



Prepared for the Advisory Committee on Water Information Subcommittee on Ground Water

Results of the Texas Pilot Study for the National Ground Water Monitoring Network

By Janie Hopkins, P.G. Radu Boghici, P.G., and Bryan Anderson

Contents

1. Executive Summary.....	1
2. Introduction.....	3
3. Purpose of Study.....	6
4. Special considerations concerning the NGWMN design in Texas.....	8
5. Description of Study Area.....	9
6. Collaboration and Cooperation.....	14
6.1 Pilot Study.....	14
6.2 Future Opportunities.....	17
7. Water Level Network Well Selection.....	18
7.1 Network Design.....	18
7.2 Unstressed Subnetwork.....	20
7.3 Targeted Subnetwork.....	22
7.4 Gulf Coast Aquifer (Coastal lowlands aquifer system).....	23
7.5 Carrizo-Wilcox Aquifer (Texas coastal uplands aquifer system).....	26
7.6 Trinity, Edwards-Trinity (BFZ), and Edwards-Trinity Plateau aquifers (Edwards-Trinity aquifer system).....	28
7.7 Seymour Aquifer.....	31
7.8 Pecos Valley Aquifer (Pecos River Basin alluvial aquifer).....	34
7.9 Hueco-Mesilla Bolsons Aquifer (Rio Grande aquifer system).....	35
7.10 Gap Analysis.....	36
8. Water Quality Network Well Selection.....	37
8.1 TWDB Water Quality Network Design.....	37
8.2 Gulf Coast Aquifer (Coastal lowlands aquifer system).....	38
8.3 Carrizo-Wilcox Aquifer (Texas coastal uplands aquifer system).....	41
8.4 Trinity, Edwards-Trinity (BFZ), and Edwards-Trinity Plateau aquifer (Edwards-Trinity aquifer system).....	43
8.5 Seymour Aquifer.....	45
8.6 Pecos Valley Aquifer (Pecos River Basin alluvial aquifer).....	47
8.7 Hueco-Mesilla Bolsons Aquifer (Rio Grande aquifer system).....	48
8.8 TCEQ Water Quality Subnetwork Wells.....	49
8.9 Gap analysis.....	50
9. Field Practices.....	52
9.1 Groundwater Level Field Practices.....	52
9.2 Groundwater Quality Field Practices.....	52
9.3 Comparison to Framework Document.....	53
10. Data Management System.....	54
10.1 TWDB Data Management.....	54
10.2 Comparison to Framework Document and Gap Analysis.....	55
11. Summary of Gap Analyses.....	55
12. Proposed Changes to the Framework Document.....	56
13. Benefits of the Network.....	57
14. Cost Estimates.....	58
14.1 Cost to participate in the NGWMN pilot project.....	58
14.2 Cost to Operate and Manage NGWMN Wells.....	58
14.3 Cost to Implement the Changes Identified in the Gap Analysis.....	59
15. Acknowledgements.....	61
16. References Cited.....	62
17. Appendices.....	62

Figures

5-1	Major and minor aquifers of Texas	10
6-1	TWDB and cooperator measured wells in fiscal years 2007-2008.....	15
7-4	Water-level network wells in the Gulf Coast Aquifer	25
7-5	Water-level network wells in the Carrizo-Wilcox Aquifer.....	27
7-6	Water-level network wells in the Edwards, Trinity, and Edwards-Trinity Plateau Aquifers.....	31
7-7	Water-level network wells in the Seymour Aquifer.....	33
7-8	Water-level network wells in the Pecos Valley and Hueco-Mesilla Bolsons Aquifers.....	35
8-2	Water-quality network wells in the Gulf Coast Aquifer	40
8-3	Water-quality network wells in the Carrizo-Wilcox Aquifer	42
8-4	Water-quality network wells in the Edwards, Trinity, and Edwards-Trinity Plateau Aquifers.....	44
8-5	Water-quality network wells in the Seymour Aquifer.....	46
8-6	Water-quality network wells in the Pecos Valley and Hueco-Mesilla Bolsons Aquifers.....	48
8-8	Public water supply (TCEQ) water quality subnetwork wells	51

Tables

5.1	Table of aquifers and relation to principal aquifer codes.....	11
14.3	Summary of costs to implement changes identified in the gap analysis.	60



My seal appearing on this document was authorized on December 29, 2011 by

Janie Hopkins
Janie Hopkins, P.G.



My seal appearing on this document was authorized on December 29, 2011 by

Radu Boghici
Radu Boghici, P.G.

1. Executive Summary

Familiar challenges to the nation's water supply, as documented in a 2003 Government Accountability Office report noting that 36 states are expecting shortages within the next 50 years and that groundwater data are "inadequate for national reporting," serve as drivers for a pilot project initiated by the Federal Advisory Committee on Water Information's Subcommittee on Ground Water (SOGW). The SOGW issued a June 2009 report, "A National Framework for Ground Water Monitoring in the United States," that describes a model for the establishment and long-term operation and use of a National Ground-Water Monitoring Network (NGWMN). To implement a key recommendation of the framework document, the SOGW requested statements of interest in the fall of 2009 to participate in a pilot project to test NGWMN concepts and approaches and evaluate the feasibility and resources necessary to implement a national network. The SOGW chose Texas, with the Texas Water Development Board (TWDB) as lead agency, and four other states as pilot projects.

TWDB chose eight of its nine major aquifers as the study area for the project, eliminating the Ogallala Aquifer to focus more attention on aquifers not as thoroughly studied. The eight major aquifers are also considered as US Geological Society principal aquifers (with three of the TWDB aquifers combined as the Edwards-Trinity principal aquifer).

The TWDB considered the feasibility of a systematic or random sampling within grid design to determine suitable wells for inclusion in its water level and water quality portions of the NGWMN. The design for both networks was ultimately based on a minimum of 30 wells per aquifer, where possible, but also reflects a hybrid of styles. In limiting our choice of wells from 2,250 suitable sites that included wells with much longer than the suggested minimum baseline measurement history of five years and wells with minimum metadata (latitude, longitude, driller's logs and adequate completion data), we chose a water level network of 425 wells. Of these, 368 are surveillance wells measured at least yearly by TWDB and cooperators (groundwater conservation districts and the USGS); and 57 are trend, or recorder wells, that provide a much higher frequency of measurements (daily or hourly).

Within the water level network, the TWDB also considered defining wells with essentially unchanged measurement histories as part of an unstressed subnetwork versus those with water level declines in excess of 2.0 feet per year as part of a targeted subnetwork. However, this exercise in classification was only conducted for purposes of the pilot project; the TWDB will not attach these labels to wells should the data be made public through a NGWMN portal.

In determining the water quality network and subnetwork, the TWDB chose wells, almost all of which were sampled by the agency, using the most rigorous sampling protocols established after 1988; wells with balanced analyses; and wells sampled more than once after 1988. Following this approach resulted in a network of 851 wells with inorganic, nutrient, and radionuclide quality data. The water quality subnetwork consists of 65 public supply wells that include chemical analyses required by the Texas Commission on Environmental Quality consisting of organic constituents—primarily introduced through anthropogenic means—in addition to similar inorganic data collected by the TWDB.

TWDB's current field practices and data management standards are consistent with similar suggested framework standards. Because the agency is in the process of groundwater database restructuring, the timing of the pilot project has been beneficial in helping us decide what fields to add to the database and what Web Services to develop to facilitate data transfer to the portal that will provide access to all national network wells.

The main benefit of participating in the project and ultimately the NGWMN will be to planners at local, regional, state, and national levels; accessibility to data could become more efficient and user-friendly. In Texas, groundwater districts and management areas could benefit from immediate access to hydrographs in as near real-time as possible; and the Texas Groundwater Protection Committee could realize a long-held dream of a common portal for water quality data.

The cost of operating the NGWMN networks by the TWDB is equivalent to \$770,000 a year. Additional costs to adhere to suggested framework practices and standards, as identified in the gap analyses, are estimated at \$154,000 for one-time costs to determine all completion data, and \$78,350 for yearly operation and maintenance costs of more frequent monitoring of water level sites.

2. Introduction

Groundwater is the source of drinking water for more than 130 million Americans each day. Of the 83,300 million gallons per day (Mgal/d) of groundwater used in 2000, 68 percent was used for irrigation, about 23 percent was used for public supply and domestic use, 4% for industrial use, and the remainder for livestock, aquaculture, mining, and power generation (Hutson and others, 2004).

About 35 percent of the nation's irrigation water supply is obtained from groundwater. Although overall water use in the USA has been relatively steady for more than 20 years, groundwater use has continued to increase, primarily as a percentage of public supply and irrigation. In addition to human uses, many ecosystems are dependent on groundwater discharge to streams, lakes, and wetlands.

The nation's groundwater resources are under stress and require increased interstate and national attention to assure sustainable use of the resource. Federal, state, and local agencies have documented significant impacts to groundwater resources throughout the USA. Impacts include declining water levels and groundwater contamination from chemical use and waste disposal. Increased groundwater demand is expected in all sectors of the economy, including the heavy use sectors of agriculture, drinking water, and energy production. Increased biomass production will increase demand on groundwater for water supply to produce fuels and will further degrade water quality as a result of increased agrichemical application and residuals disposal. These activities threaten the aquifers directly as well as groundwater dependent ecosystems and the baseflow of streams supported by groundwater discharge. Proposals for geologic sequestration of carbon dioxide present the potential to acidify groundwater if migration of the carbon dioxide to adjacent aquifers occurs. Additionally, brackish and saline groundwaters are likely to be increasingly developed and treated in water deficient areas and may compete as locations for carbon sequestration. As groundwater uses increases it is imperative to improve the overall management of the resource. An integrated local, state, tribal, and federal partnership

approach is needed to accommodate multi-jurisdictional issues, effective management of transboundary aquifers, and promote stakeholder involvement.

Groundwater management is currently constrained by the lack of a nationally integrated groundwater monitoring network focused on providing water level and water quality data for regionally and locally important aquifers. The need for a national groundwater monitoring network has been recognized by numerous water resource agencies. To address this concern the Subcommittee on Ground Water (SOGW) was established in 2007 as an ad-hoc committee under the Federal Advisory Committee on Water Information (ACWI). The SOGW, which includes more than 70 people representing 55 different organizations, was charged with developing a framework that establishes and encourages implementation of a long-term groundwater quantity and quality monitoring network. This network is intended to provide data and information necessary for the planning, management, and development of groundwater resources in a sustainable manner. The SOGW issued a June 2009 report entitled A National Framework for Ground Water Monitoring in the United States (http://acwi.gov/sogw/pubs/tr/sogw_tr1_framework_june_2009_Final.pdf). This report describes a framework for the establishment and long-term operation and use of a National Ground-Water Monitoring Network (NGWMN).

The NGWMN is envisioned as a voluntary, integrated system of data collection, management, and reporting that provides the data needed to help address present and future groundwater management questions raised by Congress, federal, state, and tribal agencies and the public. The NGWMN will be comprised of a compilation of selected wells from existing state, federal, and tribal groundwater monitoring programs. The focus of the network will be on assessing the baseline conditions and long-term trends in water levels and water quality. As proposed, the NGWMN will include two monitoring sub-networks: a sub-network that focuses on monitoring unstressed parts of principal aquifers and aquifer systems and a sub-network that targets areas of concern within aquifers and aquifer

systems (typically contaminated areas and areas where water-level declines are of concern). Monitoring within the NGWMN will include four different categories: baseline monitoring, trend monitoring, surveillance monitoring, and special studies monitoring.

Groundwater level monitoring has been conducted for many decades in many states. Data from these networks have been used to help identify, develop, and manage groundwater supplies at the local and state level. Groundwater quality monitoring programs have been developed more recently in response to the focus on water quality that resulted from passage of the Safe Drinking Water Act; the Clean Water Act; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and other environmental laws. As of 2007, 37 states operated statewide or regional groundwater monitoring networks and 33 states have at least one active groundwater quality monitoring program. The state monitoring networks are funded using a combination of state and federal funds. The networks are operated by a variety of state agencies, many of them in cooperation with the United States Geological Survey (USGS). The networks operate under a variety of specific state/tribal/local goals and objectives and are not necessarily focused on all of the important aquifers within a state or reservation. As a result it is very difficult to use these groundwater monitoring programs to evaluate water availability, rates of use, and sustainability on a regional or national basis. Because many aquifers support multiple jurisdictions, a focus on monitoring at the aquifer level rather than at a political subdivision is critical to facilitate sustainable groundwater use.

Based on statements of interest from numerous states, the SOGW selected five pilot projects: Illinois-Indiana, Texas, New Jersey, Montana, and Minnesota. These five pilots vary in scale from an intra-state monitoring network that covers only a portion of one individual state to an inter-state network where two states share an aquifer. Information obtained from the pilot projects will help to better understand the current status, range of coverage, and level of coordination of groundwater monitoring networks in the US, and will serve as a foundation for developing an estimate of the number and type of

resources needed for full-scale implementation of the national monitoring network. The five pilot projects have been conducted through cooperative efforts between the state monitoring network managers and SOGW and USGS staff.

3. Purpose of Study

One of the three key recommendations included in A National Framework for Ground-Water Monitoring Network in the United States is to develop and conduct a limited number of pilot studies to: (a) test the NGWMN concepts and approaches detailed in the framework document; (b) evaluate the feasibility and resources necessary to implement a national network and (c) produce recommendations leading to full scale implementation. The pilot projects were initiated in early 2010 and are expected to be completed by March 2011. Each of the pilot projects has addressed the following objectives to:

evaluate the feasibility of designing network segments within one or more principal, major, or other important aquifers, using conceptual groundwater flow models as the primary network design element,

determine methods to establish unstressed and targeted sub-networks within the target aquifer(s),
test the design of the NGWMN and its ability to provide water level and quality data to large-scale assessments of the groundwater resource,

determine the feasibility and design parameters of a central, web-based data portal that will allow NGWMN to gather and disseminate data, as well as promote data sharing among data providers and the public,

test and assess the effectiveness of coordination, cooperation, and collaboration mechanisms among federal, state, regional, and local, and tribal data collectors, providers, and managers,

investigate methods to ensure that data collected by the data providers and, therefore, the NGWMN as a whole are comparable. Data elements, including site characteristics, well construction

and details, the frequency of water-level measurements, water-quality analytes, water-level measurement procedures, water-quality sampling procedures, and written standard operating procedures, will all be evaluated, and

determine the timeframe and costs associated with adding, upgrading, or developing a state, tribal, or local well network and data management system that meets the criteria and needs of the NGWMN and its ongoing implementation.

Each pilot has evaluated potential monitoring points within each principal, major, or other important aquifer for potential inclusion in the NGWMN and identified a subset of proposed monitoring points as meeting NGWMN's "stressed" or "unstressed" sub-network design criteria. In addition, each pilot identified all costs of potential participation in a NGWMN that are specific to the particular pilot state on a total and per well basis, as appropriate, including historical costs for the development and maintenance of their existing network; one-time start-up costs; and capital, operational, and maintenance costs associated with filling data gaps. Each pilot will interface with the NGWMN data portal that is under development by the USGS.

4. Special considerations concerning the NGWMN design in Texas

The preceding introductory remarks and purpose of the study are applicable to all pilot projects; however, the remainder of this report specifically discusses Texas' experience with the project. The background influence that cannot be underestimated in understanding the nature and history of the groundwater monitoring program and TWDB's current involvement in this pilot project is the general independent zeitgeist embodied by the state's population. Texas is dealing with the ever increasing demand on the state's groundwater resources while supplies are diminishing. Groundwater is managed through local groundwater conservation districts. In a state where 98 percent of the land is privately owned, the fact that the TWDB or its predecessors have been allowed access to measure water levels and sample groundwater by private landowners is due to the non-regulatory nature of the agency. The agency's dependence on privately owned wells, having never had funds to drill more than a handful of dedicated monitoring wells, is another indication of the status of groundwater monitoring in the state. This funding situation is not going to change, or at least not going to change simply and easily in the foreseeable future.

