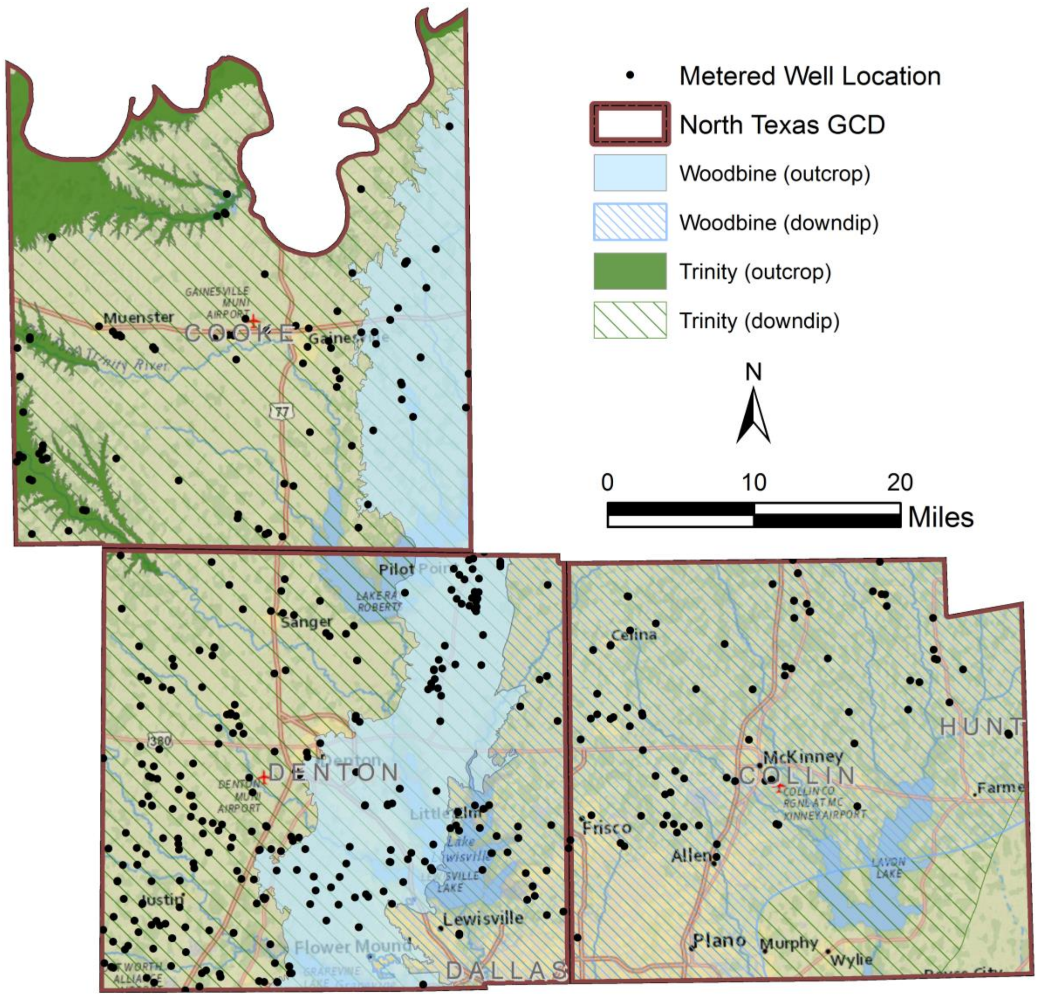
NORTH TEXAS
GROUNDWATER CONSERVATION DISTRICT
MANAGEMENT PLAN



As Adopted on March 14, 2017

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North Texas GCD 2017 Management Plan Revisions

Feb. 1, 2017

Statute requires groundwater conservation districts (GCDs) to review, amend as necessary, and readopt management plans at least every five years. The North Texas GCD Management Plan developed in April 2012 has been updated to meet statute requirements and is in accordance with the Texas Water Development Board (TWDB) GCD management plan criteria checklist.

Below is a summarized list of revisions that have been made to the 2012 Plan in the development of the 2017 North Texas GCD Management Plan.

- Section 2 – History and Purpose of the Management Plan was enhanced to include text regarding new legislation (Senate Bill 660 and 737) which impacts the development of DFCs and the water planning process.

- Revisions to Goal 1 – Providing the Most Efficient Use of Groundwater.

Discussion was added to update the Plan regarding the current registration process of all non-exempt and exempts wells. In addition, the Plan includes mention of a groundwater monitoring program, meter inspection program, and updates to the District's geodatabase.

- Enhanced Goal 5 – Addressing natural resource issues within the District.

The District has recently engaged a firm to monitor all injection well applications who will notify the General Manager of any potential impacts. In addition, the District will monitor compliance by oil and gas companies of well registration, metering, production reporting, and fee payment requirements of the District's rules.

- Enhancement of Section 8 – Estimates of Technical Information.

Update summary table of newly adopted DFCs and incorporate new GAM runs as an appendix.

Update the general overview discussion to include District specific hydrogeology to include new figures, maps, and cross-sections. In addition, a section was developed to discuss District specific outcrop and downdip groundwater management issues.

- Update to all text, tables, appendices and the addition of new figures using the most recent data provided by the Texas Water Development Board (TWDB). The Board reports were relocated as separate appendices for clarity.

- Update supplemental content in Section 10 – Groundwater Resources. This information is helpful for stakeholders in understanding relevant groundwater issues within the District.

NORTH TEXAS GROUNDWATER CONSERVATION DISTRICT MANAGEMENT PLAN

1. INTRODUCTION

The North Texas Groundwater Conservation District (the District), after notice and hearing, adopts this Management Plan according to the requirements of Texas Water Code §36.1071. The North Texas Groundwater Conservation District Management Plan represents the management goals of the District for the next five years, including the desired future conditions of the aquifers within the jurisdictional boundaries of the District. These desired future conditions were adopted through the joint planning process in Groundwater Management Area 8 as prescribed in Chapter 36, Texas Water Code.

DISTRICT MISSION

The mission of the District is to develop and adopt a management plan and develop and enforce rules to provide protection to protect existing wells and the rights of landowners, prevent waste, promote conservation, provide a framework that will allow availability and accessibility of groundwater for future generations, protect the quality of the groundwater in the recharge zone of the aquifers, ensure that the residents of Collin, Cooke, and Denton counties maintain local control over their groundwater, and operate the District in a fair and equitable manner for all residents.

STATEMENT OF GUIDING PRINCIPLES

The District is committed to manage and protect the groundwater resources within its jurisdiction and to work with others to ensure a sustainable, adequate, high quality and cost effective supply of water, now and in the future. The District will strive to develop, promote, and implement water conservation, augmentation, and management strategies to protect water resources for the benefit of the citizens, economy, and environment of the District. The preservation of this most valuable resource can be managed in a prudent and cost effective manner through conservation, education, and management. Any action taken by the District shall only be after full consideration and respect has been afforded to the individual property rights of all citizens of the District.

2. HISTORY AND PURPOSE OF THE MANAGEMENT PLAN

The purpose of the management plan is to identify the goals of the District and to document the management objectives and performance standards that will be used to accomplish those goals.

The 75th Texas Legislature in 1997 enacted Senate Bill 1 ("SB 1") to establish a comprehensive statewide water planning process. In particular, SB 1 contained provisions that require each groundwater conservation district ("GCD") to prepare a management plan to identify the water supply resources and water demands that will shape the decisions of the GCD. SB 1 designed the management plans to include management goals for each GCD to manage and conserve the groundwater resources within their boundaries. In 2001, the Texas Legislature enacted Senate Bill 2 ("SB 2") to build on the planning requirements of SB 1 and to further clarify the actions necessary for GCDs to manage and conserve the groundwater resources of the state of Texas.

The Texas Legislature enacted significant changes to the management of groundwater resources in Texas with the passage of House Bill 1763 ("HB 1763") in 2005. HB 1763 created a long-term planning process in which GCDs in each Groundwater Management Area ("GMA") were required to meet and determine the Desired Future Conditions ("DFCs") for the groundwater resources within their boundaries by September 1, 2010. In 2011, Senate Bills 660 and 737 further modified these groundwater laws and GCD management requirements in Texas.

Texas groundwater law is clear in establishing the sequence that a GCD is to follow in accomplishing statutory responsibilities related to the conservation and management of groundwater resources. The three primary steps, each of which must occur at least once every five years, are the following: (1) to adopt desired future conditions (Texas Water Code Section 36.108(c)), (2) to develop and adopt a management plan that includes goals designed to achieve the desired future conditions (Texas Water Code Section 36.1071(a)(8)), (3) to amend and adopt rules necessary to achieve goals included in the management plan (Texas Water Code Section 36.101(a)(5)).

Senate Bill 660 required that GMA representatives must participate within each applicable RWPG. It also required the Regional Water Plans (RWP) be consistent with the DFCs in place when the regional plans are initially developed. TWDB technical guidelines indicate that the MAG volume (within each county and basin) is the maximum amount of groundwater that can be used for existing uses and new strategies in 2016 Regional Water Plans. In other words, the MAG volumes are a cap on groundwater production for TWDB planning purposes.

"Managed available groundwater" was redefined as "modeled available groundwater" in Senate Bill 737 by the 82nd Legislature. Modeled available groundwater is "the amount of water that can be produced on an average annual basis" to achieve a desired future condition.

3. DISTRICT INFORMATION

3.1 CREATION

The District was created by the 81st Texas Legislature under the authority of Section 59, Article XVI, of the Texas Constitution, and in accordance with Chapter 36 of the Texas Water Code by the Act of May 19, 2009, 81st Leg., R.S., Chapter 248, 2009 Tex. Gen. Laws 686, codified at TEX. SPEC. DIST. LOC. LAWS CODE ANN. Chapter 8856 (the District Act).

The District is a governmental agency and a body politic and corporate. The District was created to serve a public use and benefit, and is essential to accomplish the objectives set forth in Section 59, Article XVI, of the Texas Constitution. The District's boundaries are coextensive with the boundaries of Collin, Denton, and Cooke counties, Texas (Figure 1~~Figure 1~~) and all lands and other property within these boundaries will benefit from the works and projects that will be accomplished by the District.

The creation of the District was confirmed by the Commissioners Court of Collin County on August 10, 2009; the Commissioners Court of Denton County on August 11, 2009; and the Commissioners Court of Cooke County on August 10, 2009.

3.2 DIRECTORS

The District is governed by a Board of Directors, which is comprised of nine appointed Directors, three from each of the three counties' commissioners' courts comprising the District.

3.3 AUTHORITY

The District has the rights and responsibilities provided for in Chapter 36 of the Texas Water Code and Chapter 356, Title 31 of the Texas Administrative Code. The District is charged with conducting hydrogeological studies, adopting a management plan, providing for the permitting of certain water wells and implementing programs to achieve statutory mandates. The District has rulemaking authority to implement the policies and procedures needed to manage the groundwater resources of Cooke, Collin and Denton counties.

3.4 LOCATION AND EXTENT

The District's boundaries are coextensive with the boundaries of Cooke, Collin and Denton Counties, Texas. The District covers an area of approximately 2,740 square miles. A map is included as Figure 1~~Figure 1~~.

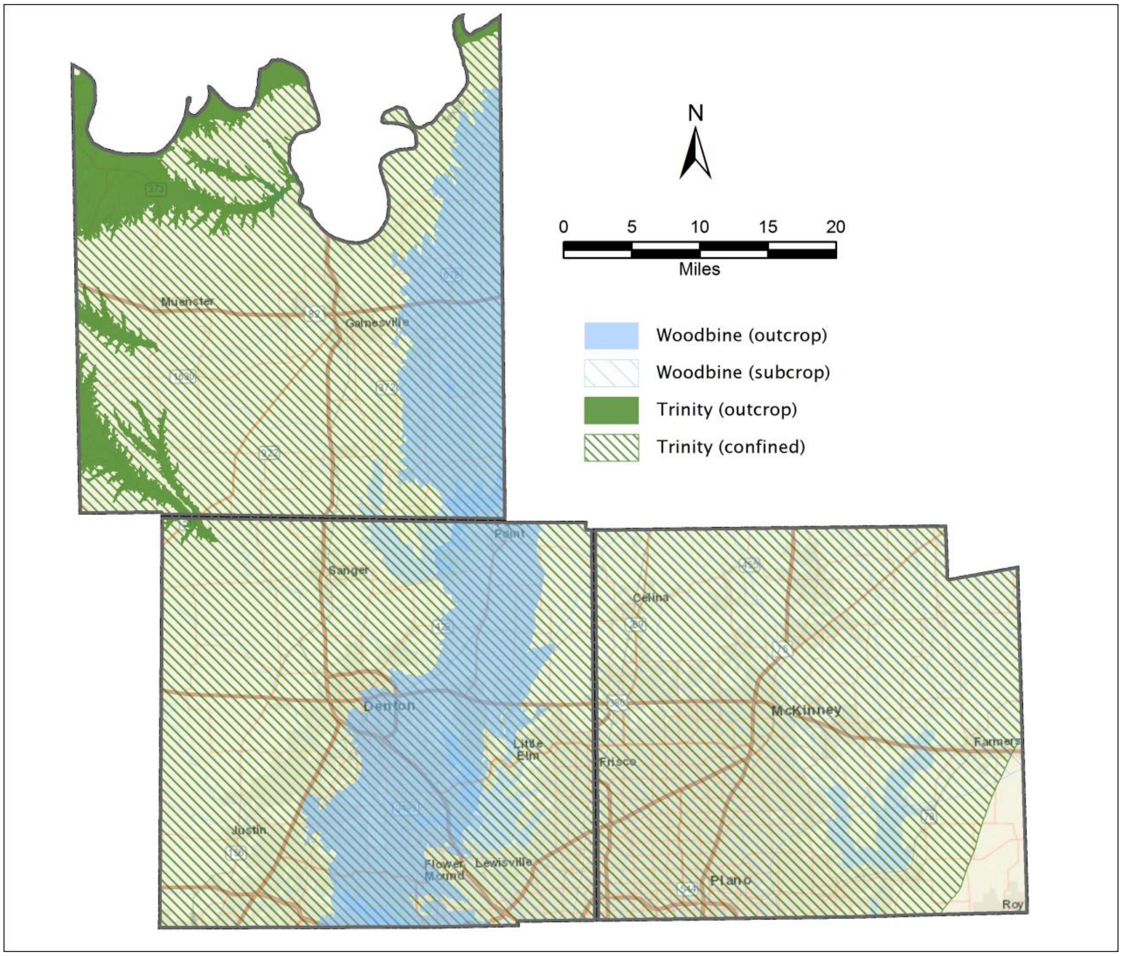


Figure 1. District aquifer map

4. CRITERIA FOR PLAN APPROVAL

4.1 PLANNING HORIZON

This management plan becomes effective upon adoption by the District Board of Directors and subsequent approval by the Executive Administrator of the Texas Water Development Board (TWDB). This management plan incorporates a planning period of ten years in accordance with 31 Texas Administrative Code (TAC) §356.5(a).

