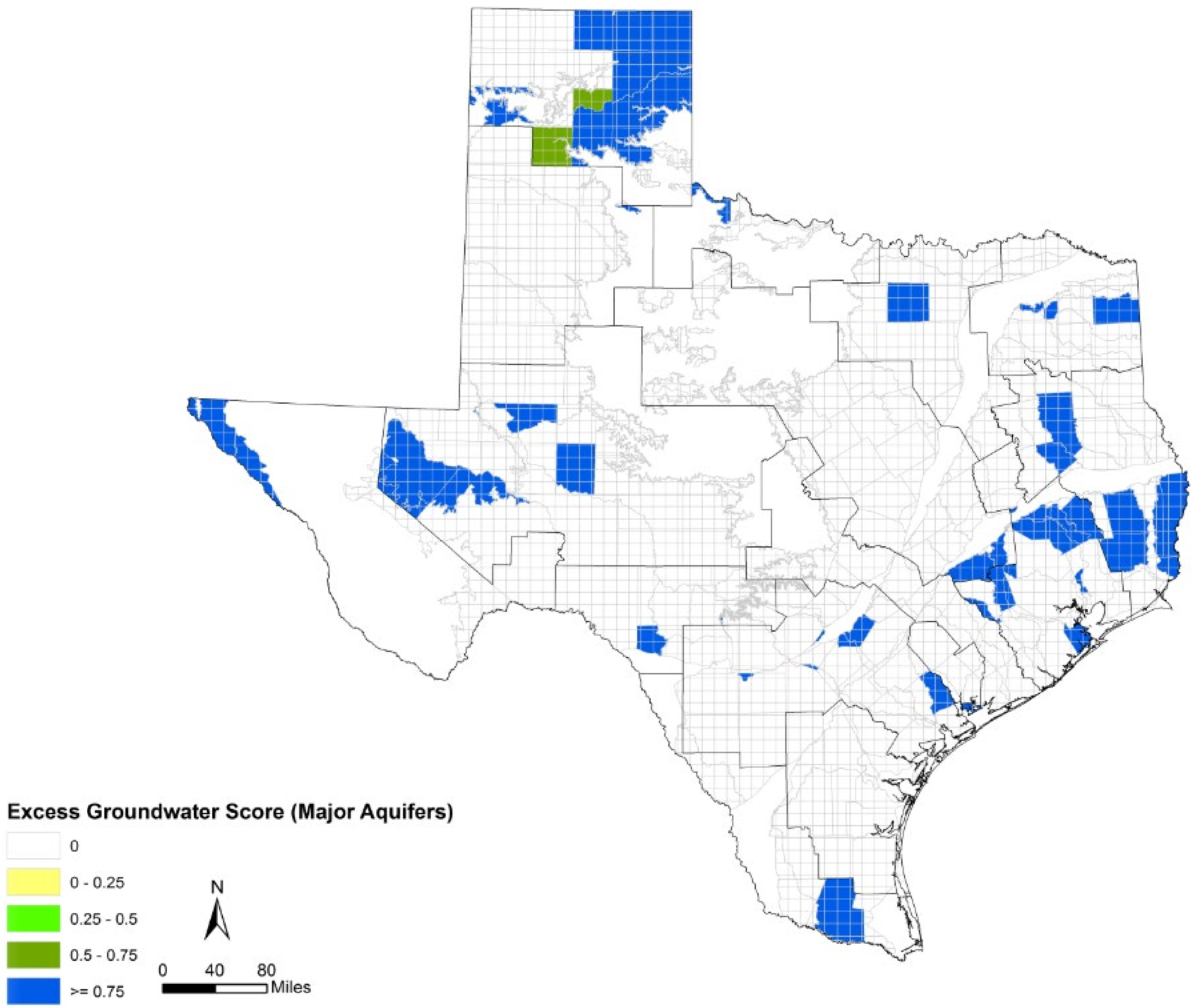

Figure 15. Excess groundwater scoring results for major aquifers

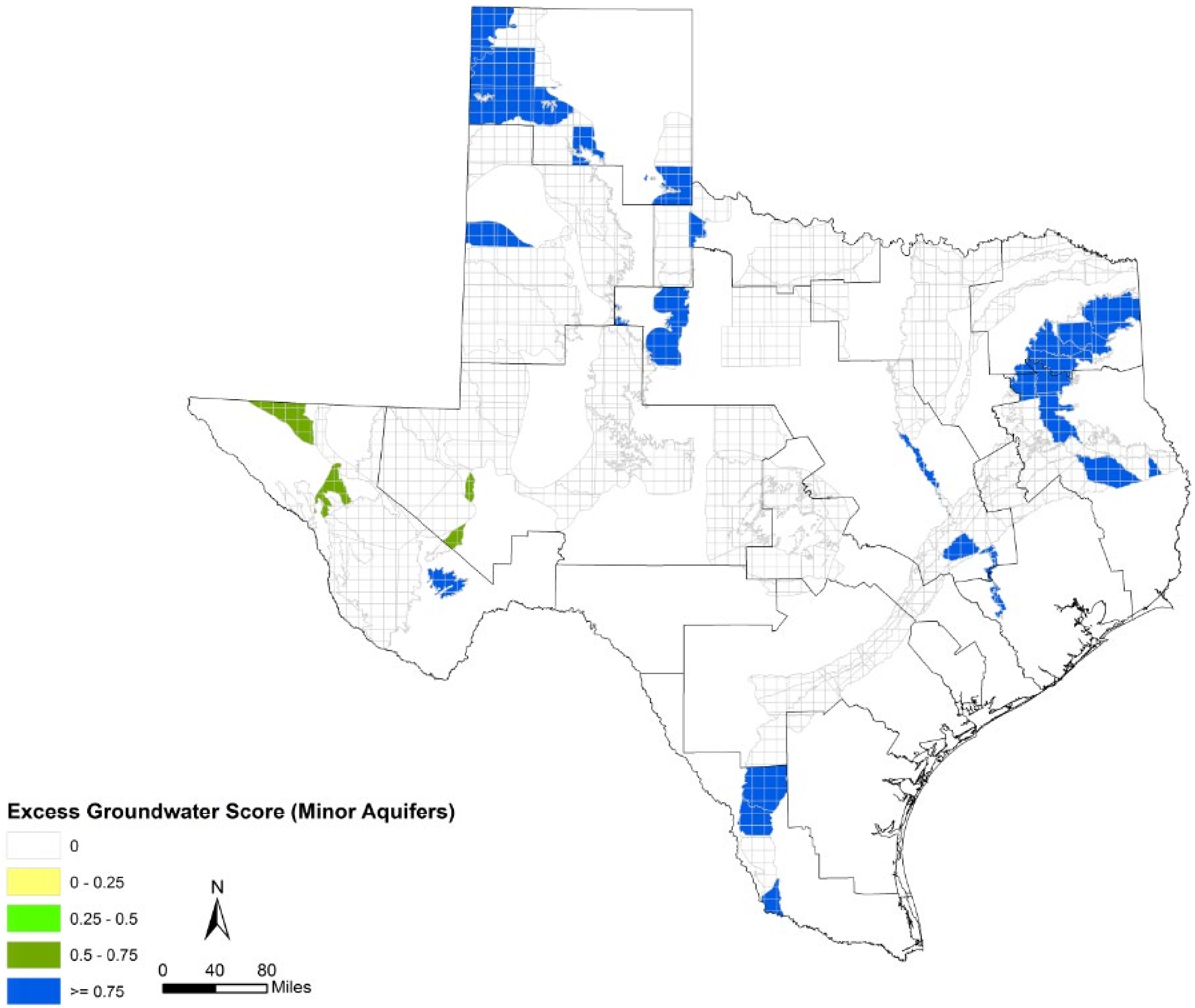

Figure 16. Excess groundwater scoring results for minor aquifers

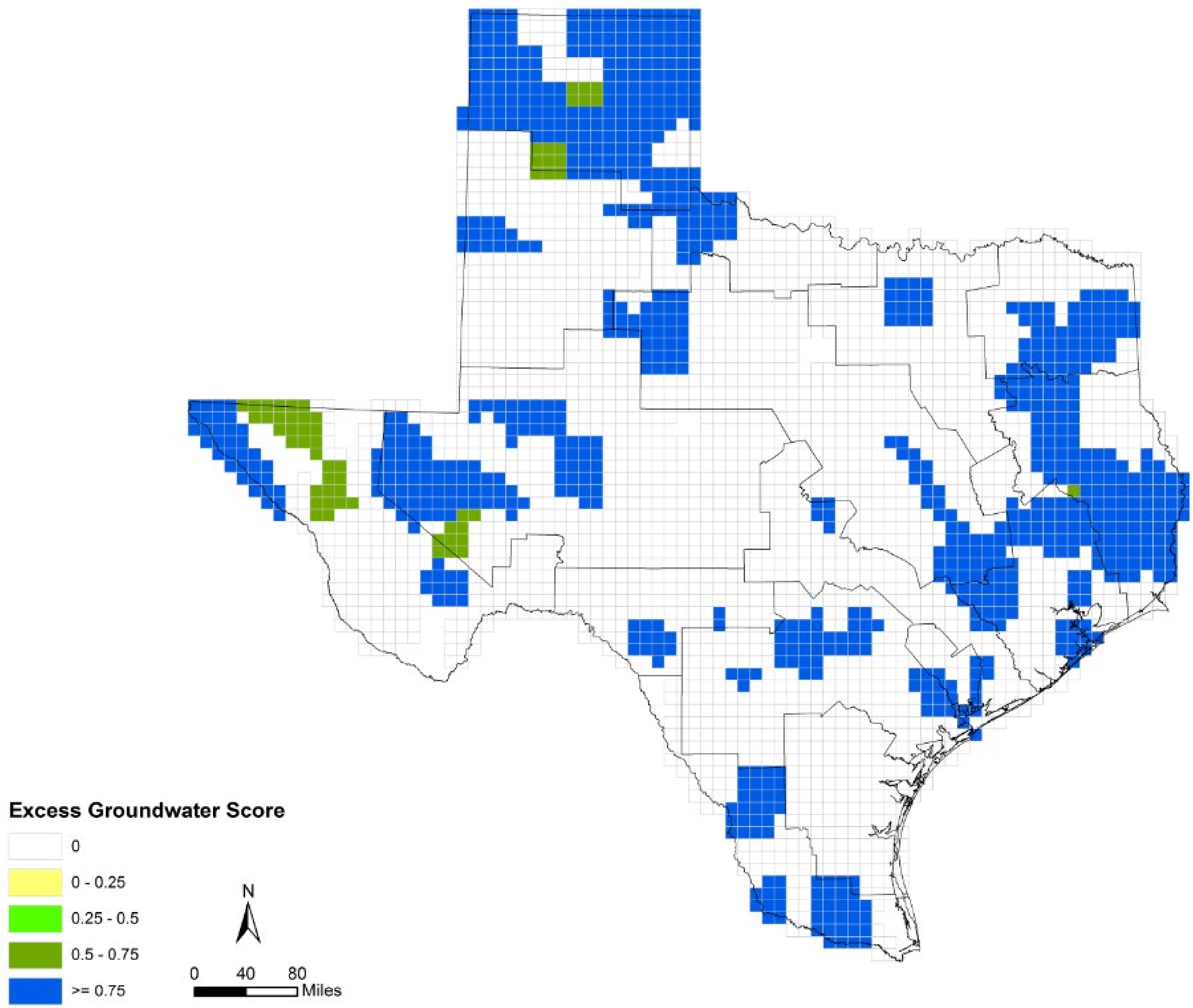

Figure 17. Excess groundwater scoring results (maximum of Texas' 31 major and minor aquifers)