Thus, while the following sections of this report recognize and describe the Texas Water Development Board's (TWDB) initial attempts at classifying wells as targeted and unstressed for the water level network, an effort which influenced our choice of network wells, we fundamentally disagree with the utility of such designations and will not release well data with these labels in the final online offering of well data to the portal's website. Groundwater monitoring data provide the foundation for studies and analyses of groundwater resources; these objective-driven studies are more appropriately suited to evaluate groundwater availability and sustainability and identify threats to groundwater use. For the TWDB to define the terms stressed and targeted in the context of a database application would be inappropriate. Only for purposes of this report is the TWDB prepared to discuss these distinctions.

5. Description of Study Area

We chose eight of the nine major aquifers as designated by the TWDB as the study area for the monitoring network. TWDB recognizes its nine major aquifers as those that produce large amounts of water over large areas, whereas its 21 minor aquifers produce minor amounts of water over large areas or large amounts of water over small areas (Figure 5-1). All major aquifers in Texas are also considered primary aquifers as defined by the USGS (Table 1). The Coastal Plain aquifer system in semi-consolidated sand and gravel includes the Texas portion of the Coastal lowlands aquifer system, or the Gulf Coast Aquifer, and the Texas coastal uplands aquifer system, or the Carrizo-Wilcox Aquifer. Three other unconsolidated and semi-consolidated sand and gravel aquifers included in the Texas network are the Seymour Aquifer; the Pecos River Basin alluvial aquifer, primarily equivalent to the Pecos Valley Aquifer; and the Rio Grande aquifer system, of which Texas is including its Hueco-Mesilla Bolsons major aquifer which comprises approximately 1/10th of the USGS defined Rio Grande aquifer. The sandstone and carbonate-rock principal Edwards-Trinity aquifer system consists of three major aquifers in the Texas portion: the Trinity, the Edwards (Balcones Fault Zone, or BFZ), and the Edwards-Trinity Plateau aquifers.

The one major and principal aquifer in Texas not included is the High Plains, or Ogallala Aquifer. This omission has allowed us to focus on wells and their associated data in the entirety of aquifers not as well studied as the Ogallala, an aquifer whose multi-state coverage and overall agricultural importance have long made it a target of USGS water level and water quality studies.

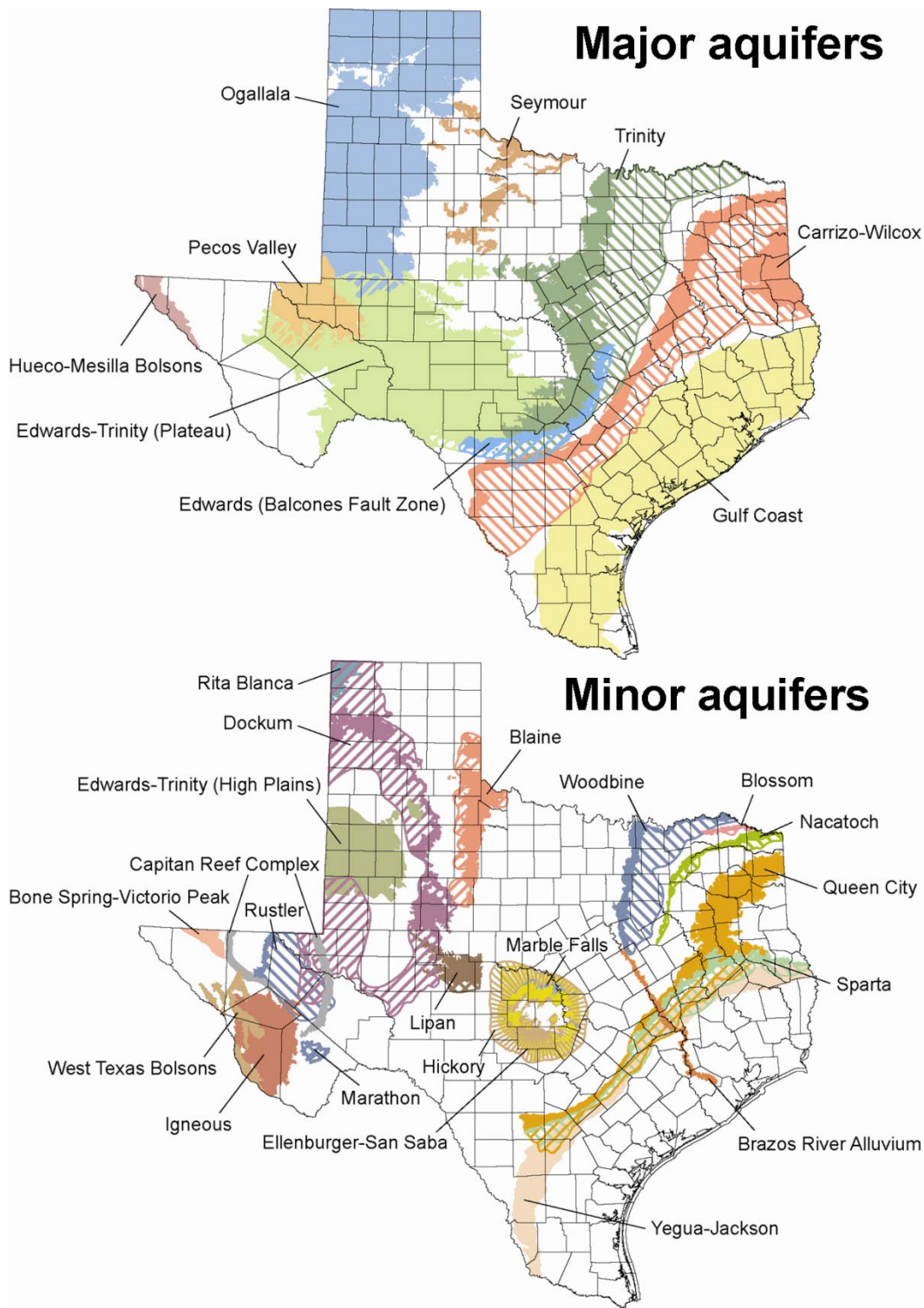


Figure 5-1. Major and minor aquifers of Texas.

Table 5.1 Table of aquifers and relation to principal aquifer codes.

USGS Principal Aquifer	Texas Aquifer Name
Coastal lowlands aquifer system	Gulf Coast Aquifer
Texas coastal uplands aquifer system	Carrizo-Wilcox Aquifer
Seymour aquifer	Seymour Aquifer
Pecos River Basin alluvial aquifer	Pecos Valley Aquifer
Rio Grande aquifer system	Hueco-Mesilla Bolsons Aquifer
Edwards-Trinity aquifer system	Trinity Aquifer
Edwards-Trinity aquifer system	Edwards (Balcones Fault Zone) (BFZ) Aquifer
Edwards-Trinity aquifer system	Edwards-Trinity Plateau Aquifer

The other principal aquifer in Texas as designated by the USGS is the Blaine; however, the high average salinity of water in this aquifer, suitable mainly for irrigation of certain salt-tolerant crops, has resulted in its designation as a minor aquifer by the TWDB.

All major and minor aquifers are a critical source of water for Texas, supplying 59 percent of the 15.6 million acre-feet of water used in the state in 2003. In addition, nearly 220,000 acre-feet of groundwater are produced from local aquifers that are not designated as major or minor. About 79 percent of groundwater produced from major and minor aquifers is used for agriculture (mostly for irrigation), with irrigators withdrawing most of this water from the Ogallala Aquifer (82 percent of all groundwater used for irrigation or 6.0 million acre-feet per year). About 36 percent of water used to meet municipal demands is from groundwater. More than 99 percent of rural households rely on groundwater for their drinking water supply.

TWDB has operated groundwater data collection programs throughout the state of Texas since the agency's inception in 1957. Sections of the Texas Water Code (TWC) mandate and allow studies and data collection of the state's groundwater resources, analysis and dissemination/publication of the data, and assistance to the state's groundwater conservation districts (TWC §16.012(a), (b), (d));

§16.013; §16.015). For thirty years, during different incarnations of the agency, the goals of water level and water quality monitoring programs were generally focused on studies of specific areas, and there was arguably no statewide perspective or coordination. After 1988, TWDB management centralized decisions about groundwater data collection and initiated three monitoring programs that complement other local, state, and federal monitoring programs within the state. TWDB recognized that attention to systematic collection of data was essential for more accurate reporting of current conditions and to collect data allowing for determination of any changes in water levels and water quality over time.

Primary objectives of the TWDB groundwater data collection programs include monitoring of water levels to track changes in levels over time; sampling to characterize baseline, spatial, and temporal characterization of ambient or background water quality and to track any changes that may be occurring over time; and contamination assessments of naturally occurring constituents. Secondary objectives include scientific investigations: TWDB data are used by outside consultants, university staff, and agency employees in a variety of publications. TWDB monitoring personnel collect information essential to regional and state water planning and groundwater management; maintain the state's water well database; and provide and communicate the results of their work through a number of portals available online and in publications ranging from monthly reports to regional or aquifer characterization studies.

Two of the three TWDB programs that monitor groundwater levels are the most comprehensive in existence in the state, both geographically and hydrogeologically; the agency has historically solicited and incorporated into its database as much existing water level data as possible, whether from local groundwater districts or the USGS. The goal of the TWDB's third monitoring program, to collect inorganic water quality data including trace minerals (metals) and radionuclides, is also the only statewide water quality data program dedicated to the collection of this type of information from raw water sources. Although the state's regulatory agency, the Texas Commission on Environmental Quality

(TCEQ), requires its public water suppliers also to collect these types of data in addition to bacterial concentrations and organic compounds that have primary drinking water standards, the majority of such analyses is from treated water or mixed sources from distribution systems. The small percentage of public supply wells with untreated or “raw” water samples has not been included in the TWDB database until this project.

6. Collaboration and Cooperation

6.1 Pilot Study

Texas' involvement with the pilot project relied on our cooperators, but also new players, whether in reviewing types of data or discussing challenges associated with portal development and transfer of data. TWDB's water level information includes data from cooperating entities that have contributed water level data for decades. The most important contributors—in terms of amount of data—to the TWDB database, facilitated by constant encouragement from TWDB staff through informal agreements, are the local groundwater conservation districts and the USGS (Figure 6-1). With the exception of initial water level readings upon completion of water well drilling as recorded in the submitted driller's database from statutorily required drillers' reports for new wells, we believe the database includes nearly all water level measurements collected by any entity engaged in this activity throughout the state.

However, the TWDB database is not the de facto repository of all water quality data collected by any entity engaged in these activities as it is for water level data. The most obvious set of data that we consider to be a logical addition to our database includes information from the raw samples collected at approximately 700 (of the 21,000) public supply wells from small systems throughout the state. These data, collected from one well before treatment or mixing, are most similar to the data collected by the TWDB; although in accordance with TCEQ regulations, these are not analyzed from filtered water as they are for TWDB analyses. Typically, however, inorganic constituents are part of the analysis suite in addition to bacteria and many volatile organic compounds, including chlorination disinfection byproducts. Sampling requirements, including frequency, depend on the number of constituents found in excess of their primary Maximum Contaminant Levels (MCL).

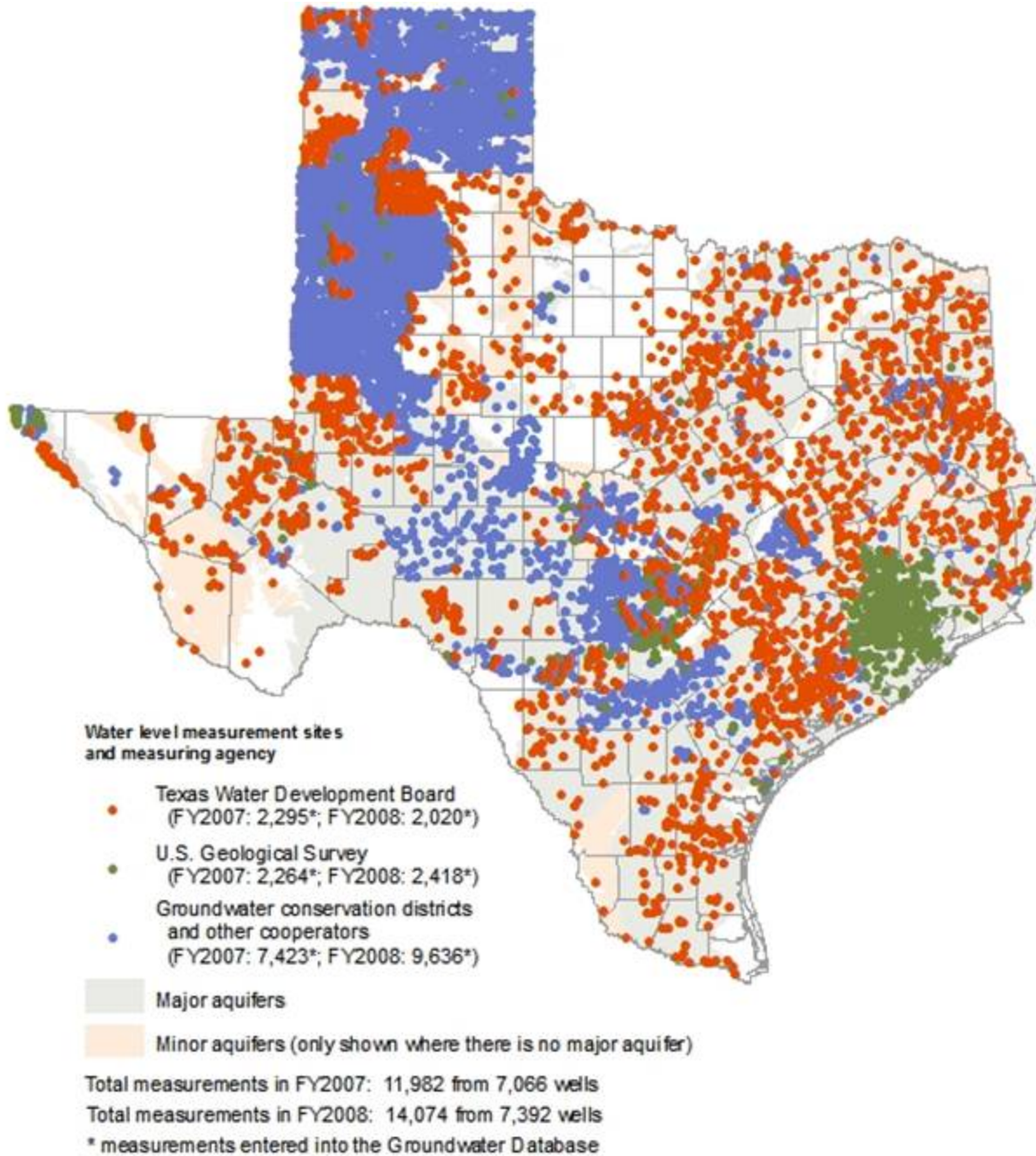


Figure 6-1. TWDB and cooperator measured wells in fiscal years 2007-2008.

The Texas Groundwater Protection Committee, a non-funded consortium of nine agencies and the Texas Association of Groundwater Districts chaired by the TCEQ and technically considered a state agency, was created in 1989 to identify opportunities to improve existing groundwater quality programs and promote coordination among agencies (<http://www.tgpc.state.tx.us/>). Two of its Data Management Subcommittee goals have been to promote greater access to TCEQ public supply groundwater quality data in an effort to assess the effectiveness of regulatory programs and, indirectly, to identify potential problem areas where additional monitoring is needed. These goals, in addition to the TWDB's objective to describe existing groundwater quality (or to define status) and any changes over time (or to define trends) dovetail with the pilot project's networks' goals and objectives as defined in Chapter 3 of the framework document.