4.2 BOARD RESOLUTION

A certified copy of the North Texas Groundwater Conservation District resolution adopting the plan is located in Appendix A – District Resolution.

4.3 PLAN ADOPTION

Public notices documenting that the plan was adopted following appropriate public meetings and hearings are located in Appendix B – Notice of Meetings.

4.4 COORDINATION WITH SURFACE MANAGEMENT ENTITIES

A template letter transmitting copies of this plan to the surface water management entities in the District along with a list of the surface water management entities to which the plan was sent are located in Appendix C – Letters to Surface Water Management Entities.

5. ACTIONS, PROCEDURES, PERFORMANCE, AND AVOIDANCE FOR PLAN IMPLEMENTATION, AND MANAGEMENT OF GROUNDWATER SUPPLIES

In order to effectuate the District's management plan, the District continually works to develop, maintain, review, and update the District rules and procedures for the various activities contained in the management plan. In order to monitor performance, (a) the Board of Directors routinely meets to track progress on the various objectives and standards adopted in this management plan and (b) the General Manager prepares and submits an annual report documenting progress made towards implementation of the management plan to the Board of Directors for its review and approval. Also, as needed, and at least annually, the Board of Directors reviews District rules to ensure that all provisions necessary to implement the plan are contained in the rules. The Board of Directors will revise the rules as needed to manage and conserve groundwater resources within the District more effectively and to ensure that the duties prescribed in Texas Water Code and other applicable laws are carried out.

The District is currently operating pursuant to a set of ~~temporary~~ rules ~~adopted on October 19, 2010 and amended January 21, 2013, November 12, 2013, August 12, 2014, and on March 1, 2017. (Appendix D). The District anticipates operating under permanent rules in the Spring of 2018 and will amend the Plan accordingly at that time.~~that became effective January 1, 2019 A copy of the District's rules may also be found on the District's website located at www.northtexasgcd.org/.

The District will work diligently to ensure that all citizens within the District's jurisdictional boundaries are treated as equitably as possible. The District, as needed, will seek the cooperation of federal, state, regional, and local water management entities in the implementation of this management plan and management of groundwater supplies.

The District will continue to enforce its rules to conserve, preserve, protect, and prevent the waste of groundwater resources within its jurisdiction. Texas Water Code Chapter 36.1071(a)(1-8) requires that all management plans contain the following management goals, as applicable:

- providing the most efficient use of groundwater;
- controlling and preventing waste of groundwater;
- controlling and preventing subsidence;
- addressing conjunctive surface water management issues;
- addressing natural resource issues;
- addressing drought conditions;
- addressing conservation, recharge enhancement, rainwater harvesting, precipitation enhancement, or brush control, where appropriate and cost-effective; and
- addressing desired future conditions of the groundwater resources in a quantitative manner.

The following management goals, management objectives, and performance standards have been developed and adopted to ensure the management and conservation of groundwater resources within the District's jurisdiction.

6. METHODOLOGY FOR TRACKING DISTRICT PROGRESS IN ACHIEVING MANAGEMENT GOALS

The District's General Manager and staff will prepare an annual report ("Annual Report") and will submit the Annual Report to members of the Board of the District. The Annual Report covers the activities of the District including information on the District's performance in regards to achieving the District's management goals and objectives. The Annual Report will be delivered to the Board by July 1 following the completion of the District's fiscal year. A copy of the Annual Report will be kept on file and available for public inspection at the District's offices upon approval by the Board.

7. GOALS, MANAGEMENT OBJECTIVES AND PERFORMANCE STANDARDS

The following goals, management objectives, and performance standards have been developed and adopted to ensure the management and conservation of groundwater resources within the District's jurisdiction.

For purposes of this management plan, an exempt well means wells that meet any one of the following, unless the context clearly provides otherwise: (1) any ~~new~~ well that was applied for or existed prior to January 1, 2019 or existing well of any size or capacitythat is used solely for domestic use, livestock use, or poultry use; (2) any well that was applied for or existed prior to January 1, 2019 new or existing well that does not have the capacity, as equipped, to produce more than 25 gallons per minute and is used in whole or in part for commercial, industrial, municipal, manufacturing, or public water supply use, use for oil or gas or other hydrocarbon exploration or production, or any other purpose of use other than solely for domestic, livestock, or poultry use, except that if the total sum of the capacities of wells that operate as part of a well system is greater than 25 gallons per minute, the well system and individual wells that are part of it are not considered to be exempt; (3) any new well applied for after January 1, 2019 that does not have the capacity, as equipped, to produce more than 17.36 gallons per minute; or (34) leachate wells, monitoring wells, and piezometers. All wells that do not meet one of these criteria are considered to be non-exempt for purposes of this management plan. The characterization of exempt and non-exempt wells is intended to apply only to wells described in this management plan and shall not be interpreted to mean that the wells will be considered exempt or not exempt from permitting under any permanent rules adopted by the District in the future.

GOAL 1 - PROVIDING THE MOST EFFICIENT USE OF GROUNDWATER

The District, through strategies and programs adopted in this management plan and rules, strives to ensure the most efficient use of groundwater in order to sustain available resources for the future while maintaining the vibrant economic growth of the District.

Management Objective 1.1

The District will require that all wells be registered in accordance with its current rules.

Performance standard 1.1

The Board of Directors will receive quarterly briefings by the General Manager regarding the District's well registration program. These quarterly reports will be included in the Annual Report to the Board of Directors. The District is currently in the beginning phase of making improvements to the online geodatabase that will make additional statistics available for this report such as the aquifer in which wells are being completed. In addition, a handout will be provided annually to local realtor associations detailing the requirement of new property owners to register their existing wells within 90 days of transfer of ownership.

Management Objective 1.2

It is the goal of the District that all non-exempt wells and exempt wells be registered. In order to ensure that all wells required by District rules to be registered have been accurately registered the District's Field Technician manages a Field Inspections Program, with the objective of conducting field inspections of at least 5 wells per month. These inspections will confirm that a well has been registered, accuracy of well location, and accuracy of certain other required well registration information.

Performance Standard 1.2

Quarterly briefings by the General Manager will be provided to the Board of Directors regarding the number of well sites inspected each month to confirm well registration requirements have been met. This information will also be included in the Annual Report to the Board of Directors.

Management Objective 1.3 (a)

In order to evaluate continually the effectiveness of the District's rules in meeting the goal of ensuring the efficient use of groundwater, the District will operate a groundwater monitoring program to collect information on the quantity and quality of groundwater resources throughout the District. This monitoring program is based on the establishment of a network of monitoring wells. The District staff has assumed the responsibility of monitoring all available TWDB wells at least annually. In addition, one additional well will be added in each county, for a total of three new wells to the system in accordance with the District's well monitoring plan. For the purpose of water quality sampling, samples collected for water quality taken by Texas Commission on Environmental Quality staff every five years will be used for monitoring purposes initially, and may be supplemented in the future as determined by the Board. All information collected in the monitoring program will be entered into the District's geodatabase after the current geodatabase improvements project is complete. The results of the monitoring program will be included in the Annual Report presented by the General Manager.

Performance Standard 1.3 (a)(1)

Track the number of wells in Collin, Cooke, and Denton counties for which water levels were measured per year as reported in the Annual Report presented by the General Manager to the Board of Directors.

Performance Standard 1.3 (a)(2)

Track the number of wells in Collin, Cooke, and Denton Counties for which water samples were collected for the testing of water quality: The Texas Commission on Environmental Quality provides a Consumer Confidence Report that provides consumers with information about the quality of drinking water.

This data may be reviewed at: www.tceq.texas.gov/drinkingwater/ccr/ for water systems.

Management Objective 1.3 (b)

In order to ensure the efficient use of groundwater, adequate data must be collected to facilitate groundwater availability modeling activities necessary to understand current groundwater resources and the projected availability of those resources in the future. Monitoring wells will be established by the District on a schedule determined by the Board of Directors as funds are available.

Performance Standard 1.3 (b)

The number of wells for which water level data is available will be accessible online after the current geodatabase improvements project is complete.

Management Objective 1.4

A critical component of the District's goal of ensuring the efficient use of groundwater is the collection of accurate water use information. The District has established by temporary rule a requirement that all non-exempt wells be equipped with meters to measure the use of groundwater. The well owner/operator is responsible for maintaining a meter log with at least monthly records of water use. Cumulative water use is to be reported to the District by the well owner/operator quarterly. All water use information will be entered and maintained in the District's geodatabase. It is the objective of the District that 95 percent of all registered non-exempt wells will report water use by the reporting deadlines established in the District's rules.

Performance Standard 1.4

Percent of registered non-exempt wells meeting reporting requirements of water use will be provided in the Annual Report to the Board of Directors.

Management Objective 1.5

In order to ensure that registered non-exempt wells have been equipped with District-approved meters and that water use is being accurately reported, the District Field Technician facilitates a meter inspection program to insure that all registered non-exempt wells will be inspected on at least a five-year cycle by District personnel. These inspections will, at a minimum, verify proper installation and operational status of meters and record the meter reading at the time of inspection. This meter reading will be compared to the most recent water use report for the inspected well. Any potential violations of District rules regarding meter installation and reporting requirements will be reported to the Board of Directors at the next practicable meeting for consideration of possible enforcement actions. Annual water use will be included in the Annual

Report presented by the General Manager to the Board of Directors.

Performance Standard 1.5 (a)

Percentage of registered non-exempt wells inspected by District personnel annually is provided in the Annual Report presented by the General Manager.

Performance Standard 1.5 (b)

Comparison of annual water use versus estimates of modeled available groundwater established as a result of the adopted Desired Future Conditions shall be included in the Annual Report presented by the General Manager no later than ~~2019~~2021, after the current geodatabase improvements project is completed.

Management Objective 1.6

A critical component to accomplishing the District's mission is to ensure that proper data is being collected and that the data is being utilized to the fullest extent and efficiently. Shortly after the District's creation, the District hired a consultant to build an online geodatabase that would make workflows, data entry and data utilization easier and more efficient for well owners, well drillers, general public, District staff and the Board of Directors. After several years of utilizing the geodatabase the District had built, the District has identified areas in which the existing system can be upgraded

Performance Standard 1.6

The District will make substantial upgrades and improvements to the online geodatabase by ~~2019~~, in order to make workflows, data entry and data utilization easier and more efficient.

Management Objective 1.7

The District will develop a methodology to quantify current and projected annual groundwater production from exempt wells.

Performance Standard 1.7

The District will provide the TWDB with its methodology and estimates of current and projected annual groundwater production from exempt wells. The District will also utilize the information in the future in developing and achieving desired future conditions and in developing and implementing its production allocation and permitting system and rules. Information related to implementation of this objective will be included in the Annual Report to the Board of Directors by 2019.

GOAL 2 - CONTROLLING AND PREVENTING THE WASTE OF GROUNDWATER

Another important goal of the District is to implement strategies that will control and prevent the waste of groundwater.

Management Objective 2.1

The District will annually provide information to the public on eliminating and reducing wasteful practices in the use of groundwater by publishing information on groundwater waste reduction on the District's website at least once a year.

Performance Standard 2.1

Information on groundwater waste reduction will be provided on the District's website and the information published on the website will be included in the District's Annual Report to be provided to the Board of Directors.

Management Objective 2.2

The District will encourage the elimination and reduction of groundwater waste through a collection of water-use fees for non-exempt production wells within the District.

Performance Standard 2.2

Annual reporting of the total fees paid and total groundwater used by non-exempt wells will be included in the Annual Report provided to the Board of Directors.

Management Objective 2.3

The District will identify well owners that are not in compliance with District well registration, reporting, and fee payment requirements and bring them into compliance.

Performance Standard 2.3

The District will compare existing state records and field staff observations with well registration database to identify noncompliant well owners.

Management Objective 2.4

The District will investigate instances of potential waste of groundwater.

Performance Standard 2.4

District staff will report to Board of Directors as needed regarding potential waste of groundwater and include number of investigations in Annual Report.

GOAL 3 - CONTROLLING AND PREVENTING SUBSIDENCE

Due to the geology of the Northern Trinity/Woodbine Aquifers in the District, problems resulting from water level declines causing subsidence are not technically feasible and as such, a goal addressing subsidence is not applicable.

GOAL 4 - ADDRESSING CONJUNCTIVE SURFACE WATER MANAGEMENT ISSUES

Surface water resources represent a vital component in meeting current and future water demands in all water use sectors within the District. The District coordinates with surface water management entities within the region by designating a board member or the general manager to attend and coordinate on water supply and management issues with the Region C Water Planning Group.

Management Objective 4.1

Coordination with surface water management agencies - the designated board member or General Manager will attend, at a minimum 75 percent of the meetings and events of the Region C Water Planning Group. Participation in the regional water planning process will ensure coordination with surface water management agencies that are participating in the regional water planning process.

Performance Standard 4.1

The designated board member or General Manager will report on actions of the Region C Water Planning Group as appropriate to the board, and the General Manager will document meetings attended in the Annual Report.

Management Objective 4.2

The General Manager of the District will monitor and participate in relevant stakeholder meetings concerning water resources relevant to the District.

Performance Standard 4.2

The General Manager of the District will monitor and participate in relevant stakeholder meetings that concern water resources relevant to the District. The meetings that are attended will be presented in the District's Annual Report.