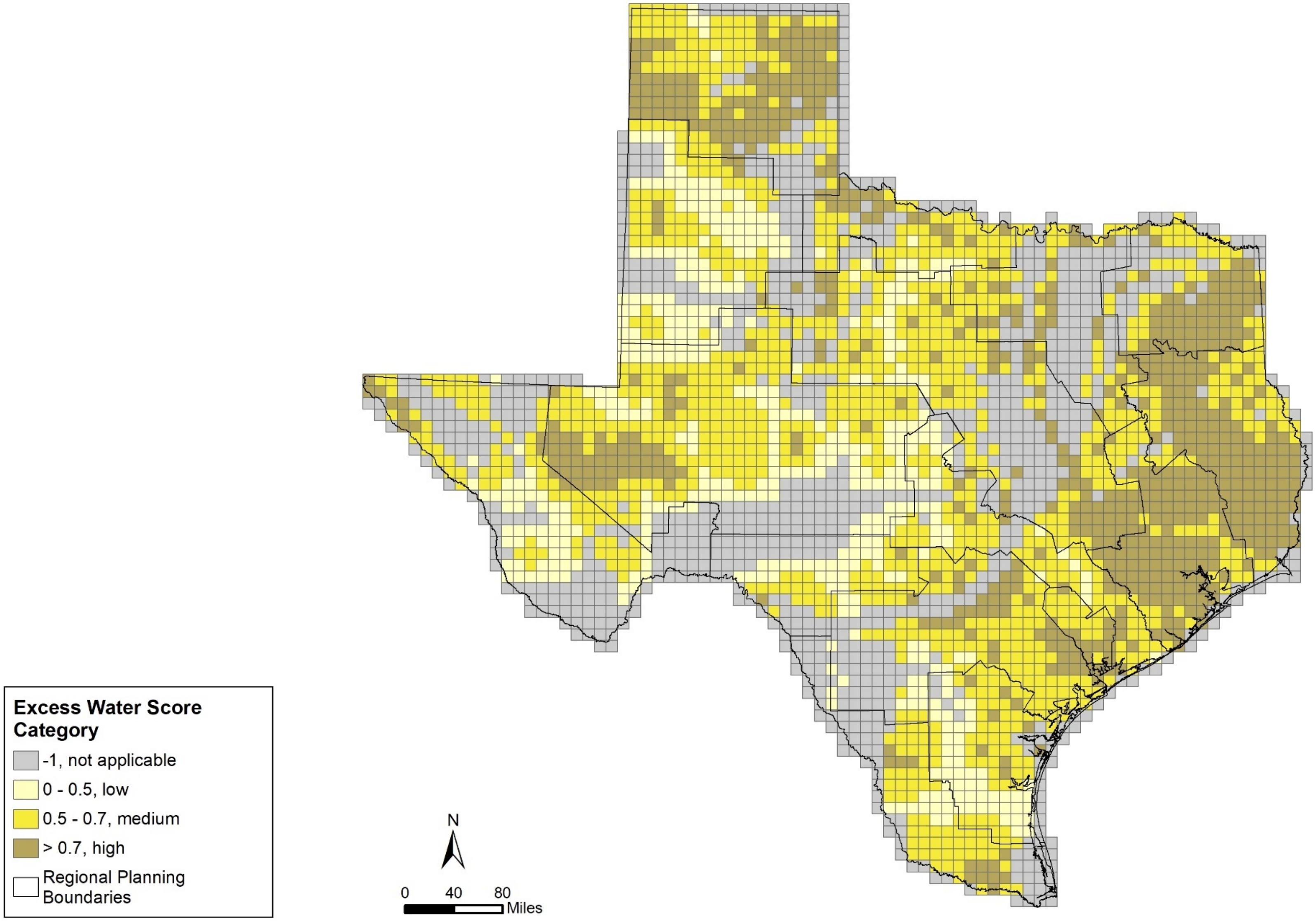

Figure 18. Excess water screening scores by category

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Future work

This survey has provided a good statewide look at excess water that could be available for ASR or AR. Several items were identified during the process that could be used to update and refine the screening tool in future work efforts such as site-specific studies. The accuracy of the excess surface water evaluation could be potentially improved by incorporating the following elements into the identification and scoring of the excess water sources:

- CCEFN instream environmental flow requirements for river basins without adopted TCEQ environmental flow standards.
- Calculation of river miles from the bay and estuary to unappropriated streamflow control points for consideration of freshwater inflow requirements.
- Inclusion of TCEQ-adopted high-flow pulse requirements at locations not already included in the current TCEQ WAMs.
- Evaluation of discharge points related to geographic proximity to water user groups that have identified existing and/or future reclaimed projects greater than 1,000 acre-feet per year.
- Evaluation of reservoirs for conjunctive use. A source of surface water identified by this survey is the use of reservoirs for conjunctive use with AR or ASR, which could be operated within conservation and flood storage for beneficial outcome. However, the timeframe, statewide scale, data availability, and uncertain permitting options did not allow for mapping these potential sources in this survey.
- Evaluation of Rio Grande operations. The Rio Grande is subject to international treaty agreements with Mexico for use, and a detailed evaluation of these operations are beyond the scope of the statewide survey. For this reason, a conservative approach was taken to omit unappropriated streamflow opportunities to avoid overestimation of availability.

Water Supply Needs Screening

Objective

The objective of the water supply needs screening is to identify the relative suitability of Texas' aquifers for ASR or AR projects based on current and future water supply needs. This screening is intended to serve as a guide for regional water planning and statewide stakeholders; however, it is not intended to substitute for local field studies that are required to “prove-up” ASR or AR suitability or to prioritize ASR or AR projects. This survey does not include economic, infrastructure, water compatibility, seasonal, or supply system operations for integration or other topics that are important considerations to determine site and project specific ASR or AR feasbility.

Approach

The general approach to evaluating water supply needs for ASR or AR relative project suitability was as follows:

1. Obtain current and future water supply needs in the draft DB22 database by category. Water supply needs in the draft DB22 are input by regional water planning groups and represent projected water demand minus existing supplies (prior to considering future water management strategies). Identify water user group categories to include in the screening, based on available data.

2. Consider water supply need parameters that are important to the probable success of an ASR or AR project pursuant to HB 721.

3. Develop strategies for scoring need parameters.

4. Combine the parameter scores to create a final water supply needs score on a grid cell basis, spatially coinciding with the hydrogeological parameter and excess water screenings.

5. Use the magnitude of the water supply needs screening scores to rank grid cells into three general categories of relative suitability, “low,” “medium,” or “high.”

6. Aggregate overlapping scores into a single, scored layer for the screening.

The attributes for water supply needs screening from the draft DB22 were transferred to grid cells with feature classes organized by water user group category consistent with the draft DB22. This multi-layered system nested within the geodatabase provides user flexibility to view current and future water needs for different water user categories that are spatially coinciding. This information could then be considered by potential project sponsors to evaluate regional opportunities. There are numerous aspects of water supply planning that affect the feasibility of an ASR or AR project, including the project objectives based on utility or project sponsor needs. This screening is focused on available data, which is better equipped to address long-term water supply needs than identifying peaking or seasonal water opportunities. Future versions of the screening may incorporate water treatment plant capacity and water demand patterns to develop a score that considers these and other important parameters affecting system operations.

Water supply needs

Methodology

The following method was used to identify parameters associated with water supply needs for scoring and weighting:

1. Obtained current and future water supply needs from the TWDB's draft DB22. Water supply needs identified there are presented on a decadal basis from 2020 to 2070 for each water user group (WUG) category: municipal, manufacturing, irrigation, mining, livestock[4], and steam-electric power.

2. Water supply needs were considered for all water user group categories included in the draft DB22 in accordance with HB 721 and TWDB scope. The volume of needs for all user categories, related information, and spatial coverages for DB22 information provided by the TWDB was compiled and assessed.

3. Based on data availability and discussions with the TWDB, it was determined that three WUG categories with spatially referenced information would be prepared for the water supply needs screening: municipal (discrete WUGs only), steam-electric, and manufacturing WUGs.

4. The municipal layer was developed by assigning municipal WUG water supply need attributes from the draft DB22 to the appropriate DB22 boundaries (Figure 19). Municipal water supply needs are presented in the draft DB22 for both individual WUGs and on a county-wide level for municipal WUGs (county-other) that have a smaller service area capacity. For individual municipal WUGs, parameter information is assigned for all grid cells located within the draft DB22 municipal WUG boundary coverage. Since municipal county-other water supply needs are presented county-wide, it's not possible to practically and accurately identify the location of these needs with certainty. Further, municipal county-other needs represent 12 percent of the total municipal needs of decade 2020, which is the largest percentage in all five decades considered in the draft DB22. After confirming with the TWDB, the contract team removed county-other needs from further evaluation in this screening. The scoring/ranking of municipal county-other WUGs cannot be meaningfully assessed since location information is not readily available

[4] Note: Livestock water users were not included in House Bill 721 or TWDB scope but considered since it is a water user category included in the draft DB22.

other than on a county-level basis, and project sponsor information to build such an ASR or AR project is unknown. If in the future, county-other interests desire to pursue ASR or AR with TWDB financing, the datasets could be revisited and customized accordingly.

5. The non-municipal water supply needs layer was developed as follows:

    a. In the draft DB22, the water supply needs for manufacturing, irrigation, mining, livestock, and steam-electric are only listed on a county-wide level. This makes determining the distance to suitable ASR and AR projects challenging, since the location of these needs within a county are unknown.

    b. For manufacturing and steam-electric water supply needs, the TWDB provided point location information based on 2017 Historical Water Use information. The TWDB shapefile was used as a proxy for assigning manufacturing and steam-electric water supply needs within a county. Future manufacturing and steam-electric growth areas were unavailable; therefore, new industrial locations are not accounted for in the screening. After plotting the point location data, it was determined that 393 out of 1,453 manufacturing points had incorrect latitude/longitude coordinates that either plotted outside of Texas or in a different county or region than specified in the dataset. In an attempt to focus on resolving spatial issues with higher use entities, the TWDB provided corrected location information for those points that showed water use over 500 acre-feet per year (48 locations). All other points that plotted incorrectly were removed, representing less than 5 percent of the total statewide manufacturing demand. The steam-electric locations did not appear to have any location discrepancies. The updated point file with reconciled locations was used to distribute county-wide manufacturing and steam-electric needs to individual points by assigning its pro rata share of 2017 water use as compared to 2017 water use of all manufacturing (or steam-electric) points within a county. For multiple points located within the grid cell, the prorated needs were aggregated (summed) and snapped to the grid level.

    c. After researching available data for mining, irrigation, and livestock needs, it became apparent that it is not practical to accurately identify the location of these needs beyond the county scale. Better location information is necessary to meaningfully assess the mining, irrigation, and livestock water supply needs for ASR or AR suitability scoring. Therefore, these county-wide needs will not be addressed by this survey. If sponsors with mining, irrigation, and livestock needs want to evaluate their ASR or AR suitability on a statewide level, they could individually compare the location of their need with the hydrogeological and excess water supply layers created by this survey.

6. The following process was used to merge municipal, manufacturing, and steam-electric needs information into grid cells:

    a. Municipal scores were distributed to grid cells that are located (even partially) within the draft DB22 municipal WUG boundary coverage. For grid cells where multiple WUGs exist, each WUG receives a record and score.

    b. Manufacturing and steam-electric needs were assigned to coinciding grid cells. For grid cells where multiple points exist, the water needs data is summed on a grid cell level (for manufacturing and steam-electric layers) prior to ranking.