During the pilot project, the TWDB contracted with an outside vendor to study the effects of anthropogenic-influenced water quality on water quantity in major aquifers in the state. In the process of working on this contract, the TWDB was able to solicit and receive TCEQ public supply data. Although the majority of the wells need location, depth, and completion data verification, the TWDB has been able to use a portion of these in the pilot project.

In addition to collaborating with our agency's Internet Technology Division, we have also discussed web services with the agency's Surface Water Division. This group currently has the most experience with web services and Water Mark-up Language (WaterML); they developed a Texas Hydrologic Information System for the four large surface water databases in Texas. This system uses the CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI), Hydrologic Information System (HIS)) Observations Data Model and WaterML web services method for time series of observations data. Including Surface Water Division staff in our discussions of our proposed data transfer to the portal has helped us benefit from that group's experience in this related

project and has helped us garner support from our agency's management for groundwater data transfer via the NGWMN portal.

6.2 Future Opportunities

Three entities could become sources of potential water quality network wells in selected geographic areas in Texas. The USGS has completed or is currently engaged in its National Water Quality Assessment (NAWQA) Program studies in parts of the Trinity, Carrizo-Wilcox, Edwards-Trinity (BFZ) and High Plains aquifers, all major aquifers in Texas. Because the USGS documented information about the dedicated existing and drilled wells that are used for providing water quality in these projects, TWDB is confident that required data elements will be available and field standards will match those identified in the framework document. Information about these wells and water-quality data are not in the TWDB database for the most part. We anticipate being able to incorporate the relevant data with appropriate TWDB database fields after completion of the restructuring of the TWDB database.

Two other potential collaborators include San Antonio Water System (SAWS) and Edwards Aquifer Authority (EAA). Both are local agencies that collect synoptic and continuous water quality data at groundwater sites in Bexar and surrounding counties. TWDB looks forward to incorporating data from these three entities into our database. Once the data are incorporated, then additional Texas trend sites could be considered for the NGWMN, although timely data transfer may present a challenge.

7. Water Level Network Well Selection

7.1 Network Design

One major influence on the design of the water level network for the pilot project stems from the design in our existing Texas water-level observation program. This design is a hybrid of several styles that reflects the original random sampling and study specific sampling on which was later imposed a more systematic sampling within grids that was intended to be modified based on external factors, primarily pumping. In the last twenty years, the agency has systematically and formulaically based its groundwater level (and quality) monitoring program on production by county, by aquifer, with attention to areal distribution of wells within 7 ½ minute grids (USGS topographic quadrangles) within county-aquifer units, but it has not always been feasible to monitor wells in a systematic grid pattern when typically the greater amount of pumpage, resulting in a need for more wells per county-aquifer unit, is limited geographically. A second influence reflected in the network design is the agency's continued inclusion of wells with long measurement histories in the water level program; these were initially chosen for a variety of projects over the last seventy years and don't necessarily conform to any design standards.

One factor that has not modified the design of the TWDB's water level observation program but could subsequently alter the design of and suggested measurement frequencies in the water level portion of the NGWMN is the increased participation of cooperators (districts). The TWDB collects measurements yearly in 150 counties covered by the eight study area aquifer. Cooperators collect data at least annually in nearly 100 counties, a few of which are the same counties where the TWDB collects but in different areas. Cooperators begin to collect more frequently at well sites after their water level monitoring programs become better established, while the TWDB usually stops measuring in these counties. As they have taken over monitoring responsibilities at former TWDB sites, cooperators also

monitor more wells and measure more frequently, typically as pumpage or anticipation of pumpage increases. Districts very rarely, at least thus far, have the funds to drill new dedicated monitoring wells in anticipation of the need to monitor.

For this pilot project, in working with what wells are available for measuring and further imposing limitations of choosing wells with long histories and minimum data elements—resulting in a little more than 2,250 potential sites, we attempted to base our design on a minimum number of 30 wells per aquifer. Three aquifers—the Seymour, Pecos Valley, and Hueco-Mesilla Bolsons—have only 20, 19, and 19 wells, respectively, as of December 2010, resulting in one well per 175, 154, and 295 square miles, respectively. The three larger aquifers or aquifer systems, the Gulf Coast, Carrizo-Wilcox, and Trinity/Edwards-Trinity (BFZ)/Edwards-Trinity Plateau, with 89, 109, and 170 wells each, respectively, surpass the minimum; but in these there is a larger number of square miles represented by one well, or 1,111, 593, and 442 square miles, respectively. Overall, the network consists of 426 wells (Appendix 1) chosen from nearly 2,250 sites in our annual water level observation and continuous automatic recorder programs.

TWDB defines its (and its cooperators') synoptic-type measuring events (our annual water-level observation program) historically conducted during the same one of four months—November through February—as **surveillance** monitoring. While yearly measurements from these wells allow us also to determine trends in water level changes over time, we classify our automatic water level recorders as **trend** wells. As discussed, cooperators provide us with the bulk of measurements from all surveillance wells, and all conduct yearly or more frequent monitoring.

Once we tabulated wells with annual water level measurements that TWDB collects or receives from cooperators that are considered to have associated minimum data elements in spreadsheets by aquifer, we created hydrographs for each well using land surface as the horizontal datum for each for ease of comparison. While total depths to water differed and necessitated different vertical axes,

typically we used the same time scale, beginning in the 1930s, as frequently as possible; a few wells had longer measurement histories, such as an irrigation well in Reagan County dating back to 1906.

Spreadsheets also include years between first and last measurements, total change in depth, and change in feet per 10 years.

After culling out a set of wells with all minimum data elements and longest periods of record (relative to those in wells in the same aquifer), our second tier of possibilities included wells without drillers or geophysical logs. We mapped both sets to determine spatial relationships. Only six of the 425 water-level network wells did not meet five years of baseline measurements. Consideration of each well's hydrograph allowed us to eliminate, to the extent possible, wells with pumping spikes or other inexplicable anomalies. Although all of the wells have unique identifiers sufficient for the TWDB groundwater database purposes, we are currently restructuring our database and will be adding a second field with unique identification for purposes of this national network.

7.2 Unstressed Subnetwork

As discussed in the introductory remarks, the definitions we chose for unstressed and targeted wells helped us choose wells whose data we believe portray a more representative picture of background water level conditions in the eight major aquifers, particularly with respect to human influences (pumping) and climate (drought). Our goal in choosing wells with unstressed conditions for all aquifers was to illustrate that pumping, if any was occurring in the area, was not affecting water levels, or at least to no significant degree. Our definition of "no significant degree" allowed classification of wells as unstressed if their overall decline was less than a rate of two feet a year, for the most part. We had previously used a rate of decline of greater than two feet a year as a threshold in creating aquifer-wide water level decline maps, at least in unconfined portions of aquifers.

It was a bigger challenge to label wells as unstressed in a consistent fashion after first determining a definition of unstressed than we had originally anticipated. Only after complete immersion in the data did we begin to refine the gray areas in the definitions. Although in making decline maps the TWDB had also considered five feet a year or greater as the threshold for mapping water-level decline in confined aquifers, we quickly noted that we felt less certain about declines between two and five feet a year as denoting an unstressed condition in confined aquifers. Ultimately our choices reflected a bias—an aversion to more ambiguous situations, such as with a decline between two and five feet a year, and we tended to rely on the stricter unconfined threshold definition and applied that rule to confined conditions as well. In general, we called wells unstressed if their water level histories:

- 1) showed little change, or little change throughout time despite a secondary overprint of seasonal fluctuations of whatever magnitude,
- 2) had originally shown declines from shallower depths and had subsequently recovered to the same level (or recovered sufficiently such that there is but 2 feet/year decline or less between original and most recent measurement), or
- 3) had originally been measured at deeper depths but have mainly recovered or are currently in recovery.

This last circumstance indicates that water levels were stressed in the past and may not have recovered to original levels, or levels meeting the conditions in #2. But for purposes of this exercise, despite possibility that even the current recovery may not actually qualify the water level as now unstressed (when pre-stressed levels are unknown as is generally the case), we classified these types of recent rising levels as unstressed.

7.3 Targeted Subnetwork

These wells experienced declines; originally we chose any decline over 50 feet as indicative of stress and presumably due to pumping. As discussed in the explanation of our definition of unstressed, however, every reappraisal of our definition brought up many questions; ultimately we chose a stricter definition of targeted. Generally, we considered a well as targeted if hydrographs indicated that:

- 1) overall decline from first to most recent measurement of greater than 20 feet had occurred, with or without an overprint of fluctuating water levels,
- 2) overall decline of greater than 2 feet per year, or
- 3) overall decline of 40 feet with recovery in progress but level not yet to within 20 feet of original measurement.

Even when looking at hydrographs with declines of between 15 and 20 feet, no matter the period of record, we reappraised the appropriateness of our definition. Depending on the shallowness and transmissivity of aquifer material, droughts could cause these declines over periods as long as decades, particularly in unused wells in areas not surrounded by pumping; but distinguishing the relative influences of drought vs. pumping in all network wells is beyond the scope of this pilot project (and beyond the scope of any database development of this nature).

The details of the methods used to establish unstressed and targeted wells highlights the difficulty in labeling a particular well in an interpretive vacuum. Normally, characterizing the trends in groundwater levels and evaluating groundwater conditions, groundwater availability, or groundwater sustainability are objective-driven investigations which require these data as a foundation. However, it is also important to understand the other aspects of a groundwater system to make these interpretations.

7.4 Gulf Coast Aquifer (Coastal lowlands aquifer system)

The Gulf Coast Aquifer is the second most heavily pumped aquifer in Texas, after the Ogallala, with reported use of approximately 1,100,000 acre-feet a year (TWDB, 2003) for municipal, irrigation, and industrial purposes. Objectives for choosing all water level network wells in this aquifer include a need to monitor changes in pumping in the Houston area, primarily for municipal purposes, including all of Harris and surrounding counties. There is a need to determine if recoveries are continuing in Galveston and southeastern Harris counties as population growth continues to the north and west and to determine if more pumping is affecting water levels in Fort Bend and Montgomery counties and the northern portion of Harris County. Monitoring water levels in counties along the Colorado River—Colorado, Wharton, and Matagorda—where groundwater is used primarily for irrigation and where cones of depression have developed in Wharton County in the late eighties and nineties, is of primary concern. Uranium mining in Jim Hogg, Brooks, and Duval counties; plans for development of water in Kennedy County; and overall expected increase in population by as much as 50 percent in the next fifty years in the drought-prone Rio Grande Valley are additional regional issues that demand greater monitoring (TWDB, 2007, State Water Plan).

The Gulf Coast water level network consists of 83 surveillance wells and five trend wells (Figure 6-1); 52 of the surveillance and two trend wells were originally considered unstressed. All unstressed subnetwork wells with the exception of two trend wells, each with only three years of measurements, meet baseline monitoring frequency criteria. Cooperators measure 25 surveillance wells. Periods of record for the unstressed surveillance wells range from 6 to 68 years with a median of 46 years; overall water level changes range from -19.5 feet to a rise of 137.5 feet (in a Harris County industrial supply well) with a median of +1.6 feet, and change per year ranges from -0.9 to +3.6 feet with a median of essentially 0 feet (+0.03 feet). Periods of record for the two unstressed trend wells in Victoria and

Washington counties were 52 and 47 years; overall changes were -0.3 and +6.1 feet, and changes per year were 0.0 and +0.1 feet, respectively.

TWDB Water Level Network Wells in the Gulf Coast Aquifer

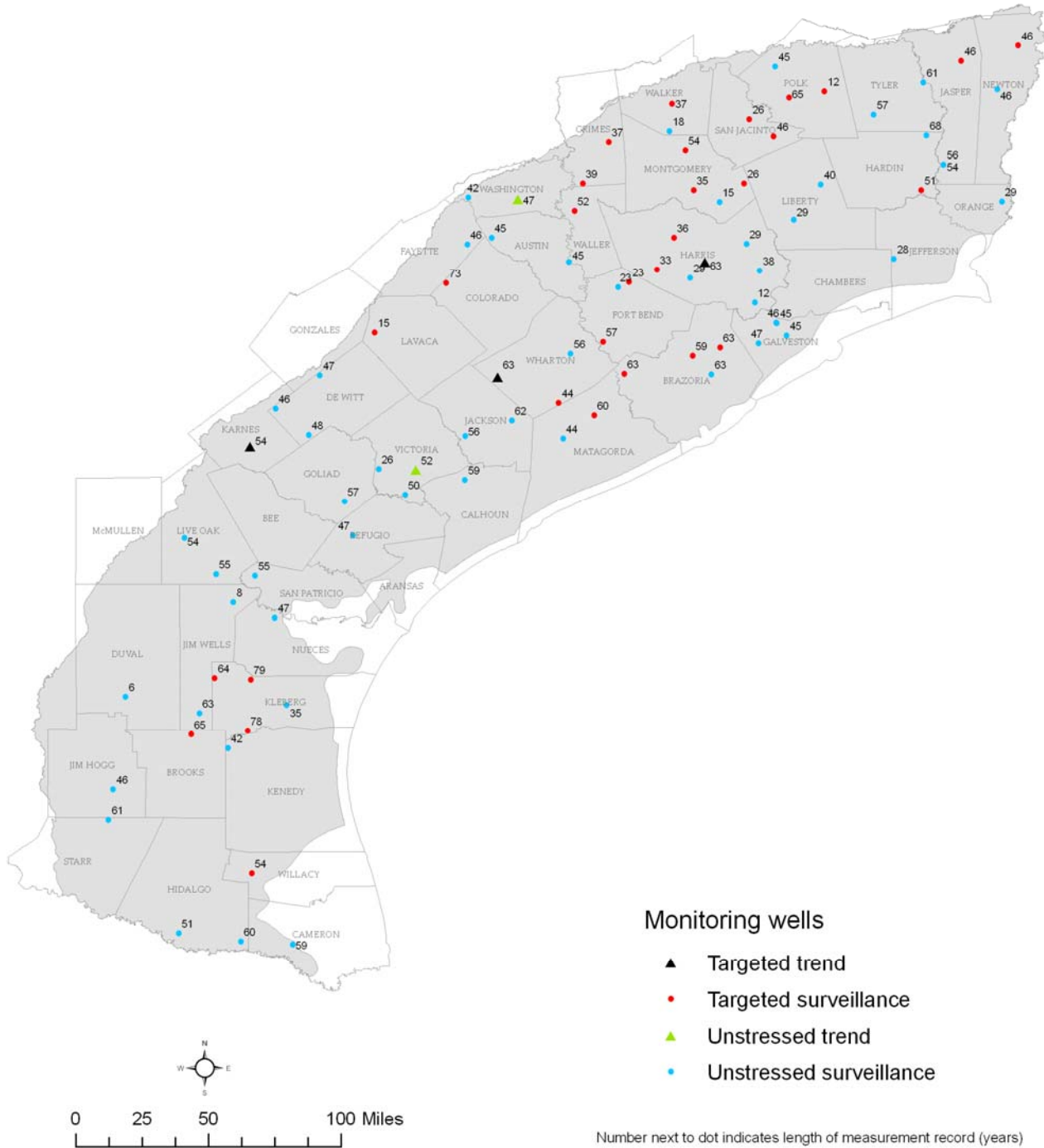


Figure 7-4. Water level network wells in the Gulf Coast Aquifer.

In the Gulf Coast water level network, 31 surveillance wells and three trend wells were originally considered as targeted; all targeted subnetwork wells with the exception of two trend wells, each with only 3 years of measurements, meet baseline monitoring frequency criteria. Cooperators measure 17 surveillance wells. Periods of record for the targeted surveillance wells range from 12 to 79 years with a median of 51 years; overall water level changes range from -21.2 to -271.6 feet (in a Montgomery County public supply well) with a median of -58.9 feet; and change per year ranges from -0.4 to -7.8 feet with a median of -1.1 feet per year. Periods of record for the three targeted trend wells in Wharton, Harris, and Karnes counties are 63, 63, and 54 years; overall changes are -28.1, -63.4, and -114.7 feet; and changes per year are -4.1, -10.5, and -21.3 feet, respectively.