GOAL 5 - ADDRESSING NATURAL RESOURCE ISSUES

The District understands the important nexus between water resources and natural resources. The exploration and production of natural resources such as oil and gas along with mining efforts for road aggregate materials such as sand and gravel clearly represent potential management issues for the District. For example, improperly plugged oil and gas wells may provide a conduit for various hydrocarbon and drilling fluids to potentially migrate and contaminate groundwater resources in the District.

Management Objective 5.1

The District has engaged a firm to monitor all injection well applications within the District and notify the General Manager of any potential impacts.

Performance Standard 5.1

General Manager will report to the Board of Directors any information provided by the consultant engaged to monitor injection well applications within the District to the Board of Directors and document the information in the Annual Report to the Board of Directors.

Management Objective 5.2

The District will monitor compliance by oil and gas companies of well registration, metering, production reporting, and fee payment requirements of the District's rules.

Performance Standard 5.2

As with other types of wells, instances of non-compliance by owners and operators of water wells for oil and gas activities will be reported to the Board of Directors as appropriate for enforcement action. A summary of such enforcement activities will be included in the Annual Report to the Board of Directors.

GOAL 6 - ADDRESSING DROUGHT CONDITIONS

Management Objective 6.1

The District will make available through the District's website easily accessible drought information with an emphasis on developing droughts and on any current drought conditions. Examples of links that will be provided include routine updates to the Palmer Drought Severity Index (PDSI) map for the region, the Drought Preparedness Council Situation Report (routinely posted on the Texas Water Information Network, and the TWDB Drought Page at https://waterdatafortexas.org/drought.

Performance Standard 6.1

Current drought conditions information from multiple resources including the Palmer Drought Severity Index (PDSI) map for the region and the Drought Preparedness Council Situation Report is available to the public through the District's website

GOAL 7 - ADDRESS CONSERVATION, RECHARGE ENHANCEMENT, RAINWATER HARVESTING, PRECIPITATION ENHANCEMENT, AND BRUSH CONTROL

Texas Water Code §36.1071(a)(7) requires that a management plan include a goal that addresses conservation, recharge enhancement, rainwater harvesting, precipitation enhancement, or brush control, where appropriate and cost-effective. The District has determined that a goal addressing recharge enhancement and precipitation enhancement is not appropriate or cost-effective, and therefore is not applicable to the District.

Management Objective 7.1

The primary goal, perhaps viewed as the *"umbrella goal"* of the District is to provide for and facilitate the conservation of groundwater resources within the District. The District will include a link on the District's website to the electronic library of water conservation resources supported by the Water Conservation Advisory Council. For example, one important resource available through this internet-based resource library is the Water Conservation Best Management Practices Guide developed by the Texas Water Conservation implementation Task Force. This Guide contains over 60 Best Management Practices for municipalities, industry, and agriculture that will be beneficial to water users in the District.

Performance Standard 7.1

Link to the electronic library of water conservation resources supported by the Water Conservation Advisory Council is available on the District's website.

Management Objective 7.2

The District will submit at least one article regarding water conservation for publication each year to at least one newspaper of general circulation in the District's Counties.

Performance Standard 7.2

A copy of the article submitted by the District for publication to a newspaper of general circulation in one of the District's Counties regarding water conservation will be included in the Annual Report to the Board of Directors.

Management Objective 7.3

The District will provide educational curriculum regarding water conservation offered by the Texas Water Development Board (Major Rivers) to at least one elementary school in each county of the District.

Performance Standard 7.3

Each year the District will seek to provide water conservation curriculum to at least one elementary school in each county within the District. The elementary schools for which the curriculum is provided will be listed in the Annual Report to the Board of Directors.

Management Objective 7.4

Rainwater harvesting is assuming a viable role either as a supplemental water supply or as the primary water supply in both urban and rural areas of Texas. As a result, Texas has become internationally recognized for the widespread use and innovative technologies that have been developed, primarily through efforts at the TWDB. To ensure these educational materials are readily available to citizens in the District, a link to rainwater harvesting materials including system design specifications and water quality requirements will be maintained on the District's website.

Performance Standard 7.4

Link to rainwater harvesting resources at the TWDB is available on the District's website.

Management Objective 7.5

Educate public on importance of brush control as it relates to water table consumption.

Performance Standard 7.5

Link to information concerning brush control is available on the District's website.

GOAL 8 - ACHIEVING DESIRED FUTURE CONDITIONS OF GROUNDWATER RESOURCES

The desired future conditions of the aquifers in Groundwater Management Area 8 represent average water levels in the various aquifers at the end of 50-years based on meeting current and projected groundwater supply needs. The Board of Directors has adopted a strategic approach that includes the adoption of this management plan and rules necessary to achieve the desired future conditions. This management plan and the companion rules have been designed as an integrated program that will systematically collect and review water data on water quantity, water quality, and water use, while at the same time, implementing public awareness and public education activities that will result in a better informed constituency.

Management Objective 8.1

Statute requires GCDs to review, amend as necessary, and readopt management plans at least every five years. The General Manager will annually present a summary report on the status of achieving the adopted desired future conditions. Prior to the adoption date of the next management plan, the General Manager will work with the Board of Directors to conduct a focused review to determine if any elements of this management plan or rules need to be amended in order to achieve the adopted desired future conditions, or if the adopted desired future conditions need to be revised to better reflect the needs of the District.

Performance Standard 8.1

The General Manager will include a summary report on the status of achieving the adopted desired future conditions in the Annual Report beginning by ~~2019~~2021, after the geodatabase improvements project is complete. This summary report will primarily be based on data collected from the District's groundwater monitoring program.

Four years after the adoption of this management plan, and based on the annual review conducted by the General Manager and the Board of Directors, the Board of Directors will determine which of the following are needed for the District; (1) the current management plan and rules are working effectively to meet the adopted desired future conditions, (2) specific amendments need to be made to this management plan and/or rules in order to achieve the adopted desired future conditions, (3) amendments are needed to the adopted desired future conditions in order to better meet the needs of the District, or (4) a combination of (2) and (3). This determination will be made at a regularly scheduled meeting of the Board of Directors.

8. ESTIMATES OF TECHNICAL INFORMATION

In order to better understand groundwater resources within a groundwater conservation district, Texas Water Code §36.1071 requires that estimates of recharge, discharge, and various other aspects of groundwater flow, such as cross-formational flow and flow into and out of the district, be included in the management plan if a groundwater availability model is available for use. The TWDB, in its role of providing technical assistance to the District, conducted groundwater availability modeling runs for the Northern Trinity and Woodbine aquifers and provided all required estimates for inclusion in the management plan.

8.1 MODELED AVAILABLE GROUNDWATER BASED ON THE DESIRED FUTURE CONDITIONS

The term "desired future conditions" was added by the Texas Legislature in 2005 to the list of goals that districts must address when adopting or readopting management plans required by Texas Water Code §36.1071. Desired future conditions is defined in Texas Water Code §36.001(30) as follows, "Desired future condition" means a quantitative description, adopted in accordance with Section 36.108, of the desired condition of the groundwater resources in a management area at one or more specified future times".

Even before creation of the District by the Texas Legislature in 2009, other districts in Groundwater Management Area 8 adopted, through the joint planning process required by Texas Water Code §36.108, desired future conditions for the Woodbine Aquifer on December 17, 2007 and for the Trinity Aquifer on September 17, 2008. Subsequently, and with participation by the District, designated representatives in Groundwater Management Area 8 voted on April 27, 2011 to readopt the previously adopted desired future conditions without amendment for the Woodbine and Trinity aquifers. Because the District was not in existence during the initial adoption of desired future conditions in 2008 and was still in the organizational stages of development during re-adoption of those desired future conditions in 2011, the District did not have an opportunity to participate in the development of those desired future conditions.

Upon approval of this management plan by the Texas Water Development Board, the District intends to continue collecting as much data and information on the groundwater resources within its boundaries as practically feasible in order to enable it to develop and establish meaningful and reasonable desired future conditions for the aquifers within its jurisdiction in the next round of joint planning. Once those desired future conditions have been established and adopted, the District intends to develop permanent rules that require the permitting of certain wells and that establish a management system that will be designed to achieve the desired future conditions.

To determine the DFCs, a series of simulations using the TWDB's Groundwater Availability Model ("GAM") for the Northern Trinity and Woodbine aquifers were completed. Each GAM simulation was done by iteratively applying various amounts of simulated groundwater pumping from the aquifer over a predictive period that included a simulated repeat of the drought of record. Pumping was increased until the amount of pumping that could be sustained by the aquifer without impairing the aquifer conditions selected for consideration as the indicator of the aquifer desired future condition was identified.

In the North Texas District, the geologic units comprising the Trinity are: the Antlers (which includes all of the Trinity Group Formations), the Paluxy Sand, the Glen Rose Limestone, and the Twin Mountains (which includes the Hensell and the Hosston Formations that are differentiated further to the south). Trinity Formations for which DFCs and MAGs are developed need to be modified in terms of the Antlers, Paluxy and Twin Mountains.

During the second round of joint planning, GMA-8 passed and adopted a resolution proposing DFCs for all relevant aquifers by letter dated April 1, 2016. In February 2017, GMA-8 submitted to the TWDB a Resolution package containing GMA-8's approved and adopted DFC's. ~~The adopted DFCs for the Trinity and Woodbine aquifers are documented in Table 1. The DFCs are based on average drawdown in feet after 50 years for the Woodbine aquifer and for each Trinity aquifer units.~~

The Modeled Available Groundwater (MAG) estimates in GMA-8 for the Woodbine and Trinity aquifers are documented in Table ~~2~~ 1 and are based on ~~the following GAM runs:~~ GAM Run 17-029 ~~10-063 MAG (Trinity aquifer) and GAM Run 10-064 MAG (Woodbine aquifer).~~ The GAM Run~~s~~ ~~are~~is included as Appendix E. ~~These estimates will be updated when the TWDB completes the development of the new GAM Runs based on the newly adopted DFCs mentioned above. When the updated MAG estimates are made available to the District, the District will follow the required process to amend the Plan.~~

~~**Table 1. Current desired future conditions for the Trinity and Woodbine aquifers based on total average feet of drawdown**~~

~~GMA-8 Adopted DFCs~~					
~~**County**~~	~~**Woodbine**~~	~~**Paluxy**~~	~~**Glen Rose**~~	~~**Twin Mountain**~~	~~**Antlers**~~
~~Collin~~	~~459~~	~~705~~	~~339~~	~~526~~	~~570~~
~~Cooke~~	~~2~~	~~-~~	~~-~~	~~-~~	~~176~~
~~Denton~~	~~22~~	~~552~~	~~349~~	~~716~~	~~395~~

Table 12. Estimates of Modeled Available Groundwater for pumping in the Trinity and Woodbine aquifers (GAM Run 17-02910-063 and GAM Run 10-064)

County	Aquifer	Modeled Available Groundwater (acre-feet per year)							
		2009	2010	2020	2030	2040	2050	2060	2070
Collin	Antlers	629	1,961	1,966	1,961	1,966	1,961	1,966	1,961
Collin	Twin Mountains	163	2,201	2,207	2,201	2,207	2,201	2,207	2,201
Collin	Paluxy	616	1,547	1,551	1,547	1,551	1,547	1,551	1,547
Collin	Glen Rose	84	83	83	83	83	83	83	83
Collin	Woodbine	2,427	4,251	4,263	4,251	4,263	4,251	4,263	4,251
Collin	County Total	3,919	10,043	10,070	10,043	10,070	10,043	10,070	10,043
Cooke	Antlers	4,117	10,514	10,544	10,514	10,544	10,514	10,544	10,514
Cooke	Woodbine	1,646	800	802	800	802	800	802	800
Cooke	County Total	5,763	11,314	11,346	11,314	11,346	11,314	11,346	11,314
Denton	Antlers	11,427	16,545	16,591	16,545	16,591	16,545	16,591	16,545
Denton	Twin Mountains	997	8,366	8,389	8,366	8,389	8,366	8,389	8,366
Denton	Paluxy	1,532	4,819	4,832	4,819	4,832	4,819	4,832	4,819
Denton	Glen Rose	121	338	339	338	339	338	339	338
Denton	Woodbine	3,797	3,607	3,616	3,607	3,616	3,607	3,616	3,607
Denton	County Total	17,874	33,675	33,767	33,675	33,767	33,675	33,767	33,675
District Total		**27,556**	**55,032**	**55,183**	**55,032**	**55,183**	**55,032**	**55,183**	**55,032**

8.2 AMOUNT OF GROUNDWATER BEING USED WITHIN THE DISTRICT

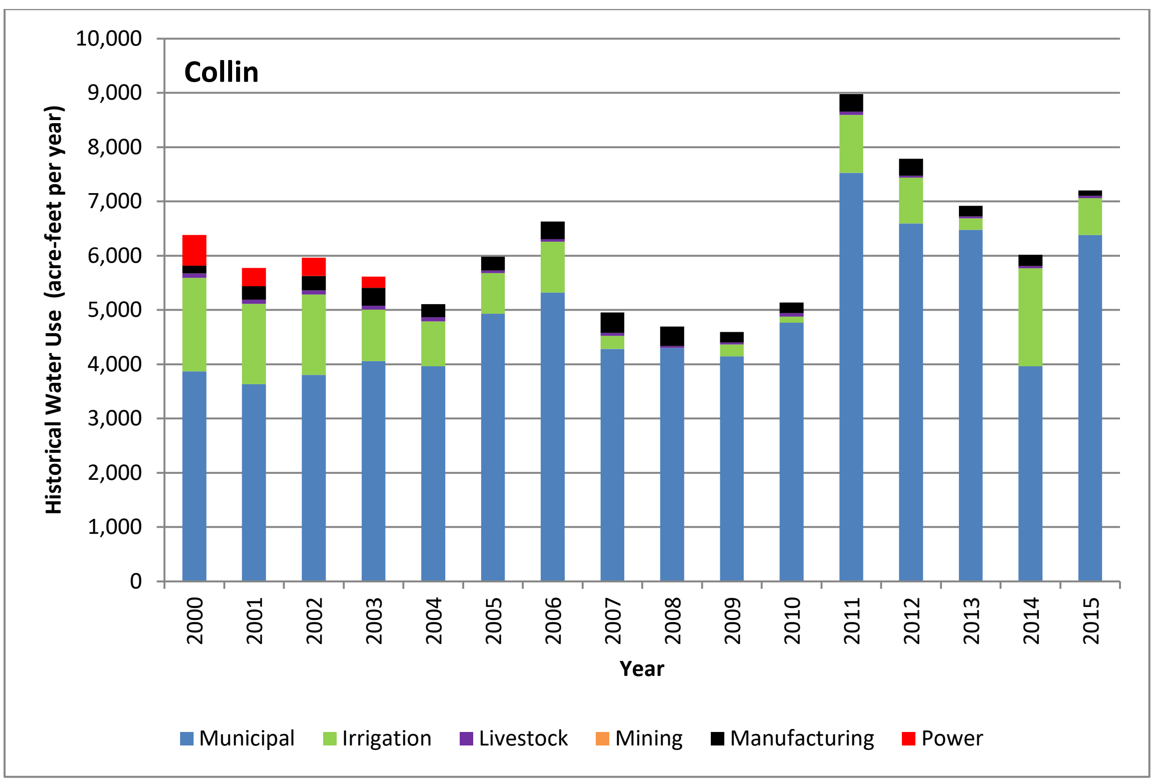
Estimates of historical water use, especially estimates from recent times, are very important during the process of developing water demand projections during the planning process. This is because changes in the volumes and types of water use, especially on a regional basis, will typically occur relatively slowly. Therefore, if one has a good understanding of recent water use statistics, then the projections of future water demands will be much more reliable.