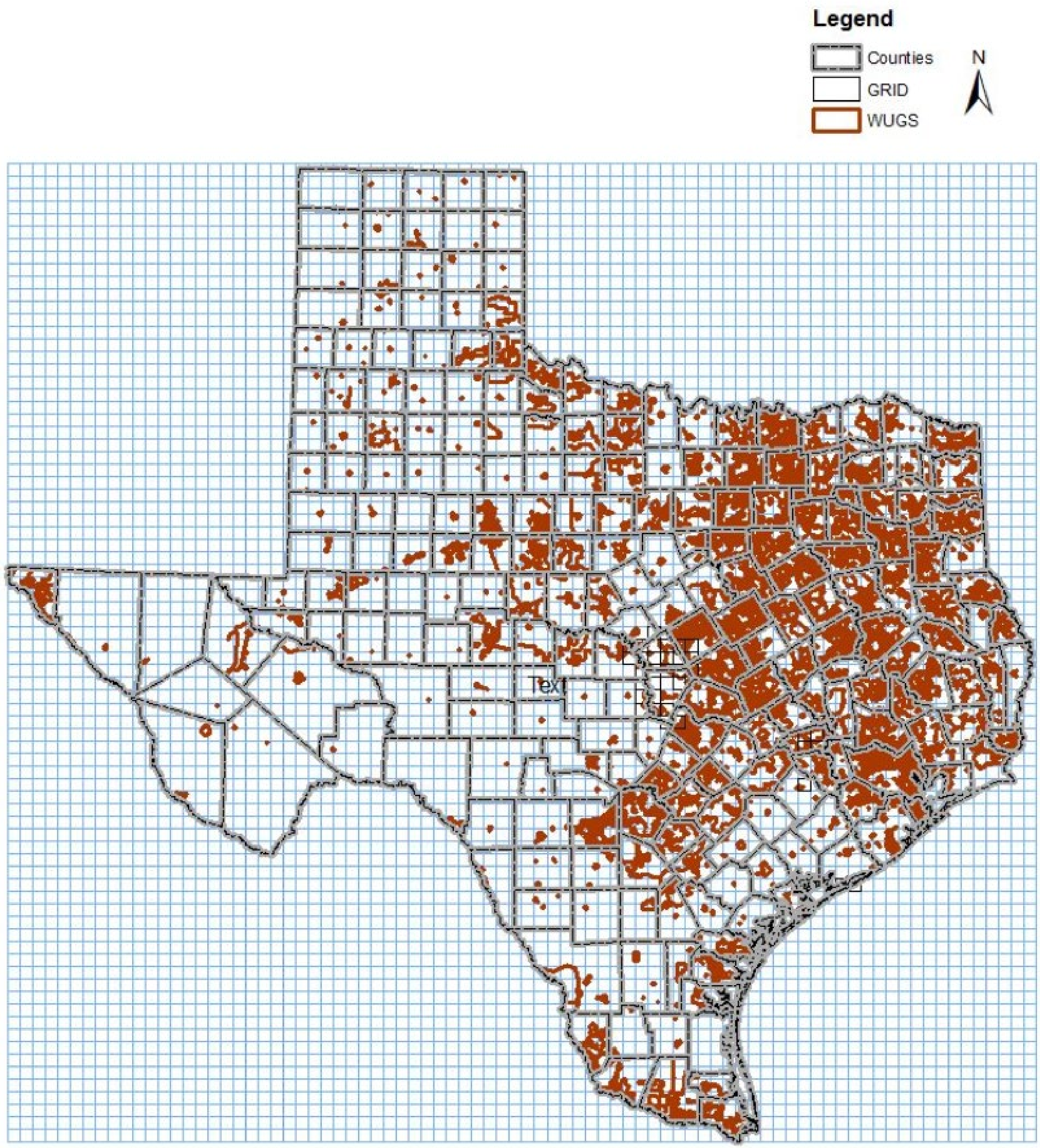

Figure 19. Grid cells, counties, and draft DB22 municipal water user group boundaries (Source: TWDB)

Table 18 includes a list of parameters included in the water supply needs screening, along with brief descriptions of the attribute table fields. The data source for all parameters is the draft DB22 and associated geospatial WUG boundary for municipal users and/or historical use point files for manufacturing and steam-electric. Proposed rankings are indicated, and bolded parameters are used explicitly in the screening to calculate the water needs score. A detailed description of each parameter is included in Appendix E of the contracted report. The parameter values are normalized to a scale from 0 to 1 after weighting is applied. This approach is consistent with the technique used for the hydrogeological parameter and excess water screenings.

The user manual "Step-Wise Procedure for Creating Water Needs Screening Tool" was prepared to list procedures needed so the TWDB can update the screening to adapt and readily accept data from future planning cycles. This excel-based spreadsheet was delivered alongside this report.

Table 18. Parameters for water supply needs screening

Field name ID	Alias grid ID	Notes
WUG_Name	WUG name 1	Feature datasets will be provided for discrete municipal (MUN), steam electric (SE), and manufacturing (MANU) WUG entities
WUG Entity ID	Draft DB22 WUG entity ID	WUG names and Entity_ID have one-to-one relationship
Active_WUG	Grid cells coinciding with active WUG	Grid contains WUG – 1; Grid does not contain WUG- 0. This field is to ease integration for Final Suitability Rating
Use_Type	Use type (WUG category in state water plan)	MUN, SE, MANU
Water_Needs_Max (and associated Water_Needs_Max_S)	Water needs (maximum 2020–2070 period)	Ranking of 0 to 1 as follows: Needs ≥ 35,000 acft/yr – 1 Needs ≥ 15,000 and < 35,000 acft/yr – 0.75 Needs ≥ 2,500 and < 15,000 acft/yr – 0.5 Needs ≥ 500 and < 2,500 acft/yr – 0.25 Needs < 500 acft/yr – 0
First_Needs_Decade (and associated First_Needs_Decade_S)	First decade of need	Ranking of 0 to 1 as follows: 2020-2030 – 1, 2040 – 0.75, 2050 – 0.5, and 2060-2070 – 0.25
Unmet_Needs	WUG has unmet needs[1] identified in RWP	Yes – 1, No – 0
Per_Volume (and associated Per_Volume_S)	Needs as percent volume of demand (maximum 2020–2070 period)	Ranking of 0 to 1 as follows: <10% – 0.25 ≥10 and ≤25% – 0.5 >25 and ≤ 40% – 0.75 >40% – 1
Existing_Supply	Existing supply	GW – 1, SW – 0.25, both – 0.5
Sole_Supply	Sole supply	Yes – 1, No – 0
Length_of_Need	Length of a need	< 20 Yrs – 0,

Field name ID	Alias grid ID	Notes
		≥ 20 Yrs – 1
Recommended_ WMS_ASR	ASR recommended as WMS in plan	Yes – 1, No – 0
Existing_ASR	Existing ASR present	Yes – 1, No – 0
Recommended _WMS_AR	AR recommended as WMS in Plan	Yes – 1, No – 0
Existing_AR	Existing AR present	Yes – 1, No – 0
Water_Needs_Score	Water supply needs score	Based on attributes above and solely related to needs. Scores and weights to be assigned and verified in TWDB workshop.

[1] Unmet needs are water supply needs identified in the draft DB22 that do not have enough supplies identified through recommended water management strategies to fully address the need or shortage.

Note: The data source for all parameters shown above as the draft DB22 is associated with the draft State Water Planning Database. The TWDB draft DB22 municipal WUG coverage was used for municipal users. For manufacturing and steam electric users, historical water use point files provided by the TWDB were used.

Parameters shown above in **Bold** text are used to calculate the Water_Needs_Score, as discussed in the Scoring section.

WUG = water user group; WMS = water management strategy; acft/yr = acre-feet per year; RWP = regional water plan; draft DB22 = TWDB draft State Water Planning Database

Assumptions, challenges, and limitations

The following are some of the key assumptions identified during development of the water supply needs screening:

- The draft DB22, associated WUG boundaries, and historical use files for manufacturing and steam-electric users were used as a basis for evaluating water supply needs for the water supply needs screening. It is anticipated that minimal changes in the draft DB22 data will occur for final DB22 data used to develop the 2022 State Water Plan.
- Excluded manufacturing and steam-electric points described previously are not anticipated to have a relevant impact on the statewide survey.

One challenge for the use of grid cells is spatially distributing the needs and demands for the WUGs developed from the draft DB22 data and applying the distributed data to the grids across the state. The draft DB22 database was created for a different purpose than for use in this survey. For this reason, some county-wide demands such as livestock, irrigation, mining, and municipal county-other, were not included because there is no locational information to distribute them. Although irrigation is the largest need in the state water plan (it represents 82 percent of the total needs in decade 2020 and 46 percent in decade 2070), there are no current projects in the 2017 State Water Plan to apply ASR or AR for irrigation purposes in Texas. As currently formulated, the screening should not seek to provide a level of refinement beyond that which is available on the regional water planning level.

ASR or AR projects are regularly used to augment supplies during peak or high seasonal water use conditions when needed to boost overall supply capacity. The length of need, based on the draft DB22 drought of record future conditions presented on a decadal basis, does not account for this operational strategy, which reduces costs over the long term by providing system flexibility and demand management. Seasonal needs are system specific and beyond the scope of this project. Data is unavailable from the TWDB or other publicly available sources to assess peaking potential consistently across the state, and for this reason, is not included in this survey.

The water needs from the draft DB22 include needs for steam-electric plants that might be closing, are now closed, or for future projects that are no longer actively being considered. It was decided to leave these needs in the screening for consistency with the draft DB22.

It is important to balance the statewide screening needs at a level appropriate to provide guidance to regional water planning groups and other entities in evaluating ASR or AR suitability.

Data sources

The data sources that were used to evaluate water supply needs include the following:

- Draft DB22
- TWDB-provided shapefile (2022WUGs) associated with regional water planning
- TWDB-provided manufacturing shapefile associated with Water Use Survey responses received by manufacturing water users in 2017
- TWDB-provided Steam_Electric_Power_Plants_2017 shapefile associated with Water Use Survey responses submitted by steam-electric water users in 2017

Data gaps

The following are the key data gaps identified during the development of the water supply needs screening:

- County-other municipal and non-municipal WUG needs (irrigation, livestock, and mining) are not included in the water supply needs screening.
    - Water supply needs for these WUGs are presented in the draft DB22 on a county-wide level. The scoring of these county-wide needs cannot be meaningfully assessed for inclusion in the screening since location information is not readily

available other than on a county-level basis, and project sponsor information to build such an ASR or AR project is challenging to assess.

- If in the future, irrigation, mining, or livestock interests want to pursue ASR or AR with TWDB financing, the screening datasets could be revisited and customized accordingly.

Scoring

The scoring of parameters at the grid-level was considered to approximate the level of data available for the screening. After consulting with the TWDB, the contract team selected three parameters for scoring (Table 18) to align with HB 721: maximum water supply need (2020–2070), first decade of need, and needs as a percent of total volume of demand. Additional draft DB22 parameters considered useful for evaluating ASR or AR project feasibility and helpful in a future phase of this screening were included in the screening, although they were not used as parameters for scoring or weighting.

The parameters and weights used to calculate a needs score is shown in Table 19. A needs score was calculated for each grid cell with municipal, manufacturing, or steam-electric needs greater than 500 acre-feet per year. Some parameters that did not factor in the water needs score may be important for stakeholders and regional water planning consideration. These parameters are included in Table 20 and will be included in the screening to allow reviewers to add subjective factors or parameters most relevant to their scoring of water supply needs. Furthermore, the accompanying geodatabase has a blank field to allow regional planning groups to calculate parameters that they deem most relevant to the region related to needs and relative suitability for ASR or AR.

Table 19. Parameters recommended for use in calculating a water needs score

	Water_Needs_ max	First_Needs_ decade	Per_ volume	Water_Needs_ score
Weighting	0.33	0.34	0.33	
Score	0 (low) 1 (high)	0.25 (low) 1 (high)	0.25 (low) 1 (high)	Calculated (0-1)

Table 20. Additional parameters that could be used by stakeholders as a polishing step in evaluating water needs score

	Unmet needs	Length of need	Sole supply	ASR_Rec WMS	Existing ASR	AR_Rec WMS	Existing AR
Score	0 (no) 1 (yes)	0 (<20 yrs) 1 (>20 yrs)	0 (no) 1 (yes)	0 (no) 1 (yes)	0 (no) 1 (yes)	0 (no) 1 (yes)	0 (no) 1 (yes)

WMS = water management strategy; yrs = years

Results

The results of the water supply needs screening serve as a guide for regional water planning stakeholders. Figure 20 shows the scoring results for municipal needs. There were 624 grid cells that showed municipal water needs, some of which reported needs for multiple municipal users where service areas overlapped. Municipal supply needs are identified throughout Texas; however, the highest scoring needs generally are along the Interstate Highway 35 corridor from the Dallas-Fort Worth Metroplex south toward San Antonio and also near Houston, which affect water supply utilities serving those areas. Municipal needs also scored high in South Texas, including Hidalgo, Willacy, and Cameron counties.