7.5 Carrizo-Wilcox Aquifer (Texas coastal uplands aquifer system)

More than half of the groundwater pumped from the Carrizo-Wilcox aquifer is used for irrigation (53 percent in 2003), municipal public water supply, rural domestic use, and manufacturing in approximately 60 counties in Texas. With a reported water use of 450,000 acre-feet a year comprising less than half of the 1,000,000 feet accepted as available supply (TWDB, 2003), many are interested in monitoring wells in these aquifers to pinpoint baseline levels as accurately as possible. Declines have already occurred throughout the past several decades locally due to irrigation in the Winter Garden area in the southwestern portion of the aquifer and municipal pumping in the Bryan-College Station, Lufkin-Nacogdoches, and Tyler areas. Other concerns such as lignite mining operations in the central part of the aquifer, with neighboring districts not always in agreement over what constitutes significant (or undesirable) pumping, are also drivers behind the need for monitoring.

The Carrizo-Wilcox water level network consists of 101 surveillance wells and eight trend wells (Figure 7.5), of which 34 surveillance and five trend wells were originally considered as unstressed. All

unstressed subnetwork wells, with the exception of one trend well in Atascosa County with only two years of measurements, meet baseline monitoring frequency criteria. Cooperators measure 14 surveillance wells. Periods of record for the unstressed wells range from 9 to 74 years with a median

TWDB Water Level Network Wells in the Carrizo-Wilcox Aquifer

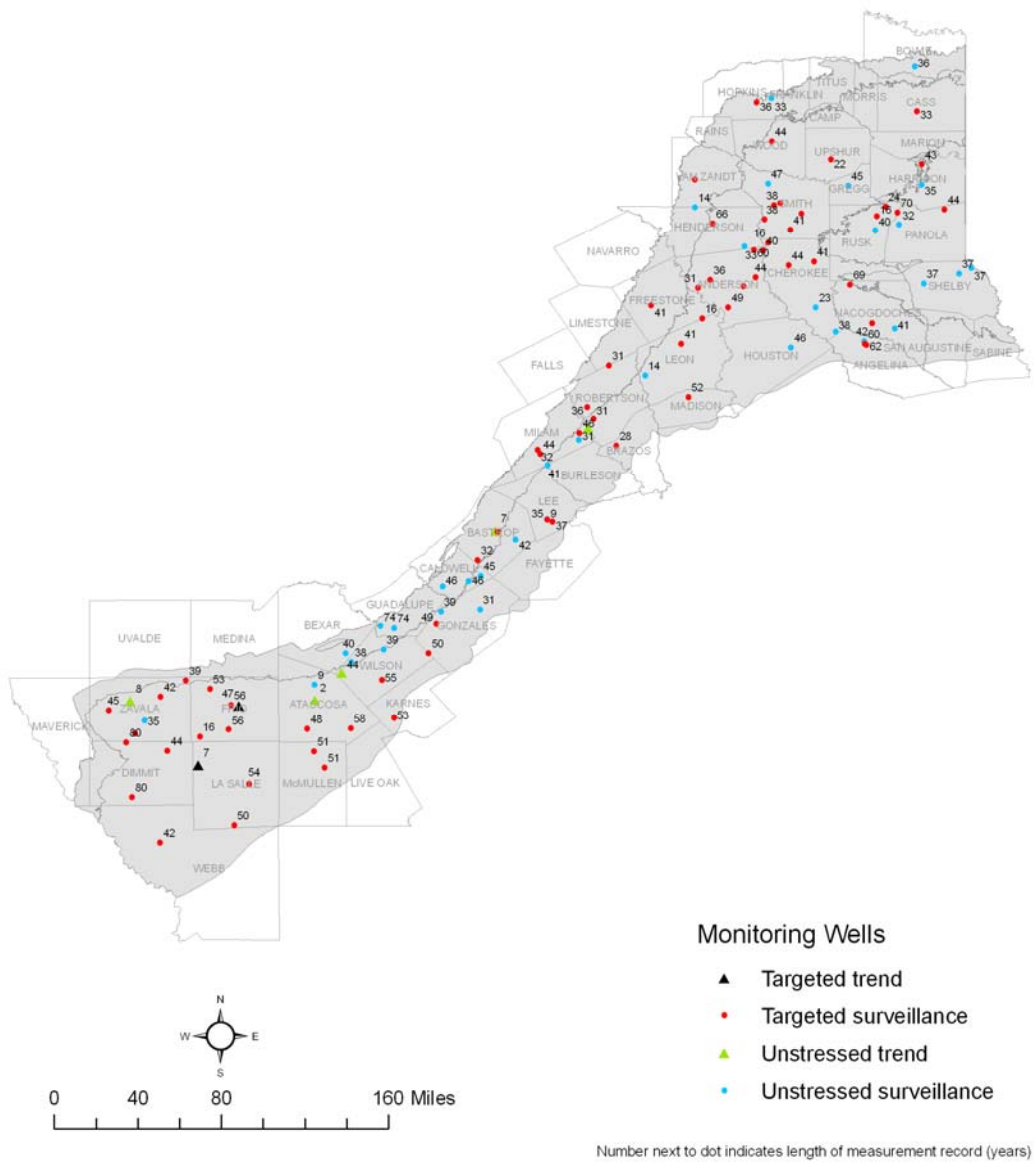


Figure 7-5. Water level network wells in the Carrizo-Wilcox Aquifer.

of 38 years; overall water level change ranges from -19.9 feet to a rise of 117.6 feet (in a Panola County industrial supply well) with a median of +3.0 feet, and change per year ranges from -0.8 to +3.9 feet with a median of +0.1 feet. Periods of record for the five unstressed trend wells in Atascosa, Zavala, Wilson, Bastrop, and Milam counties were 2, 7, 8, 29, and 44 years; changes were -0.7, +18.0, -14.7, -3.7, and +9.8 feet; and changes per year were -0.3, +2.6, -1.8, -0.1, and +0.2 feet per year, respectively. The Zavala recorder, with only 8 years of measurement, is approaching the -2.0 feet per year rate of change, that if it continues, would classify it as targeted.

In the Carrizo-Wilcox water level network, 67 surveillance and three trend wells were originally determined to be targeted. All targeted subnetwork wells meet baseline monitoring frequency criteria. Cooperators measure 27 surveillance wells. Periods of record for the targeted wells range from 16 to 81 years with a median of 44 years; overall water level changes range from a -21.1 to -281.0 (in a Smith County public supply well) feet with a median of -99.0 feet, and change per year ranges from -0.5 to -11.2 feet with a median of -2.5 feet. Periods of record for the three targeted trend wells in La Salle, Smith, and Frio counties were 7, 33, and 47 years; overall changes were -43.5, -133.4, and -154.2 feet, and changes per year were -6.2, -4.0, and -3.3 feet, respectively.

7.6 Trinity, Edwards-Trinity (BFZ), and Edwards-Trinity Plateau aquifers (Edwards-Trinity aquifer system)

The Trinity, Edwards (BFZ), and Edwards-Trinity Plateau, each considered major aquifers in Texas but for purposes of this study considered as one principal aquifer, most recently report as producing large volumes of water: 170,000, 320,000, and 150,000 acre-feet a year, respectively (TWDB, 2003). Groundwater in the Trinity Aquifer, although primarily used for municipalities, is also used for irrigation, livestock, and other domestic purposes. Monitoring is essential in portions of the aquifer. As

the aquifer is one of the most extensive and highly used groundwater resources in Texas, it has also experienced some of the largest water level declines in the state, ranging from 350 to more than 1,000 feet in counties along the Interstate 35 corridor from McLennan County to Grayson County. These declines are primarily attributed to municipal pumping and have lessened in the past decade as a result of increased reliance on surface water. The Edwards (BFZ) Aquifer produces water for municipal, irrigation, and recreational purposes and feeds several well-known springs including Comal Springs in Comal County, which is the largest spring in the state, and San Marcos Springs in Hays County. San Antonio obtains almost all of its water supply from the Edwards (Balcones Fault Zone) Aquifer. Water levels and spring flows in this aquifer that respond rapidly to rainfall, drought, and pumping, while also rebounding quickly with adequate rainfall, necessitate real-time monitoring. Two-thirds of the groundwater pumped from the Edwards-Trinity Plateau Aquifer is used for irrigation, with the remainder used for municipal and livestock supplies. Water levels have remained relatively stable because recharge has generally kept pace with the relatively low amounts of pumping over the extent of the aquifer (TWDB, 2007, State Water Plan).

In the Trinity water level network of 131 surveillance wells and 39 trend wells, 80 surveillance wells and 20 trend wells were originally considered as unstressed; all unstressed subnetwork wells, with the exception of one trend well in Bandera County with only 2 years of measurements, meet baseline monitoring frequency criteria. Cooperators measure 31 surveillance wells. Periods of record for the unstressed wells range from 2 to 97 years with a median of 40 years; overall water level changes range from -37.6 feet to a rise of 155.5 feet (in an unused Val Verde County well) with a median of -0.9 feet; and change per year ranges from -0.9 to +3.7 feet with a median of essentially 0 feet (-0.01). Periods of record for the 20 unstressed trend wells range from 2 to 81 years with a median of 14; overall changes range -17.4 to +36.5 feet with a median of 1.0 feet; and changes per year range from -1.2 to +2.7 feet with a median of +0.1 feet.

In the Trinity water level network, 51 surveillance and 19 trend wells were originally determined to be targeted. All targeted subnetwork wells meet baseline monitoring frequency criteria. Cooperators measure 11 surveillance wells. Periods of record for the targeted wells range from 6 to 81 years with a median of 41 years; overall water level changes range from -32.8 to -737.0 feet (in an Ellis County public supply well) with a median of -138.5 feet; and change per year ranges from -18.0 to -0.9 feet with a median of -3.2 feet. Periods of record for the 19 targeted trend wells range from 6 to 78 years with a median of 26 years; overall changes range -18.5 to -700.6 feet (in a McLennan County recorder) with a median of -57.1 feet; changes per year range from -0.3 to -15.2 feet with a median of -2.5 feet.

TWDB Water Level Network Wells in the Edwards (Balcones Fault Zone), Trinity, and Edwards-Trinity (Plateau) Aquifers

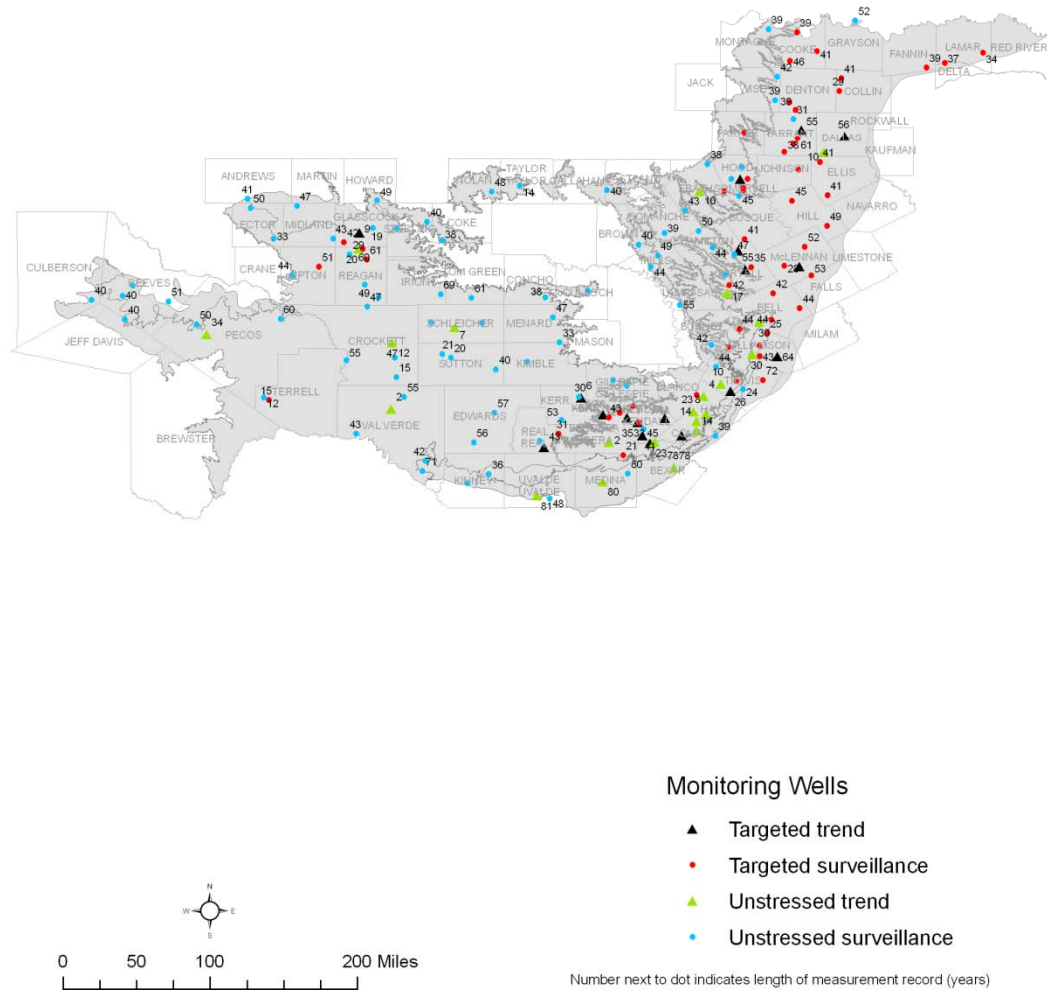


Figure 7-6. Water level network wells in the Edwards-Trinity Aquifer.

7.7 Seymour Aquifer

Almost all of the 190,000 acre-feet a year (TWDB, 2003) of groundwater pumped from the aquifer—90 percent—is used for irrigation in the Seymour, with the remainder primarily used for

municipal supply. Water level declines have reduced the saturated thickness in some areas (TWDB, 2007, State Water Plan).

The Seymour water level network consists of 18 surveillance wells and two trend wells, of which 14 surveillance wells and both trend wells were originally considered as unstressed. All unstressed subnetwork wells, with the exception of the trend well in Baylor County with two years of measurements, meet baseline monitoring frequency criteria. Cooperators measure two surveillance wells. Periods of record for the unstressed surveillance wells range from 13 to 71 years with a median of 43 years; overall water level changes range from -18.2 to +8.5 feet with a median of -2.7 feet; and change per year ranges from -1.4 to +0.1 feet with a median of 0 feet. Periods of record for the two unstressed trend wells in Haskell and Baylor counties are 8 and 2 years; overall changes are -2.4 and +2.0 feet; and average changes per year are -0.3 and +1.0 feet, respectively.

In the Seymour water level network, four of the surveillance and none of the trend wells were originally determined to be targeted. All targeted subnetwork wells meet baseline monitoring frequency criteria. Cooperators measure one surveillance well. Periods of record for the targeted surveillance wells are 53, 56, 57, and 59 years; overall water level changes are -21.8, -21.8, -37.3, and -54.2 (in a Childress County public supply well); with average changes per year at -0.4, -0.4, -0.7, and -0.9 feet.