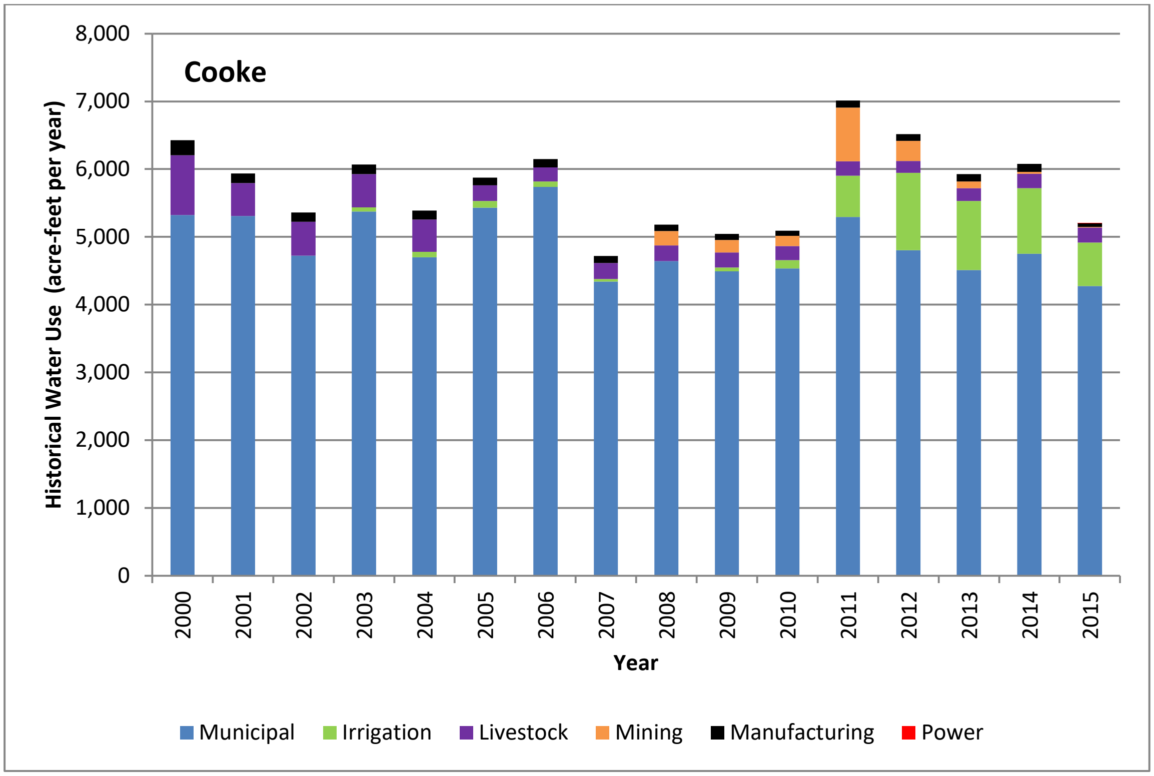
Texas Water Code §36.1071(e)(3)(B) requires that a management plan must include recent estimates of groundwater use. The primary source of this information is the TWDB Water Use Survey. Groundwater use estimates for the District for years 2000 through 2015 for the six primary water use sectors from the TWDB Water Use Survey are presented in Appendix F and Figure 2Figure 2.

Estimated historical groundwater use in the District by category in 2015 was 90 percent for municipal use, seven percent for irrigation use, two percent for livestock use, less than one percent for manufacturing and mining use, and zero percent for steam-electric power use. In the

TWDB Water Use Survey, the municipal use category includes small water providers and rural domestic pumping in addition to municipalities.

Total use was about 26,530 acre-feet in 2000, around 20,000 acre-feet per year from 2000 through 2006, generally increased between 2008 and 2012 to a maximum of about 37,525 acre-feet in 2011, generally decreased from 2011 through 2015. Total groundwater use reached a total volume in 2015 of 27,313 acre-feet. Usage for irrigation purposes was greatest from 2000 through 2006 and decreased to zero in 2008. Water use for mining purposes increased significantly in 2008 through 2011. Livestock use remained on average, 1,000 acre-feet per year from 2000 through 2004 and then decreased by about half to around 589 acre-feet per year from 2008 through 2011. Water use for steam-electric power generation varied from over 500 acre-feet per year in 2000 to approximately 336 acre-feet per year in 2001 and 337 acre-feet in 2002. No usage for power occurred in 2004 through 2015. Generally, municipal use has been greater than about 15,000 acre-feet per year throughout the historical record with maximum usage in 2011 (29,919 acre-feet), 2012 (26,424 acre-feet, and 2015 (24,479 acre-feet).





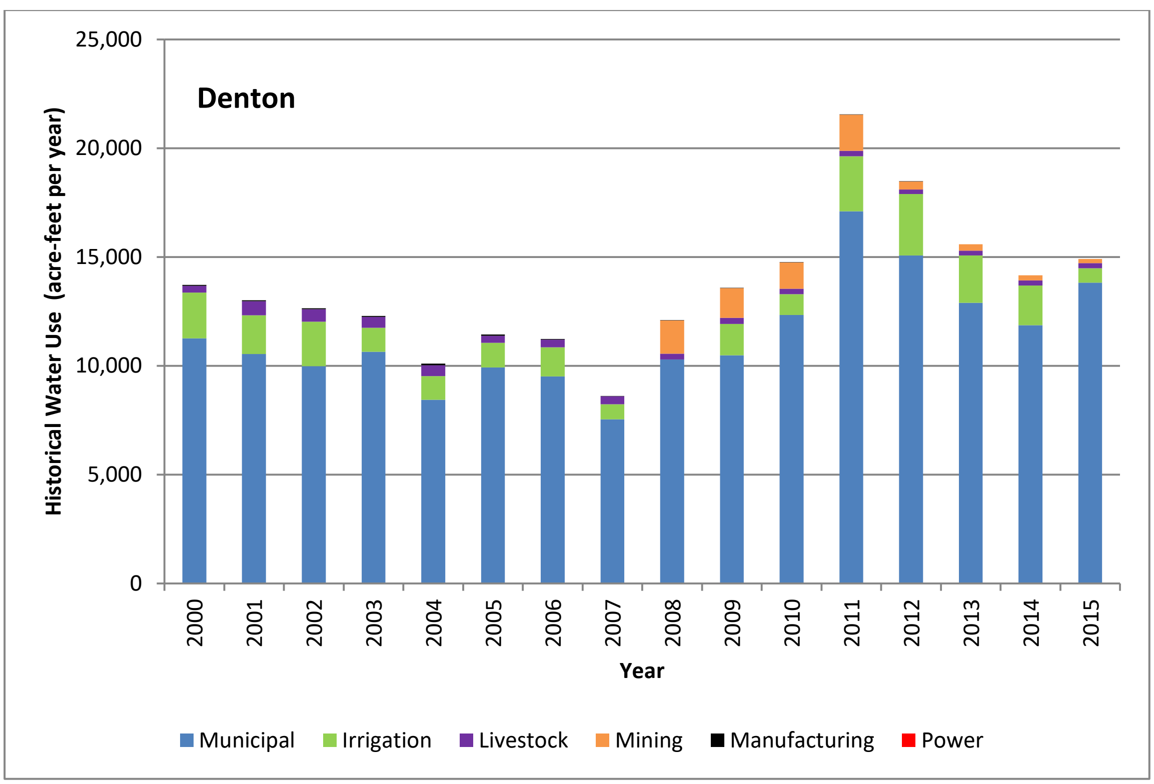


Figure 2. Historical groundwater use estimates by county, 2000-2015

8.3 ANNUAL AMOUNT OF RECHARGE OF PRECIPITATION

Recharge from precipitation falling on the outcrop of the aquifer (where the aquifer is exposed to the surface) within the North Texas GCD was estimated by the TWDB in the GAM Run 16-004 dated May 16, 2016. Water budget values of recharge extracted for the transient model period indicate that precipitation accounts for 13,851 acre-feet per year of recharge to the Trinity aquifer and 55,555 acre-feet per year of recharge to the Woodbine aquifer within the boundaries of the North Texas GCD (Appendix E).

8.4 ANNUAL VOLUME OF DISCHARGE FROM THE AQUIFER TO SPRINGS AND SURFACE WATER BODIES

The total water discharged from the aquifer to surface water features such as streams, reservoirs, and springs is defined as the surface water outflow. Water budget values of surface water outflow within the North Texas GCD were estimated by the TWDB in the GAM Run 16-004 (Appendix E). Values from the transient model period are 27,471 acre-feet per year of discharge from the Trinity aquifer and 35,588 acre-feet per year of discharge from the Woodbine aquifer to surface water bodies that are located within the North Texas GCD.

8.5 ANNUAL VOLUME OF FLOW INTO AND OUT OF THE DISTRICT AND BETWEEN AQUIFERS IN THE DISTRICT

Flow into and out of the District is defined as the lateral flow within an aquifer between the District and adjacent counties. Flow between aquifers is defined as the vertical flow between aquifers or confining units that occurs within the boundaries of the District. The flow is controlled by hydrologic properties as well as relative water levels in the aquifers and confining units. Water budget values of flow for the North Texas GCD were estimated by the TWDB in the GAM Run 16-004 (Appendix E). Values extracted from the transient model period represent the model's calibration and verification time period (years 1980 through 2012).

For the Woodbine Aquifer, estimated annual flow into and out of the District is 7,668 and 16,202 acre-feet per year, respectively. These volumes indicate that the District gains only half as much water from neighboring portions of the Woodbine Aquifer than it loses. For the Northern Trinity Aquifer, estimated annual flow into and out of the District is 41,751 and 18,411 acre-feet per year, respectively. These volumes indicate that the District gains over twice as much water from neighboring portions of the Northern Trinity Aquifer than it loses.

The estimated amount of annual flow between aquifers in the District based on GAM Run 16-004 provided by the TWDB are given in Appendix E. The GAM run estimates flow of 3,280 acre-feet per year from the Woodbine Aquifer to younger units and flow of 6,595 acre-feet per year from the Woodbine Aquifer to the Washita and Fredericksburg confining units. The run also estimated that 16,473 acre-feet per year flows from overlying units to the Trinity Aquifer.

8.6 PROJECTED SURFACE WATER SUPPLY IN THE DISTRICT

Although the primary focus of this management plan is on groundwater resources, the reality is that in areas like the District, decision makers must also consider surface water resources available to meet water supply needs when planning for the sustainable utilization of the resource. Texas Water Code §36.1071 recognizes this need for a more comprehensive evaluation, and as such requires groundwater conservation districts to consider surface water resources available in the District and also water management strategies that are included in the most recently adopted state water plan, regardless of whether the original source is surface water or groundwater. Appendix F summarizes the projected surface water supplies in the District based on the 2017 Texas State Water Plan, as provided by Allen (2017). This table is organized by county and water user groups and provides projected values for every decade from2020 to 2070.

Total projected surface water supplies by county are illustrated in Figure 3~~Figure 3~~. The estimated projections range from a maximum of 150,370 acre-feet per year in 2020 to a minimum of 112,754 acre-feet per year in 2070 for Collin County, from a maximum of 3,344 acre-feet per year in 2070 to a minimum of 1,929 acre-feet per year in 2020 for Cooke County, and from a maximum of 143,405 acre-feet per year in 2030 to a minimum of 130,146 acre-feet per year in 2070 for Denton County. These values indicate very little projected surface water supplies in Cooke County. They also indicate that projected surface water supplies for the District, which are on the order of 264,000 acre-feet per year, are significantly greater than historical groundwater use in the District, which is on the order of 20,000 to 30,000 acre-feet per year for 1980 through 2008.