Figure 21 shows manufacturing need scores throughout Texas. There were 203 grid cells that showed manufacturing water needs. Of these, 55 cells received scores based on maximum water needs exceeding 500 acre-feet per year. Only seven cells reported manufacturing needs exceeding 10,000 acre-feet per year; they were located along the Gulf of Mexico coastline. Water supply needs scores were based on combining maximum water supply need, first decade of need, and needs as a percent of total volume of demand. Dividing manufacturing needs scores into quarters (<0.25, 0.25-0.5, 0.5-0.75, >0.75) for review revealed that 32 grid cells had a score in the top quarter of the scale (exceeding 0.75). These are scattered throughout Texas and with no discernible trend observed. A few clustered areas are located in the Beaumont/Port Arthur and Corpus Christi areas.

Figure 22 shows steam-electric need scores throughout Texas. Fifty grid cells showed steam-electric water needs. Of these, only 36 received scores based on maximum water needs exceeding 500 acre-feet per year. The same quartile data analysis that was done on the manufacturing needs revealed there are 20 grid cells that had a steam-electric needs score in the top quarter of the scale (exceeding 0.75). Similar to the manufacturing needs, these are scattered throughout Texas and with no discernible trend observed.

Summary of water supply needs

The water supply needs for the three user categories were combined in a final water needs grid cell where either a single or multiple water needs were present.

The water supply need screening scores were categorized for each grid cell with water needs identified (Figure 23). Threshold values used for water supply needs divided suitability into classes of "low," "medium," and "high" as follows:

- Low: Excess water score < 0.5
- Medium: Excess water score 0.5 to 0.7
- High: Excess water score > 0.7

About 20 percent of the grid cells (or 645) scored low suitability, 17 percent (or 527 cells) scored medium suitability, and 12 percent (or 365 cells) scored high suitability for water supply needs. The remaining 51 percent (or 1,623 cells) did not have water supply needs identified for the water user categories evaluated.

These actual values were used in the Final Suitability Rating to evaluate ASR or AR project suitability.