TWDB Water Level Network Wells in the Seymour Aquifer

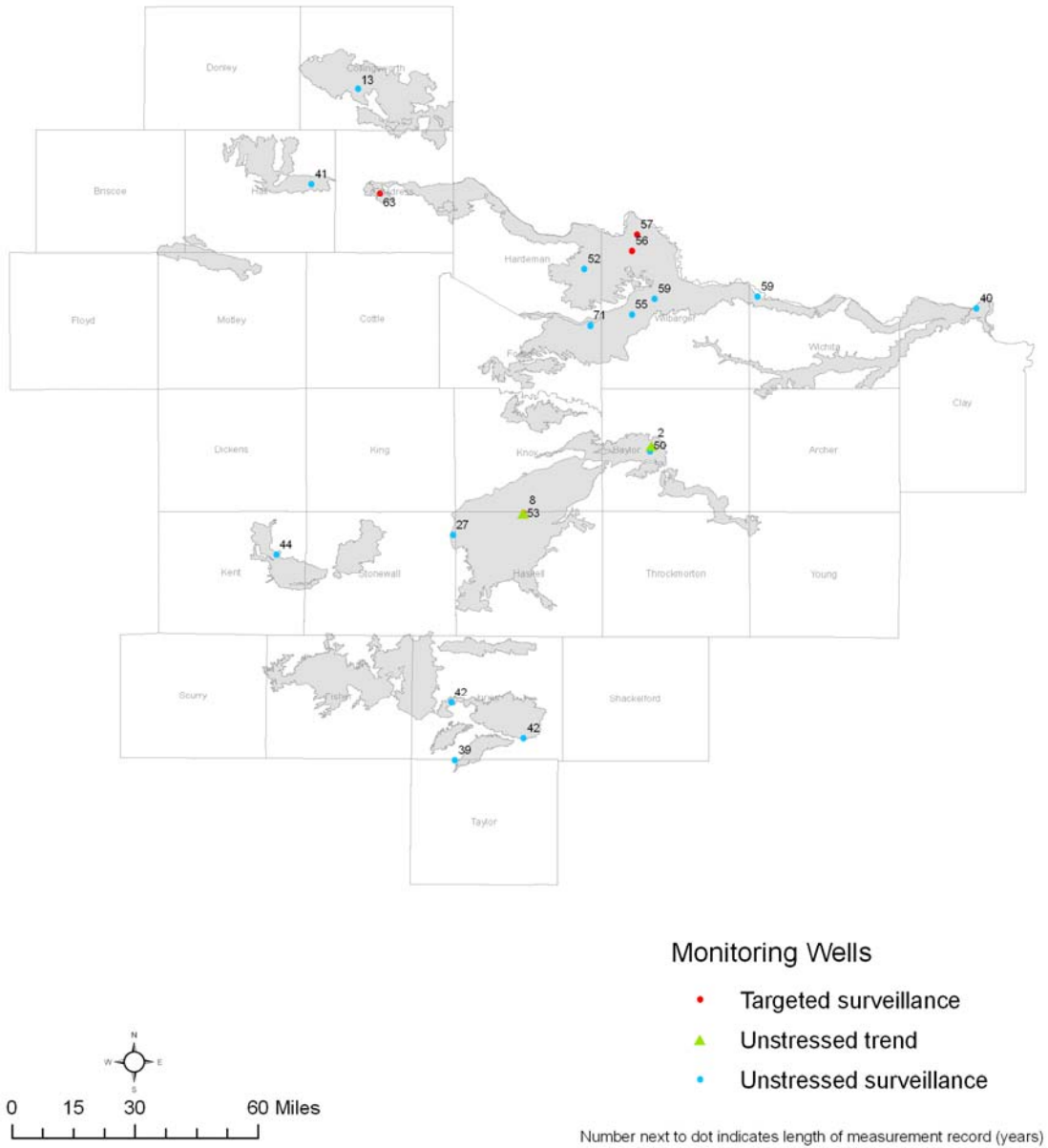


Figure 7-7. Water level network wells in the Seymour Aquifer.

7.8 Pecos Valley Aquifer (Pecos River Basin alluvial aquifer)

With most recent reported pumping of 55,000 acre-feet a year (TWDB, 2003), 80 percent of groundwater from the Pecos Valley Aquifer is used for irrigation, with the rest withdrawn for municipal supplies, industrial use, and power generation. Localized water level declines in south central Reeves and northwest Pecos counties have moderated since the late 1970s as irrigation pumping has decreased. However, water levels continue to decline in central Ward County due to increased municipal and industrial pumping (TWDB, 2007, State Water Plan).

The Pecos water level network consists of 17 surveillance wells and two trend wells, of which 11 surveillance wells and none of the trend wells were originally considered as unstressed; all unstressed subnetwork wells meet baseline monitoring frequency criteria. Cooperators measure one surveillance well. Periods of record for the unstressed surveillance wells range from 36 to 70 years with a median of 55 years; overall water level changes range from -16.6 feet to a rise of 33.2 feet (in an unused Pecos County well) with a median of +1.9 feet; and change per year ranges from -0.3 to a rise of 0.6 feet with a median of +0.1 feet.

In the Pecos water level network, six of the surveillance and two of the trend wells were originally determined to be targeted. All targeted subnetwork wells meet baseline monitoring frequency criteria. Cooperators measure three surveillance wells. Periods of record for the targeted surveillance wells range from 38 to 69 years with a median of 53 years; overall water level changes range from a decline of -145.1 feet (in an unused Reeves County well) to -33.1 feet with a median of -102.3 feet, and change per year ranges from -0.9 to -1.9 feet with a median of -2.0 feet. Periods of record for the two targeted trend wells in Reeves and Pecos counties were 58 and 52 years; overall changes were -60.9 and -161.6 feet, and changes per year are -1.1 and -3.1 feet, respectively.

TWDB Water Level Network Wells in the Hueco-Mesilla Bolsons and Pecos Valley Aquifer

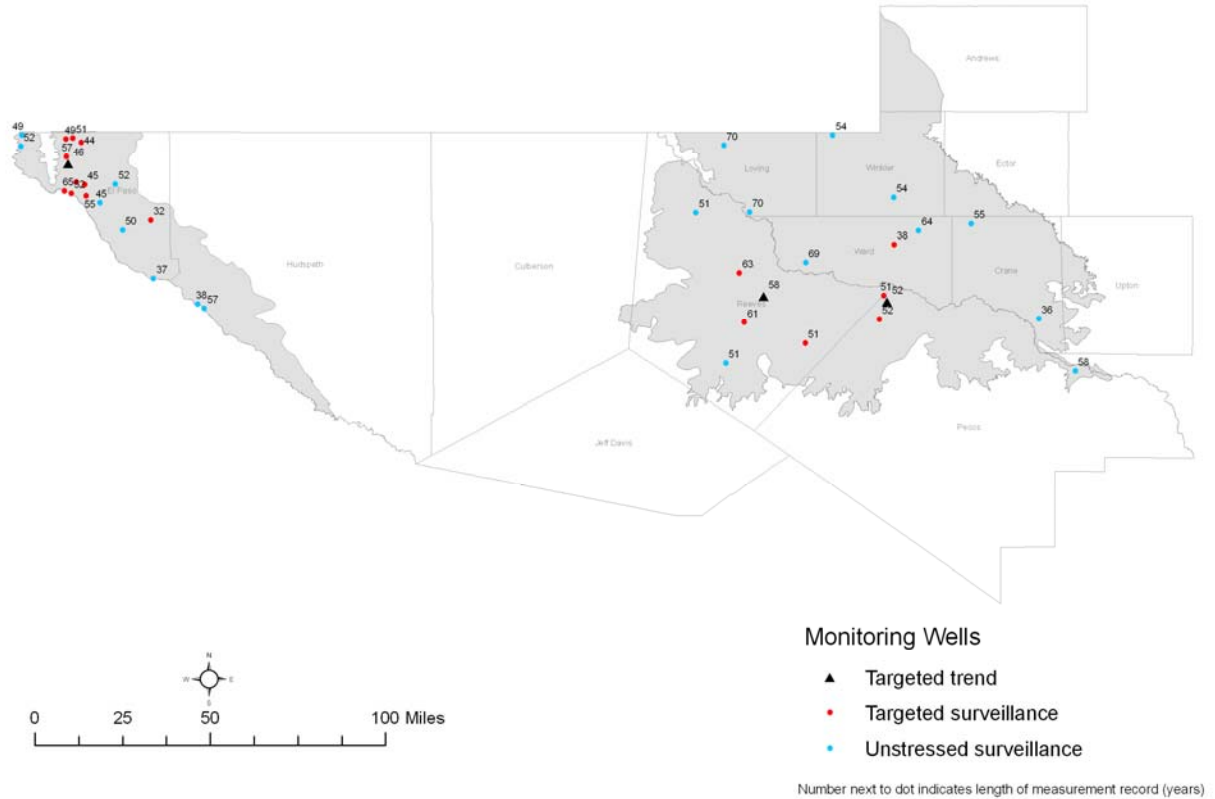


Figure 7-8. Water level network wells in the Hueco-Mesilla Bolsons and Pecos Valley aquifers.

7.9 Hueco-Mesilla Bolsons Aquifer (Rio Grande aquifer system)

The Hueco-Mesilla Bolsons Aquifer, located east and west of the Franklin Mountains in Far West Texas and recognized as a major aquifer in Texas, constitutes approximately one-tenth of the larger USGS designated Rio Grande aquifer system that extends into New Mexico and Colorado. Most recent reported pumping of 110,000 acre-feet a year (TWDB, 2003) has primarily occurred in the Hueco Bolson, the principal aquifer for the El Paso area and Ciudad Juarez in Mexico. Nearly 90 percent of the

water pumped from the Hueco-Mesilla Bolsons in Texas is used for public supply (TWDB, 2007, State Water Plan). With water level declines of several hundred feet that have also contributed to increased salinity, monitoring is crucial.

The Hueco-Mesilla Bolsons water level network consists of 18 surveillance wells and one trend well, of which eight surveillance wells and none of the trend wells were originally considered as unstressed; all unstressed subnetwork wells meet baseline monitoring frequency criteria. Cooperators measure four surveillance wells. Periods of record for the surveillance wells range from 37 to 57 years with a median of 50 years; overall water level changes range from -17.2 feet to a rise of 5.7 feet with a median of -0.8 feet; and change per year ranges from -3.3 to +0.2 feet with a median of nearly 0 (+0.04) feet.

In the Hueco-Mesilla Bolsons water level network, 10 of the surveillance wells and the one trend wells were originally determined to be targeted. All targeted subnetwork wells meet baseline monitoring frequency criteria. Periods of record for the targeted surveillance wells range from 32 to 65 years with a median of 50 years; overall water level changes range from -123.0 to -37.9 feet with a median of -59.8 feet, and change per year ranges from -2.8 to -0.8 feet with a median of -1.2 feet. Period of record for the one targeted trend well in El Paso County is 46 years; overall change is -59.9 feet, and change per year is -1.3 feet.

7.10 Gap Analysis

Gaps in the water level network exist, but (with the exception of the Seymour, Pecos Valley, and Hueco-Mesilla Bolsons aquifers) primarily not in terms of location and aquifer. Currently enough suitable potential surveillance wells exist in the TWDB database, but choosing the additional wells so that each of these three aquifers has a minimum of 30 will not happen until after the completion of the pilot project. Also, after recent and better coordination with the modelers in the Groundwater Resources Division of the TWDB, we have come to agree that some areas in the Gulf Coast and Carrizo-Wilcox

aquifers would benefit from a greater concentration of surveillance wells. These areas also have more suitable potential surveillance wells in our database, but we will have not incorporated them by the end of pilot report period.

The other gaps that exist in the water level network wells are monitoring site attributes—specifically, screened interval and completion data—and frequency of measurement in comparison to the ideal surveillance monitoring in aquifers with low and high hydraulic frequencies. These gaps are addressed in the data management and final gap analysis sections.

8. Water Quality Network Well Selection

8.1 TWDB Water Quality Network Design

The water quality network design is similar to that of the Texas water level network, or a hybrid that reflects the original systematic grid sampling within grids; as such, the TWDB has experienced the same challenges of monitoring in a systematic grid pattern when typically the greater amount of pumpage, resulting in a need for more wells per county-aquifer unit, is limited geographically. TWDB samples a representative number of wells by aquifer on a cyclic basis, currently once every four years, at the same well or spring as previously sampled when feasible. Unlike the water level network, however, the TWDB has few cooperators; those few use our sampling protocols and contracted lab for analysis, and their data are sent to us for electronic upload to our groundwater database along with data from samples that we collect.

Rather than define a subnetwork of water quality wells based on a premise of unstressed vs. stressed (or targeted), we considered all TWDB wells with reliable sample analyses, mainly based on that year in which our sampling protocols became more rigorous, consistent, and documented in our sampling manual (or 1988) as potential network wells, regardless of the variability of their water quality data. Generally, changes in inorganic water quality over time are not substantial or significant, and

assigning such definitions as unstressed could be misleading and confusing. Further, are analyses with naturally occurring inorganic constituents—such as arsenic, when found in excess of the Maximum Contaminant Level (MCL) as set by the TCEQ with regard to the Environmental Protection Agency guidelines—characteristic of an “unstressed” groundwater quality site; or would such values exceeding primary drinking water standards be defined as “stressed” (targeted), despite the fact that high levels are actually naturally occurring and typical of the ambient quality? Not classifying TWDB wells with ambient water quality data allowed us to avoid this possible confusion.

In addition to choosing wells sampled by the strictest protocols that the agency uses, we also chose wells with analyses with cation-anion charge balances within five percent (indicative of analysis accuracy); eliminated wells sampled in one year in which the contracted lab results were not consistently reliable; and attempted to use wells with at least two sampling events spaced six years apart (our initial sampling cycle period) after 1988, as an independent quality control of the validity of the oldest analysis (rather than as a means for determining changes in water quality). Following this approach resulted in a TWDB water quality network of 851 wells (Appendix 2), 61 of which have only one sampling event after 1988, although previous sampling events before that time.

8.2 Gulf Coast Aquifer (Coastal lowlands aquifer system)

Water quality varies in the Gulf Coast Aquifer with depth and locality. In the central and northeastern parts of the aquifer it is generally good and typically contains less than 500 milligrams per liter (mg/l) of total dissolved solids, but it declines to the south where the productivity of the aquifer decreases and where it may contain 1,000 to more than 10,000 mg/l of total dissolved solids. High levels of radionuclides, believed mainly to be naturally occurring, are found in some wells in Harris County in the outcrop and in South Texas, and arsenic is also found in excess of the primary drinking water standard of 10 mg/l in the southwestern portion of the aquifer.

The Gulf Coast water quality network consists of 230 wells (Figure 8-2) that have been sampled at least twice over at least a six-year period since 1988, ranging up to 21 years, thus indicating three or more sampling events in the last 22 years, with a median number of 12 years. In this sample population, 27 out of 230 analyses for arsenic exceeded the primary MCL of 10 mg/l (with 114 of the 230 samples below detection); and 29 of 226 analyses exceeding the primary MCL of 15 picoCuries/liter. As determined from the most recent sampling events in these 230 wells, nitrate was not found in excess of its MCL; only 2 of the 230 wells contained fluoride in excess of its MCL; and fluoride and sulfate were found in seven and 11 wells in excess of their secondary drinking water standards of 2.0 mg/l and 300 mg/l, respectively. Chloride and total dissolved solids were more frequently detected in excess of their secondary standards, 300 mg/liter and 1,000 mg/liter, in 39 and 35 wells, or approximately 17 percent of the sample population.