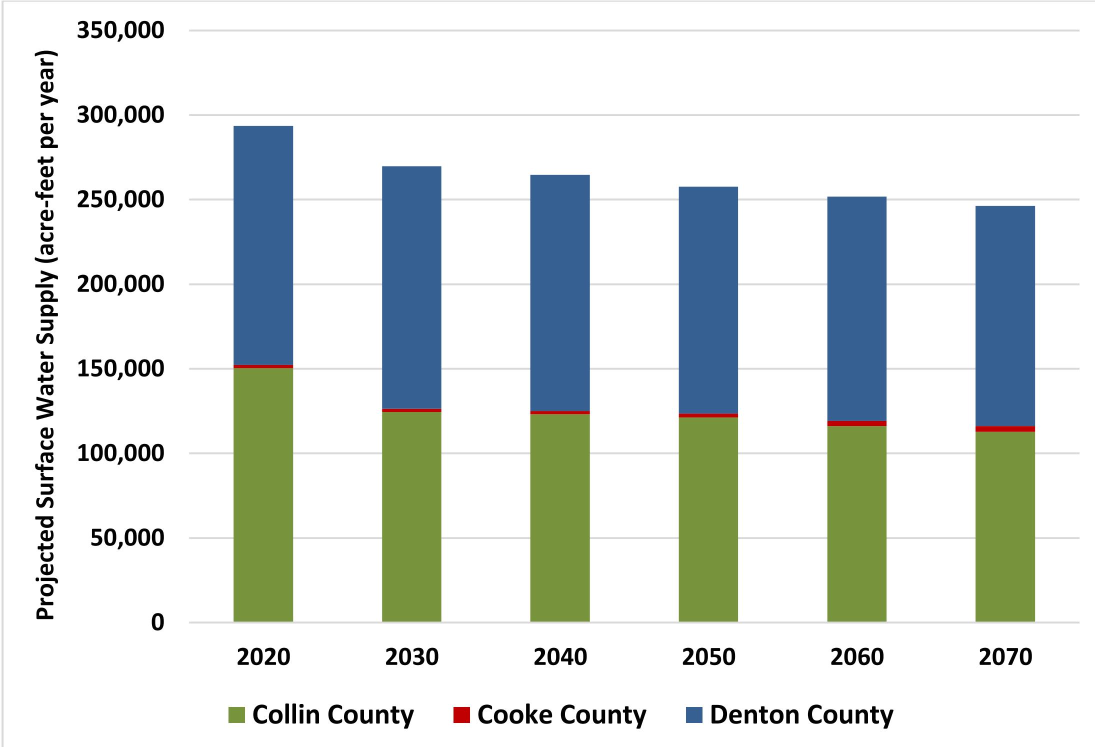


Figure 3. Projected surface water supply within the District by county

8.7 PROJECTED TOTAL DEMAND FOR WATER IN THE DISTRICT

The analyses to develop water demand projections are primarily conducted in Texas as part of the regional water supply planning process (created by the 75th Texas Legislature through the passage of Senate Bill 1 in 1997). Water demand projections are developed for the following water user categories; municipal, rural (county-other), irrigation, livestock, manufacturing, mining, and steam-electric power generation.

Texas Water Code §36.1071(e)(3)(G) requires that a management plan include projections of the total demand for water (surface water and groundwater) from the most recently adopted state water plan. Water demand projections from the 2017 Texas State Water Plan are presented in Appendix F. The projected total demand for the District increases significantly from 419,457 acre-feet per year in 2020 to 820,443 acre-feet per year in 2070. Projected demands are significantly higher in Collin and Denton counties than in Cooke County (Figure 4~~Figure 4~~).

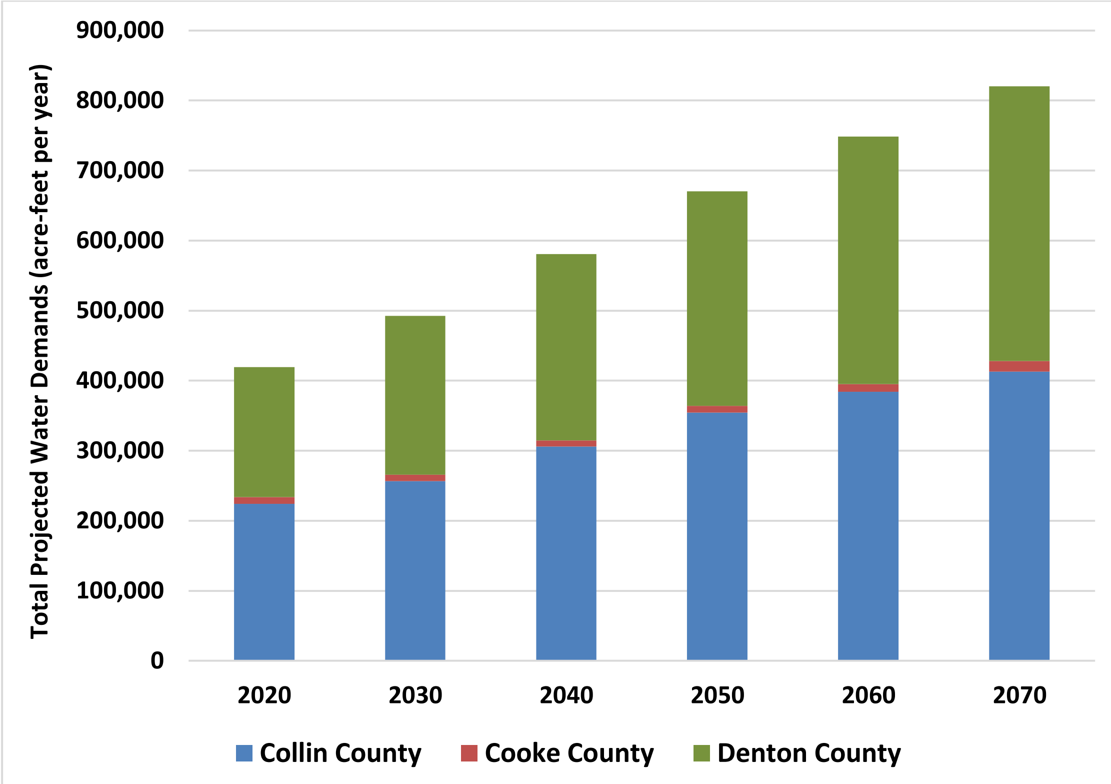


Figure 4. Water demand projections within the District by county

8.8 PROJECTED WATER SUPPLY NEEDS

This section replaces part of the former Section 6.0 Water Supply Plans.

Projected water needs for the counties in the District have been developed for inclusion in the 2017 Texas State Water Plan. The projected water needs reflect the volume of water needed in the event of a drought of record based on projected water supplies and projected water demands. A need occurs when the projected water demand is greater than the projected water supply. Projected water needs were estimated for all water user groups for every decade from 2020 through 2070 on a county-basin level. Appendix F summarizes the projected water needs for the District based on the database for the 2017 Texas State Water Plan received from Allen (2017). Data in this table are organized by county, water user group, and basin. The projected total water needs by county are illustrated in Figure 5~~Figure 5~~.

Data for the 2017 State Water Plan projects future water needs for all three of the counties in the District. There are 51 water user groups in Collin County. A water need at some point between 2020 and 2070 is projected for all but five of those water user groups. The projected need in Collin County increases significantly from 18,865 acre-feet per year in 2020 to 207,655 acre-feet per year in 2070. Of the 19 water user groups in Cooke County, a need at some point between 2020 and 2070 is projected for 15. The projected need in Cooke County increases from 849 acre-feet per year in 2020 to 5,017 acre-feet per year in 2070. Fifty-three water user groups are listed for Denton County. Of those, a need at some point between 2020 and 2070 is projected for all but four of those water user groups. The need in Denton County significantly increases from 12,241 acre-feet per year in 2020 to 216,283 acre-feet per year in 2070. For the District as a whole, the total projected water need increases from 31,955 acre-feet per year in 2020 to 428,955 acre-feet per year in 2070.

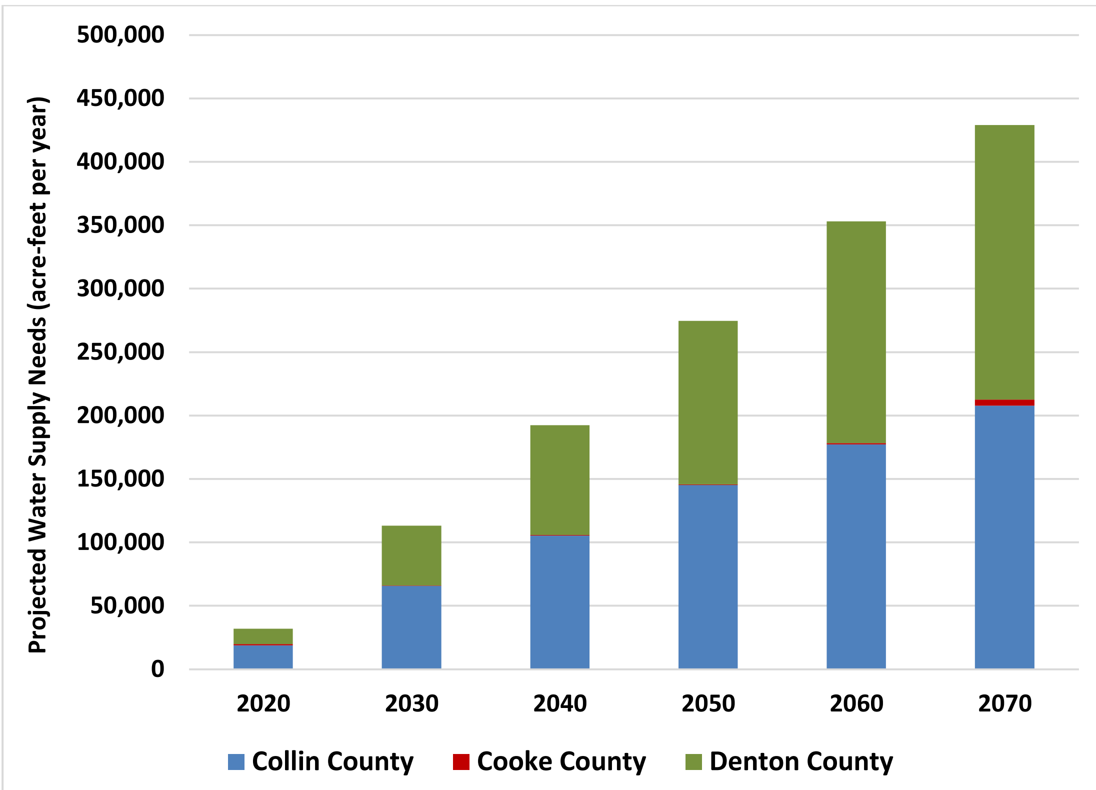


Figure 5. Total projected water supply needs within the District by county

8.9 WATER MANAGEMENT STRATEGIES

The database for the 2017 Texas State Water Plan also includes recommended water management strategies to meet the identified water needs in the District for every decade from 2020 through 2070. Potential strategies identified include conservation, water reuse, expansion, and improvement of existing water supplies, development of additional groundwater and surface water supplies, expansion of existing water treatment plants and construction of new water treatment plants, facility improvements, and purchase of water from water providers. The projected water management strategies for the counties in the District from the 2017 State Water Plan are shown in Appendix F by water user group ("WUG").

9. POPULATION

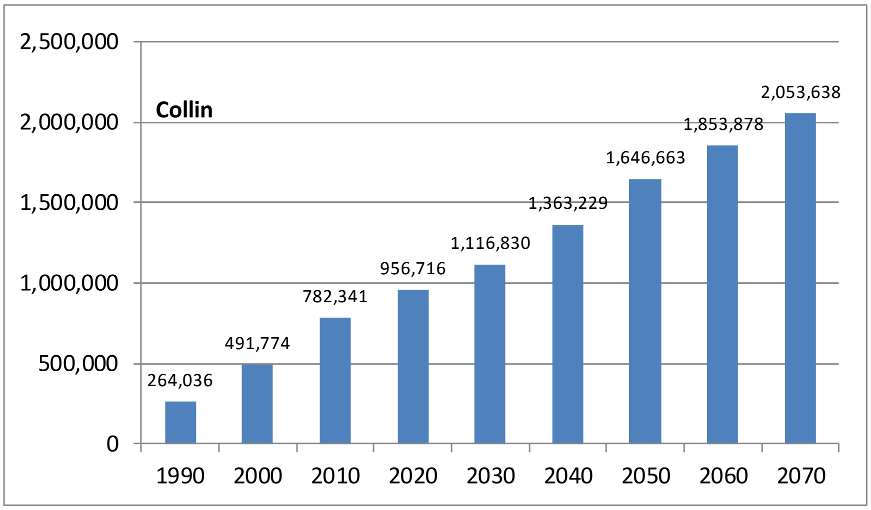
Water Use and Water Demands are now addressed in Sections 10.B and 10.G.

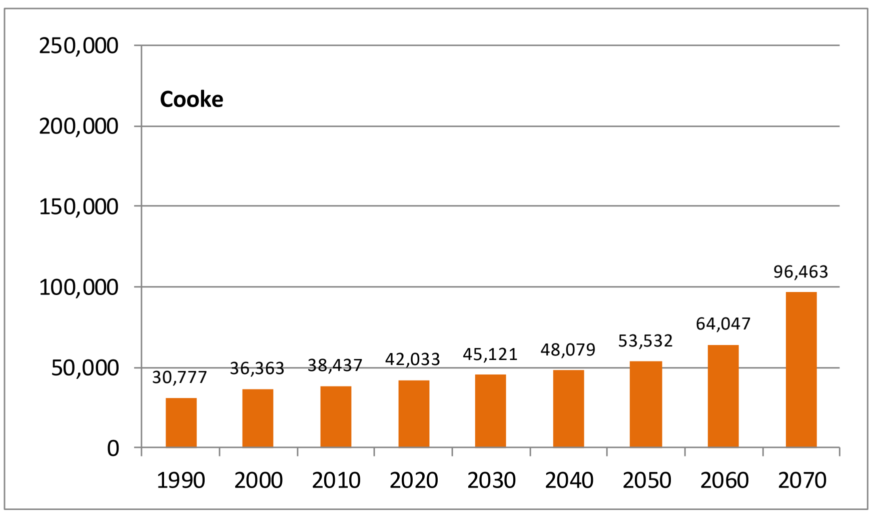
Primary activities involved in the development of a water resources management plan include the analysis and development of projections of population, historical and current water use, and water demands in the future (for a defined period of time). In order to develop projections for how much water supply we will need in the future, three questions must be answered: (1) how many people are there now and how much water has been used in the recent past, (2) how many people will there be in the future (population projections), and (3) how much water will be required to meet the needs of the projected population and other water use sectors in the future. These analyses to develop water demand projections are primarily conducted in Texas as part of the regional water supply planning process (created by the 75th Texas Legislature through the passage of Senate Bill 1 in 1997). Water demand projections are developed for the following water user categories; municipal, rural (county-other), irrigation, livestock, manufacturing, mining, and steam-electric power generation.