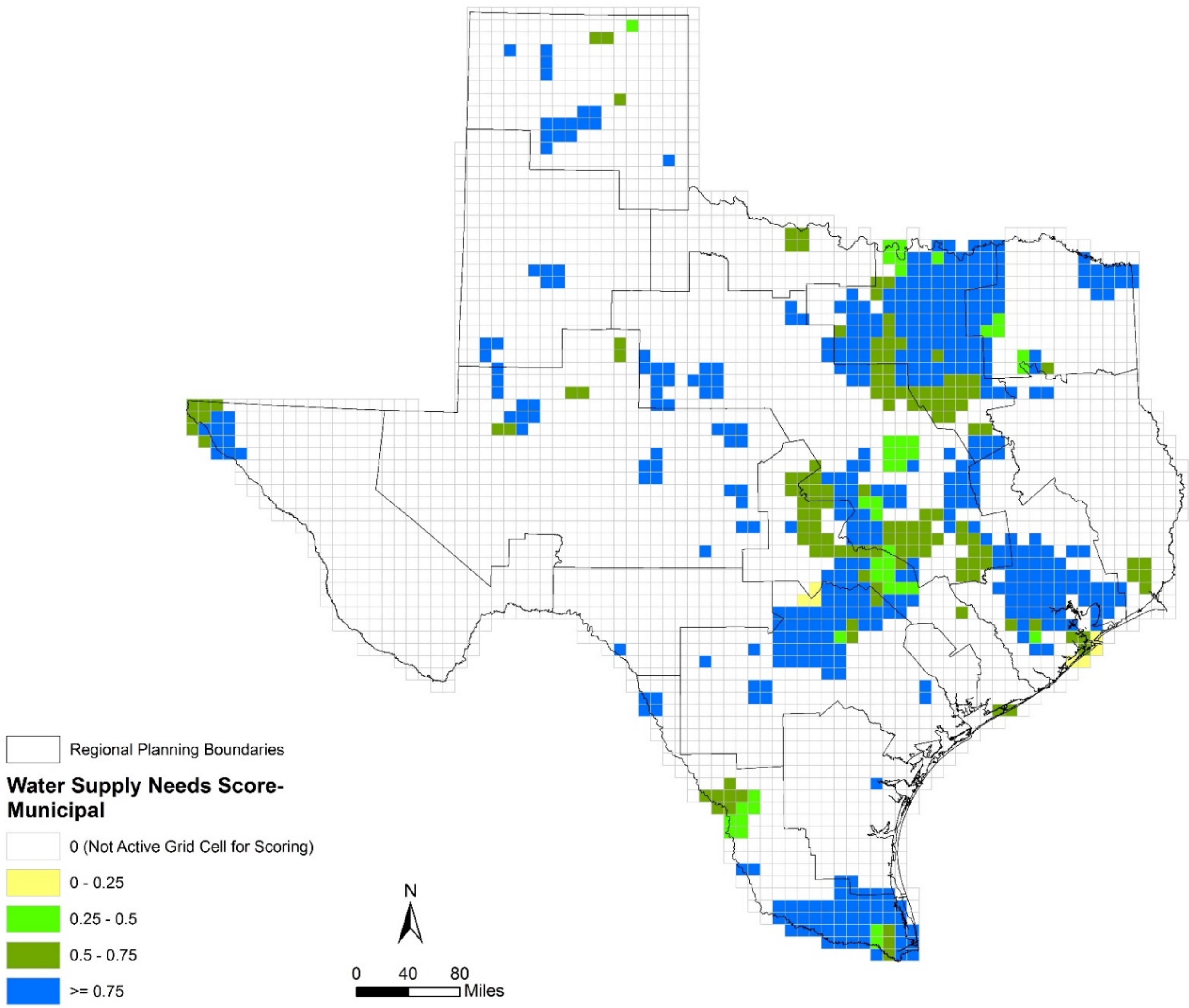

Figure 20. Municipal water needs scoring results

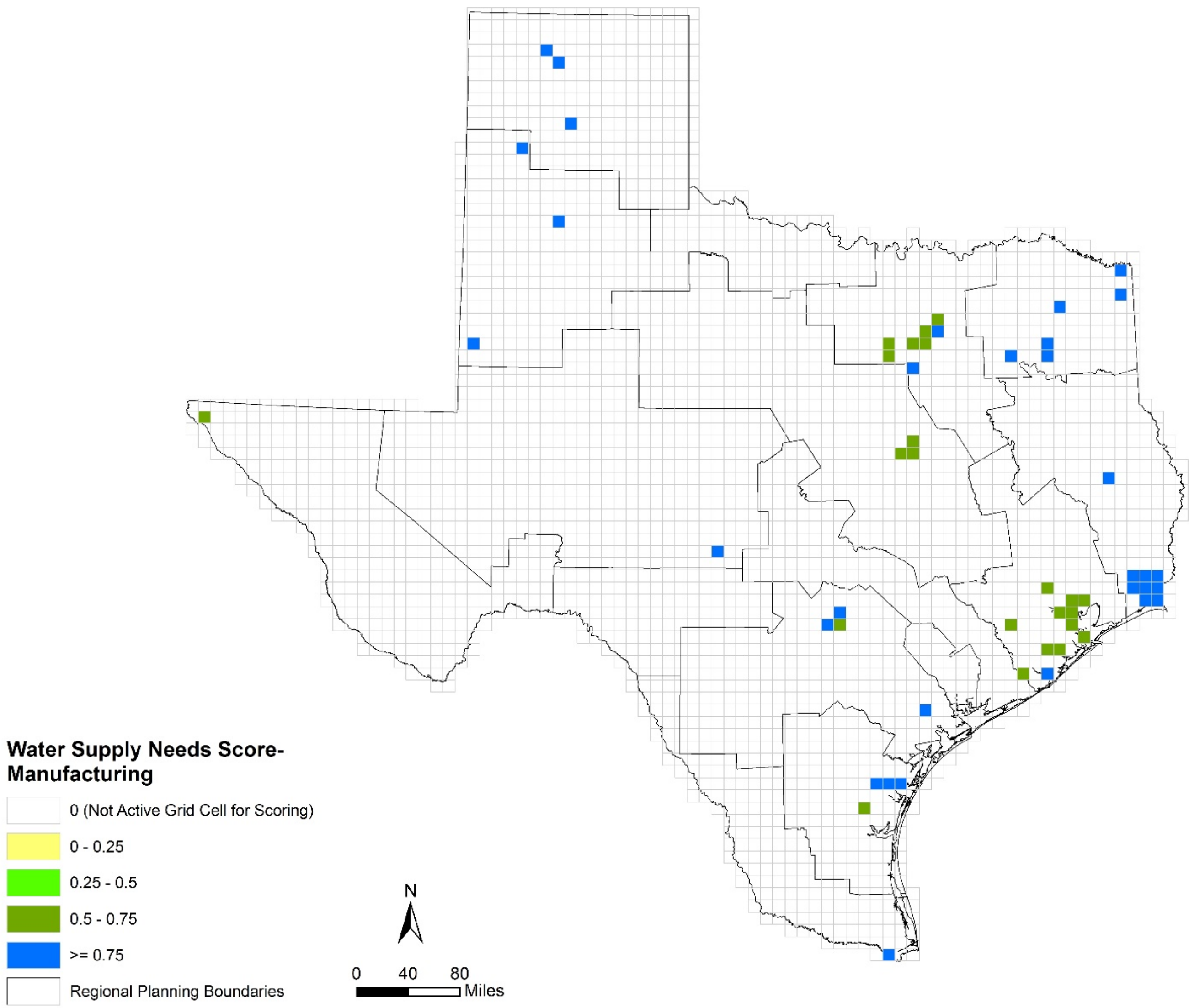

Figure 21. Manufacturing water needs scoring results

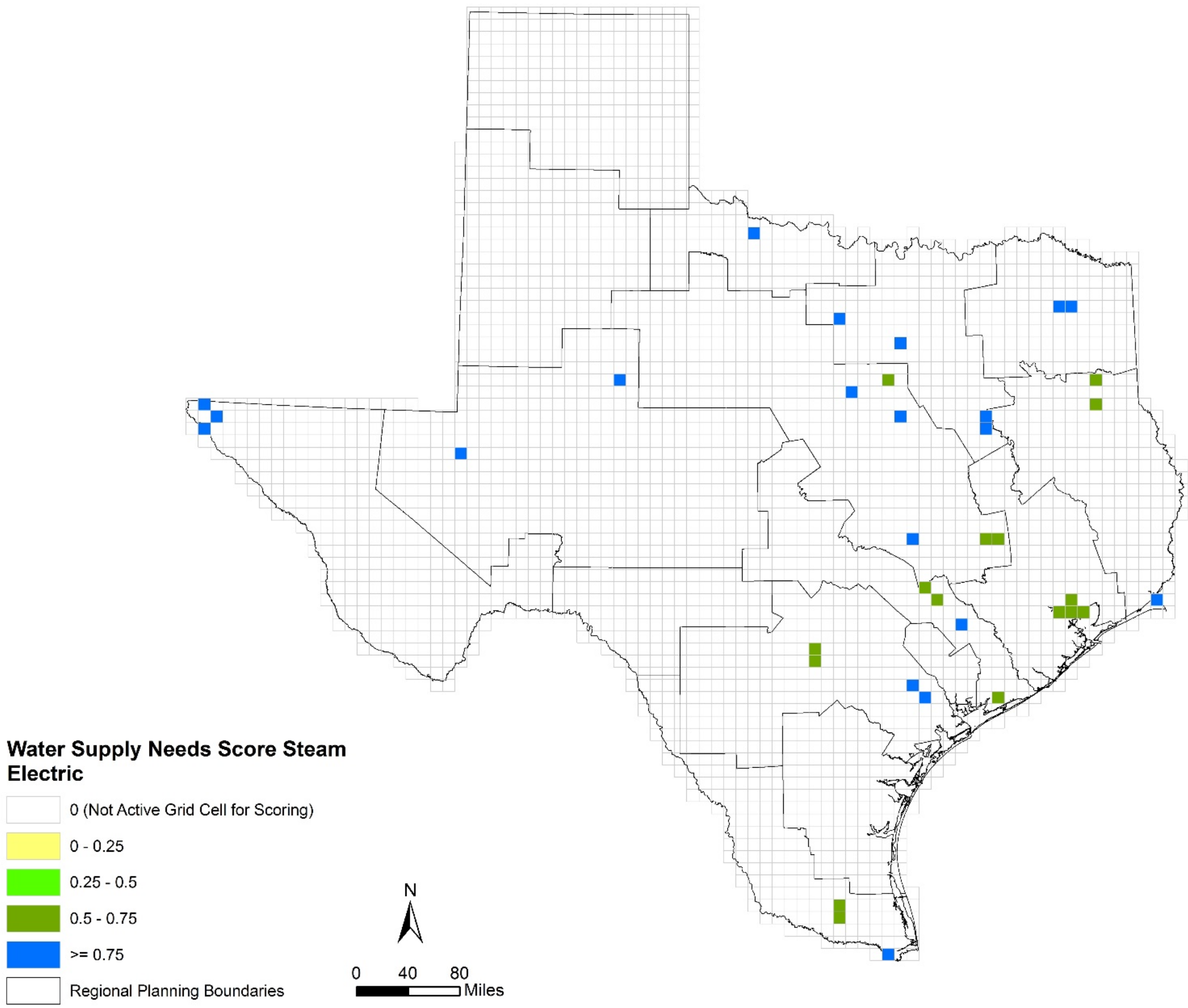

Figure 22. Steam-electric water needs scoring results

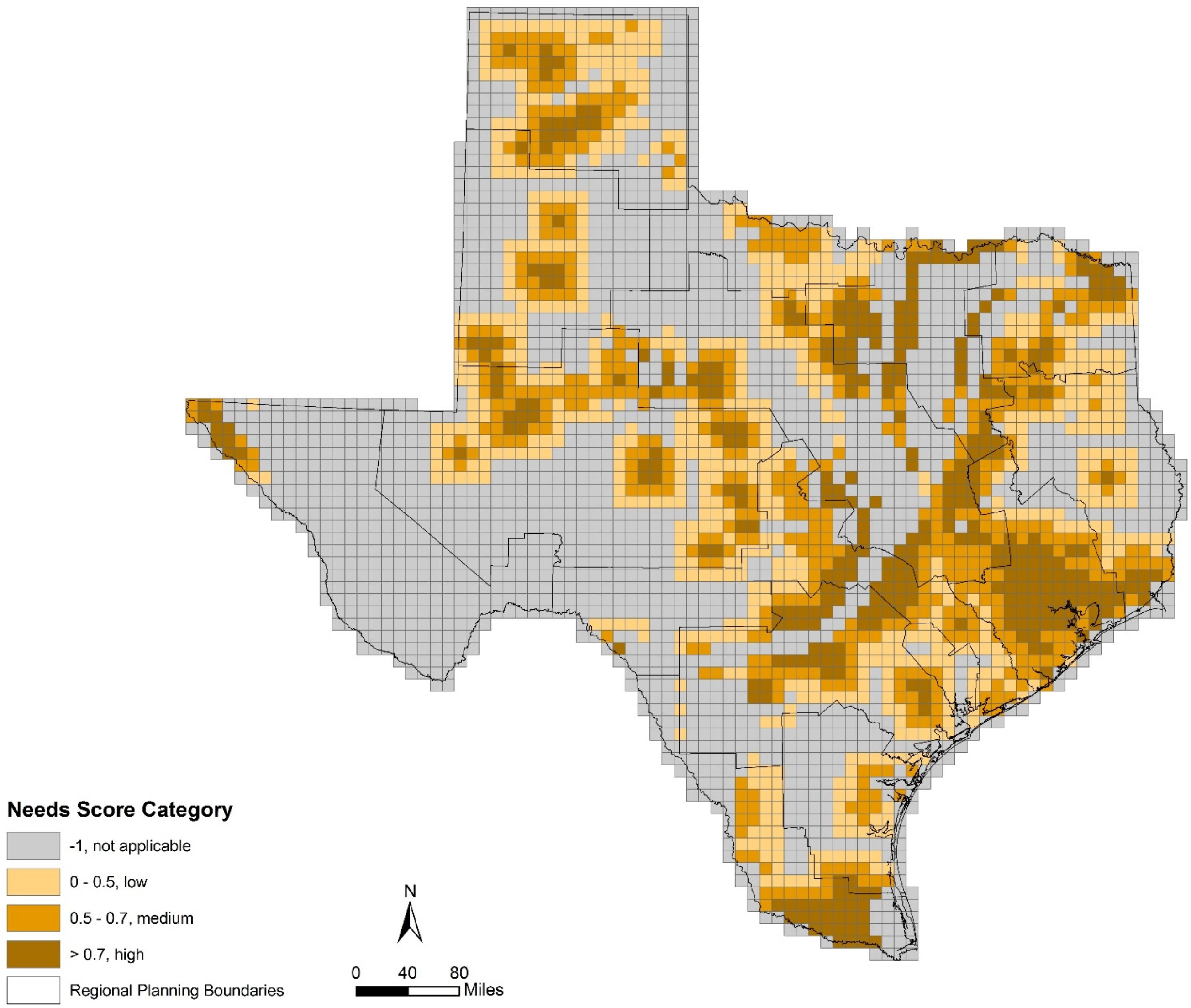

Figure 23. Water supply needs screening score categories

Future work

This survey provided a statewide evaluation of water supply needs. Several items were identified during the process that will benefit from updating and refining in future work efforts:

- There are large gaps in coverage for West Texas and the Panhandle needs due to a lack of specific information on location of current and future use for county-wide municipal, irrigation, and mining users at a level of detail that could be accurately applied on the grid cell level.
- Additional data and tools may be useful for future ASR or AR evaluation, particularly in areas relying on a single supply and for which water management strategies have not been identified in the draft DB22 to fully meet needs.

In many cases, developing an ASR or AR project may be challenging and impractical especially in widespread areas of need in the absence of project sponsors.

Final Suitability Rating

Objective

The objective of the Final Suitability Rating is to integrate results from the three screening geodatabases related to hydrogeological parameters, excess water, and water supply needs into a Final Suitability Rating. This rating will serve as a statewide survey to identify the relative suitability of various major and minor aquifers for use in ASR or AR projects.

Approach

Each grid cell scored for ASR or AR potential in the hydrogeological parameter screening is given an overall relative final suitability rating. This Final Suitability Rating draws upon scores stored in the previous hydrogeological parameter, excess water, and water supply needs screening geodatabases and the distance of the excess water and water supply needs from the hydrogeological grid cell.

The general approach used to determine the Final Suitability Rating for ASR or AR was as follows:

1. Consider hydrogeological parameter scores identified in the screening and select the highest-scoring aquifer by cell for final suitability scoring.

2. Combine scores from the excess water and water supply need screenings and develop an approach to score the distance of these features relative to suitable ASR or AR locations identified in the hydrogeological parameter screening.

3. Combine the parameter scores to create a Final Suitability Rating for ASR and AR. Each grid cell has a single score layer for the screening.

4. Use the magnitude of the Final Suitability Rating to rank regions according to three general categories of relative suitability to identify those that are more suitable than others. The three categories are "less," "moderately," or "most" suitable.

Combining parameters

Methodology

The contract team developed the Final Suitability Rating to evaluate the magnitude and location of excess water and water supply needs relative to potential ASR or AR locations identified in the hydrogeological parameter screening. This was an effort to align HB 721 and survey objectives to identify the relative suitability of aquifers for ASR or AR projects. The scores from the three previous screenings were consistently normalized to 1 to support ease of integration and avoid bias in the Final Suitability Rating. For locations where multiple major or minor aquifers exist, the highest-scoring aquifer from the hydrogeological parameter screening was identified by row-column grid cell (RCID) with the aquifer noted in the Final Suitability Rating. Although the highest aquifer value is used for the Final Suitability Rating, the hydrogeological parameter screening includes results for all major and minor aquifers that coincide with the grid cell.

Table 21 lists the parameters that are included in the Final Suitability Rating, along with descriptions of the attribute table fields and data source(s). The Final Suitability Rating calculates a relative suitability score for cells where major and/or minor aquifers are present, according to the approved grid. Two feature classes (one for ASR and the other for AR) are compiled in a geodatabase at grid-level resolution, consistent and coinciding with other screenings in cell size and extent. The four-digit aquifer classification code used is consistent to the identifier used in the hydrogeological parameter screening.

Table 21. Parameters for Final Suitability Rating for aquifer storage and recovery (ASR) and aquifer recharge (AR)

Field name	Description	Notes	Data source
RCID	Row column ID	Row column unique identifier	
Highest_ASR_Hydro_Score or Highest_AR_Hydro_Score	Maximum ASR (AR) score, for all aquifers coinciding with grid cell	Score 0–1 -1: no major/minor aquifer	From hydrogeological parameter screen
Highest_Scoring_Aquifer_ID	ID of the highest hydro-scoring aquifer	Four-digit aquifer code	
Excess_Water_ID	Cell ID for excess water source	Cell ID that corresponds with Excess_Water_Score. This is the maximum of 24 cell buffer around the cell of interest (RCID)	From excess water screen
Excess_Water_Sum	Excess water score, Sum of sources	Excess water score from final grid excess water screening geodatabase	
Excess_Water_Normalized_Score	Excess water score (normalized score)	Score 0–1 for best (maximum score) within 24 cell buffer around RCID calculated as: Excess_Water_Score = Excess_Surface_Water_Score + Reclaimed_Score + Excess_GW_Water_Score normalized as described above x respective distance factor (Figure 9)	Calculated in Final Suitability Rating
Excess_Water_Distance	Distance from ASR grid cell to excess water	Miles. Score from 0 to 26.8 miles based on centroid, for cell associated with Excess_Water_ID that scored the best.	
Excess_Water_Distance_Weight	Weight to be applied due to distance	Score 0–1 based on distance to excess water	
Excess_Water_Score	Distance-weighted excess water score	Calculated by multiplying Excess_Water_Normalized_Score * Excess_Water_Distance_Weight	
Needs_ID	Cell ID for water need	Cell ID that corresponds with Needs _Score. This is the maximum of 24 cell buffer around the cell of interest (RCID)	From water supply needs screen
Needs_Sum	Water needs score, Sum of all needs	Water needs score from final grid water supply needs screening geodatabase	From water supply needs screen

Field name	Description	Notes	Data source
Needs_Normalized_Score	Water needs score (normalized score)	Score 0–1 for best (maximum score) within 24 cell-buffer around RCID based on the sum of scores from municipal, manufacturing, and steam-electric feature classes normalized as described above x distance factor (Figure 18)	Calculated in Final Suitability Rating
Needs_Distance	Distance from ASR grid cell to needs	Miles. Score from 0 to 26.8 miles based on centroid, for cell associated with Needs_ID that scored the best	
Needs_Distance_Weight	Weight to be applied due to distance	Score 0–1 based on distance to water needs	
Needs_Score	Distance-weighted needs score	Calculated by multiplying Excess_Water_Normalized_Score * Excess_Water_Distance_Weight	
Final_ASR_rating or Final_AR_rating	Integrates aquifer, excess water, and needs scores, incl. intervening distances	Score 0–1 (flags: -2, -3, or -4 described below). Final Suitability Rating = Highest_ASR(AR)_Hydro_Score*0.34 + Excess_Water_Score*0.33 + Needs_Score* 0.33	

RCID = row and column id for grid cells

Multiple combinations exist for excess water and water needs that coincide with or are close to ASR or AR grid cells. For this reason, a distance approach was used to pre-select the most preferable excess water or water needs score as follows.