TWDB Water Quality Network Wells in the Gulf Coast Aquifer

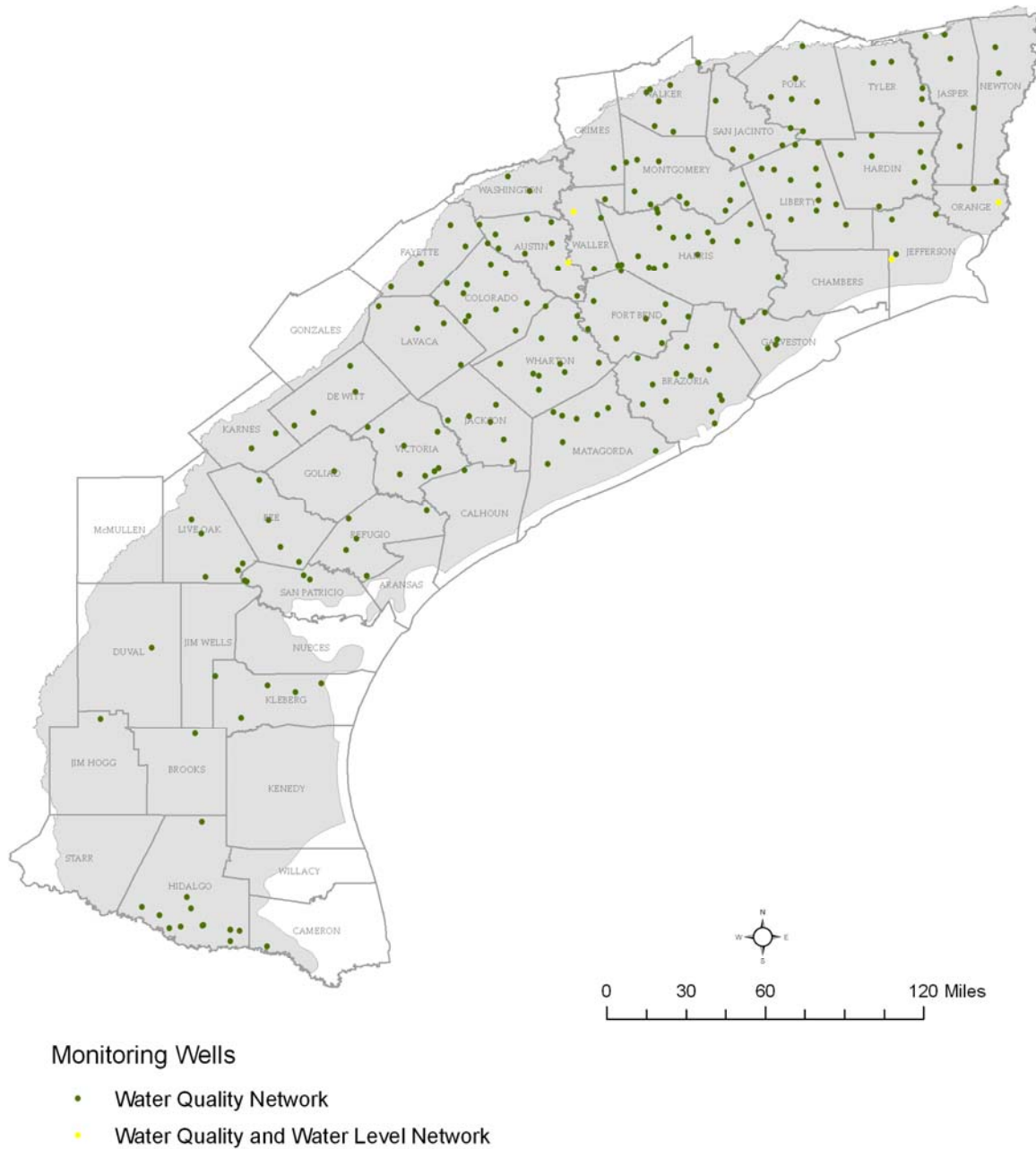


Figure 8-2. Water quality network wells in the Gulf Coast Aquifer.

8.3 Carrizo-Wilcox Aquifer (Texas coastal uplands aquifer system)

Carrizo-Wilcox groundwater, although hard, is generally fresh and typically contains less than 500 mg/l of total dissolved solids in the outcrop, whereas softer groundwater with total dissolved solids of more than 1,000 mg/l occurs in the downdip. High iron and manganese content in excess of secondary drinking water standards is characteristic in the deeper downdips portions of the aquifer, and portions of the aquifer in the Winter Garden area are slightly to moderately saline, with total dissolved solids ranging from 1,000 to 7,000 mg/l (TWDB, 2007, State Water Plan).

The Carrizo-Wilcox water quality network consists of 205 wells (Figure 8-3) that have been sampled at least twice over at least a six-year period since 1988, ranging up to 21 years, with a median number of 12 years between the earliest sampling event after 1988 and the most recent. In this sample population, only one well contained an inorganic constituent in excess of a primary standard, or fluoride, at 7.6 mg/liter; elsewhere fluoride was either below detection in 148 wells or at low values, with a median of 0.2 mg/l. The concentrations of total dissolved solids were in excess of the TCEQ determined secondary drinking water standard of 1,000 mg/l in eight wells, with a median of 366 mg/l for all samples. Iron and manganese, found below detection in 117 wells and 17 wells, exceeded secondary drinking water standards of 300 and 50 micrograms/liter in 51 and 17 wells, respectively.

TWDB Water Quality Network Wells, Carrizo-Wilcox Aquifer

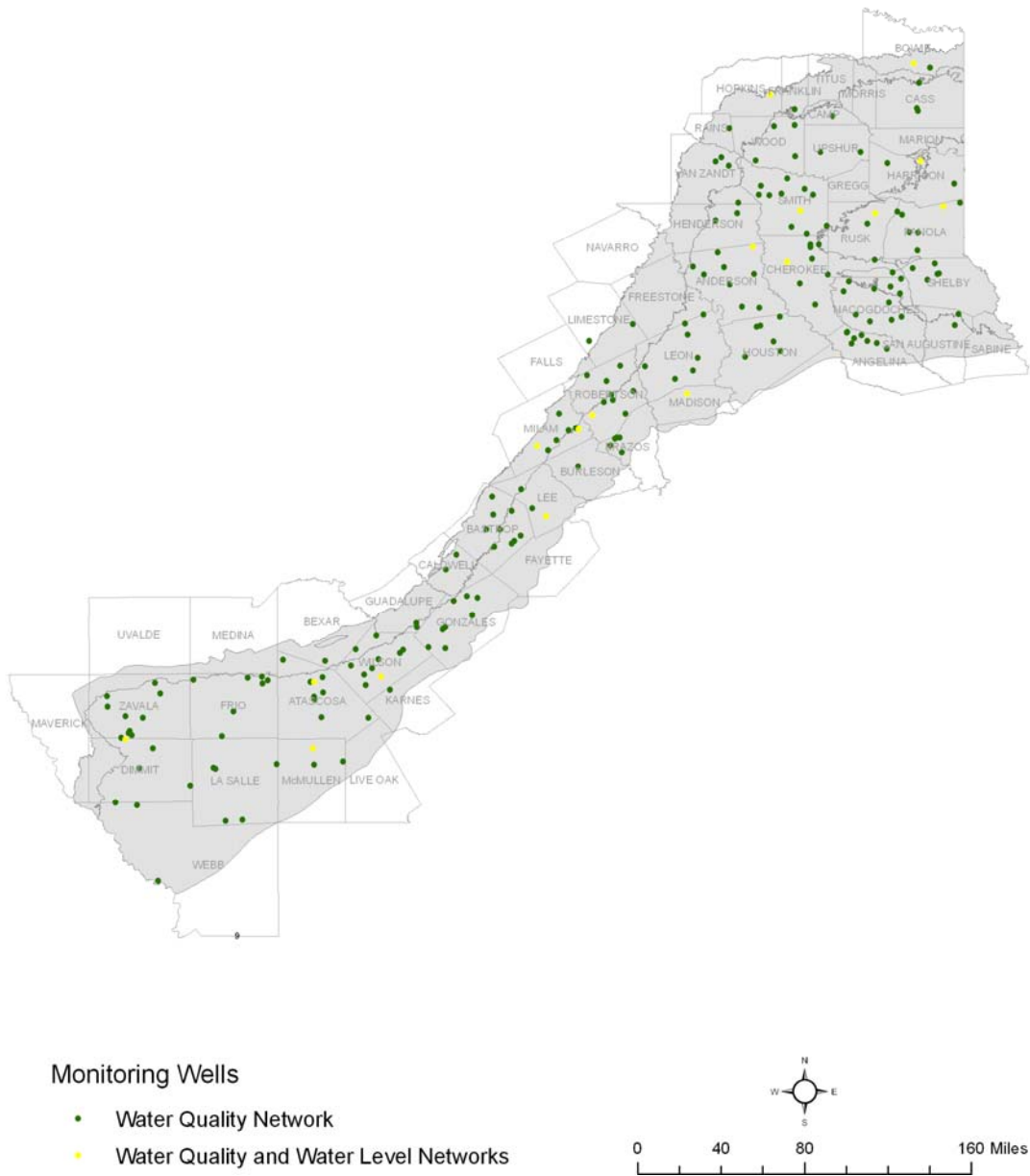


Figure 8-3. Water quality network wells in the Carrizo-Wilcox Aquifer.

8.4 Trinity, Edwards-Trinity (BFZ), and Edwards-Trinity Plateau aquifer (Edwards-Trinity aquifer system)

In the central to northern portion of the Edward-Trinity aquifer system, or the outcropping/unconfined portion of the TWDB Trinity Aquifer, groundwater is fresh but very hard. With greater depths, farther to the east and southeast in the confined portion of the Trinity Aquifer, total dissolved solids increase from below 1,000 mg/l to between 1,000 and 5,000 mg/l of total dissolved solids, or slightly to moderately saline, as do sulfate and chloride concentrations. In the thinner, crescent-shaped southeastern portion of the principal Edwards-Trinity aquifer system, or the TWDB-designated Edwards (BFZ) major aquifer, is where the best water quality in the system tends to occur. While characterized as hard, it ranges from fresh to slightly saline, with total dissolved solids ranging from 100 to 3,000 milligrams. In the Edwards-Trinity Plateau portion of the principal Edwards-Trinity Aquifer, water quality is hard, generally fresh and contains less than 500 mg/l of total dissolved solids, and salinity typically increases to the west. Elevated levels of fluoride in excess of primary drinking water standards occur within Glasscock and Irion counties (TWDB, 2007, State Water Plan).

The Edwards-Trinity aquifer system water quality network consists of 306 wells (Figure 8-4) that have been sampled at least twice over at least a six-year period since 1988, ranging up to 19 years, with a median number of 11 years between the first sampling event after 1988 and the most recent. Gross alpha, while analyzed in only 203 of the wells and not found above detection in 111 of these, was detected in excess of its primary MCL in eight of the 203 wells. Nitrate also exceeded its primary MCL in three wells of 295 wells sampled. Fluoride, detected in 45 wells above its secondary drinking water standard of 2.0 mg/l in 306 wells, was also above its primary standard of 4.0 mg/l in three of the 45 wells. Sulfate was found in 20 wells, chloride in 14, and total dissolved solids in 31 wells in excess of their secondary drinking water standards; their median values for concentrations in all wells are 55, 30, and 480 mg/l, respectively.

TWDB Water Quality Monitoring Network Wells in the Edwards-Trinity (Plateau), Edwards (BFZ), and Trinity Aquifers

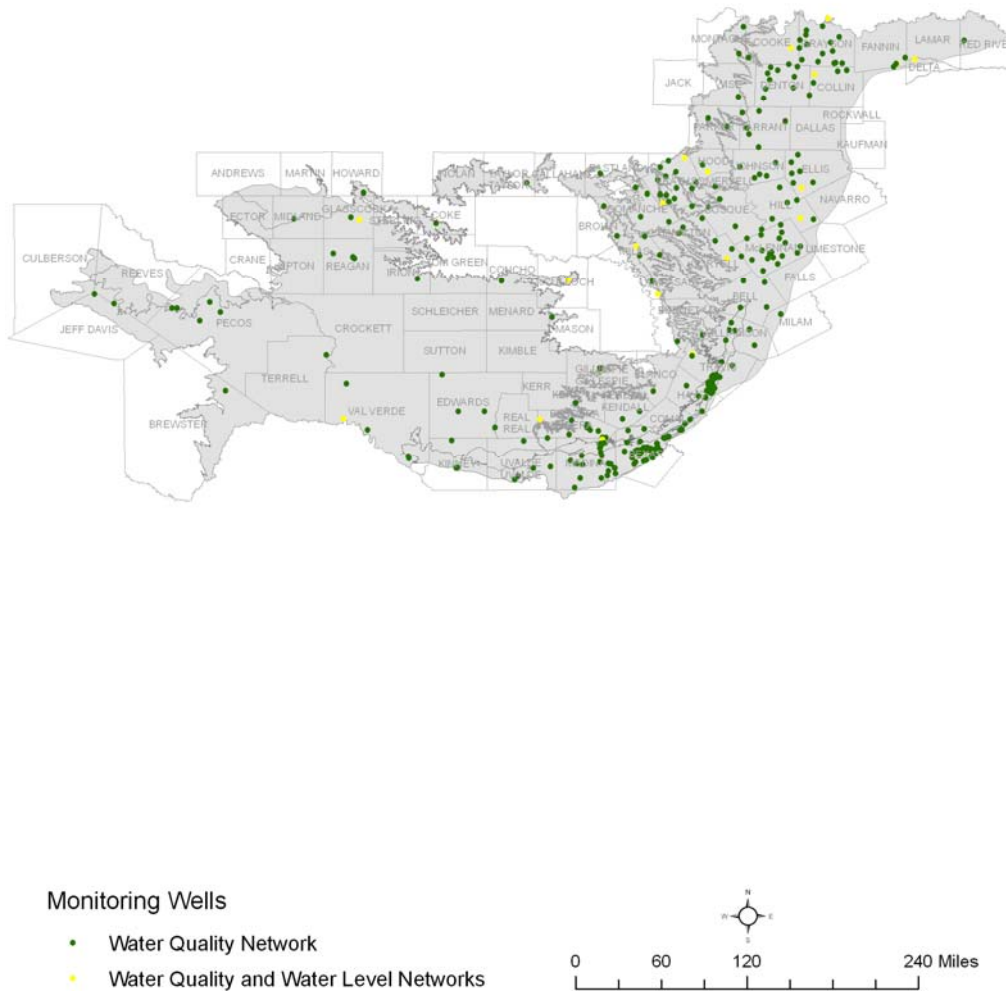


Figure 8-4. Water quality network wells in the Edwards-Trinity Aquifer.

8.5 Seymour Aquifer

Water ranges from fresh to slightly saline in the Seymour Aquifer, containing from approximately 100 to 3,000 mg/l of total dissolved solids; however, moderately to very saline water with 3,000 to more than 10,000 mg/l total dissolved solids exists in localized areas. Throughout its extent, the aquifer is affected by nitrate in excess of primary drinking water standards and chloride in excess of secondary standards (TWDB, 2007, State Water Plan).

The Seymour Aquifer water quality network consists of 45 wells (Figure 8-5) that have been sampled at least twice over at least a six-year period since before and after 1988. Initial query of the database resulted in 22 wells with multiple sampling events after 1988 in which the median number between the earliest and most recent was 11 years, with some wells sampled several times within a period of 19 years. To this group we added 23 wells first sampled before 1988 at least once, and also sampled after 1988, at least but generally only once; all of these wells were sampled by TWDB staff using similar protocols that the agency adopted after 1988. Nitrate occurred most commonly in excess of its primary MCL of 44.4 mg/liter reported as nitrate (NO^3) in 20 of the 43 wells with analyses, or nearly half; fluoride only occurred in one well sample in excess of its primary MCL of 4.0 mg/l. Fluoride was also detected above its secondary standard of 2.0 mg/l in seven wells. Sulfate was found in 16 wells, chloride in 11, and total dissolved solids in 20 wells in excess of their secondary drinking water standards; their median values for concentrations in all wells are 162, 103, and 904 mg/l, respectively.