Based on the 2016 Region C Water Plan, the population projection for the District for 2020 was 1,900,348 increasing 223 percent to 4,240,586 in 2070 (Table 1~~Table 3~~). Population trends for each county of the District are shown in Figure 6.

Table 1~~3~~. Population projections 2016 Region C Water Plan

	Historical			Projected					
County	**1990**	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Collin	264,036	491,774	782,341	956,716	1,116,830	1,363,229	1,646,663	1,853,878	2,053,638
Cooke	30,777	36,363	38,437	42,033	45,121	48,079	53,532	64,047	96,463
Denton	273,525	432,976	662,614	901,645	1,135,397	1,348,271	1,576,424	1,846,314	2,090,485
Total	568,338	961,113	1,483,392	1,900,394	2,297,348	2,759,579	3,276,619	3,764,239	4,240,586





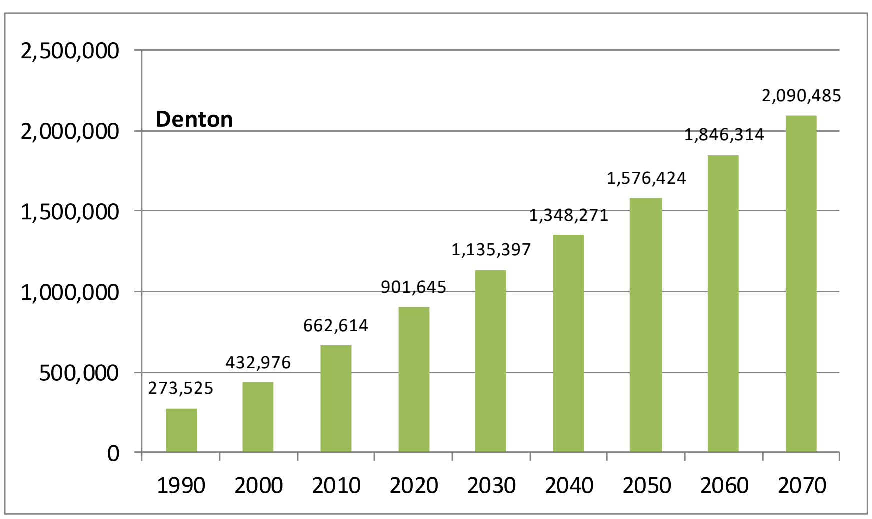


Figure 6. Population trends, by county

10. GROUNDWATER RESOURCES

A summary review of the hydrogeology and water resources of the North Texas region that includes the District is presented here to understand better the current "state of groundwater science" and to provide information necessary to develop a strategic plan for future technical efforts by the District. An understanding of currently available groundwater science in the District is important for a number of reasons including:

- Understanding the quantity and quality of groundwater resources available to meet current and future water supply needs of the different water use sectors present,
- Understanding the effects of changing conditions, such as population growth, shifting industrial demands, and climate variability on the availability of and demand for groundwater resources,
- Determining the temporal and spatial variability of aquifer dynamics so that adequate monitoring programs may be designed and implemented, and
- Determining areas of groundwater science for which current information is inadequate to make informed policy decisions, so that additional scientific investigations may be pursued to address targeted scientific deficiencies.

Recent scientific efforts have included significant literature reviews of the hydrogeology and water resources for the Northern Trinity and Woodbine aquifers. For example, Bene and others (2004) discuss the research results of over 46 different studies that were utilized in developing the most recent groundwater availability model for the Northern Trinity and Woodbine aquifers. With respect to the District, the most notable conclusion that can be drawn from Bene and others (2004) is that while the area within the District has been included in a number of regional groundwater water resources investigations, the area has never been the primary or sole focus of such a hydrogeology/water resource study. As the District works in the future to evaluate and adopt desired future conditions during future joint-planning efforts, it is clear that certain site-specific studies will be necessary in order to ensure that these critical policy decisions are based on adequate sound science.

PREVIOUS STUDIES, OVERVIEW, AND CURRENT UNDERSTANDING OF THE HYDROGEOLOGY OF THE NORTHERN TRINITY AND WOODBINE AQUIFERS IN THE DISTRICT

The vast majority of historical groundwater studies in the District may be divided into four categories; (1) water resources evaluations in support of regional water supply assessments conducted to support the need for large water supply projects and state water planning prior to 1985, (2) studies related to the Critical Area process required with the passage of House Bill 2 in 1985 and the Priority Groundwater Management Area process required with the passage of Senate Bill 1 in 1997, (3) regional water planning efforts required by the passage of Senate Bill 1 in 1997, and (4) groundwater availability modeling efforts for the Northern Trinity and Woodbine aquifers required by the passage of Senate Bill 2 in 2001 and in support of the Groundwater Management Areas/Joint Planning process resulting from the passage of House Bill 1763 in 2005.

For more than a century, there have been a number of regional studies related to the occurrence and availability of groundwater from the Northern Trinity and Woodbine aquifers. The following studies, which only represent a small fraction of the available literature, were reviewed in order to identify availability of information from those regional studies that would benefit the District and to identify any technical gaps that may exist.

In the earliest phase of groundwater development in North Texas (1880s to early 1900s), the science of groundwater hydrology was still poorly understood. The Trinity Aquifer was so charged with groundwater that many early wells flowed at the land surface (Hill, 1901; Mace and others, 1994) (Figure 7). This condition of flowing wells results when groundwater pressure (also known as artesian pressure) builds up under a confining layer. Groundwater pressure also increases with depth because of the weight of the water column confined between rock layers and in some cases, from the weight of the overlying geologic formations. The flowing well penetrates the overlying layers and provides a conduit for flow to the surface and pressure release. Decreasing fluid pressure in the aquifer causes water-level declines (drawdown) in wells. Hundreds of flowing wells were drilled in North Texas in the late 1800s and allowed to flow freely at the surface. At the time this was a novelty ("geysers"), and much of the groundwater was wasted. These wells experienced rapid pressure declines, and most had stopped flowing by 1914 (Leggatt, 1957). Groundwater use declined after 1914 as surface water (impounded lakes) began to be developed (Bene and others, 2004).

By the mid-1900s the population of North Texas was growing and groundwater use was again increasing. By the 1930s groundwater science had progressed greatly. Methods were developed for calculating productivity (yield) and water-level declines from data collected in water wells. The Texas Board of Water Engineers (predecessor agency to the TWDB) began compiling groundwater data from many Texas counties with the notable exception of the counties in the District. Texas Board of Water Engineers reports emphasized dramatic drawdowns that had already occurred in the North Texas region and documented the relationship between pumping and water level decline. Hundreds of feet of drawdown were common in the Dallas-Ft. Worth area at rates up to 20 feet per year (Bene and others, 2004). In spite of the efforts of the Texas Board of Water Engineers, few water-level measurements were recorded in wells in the District prior to 1960 (Figure 8).

Also by the mid-1900s, the geology of North Texas aquifers was becoming increasingly well understood (see summaries in Nordstrom [1982] and Bene and others [2004]). Aquifer geology describes the rock units making up the container that holds the groundwater. Groundwater is present in pores and cracks within the rocks and flows through an interconnected system. The ability of rock layers to store and transmit groundwater varies – aquifers readily store and transmit water, whereas aquitards lack well-interconnected pore systems and therefore inhibit groundwater flow. Geologic studies revealed that the Trinity and Woodbine rock formations are the primary aquifers in North Texas and that they are enclosed in aquitard formations. Thus, the Northern Trinity and Woodbine aquifers are confined by aquitards (confining layers) (Figures 9 and 10). Near land surface, where the upper part of the aquifer is exposed (outcrops), a water table develops that separates saturated (below) from unsaturated (above) parts of the aquifer. The level of the water table corresponds to the volume of groundwater in the aquifer outcrop. Deeper underground, however, the entire aquifer is usually saturated, and fluid pressure corresponds to groundwater volume. Groundwater pumping results in the lowering of water levels in wells, which corresponds directly to lower fluid pressure in the aquifer. The science of hydrogeology encompasses both groundwater (the liquid resource) and aquifer properties (the container). The main data types used to characterize groundwater resources are measured in wells: water levels to quantify volume and pumping tests to quantify yield (flow rate into wells) and aquifer properties such as hydraulic conductivity and storativity. During the 1960s and 1970s, numerous scientific and economic groundwater studies by state agencies and universities included systematic data collection from Texas aquifers and increased the number of water levels measured in the District (Figure 11). Groundwater-use data were also beginning to be collected systematically by the TWDB and other government agencies. Groundwater data and conditions during this period were documented by Nordstrom (1982). By the 1960s and 1970s, North Texas was becoming a major population center and a key focus of water planning efforts by the state through the efforts of the TWDB.

Nordstrom (1982) is one of the classic regional hydrogeologic/water resources investigations available, containing information on 22 counties in the North-Central Texas region including the entire District. Nordstrom (1982) also provides early estimates of historical groundwater use and future availability. Even more notable is the inclusion of pumping tests in this report from throughout the region. Specific to the District, results from 5, 8, and 10 pumping tests in Collin, Cooke, and Denton counties respectively, are included in the report (Figure 12). Analyses for yield, transmissivity, specific capacity, and hydraulic conductivity are provided for most of these tests. In the District, no additional pumping test analyses became available between the time of Nordstrom's study (1982) and the development of the Northern Trinity and Woodbine groundwater availability model (GAM) (Bene and others, 2004). Aquifer properties input to the GAM are based mainly on Nordstrom's (1982) data. Future technical studies by the District will need to take advantage of and add to Nordstrom's (1982) valuable data set of aquifer tests.

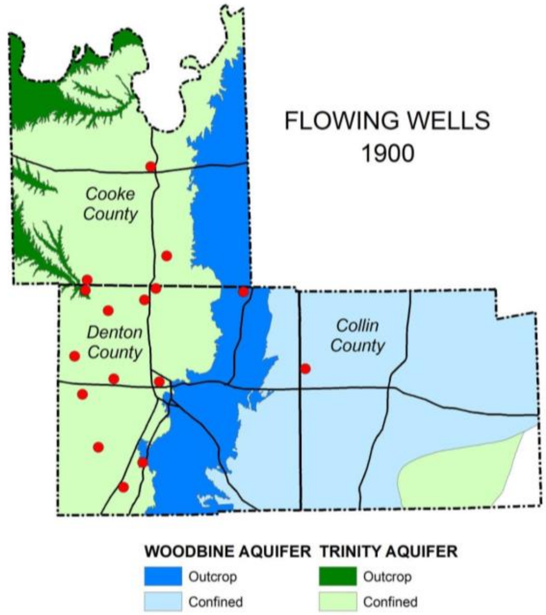


Figure 7. Location of wells flowing at the land surface in 1900 (Hill, 1901).

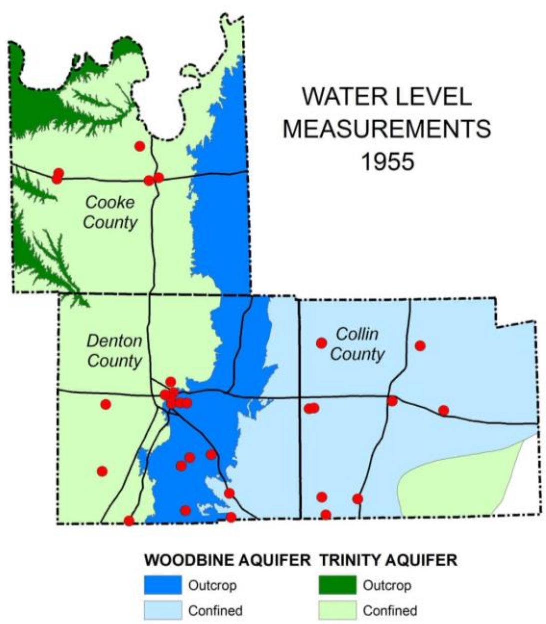


Figure 8. Location of wells having water-level measurements taken in 1955 (Nordstrom, 1982).

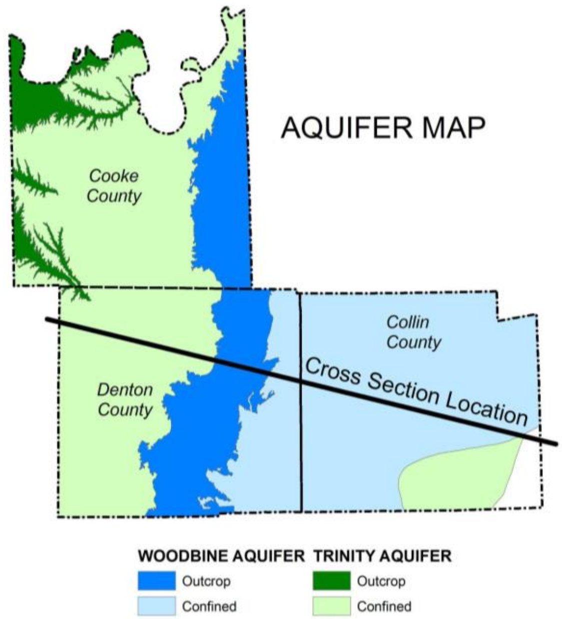


Figure 9. Aquifer Map

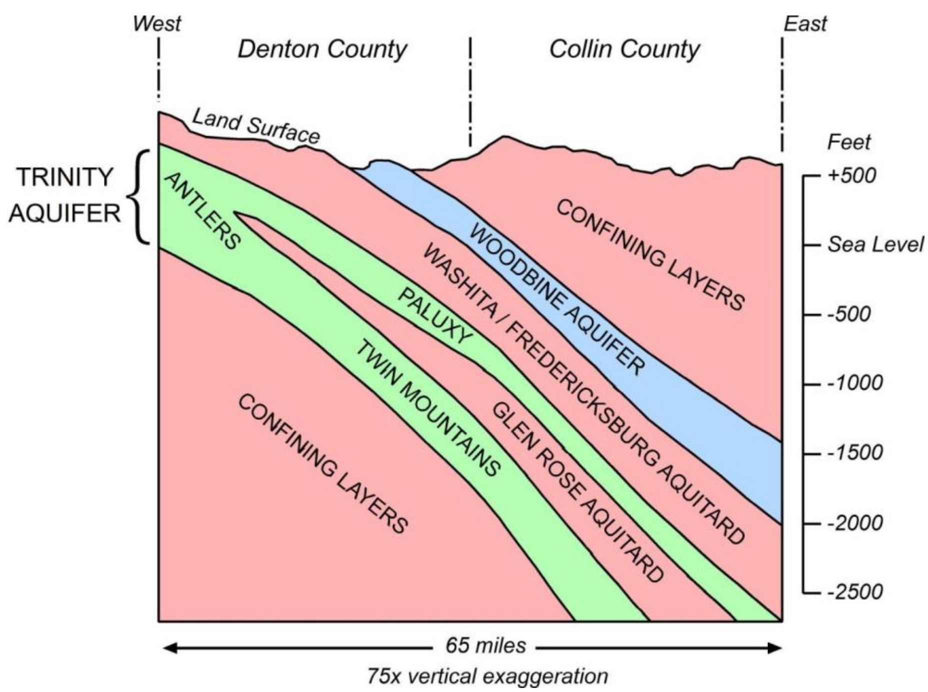


Figure 10. Cross section of the Trinity and Woodbine aquifers in the North Texas GCD.