1. Excess water or needs scores from coinciding cells and up to two cells away from a given ASR or AR grid cell (identified in the hydrogeological parameter screen) are considered. The closer the Weights are applied to excess water or needs scores, the higher the weight. A graphical depiction of the distance weights applied to the 24 grid cells surrounding the ASR or AR grid cell receiving a final suitability score is shown below (Figure 24). Since grid cells are precisely 50,000 feet by 50,000 feet, an approximately 20-mile buffer is created. moving directly north-south, or east-west, Weight assignments are as follows:

    a. 1 = excess water or needs cell coinciding with ASR or AR cell;

    b. 0.64 = excess water or needs cell is one cell away from ASR or AR cell;

c. 0.29 = excess water or needs cell is two cells away from ASR or AR cell;

d. For diagonal (corner) cells, the weights are slightly less than the adjoining cells, 0.5 and 0.25.

0	0	0	0	0	0	0
0	0.25	0.25	0.29	0.25	0.25	0
0	0.25	0.50	0.64	0.50	0.25	0
0	0.29	0.64	**1**	0.64	0.29	0
0	0.25	0.50	0.64	0.50	0.25	0
0	0.25	0.25	0.29	0.25	0.25	0
0	0	0	0	0	0	0

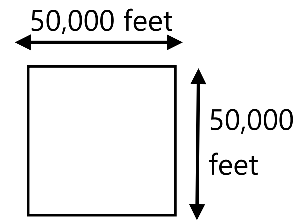

Figure 24. Distance weights applied to excess supply and water needs to select the best excess supply and needs combination by grid cell for Final Suitability Rating

2. Excess water scores were estimated for surface water, reclaimed water, and/or groundwater at each cell. If more than one excess water score was present in a cell, the scores were summed to capture the potential added benefit of having multiple scores. This excess water sum could theoretically be as high as 3, although in practice the maximum sum was 2.75. To normalize this sum to a 0 to 1 scale, the contract team took an approach that attempted to achieve two objectives:

    a. Reward scores of greater than 1.0, which mark a potential benefit of having multiple source types.

    b. Avoid penalizing individual scores that are close to 1.0, since they may represent a good source, even if only a single type.

3. The approach uses a two-part linear normalization curve that gives a normalized score between 0 and 0.75 for sums between 0 and 1.0. An excess water sum of 1.0 results in a normalized score of 0.75. For sums greater than 1.0, the normalized score is increased

linearly up to 1.0. The same approach was taken for the normalized needs score, based on the sum of the three contributing need categories. The approach uses a two-part linear normalization curve that gives a normalized score between 0 and 0.9 for sums between 0 and 1.0, and needs sum of 1.0 result in a normalized score of 0.9. For sums greater than 1.0, the normalized score is increased linearly up to 1.0. The difference between the "pivot point" for excess water versus needs was based on an inspection of the distribution of the sums. The needs distribution had many more of the sums clustered at less than 1.0.

4. The maximum Excess_Water_Score and maximum Needs_Score within the buffer area are then selected and assigned to the respective ASR or AR row and column ID (RCID). The cell for the selected score is recorded in Excess_Water_ID and Needs_ID, respectively, in addition to the distance of RCID centroid to centroid of the cell with the maximum excess water score and maximum needs score.

5. A Final_ASR(AR)_rating is then calculated based on three parameters: Highest_ASR(AR)_Hydro_Score, Excess_Water_Score, and Needs_Score, each receiving equal weights.

   This method achieves two objectives considered important for ASR or AR relative suitability:

   a. It identifies hydrogeological areas suitable for ASR or AR that have multiple excess supply sources and/or multiple water user needs to provide flexibility in project planning and identify potential regional partnership opportunities, while still supporting with a favorable score areas that indicate good hydrogeology, a suitable excess water supply, and need even if they do not have multiple supply sources or water users. Excess supply sources can be used conjunctively (especially in cells where unappropriated water, reservoirs, and available groundwater exist), and this benefit is accounted for in scores that exceed 0.75. For areas with multiple water user groups showing a need, potential regionalization opportunities are accounted for in scores that exceed 0.9.

   b. It does not limit excess water supplies or needs to those cells that coincide with the aquifer cell being considered. However, it does score nearer cells more favorably in a relative sense, thus recognizing the increased difficulty and/or cost in conveying excess water or supplying a water need over a longer distance.

Table 22. Parameters for Final Suitability Rating for aquifer storage and recovery (ASR) and aquifer recharge (AR)

Field name	Description	Notes	Data source
RCID	Row column ID	Row column unique identifier	
Highest_ASR_Hydro_Score or Highest_AR_Hydro_Score	Maximum ASR (AR) score, for all aquifers coinciding with grid cell	Score 0–1 -1: no major/minor aquifer	From hydrogeological parameter screen
Highest_Scoring_Aquifer_ID	ID of the highest hydro-scoring aquifer	Four-digit aquifer code	
Excess_Water_ID	Cell ID for excess water source	Cell ID that corresponds with Excess_Water_Score. This is the maximum of 24 cell buffer around the cell of interest (RCID)	From excess water screen
Excess_Water_Sum	Excess water score, Sum of sources	Excess water score from final grid excess water screening geodatabase	
Excess_Water_Normalized_Score	Excess water score (normalized score)	Score 0–1 for best (maximum score) within 24 cell buffer around RCID calculated as: Excess_Water_Score = Excess_Surface_Water_Score + Reclaimed_Score + Excess_GW_Water_Score normalized as described above x respective distance factor (Figure 9)	Calculated in Final Suitability Rating
Excess_Water_Distance	Distance from ASR grid cell to excess water	Miles. Score from 0 to 26.8 miles based on centroid, for cell associated with Excess_Water_ID that scored the best.	
Excess_Water_Distance_Weight	Weight to be applied due to distance	Score 0–1 based on distance to excess water	
Excess_Water_Score	Distance-weighted excess water score	Calculated by multiplying Excess_Water_Normalized_Score * Excess_Water_Distance_Weight	
Needs_ID	Cell ID for water need	Cell ID that corresponds with Needs _Score. This is the maximum of 24 cell buffer around the cell of interest (RCID)	From water supply needs screen
Needs_Sum	Water needs score, Sum of all needs	Water needs score from final grid water supply needs screening geodatabase	From water supply needs screen

Field name	Description	Notes	Data source
Needs_Normalized_Score	Water needs score (normalized score)	Score 0–1 for best (maximum score) within 24 cell-buffer around RCID based on the sum of scores from municipal, manufacturing, and steam-electric feature classes normalized as described above x distance factor (Figure 18)	Calculated in Final Suitability Rating
Needs_Distance	Distance from ASR grid cell to needs	Miles. Score from 0 to 26.8 miles based on centroid, for cell associated with Needs_ID that scored the best	
Needs_Distance_Weight	Weight to be applied due to distance	Score 0–1 based on distance to water needs	
Needs_Score	Distance-weighted needs score	Calculated by multiplying Excess_Water_Normalized_Score * Excess_Water_Distance_Weight	
Final_ASR_rating or Final_AR_rating	Integrates aquifer, excess water, and needs scores, incl. intervening distances	Score 0–1 (flags: -2, -3, or -4 described below). Final Suitability Rating = Highest_ASR(AR)_Hydro_Score*0.34 + Excess_Water_Score*0.33 + Needs_Score* 0.33	

RCID = row and column id for grid cells

Assumptions, challenges, and limitations

The following assumptions and challenges were identified while developing the Final Suitability Rating:

- Scoring coverage is constrained to only those grid cells corresponding to major or minor aquifers (consistent with the hydrogeological parameter screening).
- Excess supplies or needs located more than two cells away from ASR or AR cells do not contribute to a cell's score. This was an assumption developed during this survey, recognizing that aquifers, excess supplies, and needs shouldn't be confined to a coinciding grid cell only. An estimate of 20 miles (2 grid cells) was determined to be a reasonable estimate for various-sized water users, recognizing that some sponsors may consider ASR or AR projects over larger distances. These larger distances are not included in the Final Suitability Rating.

  - If no excess water sources are identified within a two-cell buffer from an ASR or AR cell, a value of "-1" is included in the excess supply fields (Excess_Water_Score; Excess_Water_ID, and Excess_Water_Distance).

  - If no needs are identified within a two-cell buffer from an ASR or AR cell, a value of "-1" is included in the needs fields (Needs_Score, Needs_ID, and Needs_Distance).

- This screening assumes that all key parameters (aquifers, excess water, and needs) are present in the vicinity of one another to be scored, since all are considered important for ASR or AR projects to occur except in cases where ASR is considered more suitable for seasonal peaking operations or other purposes not addressed by this survey. If a given ASR or AR cell does not have either excess supplies or needs within a distance of two cells (approximately 20 miles), the following flags are placed in the Final_ASR_rating (or Final_AR_rating):

  - -2 no excess water identified
  - -3 no need identified
  - -4 neither excess water nor need identified

- The data gaps, challenges, and limitations associated with each of the three screenings are also relevant to the Final Suitability Rating, which used scores developed from those datasets. For instance, the needs geodatabase does not include projected water needs for mining, irrigation, and municipal county-other users for which spatial data is not available from the draft DB22 other than at a county-wide level. Some of these categories represent significant regional needs (such as irrigation needs in the Panhandle and West Texas) that are not included in the screening (Figure 25).

- The Final Suitability Rating presents the best-scoring excess water supplies and needs located within approximately 20 miles from AR- or ASR-suitable locations based on the hydrogeological parameter screening. The following conditions associated with ASR or AR relative suitability are beyond the scope of the statewide survey and not considered in the screening:

  - Longer distances to excess supplies or needs (>20 miles). These may be considered viable by a project sponsor, but these opportunities are not included in the screening.

  - Site-specific considerations, including water compatibility, geochemical aspects of water storage, and other factors that are essential considerations prior to project implementation.

- Integration, system operations, treatment, and seasonal water use ASR or AR applications. This level of analysis is beyond the scope of the statewide screening.

- Site- and system-specific water quality evaluations are needed to understand source water compatibility, blending, and/or specific water quality parameter interaction before combining with existing supplies or systems. For instance, naturally occurring arsenic in aquifer minerals needs to be evaluated and carefully considered as these can be released during introduction of new waters into storage. TCEQ's study (Reedy, 2018) that assesses arsenic in groundwater and water supply systems in Texas should be considered, in addition to other sources and field-testing results as the next phase of study prior to implementing AR or ASR projects.

Data sources

Results from the hydrogeological parameter, excess water, and water supply needs screenings of this survey were used for the Final Suitability Rating.

Data gaps

The Final Suitability Rating generally provides good statewide coverage; however, there are locations scattered throughout the state that do not show water needs for specific municipal, manufacturing, and steam-electric water users (Figure 23 and Figure 25). These areas have county-level needs represented in the draft DB22 that are not included in the screening, due to a lack of spatial information on where these needs occur. There are 920 cells (out of 3,160 total grid cells statewide) for which excess supplies do not exist, representing 29 percent of the statewide coverage. There are 1,623 cells (out of 3,160 total grid cells statewide) for which water supply needs do not exist, representing 51 percent of the statewide coverage.