TWDB Water Quality Network Wells in the Seymour Aquifer

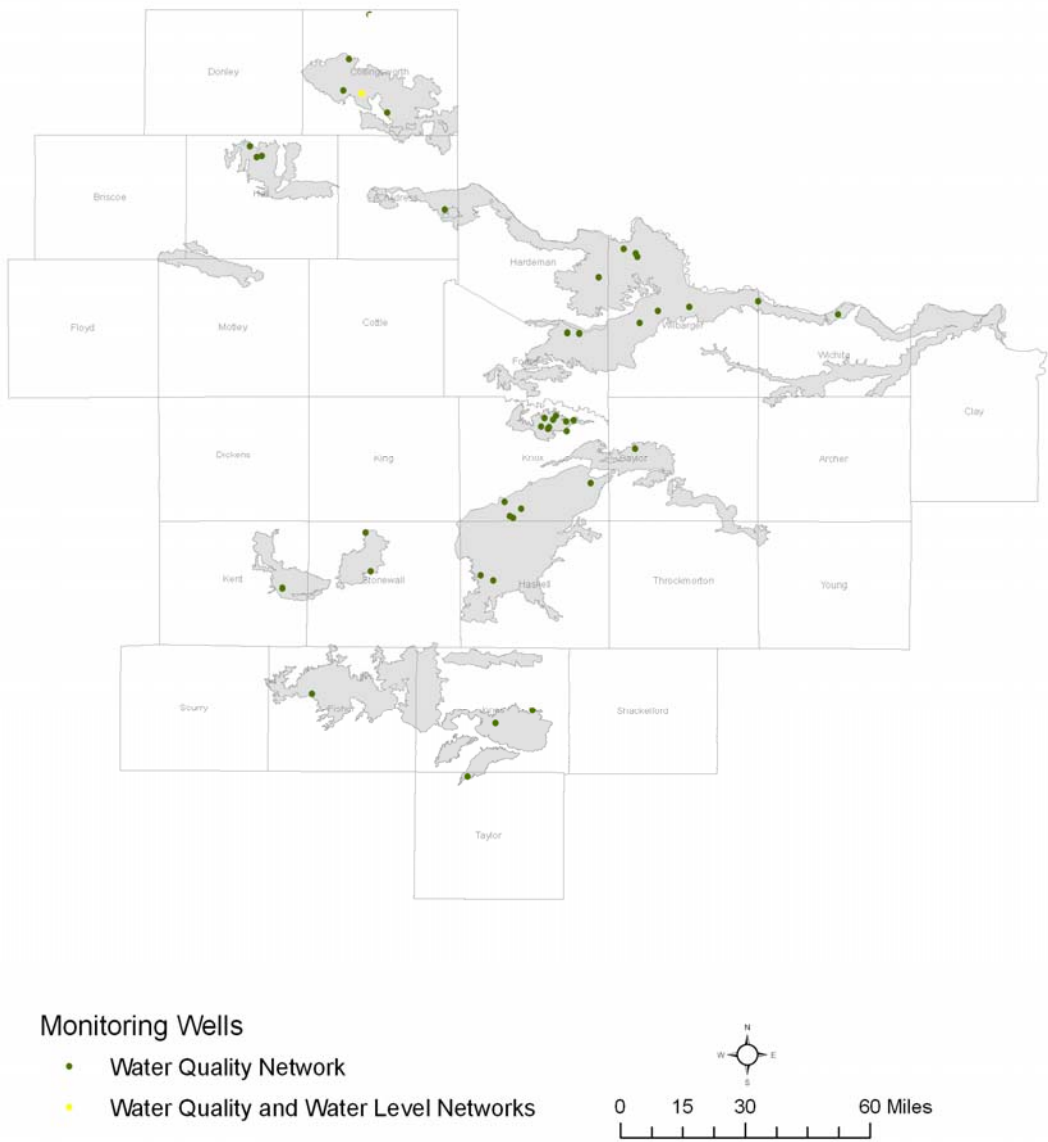


Figure 8-5. Water quality network wells in the Seymour Aquifer.

8.6 Pecos Valley Aquifer (Pecos River Basin alluvial aquifer)

Groundwater in the Pecos Valley Aquifer is highly variable, typically hard, and generally better in the Monument Draw Trough where total dissolved solids are less than 1,000 mg/l than in the Pecos Trough. Naturally occurring arsenic and radionuclides are found in some wells in excess of primary standards, and chloride and sulfate are commonly found in excess of secondary drinking water standards as a result of previous oil field activities (TWDB, 2007, State Water Plan).

The Pecos Valley Aquifer water quality network consists of 30 wells (Figure 8-6) that have been sampled at least twice over at least a six-year period since before and after 1988. Initial query of the database resulted in 18 wells with multiple sampling events after 1988 in which the median number between the earliest and most recent was 12 years, with some wells sampled several times within a period of 19 years. To this group we added 12 wells first sampled before 1988 at least once, and also sampled after 1988, at least but generally only once; all of these wells were sampled by TWDB staff using similar protocols that the agency adopted after 1988. All wells were analyzed for nitrate (NO_3^-) and arsenic, and 20 were analyzed for gross alpha; each constituent was found in excess in three wells. (One well contained excessive nitrate, arsenic, and gross alpha; a second contained excessive nitrate and gross alpha; and four other wells had only one primary standard exceedance.) Fluoride was detected above its secondary standard of 2.0 mg/l in eight wells. More than half of the wells (17) contained sulfate and total dissolved solids (18) in excess of secondary standards, with median values of 470 and 1,331 mg/l, respectively; and just over a third of the wells (12) contained chloride in excess of the secondary standard, with a median value of 230 mg/l.

TWDB Water Quality Network Wells in the Hueco-Mesilla Bolsons and Pecos Valley Aquifer

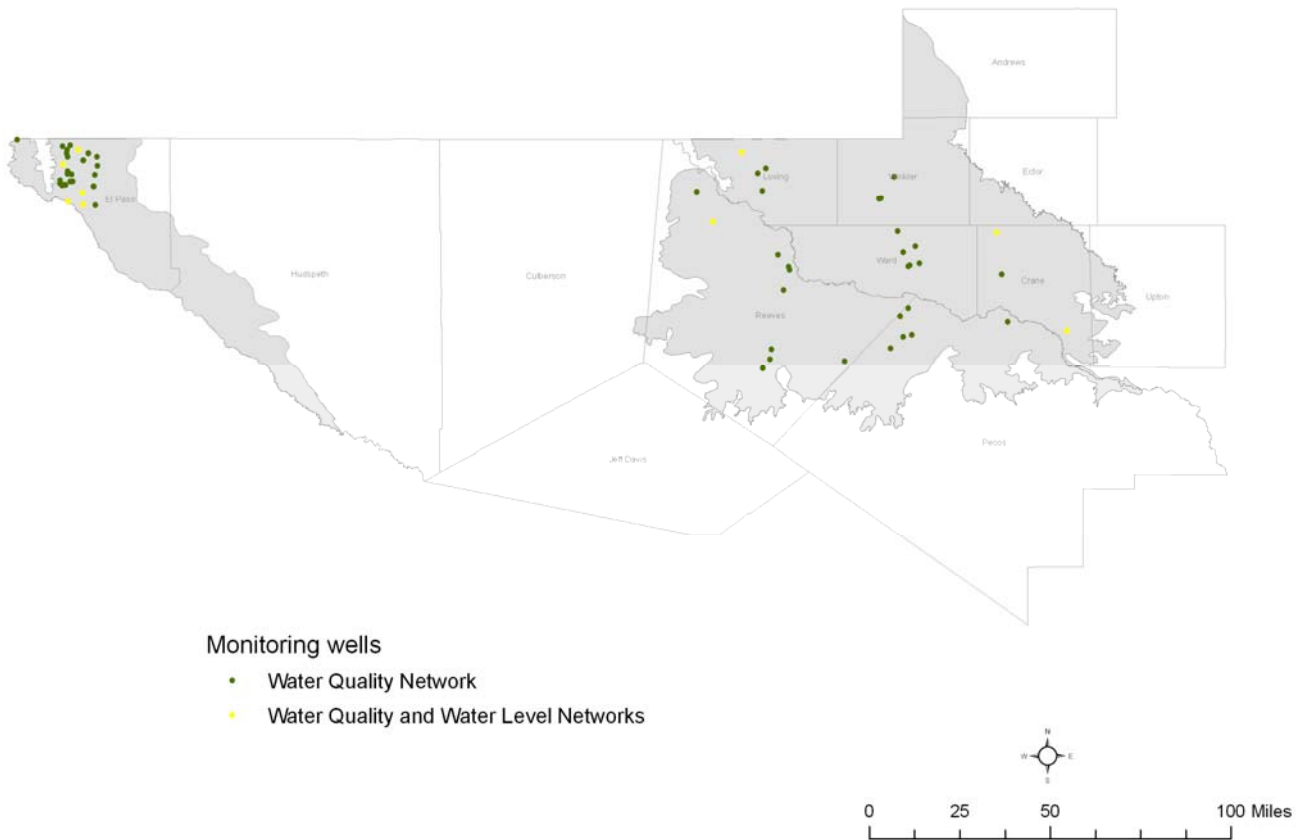


Figure 8-6. Water quality network wells in the Pecos Valley and Hueco-Mesilla Bolsons aquifers.

8.7 Hueco-Mesilla Bolsons Aquifer (Rio Grande aquifer system)

The upper portion of the Hueco Bolson contains fresh to slightly saline water, ranging from less than 1,000 to 3,000 mg/l of total dissolved solids. The Mesilla Bolson also contains fresh to saline water, ranging from less than 1,000 to 10,000 or more mg/l. Its salinity typically increases to the south and in the shallower parts of the aquifer. In both aquifers, water level declines have contributed to higher salinity (TWDB, 2007, State Water Plan).

The Hueco-Mesilla Bolsons Aquifer water quality network consists of 35 wells (Figure 8-6) that have been sampled at least twice over at least a six-year period since before and after 1988. Initial query of the database resulted in 9 wells with multiple sampling events after 1988 in which the median number between the earliest and most recent was 10 years. To this group we added 26 wells first sampled before 1988 using similar sampling protocols as those used by the agency after 1988. Nitrate, with a median of 6.6 mg/l, was not found in excess in any wells; fluoride, with a median of 0.7 mg/l, occurred in excess of its primary drinking water standard in one well. Chloride, with a median of 130 mg/l, was in excess of secondary standards in eight wells; sulfate, with a median of 81 mg/l, was in excess of secondary standards in two wells; total dissolved solids, with a median of 511 mg/l, exceeded its secondary standard in seven wells.

8.8 TCEQ Water Quality Subnetwork Wells

More than 20,000 wells are considered part of TCEQ's public drinking water program, of which nearly 14,000 are active. This program oversees the collection of water quality data that is site-specific, regulatory, and requires sampling of treated ("finished") water at points of entry into the distribution system. However, untreated or "raw" samples are collected at approximately 700 of these wells in small systems where one well provides the sole source of water. Typically, TCEQ requires analysis of the same inorganic constituents that are analyzed in the TWDB program in addition to bacteria and many volatile organic compounds, including chlorination disinfection byproducts. Sampling requirements, including frequency, depend on the number of constituents found in excess of their primary MCLs.

Whereas the TCEQ requires analysis of predominantly the same inorganic suite of constituents that the TWDB does, the value of including some of the water quality data in the NGWMN that must be provided to TCEQ is to include sampling sites with an expanded suite of constituents that are almost

exclusively introduced into groundwater through anthropogenic rather than natural means. These constituents include benzene, toluene, ethylbenzene, xylene, and other compounds that are considered petroleum hydrocarbons. Dense non-aqueous phase liquids, such as tetrachloroethylene, vinyl chloride, and carbon tetrachloride, that might be present as contaminants from dry-cleaning solvents, degreasers, and cleaners, are also part of the suite of analytes.

The majority of the ~700 wells with this type of information are not yet assigned a TWDB identification number; the TCEQ is not required to assign them to their public supply wells, although the two agencies are working together to complete this task. Currently 65 public supply wells in the study area also have TWDB identification (a prerequisite for inclusion in the TWDB database), but in only a few counties (Figure 8-8). TWDB intends to assign the additional wells identification numbers and add wells to this subnetwork, although will this task will not be completed before the end of the pilot project.

8.9 Gap analysis

As with the water level network, gaps that exist in the TWDB water quality network are primarily related to monitoring site attributes such as well completion data for some of the wells, and monitoring frequency. The TWDB's work with and receipt of data from TCEQ public supply wells is an ongoing project, in part facilitated by the pilot project and by work that will be completed by TWDB's 2010-2011 contract with its outside vendor to study anthropogenic effects on water quality. The gap analysis on these wells is incomplete at the conclusion of the pilot project.

TCEQ Water Quality Subnetwork Wells

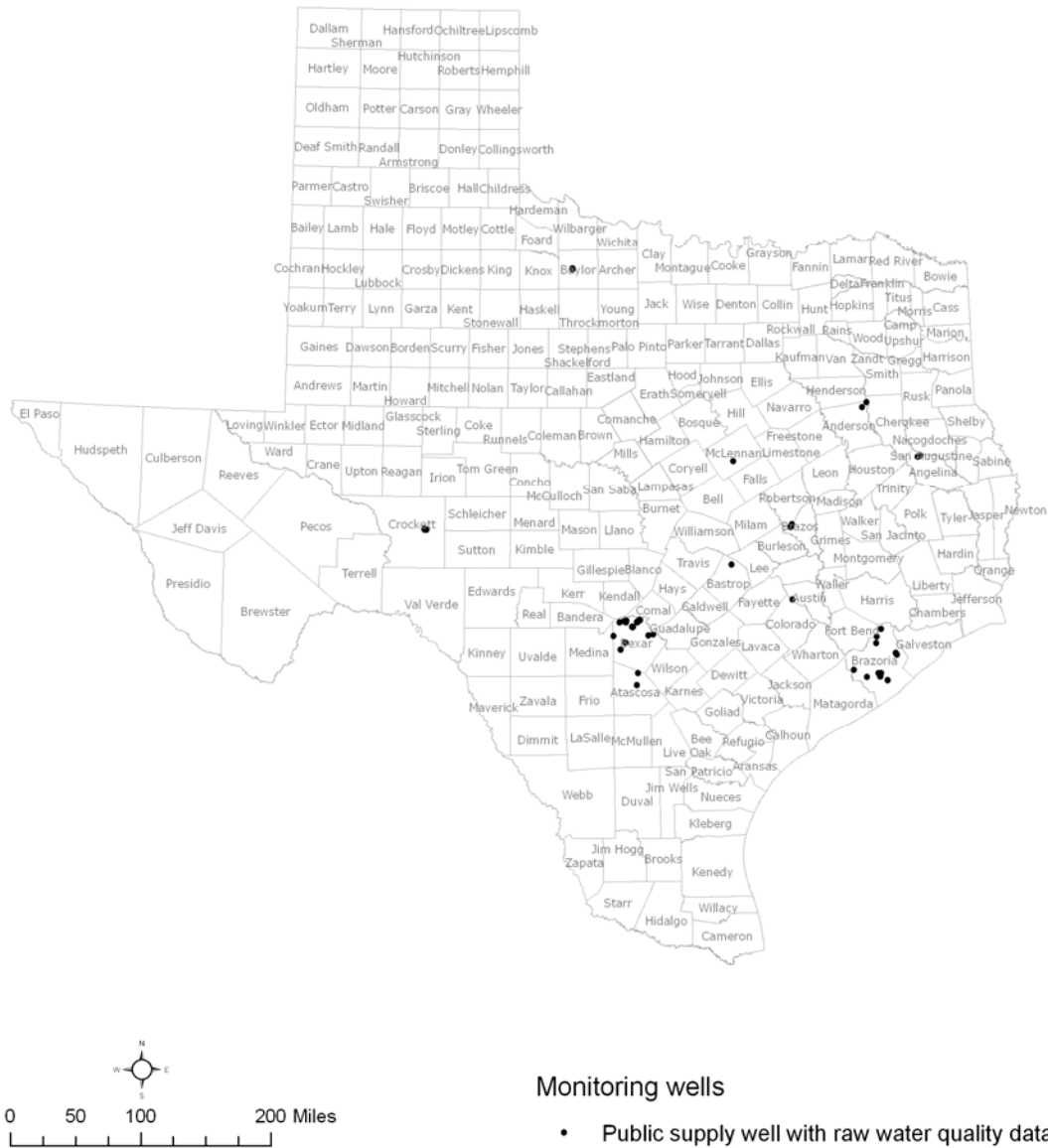


Figure 8-8. Public water supply (TCEQ) water quality subnetwork wells.