Groundwater data (primarily water levels and water quality) have been collected by the TWDB and its predecessor and partner agencies from water wells throughout Texas since the early 1900s (Rein and Hopkins, 2008). Groundwater data collected before 1988 primarily represent one-time visits to wells and springs, but since then, monitoring programs have been established to record data annually in the same observation wells. Systematically revisiting the same wells is critical for establishing historical trends in groundwater conditions. Historical trend data track changes through time and can be used to make future projections. Historical trends in groundwater conditions are necessary input data for groundwater availability modeling. Many agencies and stakeholders cooperate with the TWDB to collect the measurements that go into the TWDB groundwater database: Texas Commission on Environmental Quality, U.S. Geological Survey, GCDs, water-supply corporations, municipalities, individual landowners, and other entities. GCDs actually provide the majority of water-level measurements in the TWDB groundwater database. In 2010, the counties of the District contained 555 wells having water levels in the TWDB database, but only 39 of these were observation wells (Figure 13). In 2015, there were 24 TWDB wells in the District for which 2015 water level data were available (Figure 14). These water level data are useful for the evaluation of “state of the aquifer” conditions relative to the DFCs.

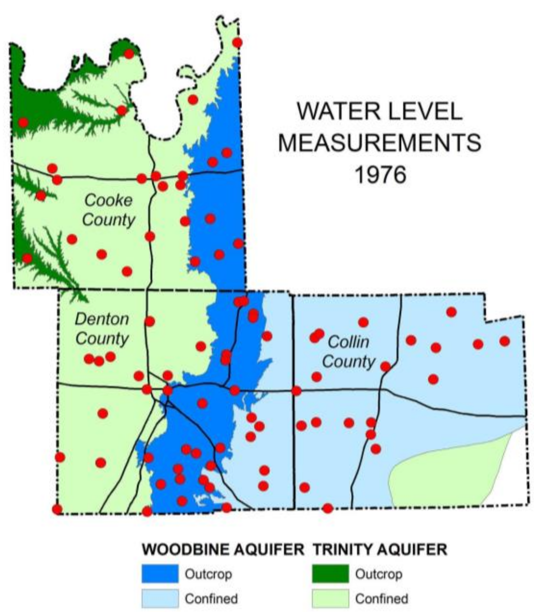


Figure 11. Location of wells having water-level measurements taken in 1976 (Nordstrom, 1982).

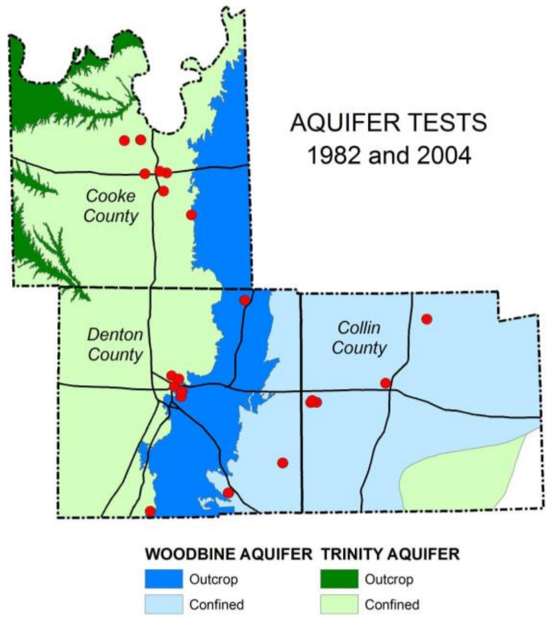


Figure 12. Location of wells having pumping test data reported by Nordstrom (1982) and used by Bene and others (2004) in the Northern Trinity/Woodbine GAM.

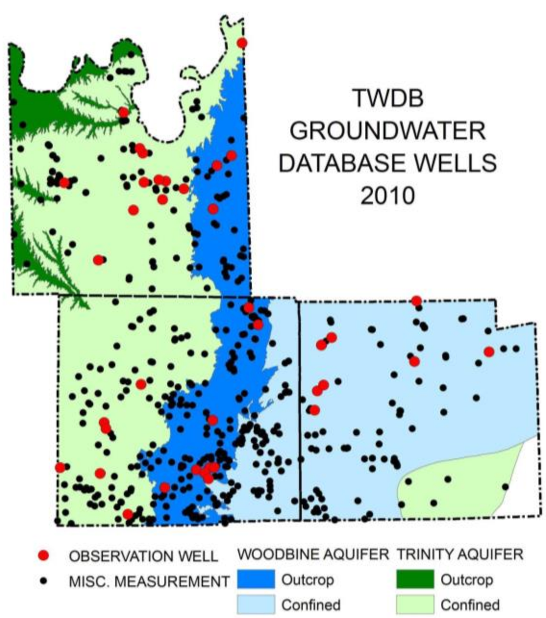


Figure 13. Location of wells having water-level measurements in the TWDB groundwater database. Observation wells that are monitored annually are shown in red.

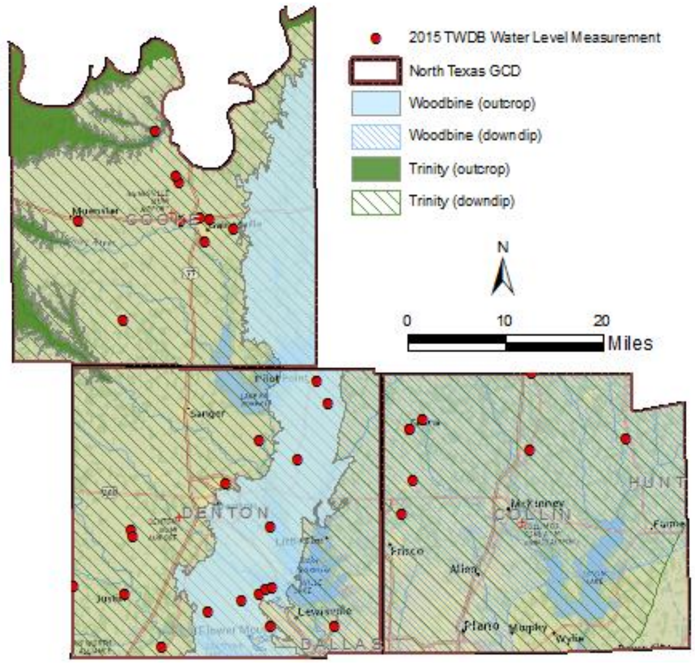


Figure 14. Location of wells having water-level measurements in the TWDB database in year 2015.

Since the passage of House Bill 2 in 1985, the reliability and vulnerability of groundwater resources in North-Central Texas have been a priority issue for the Texas Commission on Environmental Quality and its predecessor agencies. Specifically, the issue of focus has been areas of the state that are experiencing or are expected to experience critical groundwater problems in the next 20-25 years. As required by statute, the region, as a result of recognized critical groundwater problems, has been the subject of multiple studies and reviews to evaluate the status of groundwater resources in this area. Baker and others (1990) conducted the first study as a result of the critical area process. This report highlights the declines in water-level elevations between 1976 and 1989 in the Antlers and Twin Mountain aquifers from 100 to 250 feet with declines in the Paluxy and Woodbine aquifers being up to 150 feet. Baker and others (1990) also noted concerns regarding water quality in the region, some of which were naturally occurring, while others were suggested to be the result of poor well completion techniques, leaking underground petroleum storage tanks, brine contamination resulting from oil and gas activities, and industrial activities in the outcrop/recharge areas. It is interesting to note that in this study, the conclusion is drawn that if additional surface water supplies are not developed by 2010, some rural areas in the region could face water supply shortages. No groundwater availability estimates specific to the area covered by the District were included in the report. However, one significant finding was that even in 1985 (the period during which data for this report was primarily collected) it was estimated that groundwater demands for the study area were 110,000 acre-feet per year, which was estimated to be 44 percent greater than the annual recharge for the study area, which was estimated to be 76,000 acre-feet per year.

Baker and others (1990) emphasize groundwater sources (recharge), occurrence (location and movement of groundwater), and discharge (natural and pumpage). Much of the science presented by Baker and others (1990) summarizes and updates Nordstrom (1982). New material presented by Baker and others (1990) concerns groundwater use, availability, and related problems. The primary source of groundwater in North Texas is recharge from precipitation on the outcrop. In the District, average annual precipitation ranges from 35 to 40 inches per year. Most precipitation runs off the surface, evaporates, or is used by plants (transpiration), aquifer recharge being only a small fraction of precipitation. Surface-water seepage from lakes and streams on the aquifer outcrop provides a secondary source of recharge.

Water recharged to an aquifer is held in storage. Pumping tests measure aquifer storage: specific yield in outcrop and storativity in the confined part. In the aquifer outcrop water levels remain relatively constant. Lowering of the water table in outcrop requires complete dewatering of the upper part of the aquifer, effectively emptying the porous volume of the rock. Specific yield is a measure of aquifer porosity, which is 15 to 25 percent (of total rock volume) in the Trinity Aquifer and closer to 15 percent in the Woodbine Aquifer (Nordstrom, 1982). In the confined part of the aquifer, groundwater is under pressure, and storativity relates water volume to pressure decline. Much less water is available by pressured decline than by dewatering, but pressure declines have a dramatic effect on water levels in wells. Pumping-induced pressure declines, causing drawdowns of hundreds of feet, have been a major groundwater resource problem in North Texas (Baker and others, 1990).

The movement of groundwater through an aquifer is controlled by pressure gradient (from high to low pressure) and by the ease with which water flows through the aquifer pore system.

Pumping tests measure hydraulic conductivity (rate of flow) and transmissivity (volume of flow). Along with storage, hydraulic conductivity and transmissivity control how much water a well will produce for a given amount of drawdown (specific capacity or well yield). Because hydraulic conductivity and transmissivity are highly variable in the Trinity and Woodbine aquifers (Nordstrom, 1982), additional pumping test data will be needed to adequately characterize groundwater flow throughout the District.

The main groundwater resource problems identified by Baker and others (1990) are water-level declines and localized water-quality issues. Local water-level declines occur when pumpage exceeds flow rates in the aquifer, causing large drawdowns around wells (cones of depression). Cones of depression have been common around pumping centers in North Texas since the early 1900s (Mace and others, 1994). Cones of depression increase the cost of groundwater, because pumps must be lowered, well yields decrease, and it takes more energy to lift the water to the surface. Regional water-level declines occur when discharge (primarily from pumpage) exceeds recharge over large areas. Regional declines effectively mine the aquifer and are not sustainable over the long term.

In response to Senate Bill 1 passed by the Texas Legislature in 1997, Langley (1999) updated the analysis of Baker and others (1990) and addressed the potential for critical water resource problems in North-Central Texas in the following 25 years. Water levels remained relatively stable in the District during the 1990s. Southern Denton County experienced rising water levels in the Twin Mountains Aquifer due to decreased pumping in the Dallas - Ft. Worth area, but water levels in the Paluxy and Woodbine aquifers declined slightly in parts of Denton and Collin counties. Although water-level declines were less during 1989–1997 than during 1966–1989, groundwater use still exceeded availability in Cooke and Denton counties (Langley, 1999). Langley (1999) projections suggest that adequate supplies of groundwater plus surface water exist to meet demands through 2030 and that groundwater use will decline through conservation and conversion to surface water. In the District, however, these projections are based on a small number of wells and therefore subject to significant uncertainty.

Ashworth and Hopkins (1995) provide a general overview of the major and minor aquifers of Texas. In their report, regional characteristics and locations of the Trinity and Woodbine aquifers are presented. This report has served as a standard reference for subsequent hydrogeologic publications and planning documents such as the state water plan with respect to the recognized locations of the aquifers in Texas. The informative “atlas” nature of this report will be a good model for the District as it works to develop more locally- detailed information to educate the general public. This ‘atlas’ was updated in 2011 (George, and others, 2011).

The area covered by the District has now been the subject of four regional water plans, the 2001, 2006, 2011, and 2016 Region C Water Plans. Region C Water Plans summarize groundwater conditions in the Trinity and Woodbine aquifers within the region. The 2001 and 2006 Region C Water Plans include essentially identical aquifer information, much of which was derived from Nordstrom’s comprehensive study (Nordstrom, 1982). The 2001 and 2006 Region C Water Plans emphasize Nordstrom’s finding that annual pumpage is greater than aquifer recharge. Overdevelopment of aquifers and resulting water-level declines pose the greatest threat to small water suppliers and rural households. The 2001 and 2006 Region C Water Plans describe water quality as generally acceptable in the Trinity and Woodbine aquifers, although poor water quality occurs locally, and the deeper parts of both aquifers have higher concentrations of dissolved solids.

The 2006 and 2011 Region C Water Plans relied in part on the Northern Trinity/Woodbine GAM and accompanying report (Bene and others, 2004) for aquifer conditions. As reported in the 2006 Region C Water Plan, GAM simulations in 2004 (Bene and others, 2004) showed that groundwater availability in Cooke County is less than estimated in the 2001 Region C Water Plan and that overdrafting is occurring in that county. GAM simulations in 2004 also showed that groundwater use in Denton County exceeds the estimated reliable long-term supply (Bene and others, 2004).