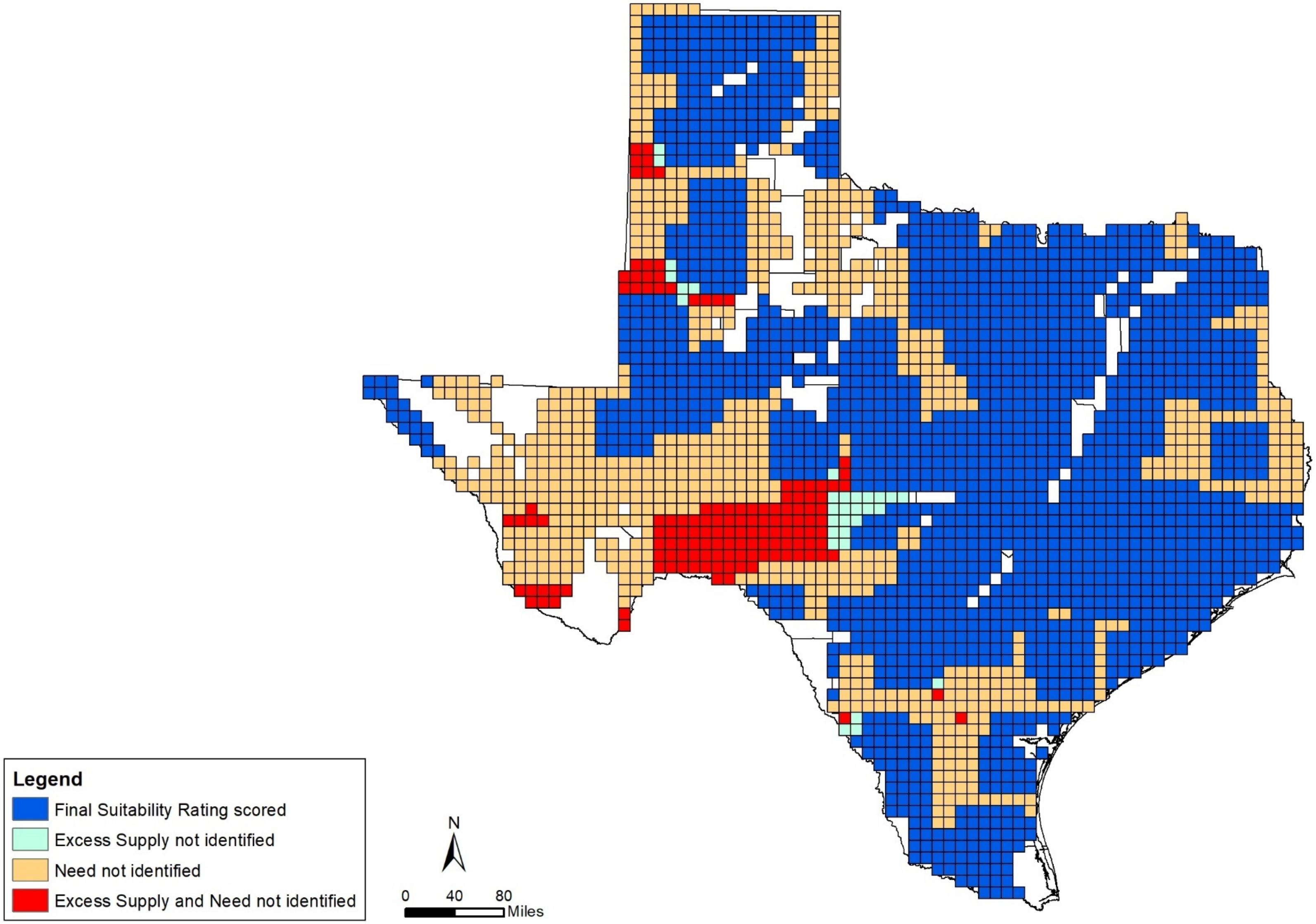

Figure 25. Summary of grid cell details affecting Final Suitability Rating

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Scoring

The Final Suitability Rating is calculated for ASR and AR cells using the following parameters:

- Highest_ASR_Hydro_Score (or Highest_AR_Hydro_Score)
- Excess_Water_Score
- Needs_Score

The scores were almost weighted equally, with Aquifer_Score, Excess_Water_Score, and Needs_score respectively weighted at 0.34, 0.33, and 0.33. One weight needed to be 0.34 so the sum could equal 1. The statewide Final Suitability Ratings range from 0 to 1, with 1 being the highest suitability rating based on the parameters of this survey's hydrogeology, excess water, and water needs mapping.

Parameters and weights used to calculate the Final Suitability Ratings for ASR or AR are summarized in Table 22.

Table 23. Parameters recommended for use in calculating a Final Suitability Rating for ASR or AR

Field name	Weighting	Score
RCID	--	--
Highest_ASR_Hydro_Score or Highest_AR_Hydro_Score	0.34	0 (low) 1 (high)
Highest_Scoring_Aquifer_ID	--	--
Excess_Water_ID	--	--
Excess_Water_Sum	--	--
Excess_Water_Normalized_Score	--	--
Excess_Water_Distance	--	--
Excess_Water_Distance_Weight	--	--
Excess_Water_Score	0.33	0 (low) 1 (high)
Needs_ID	--	--
Needs_Sum	--	--
Needs_Normalized_Score	--	--
Needs_Distance	--	--
Needs_Distance_Weight	--	--
Needs_Score	0.33	0 (low) 1 (high)
Final_ASR_rating or Final_AR_rating	--	--

Overall findings and conclusions

Figure 26 shows the ASR Final Suitability Rating after intersecting hydrogeology, excess water, and water needs. Of the 2,688 grid cells included in the statewide ASR coverage, 934 (or 35 percent) reported no water need and/or excess supply within about 20 miles (2 grid cells) of the hydrogeological parameter grid cell that received an ASR hydrogeological score in the first screening. For the remaining 1,754 grid cells (65 percent total statewide grid cells) for which hydrogeology, excess water, and needs were combined, 309 grid cells (or 18 percent) reported most suitable ratings for ASR (>0.7), and 876 grid cells (or 50 percent) reported moderately suitable ASR ratings of 0.5 to 0.7. Final ASR suitability ratings were assigned to all 9 major aquifers and 16 minor aquifers. Six minor aquifers did not receive a score either because the location coincided with another aquifer that scored more favorably, or because they occurred in areas without excess water and/or needs. The four aquifers with the most widespread coverage included the Carrizo-Wilcox, Gulf Coast, Ogallala, and Trinity aquifers, which, combined, accounted for nearly 70 percent of the scored cells. This widespread coverage reflects the extent and high productivity of these aquifers combined with the presence of certain areas with excess water and needs. The highest ASR Final Suitability Ratings (>0.85) were found in the Carrizo-Wilcox, Trinity, Gulf Coast, and Sparta aquifers. Each of these aquifers had median hydrogeological parameter screening scores that rated in or almost in the "high" category. This combined with the presence of major population centers nearby, along with available excess supplies, drives their ratings toward this high value.

Figure 27 shows the AR Final Suitability Rating after intersecting hydrogeology, excess water, and water needs. Of the 2,403 grid cells included in the statewide AR coverage, 894 (or 33 percent) reported no water need and/or excess supply within about 20 miles (2 grid cells) of the hydrogeological parameter grid cell that received an AR score in the first screening. For the remaining 1,509 grid cells (67 percent total statewide grid cells) for which hydrogeology, excess water, and needs were combined, 314 grid cells (or 21 percent) reported most suitable ratings for AR (>0.7), and 799 grid cells (or 53 percent) reported moderately suitable AR scores of 0.5 to0.7. Final AR suitability scores were assigned to all 9 major aquifers and 15 minor aquifers. Seven minor aquifers did not receive a score either because the location coincided with another aquifer that scored more favorably, or because they occurred in areas without excess water and/or needs. The four aquifers with the most widespread coverage included the Gulf Coast, Ogallala, Cross Timbers, and Carrizo-Wilcox aquifers, which, combined, accounted for 57 percent of the scored cells, indicating that AR cells had more aquifer distribution than ASR. The highest AR Final Suitability Ratings (>0.85) were found in the Brazos Valley Alluvium, Gulf Coast, Ogallala, Carrizo-Wilcox, and Hueco-Mesilla Bolsons aquifer outcrops.