9. Field Practices

9.1 Groundwater Level Field Practices

An overview of the agency's water level monitoring program, *Explanation of the Texas Water Development Board Ground-Water Level Monitoring Program and Water-Level Measuring Manual* (<http://www.twdb.state.tx.us/publications/manuals/UM-52/Um-52.pdf>), in the process of being updated, includes a discussion on measuring wells in Texas, different equipment, and the relative merits of using one type of equipment over another in different aquifer systems. Internal work process documents provide greater detail on pre-visit verifications, onsite preparations, measuring procedures, and data entry. The updated water level measuring manual will shift its focus to field practices rather than a program overview and will also address minimum data standards and data handling and management.

The TWDB also recently produced a recorder manual; however, this document is only used internally, primarily to train new staff. It provides photos of and specifications for equipment, specific steps for programming, and troubleshooting guides for sensors, loggers, and transmitters. The water level measuring manual will refer to minimum data standards and data handling and management also for recorder sites in its forthcoming revision.

9.2 Groundwater Quality Field Practices

TWDB follows procedures discussed in its *Field Manual for Groundwater Sampling* (<http://www.twdb.state.tx.us/publications/manuals/UM-51/FieldManual.pdf>), a document in which sampling protocols are described in detail and programmatic goals are not included. Work process documents used by TWDB field staff also address sampling, but primarily refer to the specific steps included in the sampling manual. The agency's sampling program is focused on the collection of inorganic data, some isotopes, and a few nutrients. TWDB's water quality sampling procedures are

relatively rigorous, but they are not considered as strict as those used by the USGS, in part due to the non-regulatory nature of the TWDB; and data are not necessarily legally defensible or admitted in cases involving anthropogenic contamination cases.

9.3 Comparison to Framework Document

One of the main differences between TWDB data collection practices and those recommended in Appendix 5 of the framework document is that TWDB and its cooperators do not decontaminate equipment during water level measuring. Our water quality sampling protocols, although not as strict as those followed by the USGS in its sampling routines, do include equipment decontamination. The TWDB has no human health concerns from groundwater contamination during water level measuring; furthermore, a significant percentage, or 34 percent of sites measured are unused; water from an additional 43 percent is for stock or irrigation; and the remaining household or public supply wells treat water for human consumption at some point in the system after measuring.

In addressing any concern for accuracy of water quality data due to possible contamination of samples from one site to the next, the goals of our sampling program and the uses of our data are not such that we require accuracy to the parts per billion level in analyzing for a predominantly inorganic suite of constituents. We avoid wells located in anthropogenically contaminated areas. Our data are not intended to be used in regulatory settings, and we are not a regulatory agency. Where we do sample in areas of natural contamination, concentrations of contaminants are great enough that contamination from any residuals on the tapes are of no significant consequence. However, addition of this decontamination step to our sampling and measuring procedures would result in a relatively minimal cost increase, as discussed in the gap analysis summary.

10. Data Management System

10.1 TWDB Data Management

The TWDB groundwater database is a relational database on a Microsoft Sequel Platform with a Microsoft Access interface. The TWDB database structure was originally modeled after the USGS' system in the 1970s, and the databases still contain many of the same elements. Since that time, the two agencies have made modifications, although they are usually not the same. Generally speaking, TWDB's system is somewhat simpler.

A number of different entities outside the agency use the agency's data for planning and research. The TWDB data dictionary and the User's Manual 50—*Explanation of the Groundwater Database and Database Entry*—contain data elements for site location, level, and quality data organized in 10 tables and 30 lookup tables, including data elements for well construction, monitoring location and time, sample and measuring results, and quality control. Descriptions of the data can be found in the data dictionary (Appendix 3) and in the User's Manual at

<http://www.twdb.state.tx.us/publications/manuals/UM50%20Data%20Dictionary/um50.pdf>.

The TWDB database is publicly accessible through a number of online avenues: a Microsoft Access version of the complete database, text files of key database tables, by county, and a mapping application using ESRI software. The agency will initiate the restructuring of the database in 2011 and begin providing Web Services; currently, however, the TWDB must coordinate with the state's Department of Information Resources which operates an information technology contract with an outside vendor.

10.2 Comparison to Framework Document and Gap Analysis

The TWDB database presently lacks several fields listed as minimum in Appendix 6 of the framework document, the most important being the unique identifier of a well as part of the NGWMN; our database also does not have a field for the principal aquifer, only the state identified major or minor and local identifier named in the aquifer code. Other fields of data for which the TWDB may have information (for example, in field books or other databases) include certain metadata for point of contact (addresses); geologic/hydrologic descriptions (aquifer conditions: confined, unconfined, leaky confined); well description (horizontal and vertical datum references, well and owner addresses, time zone); measurement sampling event (measurement time, site use); and water quality results (analytical method number) are not in the TWDB groundwater database, as none are referring to purpose of monitoring to fit into suggested NGWMN classifications (baseline, surveillance, trend, special, targeted, or unstressed).

Along with the metadata described above that are not in the TWDB groundwater database, the agency has not yet developed Web Services for any groundwater data for other projects.

11. Summary of Gap Analyses

Overall, well coverage gaps are not substantive, although we have not completed a thorough evaluation as of the end of the pilot project. (As discussed, suitable wells are available to adhere to suggested minimum coverage in the water level network, and we are in the process of including TCEQ information in our database before we identify coverage gaps.) Frequency of measurement, primarily for the water level surveillance wells, is the most significant gap. For the 231 surveillance sites in low recharge areas experiencing moderate withdrawals, 693 more visits (quarterly) would be required as

prescribed by the framework document; for the remaining 137 sites in high recharge areas (and/or a combination of other factors), we estimate 1,507 more measurements. Gaps in the frequency of sampling gaps exist to some lesser degree, but are not estimated at the time of this report.

Field practice standard gaps exist and are also minimal, involving only lack of decontamination of steel measuring tapes and collection of measurement time and land use at the measuring or sampling sites. Data management gaps mainly involve the database's lack of fields in all seven categories described in Appendix 6 of the framework document (most crucially the unique identifier for any well chosen as a NGWMN well, should or when the network materializes) and development of web services to facilitate data transfer to the portal.

12. Proposed Changes to the Framework Document

The only substantive change we suggest is in the deletion of the designation of targeted and unstressed. The initial exercise of determining this difference to choose water level subnetwork wells was enlightening. Unfortunately, however, the terms are inappropriate in the context of a database entry and should be interpreted in objective driven studies of groundwater conditions, groundwater availability and groundwater sustainability. Inclusion in a monitoring database (national or local) is inappropriate for the following reasons: 1) the intended definitions could be misread and misunderstood and/or 2) their definitions are being understood but disagreed with; this latter is especially problematic if any data users perceive that the data providers are cherry-picking facts or are attaching them to agendas. This classification was also problematic in choosing wells for the water quality subnetwork, in part for the same reason; what amount or percentage of change would have to occur, at what thresholds, over what period, and in how many analytes to justify a straightforward description of change? As discussed in the following section, “targeted” could be used as a synonym for “special.” The TWDB has taken that

approach by designating water quality data with “extended lists” of analytes (as described in the framework document) from the TCEQ as the targeted or special subnetwork.

13. Benefits of the Network

The TWDB’s mission, “to provide sustainable, affordable, and quality water for Texans, our economy, and our environment,” is embodied in its lead role in state water planning and provision of financial aid to communities for water and wastewater infrastructure projects. Participation in this network would promote an even more efficient means of displaying, choosing, transferring, and using data for the agency’s planning mission on which financial aid ultimately depends. Groundwater conservation districts, groundwater management areas, and regional water planning groups would greatly benefit from the convenience of using more than the current real-time recorder well data; to summon the most recently updated hydrographs in nearly three times as many representative water level surveillance wells would fill in gaps where more expensive trend wells do not exist. Such data availability would facilitate planning groups’ informed participation in the legislatively mandated Desired Future Conditions process.

Another benefit to the state that has been long discussed by the Texas Groundwater Protection Committee is the incorporation of public well supply data in one portal with the TWDB’s ambient inorganic water quality data. These public supply data have been collectively referred to as a potential “targeted” addition to the ambient groundwater quality monitoring, with targeted in this instance referring to a different set of constituents that are primarily analyzed to capture a more accurate understanding of anthropogenic influence, including contamination, on the naturally occurring groundwater quality.

From a national and hydrogeological standpoint, few aquifers throughout the country stop at state borders. To view well locations quickly, in relation to network sites in surrounding states, would also ultimately benefit Texans and their neighbors. Whether drilling down to a local level or moving

farther out in order to focus on the bigger picture, this network could be an incredible vehicle for all groundwater data users at local, regional, and national levels.

A last benefit from having participated in the pilot project, specifically for the TWDB, is that the agency's monitoring section has had to scrutinize all practices in its monitoring program and all elements in its database. The timing of the project has been nearly perfect, considering the imminent groundwater database restructuring, ultimately to result in more complete and more readily available data to the public.

14. Cost Estimates

14.1 Cost to participate in the NGWMN pilot project

We estimate TWDB staff worked a total of 895 hours on the project, primarily by the three authors, but also by other staff members in the Groundwater Resources Division. Adding an overhead of 20 percent, the cost to TWDB was \$36,275.

14.2 Cost to Operate and Manage NGWMN Wells

TWDB's cost to operate its annual water level observation is approximately \$178,670. TWDB collects nearly 2,000 wells at a cost per well of almost \$89; operation of the 368 network surveillance wells would be \$32,875. TWDB's cost to operate its recorder programs is \$173,170; with operation of 150 online recorder wells at \$1,155 a site, operation of the 57 network trend wells would total \$65,800. TWDB's cost to operate its water quality sampling program with collection of 800 samples a year is nearly \$370,000, not including \$300,000 for sample analysis (including analysis costs for an "extended" list of constituents and isotopes). More than 80 percent of the wells TWDB samples each year are now repeat visits; thus a total of \$670,000 a year is considered the cost to operate the water quality network

14.3 Cost to Implement the Changes Identified in the Gap Analysis

Overall, total costs to adhere to suggested practices and standards as outlined in the framework document are nearly \$154,000 (Table 14-3) for one-time costs, and nearly \$85,000 for yearly operation and maintenance costs. By category, including capital costs (CC) and operation and maintenance (O&M):

\$131,950	(CC) – determining completion data through borehole video
\$100/yr.	(O&M) – modifying field practices
\$20,000	(CC) – programming Web Services for data transfer to portal
\$78,250/yr.	(O&M) – implementing greater monitoring frequencies (water level network)
\$1,800	(CC) – class cost for Web Services programming

Table 14.3 Summary of costs to implement changes identified in the gap analysis.

NGWMN Pilot Program Element	Incremental changes needed to meet network guidelines	Estimated Capital Costs	Estimated O&M costs
Spatial gaps: *3-D spatial “gaps” in well metadata (completion/ screened interval data) only; no location gaps *TCEQ subnetwork water quality wells	*Video boreholes of 111 surveillance and 5 trend (recorder) wells currently lacking completion data *Assignment of TWDB state well numbers to ~600 public supply wells	*\$131,950 (does not include \$10,000 cost of camera TWDB bought in 2010) *No capital costs involved	*Undetermined *None (public supply well inventory part of ongoing staff job)
Field Practice Gaps: *no decontamination with sodium hypochlorite *no recording of measurement time , weather, or land use	*Purchase of cleaner and wipes and use on steel tapes during water level measuring at all network sites. *Recording of time, weather, & land use.	*No capital costs involved	*\$100/year (cost of cleaner & wipes)
Data Management Gaps: *Addition of several fields, primarily unique identifier for NGWMN wells, but also contact information, and to facilitate transmission of data to the portal	*Database restructuring. TWDB currently initiating this project in 2011, with input from the pilot project *Web Services programming	*NA (does not include already planned purchase of 64-bit boxes for ESRI upgrade and temporary placement of gw data environment in cloud) * \$20,000 (based on two months cost from similar contract with outside vendor for TWDB Surface Water CUASHI project)	*Undetermined— (some portion of overall gw database maintenance) *Undetermined (or none, unless more programming is necessary)
Temporal Gaps: *Measurement frequency in water level surveillance wells	*More measurements needed per quarter or month, based on aquifer recharge rates and relative pumping		*78,250/year for more frequent surveillance well measuring
Analyte Gaps: Currently NA for TWDB Water Level Network; Further discussion necessary with TCEQ public drinking water supply program to determine gaps in that program			
Other Gaps: Additional database management associated with Web Services and maintenance of data elements for NGWMN wells, Web Services	Possible Web Services classes; documentation of different activities associated with maintenance of NGWMN data in a work process document	\$1800 class tuition fee; Salary associated with class time and producing documentation	8 hours/month X salary X overhead

15. Acknowledgements

Thanks to our managers Bill Hutchison and Robert Mace (Director of the agency's Groundwater Resources Division and Deputy Executive Administrator for Water, Science, and Conservation), our participation in this project was made possible. Radu Boghici created too many versions of maps to count: for teleconferences, the conference in Austin, and final report illustration; in addition to performing much tabulation, along with Bryan Anderson. Bryan was also instrumental in understanding the nuances of data portal transfer issues and other issues. Many thanks to all the other TWDB staff we pulled in for certain tasks or discussions: those in the TWDB Monitoring Sections, including Andy Finnell—creator of over 1,500 hydrographs—and Chris Muller and Seth Johnson for other basic data tabulations; Dharhas Pothina and Ruben Solis (Director of the Surface Water Division and lead TWDB liaison with the CUASHI contract, respectively), for consultations with USGS portal people during and after the Austin conference; TWDB's Information Technology Division, especially Lisa Petoskey (Director) and Kevin Dahl (programmer), for discussion of Web Services programming; and Cindy Ridgeway and Ali Chowdhury (Director of and modeler in the modeling section in the Groundwater Resources Division) for their discussions about the water level and quality networks.

Outside of the agency, we have other helpful folks to acknowledge. Many thanks to Murray Freeman of Wi-Fi Texas, for installation of free Wi-Fi in the meeting room during the Austin conference. We greatly appreciate field trip speakers Chock Woodruff (independent consultant); David Johns (City of Austin); and Brian Smith (Barton Springs Edwards Aquifer Conservation District) for their explanations of our area's interesting hydrogeological features. Also, Lynne Fahlquist (USGS, Austin) graciously agreed to edit one section; and may have more suggested edits (for our consideration) for the entire document, if she really does want to engage with it over the holidays (as offered)!

16. References Cited

Water for Texas 2007: 2007 Texas Water Development Board, Austin, TX.

TWDB Water Use Survey, <http://www.twdb.state.tx.us/wuhistorical/DesktopDefault.aspx?PageID=2>.

2003 Texas Water Development Board, Austin, TX.

UM-50, Ground-Water Data System Dictionary. 2008 (rev.) Texas Water Development Board publication, Austin, TX.

UM-51, A Field Manual for Ground Water Sampling. 2003 Texas Water Development Board publication, Austin, TX.

UM-52, Explanation of the Texas Water Development Board Ground-Water Level Monitoring Program and Water-Level Measuring Manual. 1994 Texas Water Development Board publication, Austin, TX.
—1998 Report, U.S. Environmental Protection Agency Report EPA-841-F-00-006, Washington D.C.

17. Appendices

(Attached as Excel documents)