The 2011 Region C Water Plan documents that groundwater use in 2006 exceeded the managed (now referred to as modeled) available groundwater estimates in certain Region C counties, including Collin County (Mullican, 2011). Cooke County groundwater use in 2006 was close to but did not exceed managed available groundwater. The 2011 Region C Water Plan states that temporary groundwater overdrafting may be necessary while other water supplies are developed. However, it is important to note that while the concept of temporary overdrafting has been a common strategy utilized by regional water planning groups to meet certain water supply needs in the 2001, 2006, and 2011, in the 2016 round of regional water planning, planned overdrafting (the volume of groundwater utilized in a regional water plan is greater than the modeled available groundwater estimate) was not allowed. Under rules that have been developed to implement House Bill 1763, enacted by the Texas Legislature in 2005, the use of more groundwater in regional and state water planning than is determined to be available through the joint-planning process as expressed by the estimate of modeled available groundwater will result in a conflict, and prevent the approval of regional water plans by the TWDB. Therefore, either in the 2016 Region C Water Plan or in the desired future conditions adopted for GMA 8 by 2016, the volume of groundwater available to meet future water supply needs was revised so that conflicts did not exist.

Development of brackish groundwater is considered in the 2011 and 2016 Region C Water Plan. Although GAMs to determine brackish groundwater availability have not yet been developed, preliminary analysis by the TWDB indicates approximately 85 million acre-feet of brackish groundwater supply may be present in Region C. Further study, perhaps through coordinated efforts of the GCDs, is needed to identify brackish groundwater resources and to deal with water-quality issues.

In general, all Region C Water Plans (2001, 2006, 2011, and 2016) describe the ***current*** state of fresh groundwater use to be close to long-term sustainable availability. Most water management strategies in the Region C Water Plans emphasize increasing surface water supplies while conserving groundwater supplies. The 2016 Plan indicates that currently available supplies are almost constant over time at 1.7 million acre-feet per year, as sedimentation in reservoirs is offset by increases in reuse supplies due to increased return flows. With the projected 2070 demand of 2.9 million acre-feet per year, the region has a shortage of 1.2 million acre-feet per year by 2070. Meeting the projected shortage and leaving a reasonable reserve of planned supplies beyond projected needs will require the development of significant new water supplies for Region C over the next 50 years.

GROUNDWATER AVAILABILITY MODELING EFFORTS FOR THE NORTHERN TRINITY AND WOODBINE AQUIFERS

One of the initial developments to result from the initiation of regional water planning in Texas was the realization that the science and quantification of Texas' surface water and groundwater resources was not sufficiently accurate to meet the requirements of the planning process. As a result, new surface water availability models, referred to as WAMs, were developed by the Texas Commission on Environmental Quality and groundwater availability models, referred to as GAMs, were developed by the Texas Water Development Board. The GAM Program has resulted in significant advancement of our understanding of groundwater resources throughout Texas. GAMs are numerical computer models that produce three-dimensional simulations of groundwater systems that track the "water budget" (inflow, storage, outflow) and spatially distribute aquifer properties (flow rates, volumes, and directions). Once the GAM is calibrated using historical water use and aquifer property data (such as water levels through time), it can then be used to test and evaluate future water use scenarios.

Bene and others (2004) constructed the first regionally comprehensive GAM for the Northern Trinity and Woodbine aquifers in Texas. It is important to note that "Bene and others (2004)" is not the GAM itself but is the technical report that describes the GAM and summarizes, from a regional perspective, relevant data and analyses that were used to build a conceptual model of the Northern Trinity and Woodbine aquifer system. The conceptual model utilized in the development of the model ideally includes everything affecting groundwater conditions: physiography, climate, geology, water quality, water levels, aquifer properties, recharge, surface-water/groundwater interaction, and discharge (evapotranspiration and pumpage). The design of the GAM is based as closely as possible on the conceptual model. The computer model divides the real world (i.e., the conceptual model) into cells that, in the case of the Northern Trinity and Woodbine aquifer GAM, are one square mile in area and several hundred feet thick. The thickness of the cells is controlled by aquifer layering. The Northern Trinity and Woodbine GAMs contain seven layers of cells representing all of the aquifers and aquitards in the area (see Figures 4 and 5 and Table 1). By making the model cells this large (1 square mile), the GAM often times does not do a good job of modeling or predicting local groundwater conditions, rather the GAM is specifically designed to better understand regional trends. Smaller model cells for an area as large as the area covered by the Northern Trinity and Woodbine GAM, however, would require massive amounts of computing power to run the GAM. Furthermore, the regional nature of the available data (widely spaced measurements) would not support a higher resolution model. One solution to the inherent resolution problem of the GAM would be to build a geographically smaller, more focused GAM based on more closely spaced well data for the area covered by the District.

As was the case with previous regional groundwater studies in North Texas, the GAM-related data are especially sparse in the counties of the District. Water-level data for the year 2000, for example, actually include fewer measurements than Nordstrom (1982) used for 1976 (compare Figures 6 and 9), and the GAM used the same aquifer pumping tests reported by Nordstrom (1982).

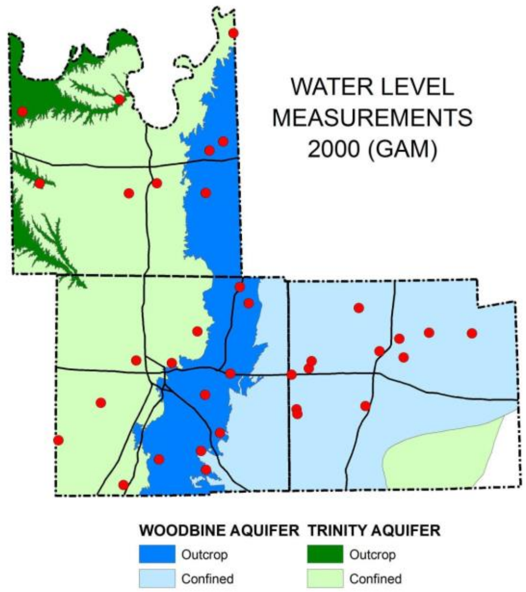


Figure 14. Location of wells having water-level measurements taken in 2000 that were used in the Northern Trinity/Woodbine GAM (Bene and others, 2004).

UPDATED GROUNDWATER AVAILABILITY MODEL OF THE NORTHERN TRINITY AND WOODBINE AQUIFERS

The purpose of the latest model update was "to make improvements to the original 2004 GAM by Bené and others (2004), including incorporation of data collected after the 2004 GAM was developed and results from recent studies in the region, and implementation of the model at a scale that better bridges the gap between regional models and a model that can be used at the scale of a typical GCD for pursuit of their groundwater management objectives. This study provides a model that has been calibrated across the entire period of record through 2012, which is a benefit to GCDs, Groundwater Management Area (GMA) 8, and stakeholders. This study provides significant advancement in the hydrogeological framework and understanding of these aquifers."

The updated GAM and the information collected and interpreted to support the study provide GCDs with the best available science to inform final rule making, groundwater management within GCD boundaries, and joint planning. The data collected and made public from this study provides a wealth of knowledge to support GCDs in local-scale hydraulic calculations with analytic tool to address such issues as well spacing.

The latest GAM update (Kelley and others, 2014) introduced hydrostratigraphic regions for the Trinity Group formations encompassed by the Northern Trinity GAM (Figure 15~~Figure 15~~). The regions are delineated based on stratigraphic and lithologic similarities (Figure 16~~Figure 16~~).

According to the GAM, Region 1 includes the western and northwestern portions of the model's study area in Texas, Oklahoma and Arkansas, and consists of undifferentiated sandstones and shales referred to as the Antlers Formation, which is locally referred to as the Antlers Aquifer.

Region 2 lies south and east of Region 1. In this region, limestones of the Glen Rose Formation separate the sandstones in the upper portion of the northern Trinity Group from the undifferentiated sandstones and shales in the lower portion of the northern Trinity Group (Figure 17~~Figure 17~~). The boundary between Regions 1 and 2 is defined by a lithological transition between thinly interbedded sandstone and shale in the northwest and thick limestones of the Glen Rose Limestone that exist elsewhere else in the model study area.

In Region 2, the upper sandstones (above the Glen Rose Limestone) are referred to as the Paluxy Formation. The undifferentiated lower sandstones and shales (below the Glen Rose Limestone) are referred to as the Twin Mountains Formation.

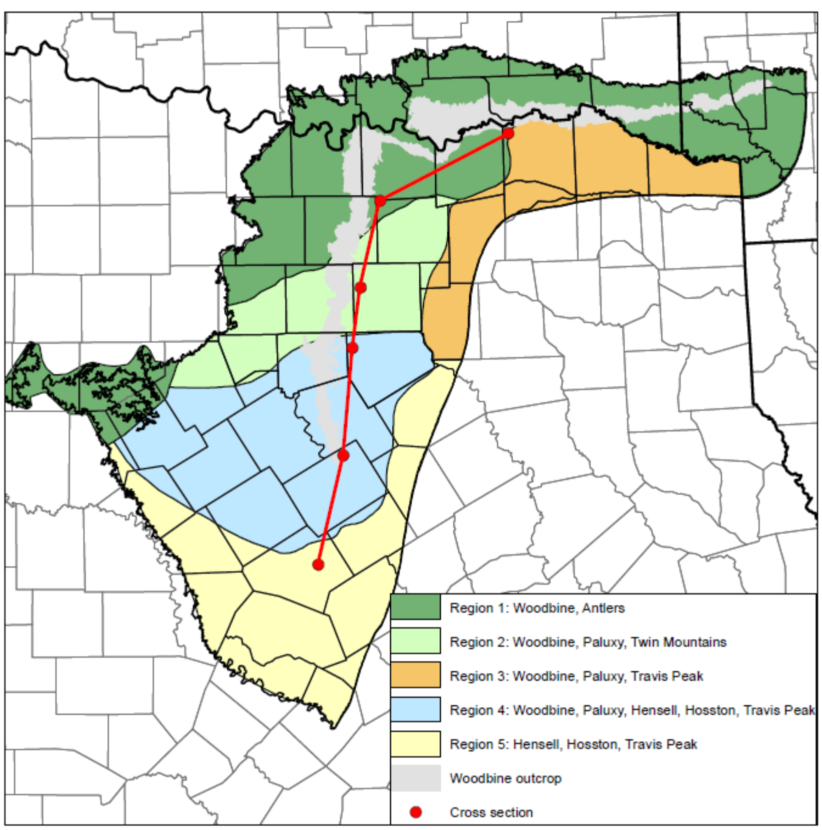
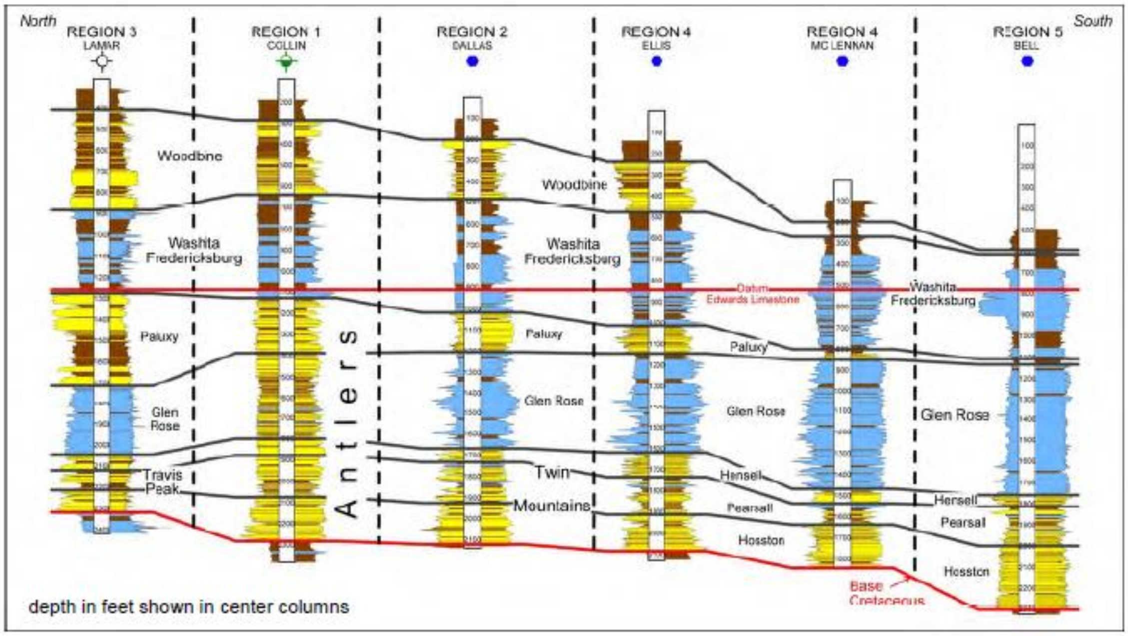


Figure 15. Northern Trinity GAM Regions (from Kelley and others, 2014).



yellow = greater than 50 percent sandstone, blue = greater than 50 percent limestone, brown = greater than 50 percent shale

Figure 16. Cross section through Regions 1 through 5 (from Kelley and others, 2014).

Model Terminology	Region 1	Region 2	Region 3	Region 4	Region 5
Woodbine Aquifer	Woodbine	Woodbine	Woodbine	Woodbine	Woodbine (no sand)
Washita/ Fredericksburg Groups	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg	Washita/ Fredericksburg
Paluxy Aquifer	Antlers	Paluxy	Paluxy	Paluxy	Paluxy (no sand)
Glen Rose Formation	Antlers	Glen Rose	Glen Rose	Glen Rose	Glen Rose
Hensell Aquifer	Antlers	Twin Mountains	Travis Peak	Hensell/ Travis Peak	Hensell/ Travis Peak
Pearsall Formation	Antlers	Twin Mountains	Travis Peak	Pearsall/ Sligo	Pearsall/ Sligo
Hosston Aquifer	Antlers	Twin Mountains	Travis Peak	Hosston/ Travis Peak	Hosston/ Travis Peak

yellow = sandstone aquifers

Figure 17. North Trinity GAM terminology for Regions 1 through 5 (from Kelley and others, 2014).

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