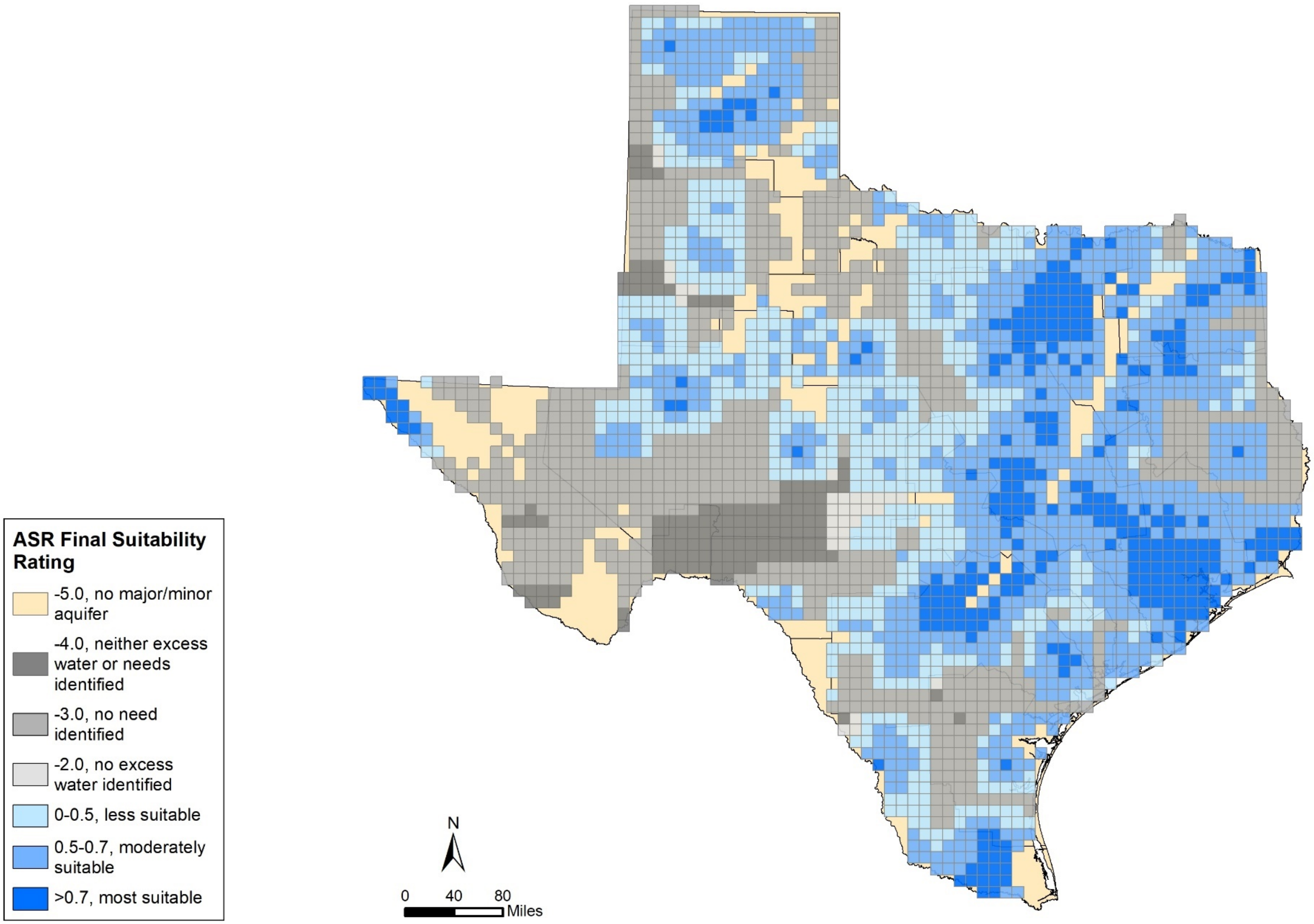

Figure 26. ASR Final Suitability Rating

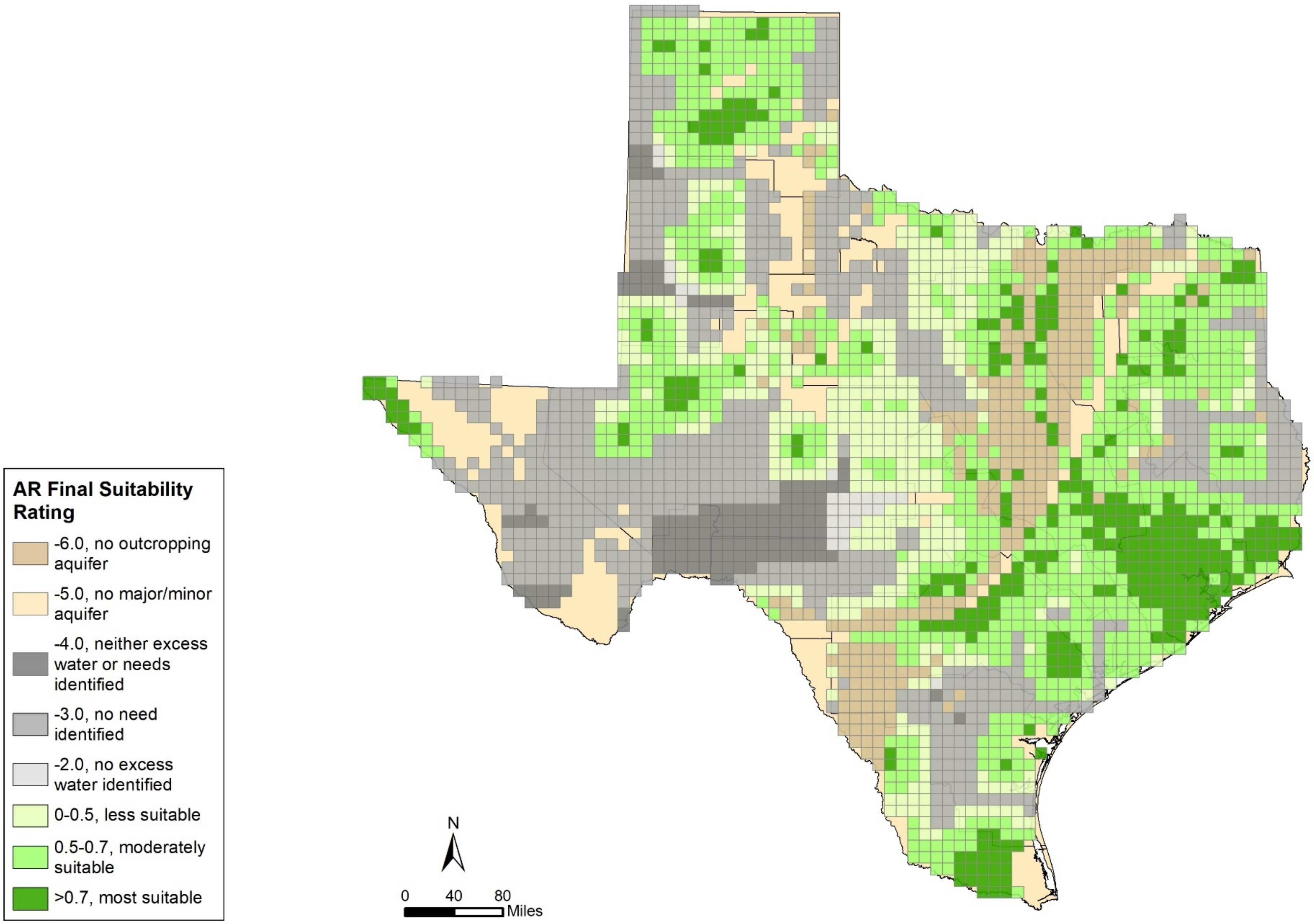

Figure 27. AR Final Suitability Rating

Future work

This survey provided a good statewide look at relative aquifer suitability for ASR and AR, including evaluating "project potential" by considering the locations of excess water available for storage and water supply needs as well as locations suitable for ASR or AR based on hydrogeology. In the future, should additional spatial information become available regarding where significant county-level water needs occur, especially in areas where data is absent in ASR and AR final suitability maps, it may be beneficial to update the screening with such information to have a more complete understanding of ASR or AR suitability across Texas.

Public data display

Objective

The objective of this work effort is to allow the public to explore the hydrogeological parameters, excess water, and water supply needs data that went into the Final Suitability Rating without license subscriptions or specialized expertise.

Approach

The results from the four screenings were compiled to develop a final, finished StoryMap to describe the process, method, and results of the statewide ASR and AR survey. ArcGIS StoryMaps is a web-based application on the ArcGIS platform. It enables sharing the immense amount of spatial data generated by this survey in the context of narrative text, lists, images, and interactive maps. The outputs/artifacts from the four screening datasets included map data/layers, graphics, static maps, scoring, and contextual descriptions. Using these artifacts and map data provided by the TWDB, the contract team developed map applications to drive the creation of the StoryMap.

Included are the following ESRI "widgets" in the interactive map capabilities of this deliverable.

- Search
- Query
- Bookmarks
- Lat-Long finder
- Location (requires location services to be turned on)
- Measure
- Pan/zoom
- Administrative boundaries (regional water planning groups, groundwater conservation districts, and legislative districts)

Viewer

StoryMaps generally use a visualization template, and the contract team selected the Sidecar template. Sidecar blocks are a combination of media and story narrative that fill the display, creating an immersive experience in stories. Sidecars are made up of slides, and each slide has a stationary media panel and scrolling narrative content such as text, media, and maps. As readers scroll through a sidecar, the media panel changes to match the narrative panel content for each slide. With sidecars, one can also highlight map locations and data in the media panel through map choreography and map actions.

Web mapping application is a browser-based map screening for users interested in a more in-depth exploration of the survey data.

Methodology

As noted, the methodology includes using existing map layers to create map applications that underlie the StoryMap.

An iterative approach was used to finalize the functionality and visualization of the elements of the StoryMap. The contract team provided the TWDB a draft of the deliverable and asked the agency to provide feedback and direction to prioritize functionality important for public data display. Multiple sessions to view the versions of the deliverable were conducted to ensure that the final product meets the legislative requirements, meets the needs of diverse audiences for the information/data, is aesthetically pleasing, and is in compliance with accessibility standards.

Assumptions, challenges, and limitations

The following assumptions were used in the development of the public data display:

- All map layers were provided as needed for the creation of the final deliverable.
- All graphics/colors/logos were to be provided and approved by the TWDB.
- All text was to be approved by the TWDB.

The following are some of the key challenges in developing the StoryMap and ArcGIS Online content such as the web map application:

- The survey development was constructed under an extremely aggressive schedule in order to meet legislative requirements.

- Agreement was reached early in the survey that the product should be achieved with "out of the box" capabilities and no custom code.

Data sources

The primary data sources that were used include the following:

- Screening geodatabases
- Base maps from the TWDB, including groundwater management districts, regional water planning boundaries, standard map layers for county boundaries, and legislative district boundaries.

Data gaps

Not applicable.

Results

The StoryMap "Statewide Survey of ASR and AR Suitability for Texas' Major and Minor Aquifers" can be reached at:

https://twdb-wsc.maps.arcgis.com/apps/MapSeries/index.html?appid=75313de26daf4994bcb590fdb8846b80

The web mapping application for "Statewide Survey of ASR and AR Suitability for Texas' Major and Minor Aquifers" can be reached at:

https://twdb-wsc.maps.arcgis.com/apps/webappviewer/index.html?id=50d9b795672243d387cef438f7c62311

Future Work

Future work could examine the available ESRI "widgets" to determine whether adding one or some would enhance the usability and/or functionality of the StoryMap.

At this time no additional widgets have been identified, and the features included in the StoryMap allow the public to review results and query scores from the screenings developed as part of the statewide ASR and AR survey.

Conclusions

This survey provides support to water planners, engineers, and government officials for consideration of ASR and AR projects in Texas.

The survey results show that Texas has numerous areas suitable for ASR or AR. Final Suitability Ratings for ASR or AR are categorized as: less, moderately, and most suitable. A "less" suitability rating does not necessarily preclude the chance of a successful project being developed in the area; rather the score is a relative indicator of statewide favorability.

The framework of source data assembled and analyzed for this survey provides versatility for stakeholders. The hydrogeological parameter, excess water, and water supply needs screenings are standalone products, and each offers value on its own. Source data can be customized as needed according to parameters that are deemed most relevant to each stakeholder. All four screenings provide a strong foundation that can be updated with future datasets or as new data becomes available.

References

Ahmadi, M., Mahdavirad, H., and Bakhtiari, B., 2017, Multi-criteria analysis of site selection for groundwater recharge with treated municipal wastewater: Water Science Technology, 76 (4): 909–919.

Bounds, R., and Lyons, B., 1979, Existing reservoir and stream management—statewide minimum streamflow recommendations: Texas Parks and Wildlife Department, Austin, Texas.

EPA (U.S. Environmental Protection Agency), ND, Enforcement and compliance history online (ECHO). Available online: https://echo.epa.gov/

House Bill 720, 86th Texas Legislature, 2019. Available online: https://legiscan.com/TX/text/HB720/id/2026232/Texas-2019-HB720-Enrolled.html

House Bill 721, 86th Texas Legislature, 2019. Available online: https://capitol.texas.gov/tlodocs/86R/billtext/html/HB00721S.htm

Oliver, W., and Kelley, V., 2014, Modification and recalibration of the groundwater model for paleozoic aquifers in the Upper Trinity Groundwater Conservation District—Draft Report: INTERA Inc., prepared for Upper Trinity Groundwater Conservation District, Austin, Texas 130 p.

Pedrero, F., Albuqueruqe, A., Marecos do Monte, H., Cavaleiro, V., Alarcon. J.J., 2011, Application of GIS-based multi-criteria analysis for site selection of aquifer recharge with reclaimed water. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0921344911001649?via%3Dihub

Reedy, R., and Scanlon, B., 2018, Assessment of arsenic in groundwater and water supply systems in Texas: Prepared for Texas Commission on Environmental Quality.

Shaw, K.S., Stein, Z.A., Deeds, N.E., George, P.G., Milczarek, M., and Yang, Q., 2020, Statewide survey of aquifer suitability for aquifer storage and recovery projects or aquifer recharge projects: contract report by HDR Engineering with support by the Bureau of Economic Geology at the University of Texas at Austin, Collier Consulting, Cooper Consulting, GeoSystems Analysis Inc., INTERA Inc., and Floodace, prepared for the Texas Water Development Board, 234 p.

SURRGO (U.S. Department of Agriculture Soil Survey Geographic Database), ND. Available online: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627

TCEQ (Texas Commission on Environmental Quality), ND, Texas pollutant discharge elimination system program. Available online: https://www.tceq.texas.gov/permitting/wastewater

TCEQ (Texas Commission on Environmental Quality), ND, Water availability models (WAM). Available online: https://www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html

TWDB (Texas Water Development Board), 2011, Aquifers of Texas: Texas Water Development Board Report 380, 172 p.

TWDB (Texas Water Development Board), ND, Brackish resources aquifer characterization system (BRACS) studies. Available online: https://www.twdb.texas.gov/innovativewater/bracs/

TWDB (Texas Water Development Board), ND, Groundwater availability models. Available online: https://www.twdb.texas.gov/groundwater/models/gam/index.asp

TWDB (Texas Water Development Board), 2021, 2021 Draft regional water plans. Available online: http://www.twdb.texas.gov/waterplanning/rwp/plans/2021/index.asp

TWDB (Texas Water Development Board), ND, Water data for Texas. Available online: https://www.waterdatafortexas.org/reservoirs/statewide

Texas Water Code, Section 27.151, 2015. Available online: https://statutes.capitol.texas.gov/Docs/WA/htm/WA.27.htm

Texas Water Code, Section 11.155, 2019. Available online: https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm

Texas Water Code, Section 11.021, 1977. Available online: https://statutes.capitol.texas.gov/Docs/WA/htm/WA.11.htm

USGS (U.S. Geological Survey, ND, Digital elevation model program. Available online: https://www.usgs.gov/core-science-systems/ngp/3dep

Yang, Q., and Scanlon, B. R., 2019, How much water can be captured from flood flows to store in depleted aquifers for mitigating floods and droughts? A case study from Texas, U.S.: Environmental Research Letters, 14(5).