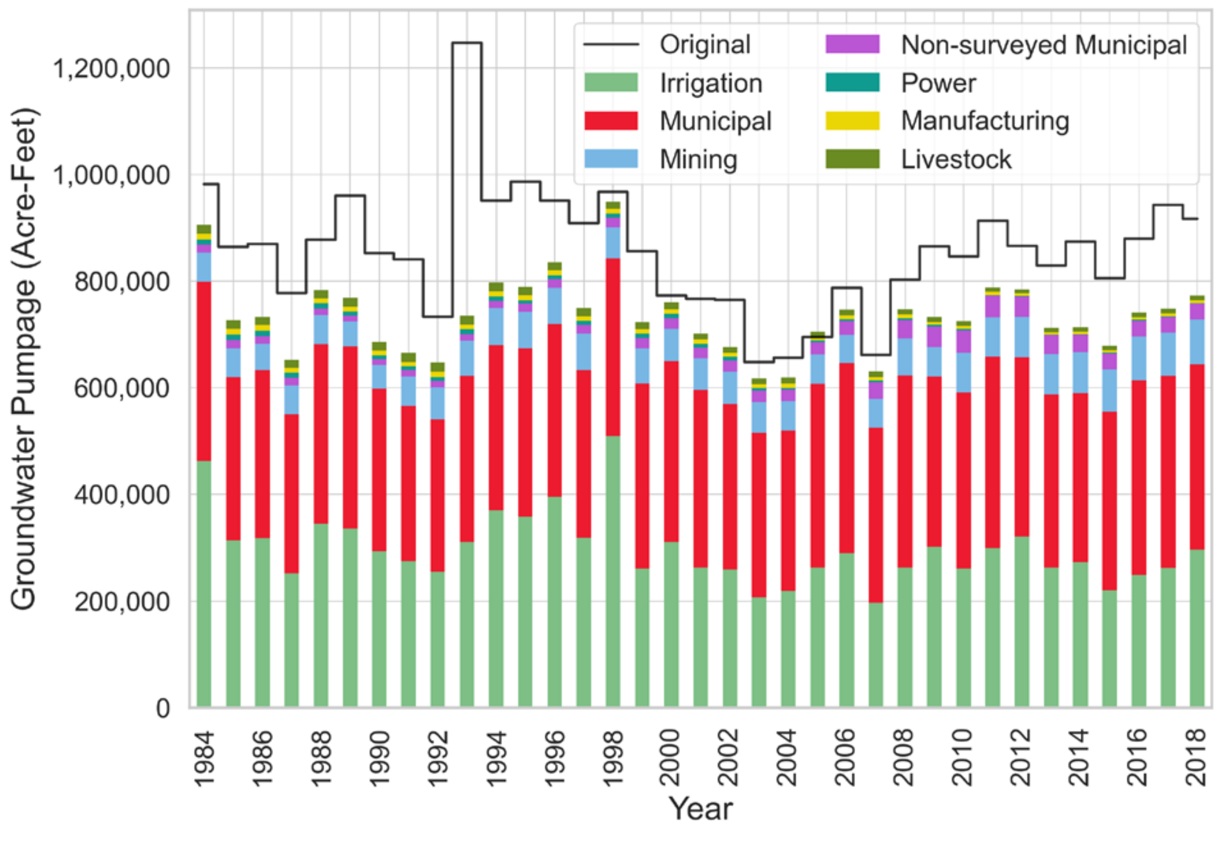
TWDB Contract No. 2048302456
Final Report Received:
February 28, 2022

FINAL

Estimation of Groundwater Pumping Volumes, Locations, and Aquifers for West Texas



Prepared for

Texas Water Development Board
Contract Number 2048302456

February 28, 2022

This page is intentionally blank.

Final Report:

Estimation of Groundwater Pumping Volumes, Locations, and Aquifers for West Texas

TWDB Contract Number 2048302456

Prepared By

Jordan Furnans, Ph.D., PE, PG
Michael Keester, PG
Micaela Pedrazas, EIT, GIT
Stephanie S. Wong, Ph.D.
Tucker Fullmer
LRE Water, LLC

Rohit Goswami, Ph.D., PE
Uvashree Janani Mohandass, EIT
WSP USA

Michael Thornhill, PG
Eric Seeger, PG
Thornhill Group, Inc.

Michelle Sutherland, PE
Michelle A. Sutherland, LLC

This page is intentionally blank.

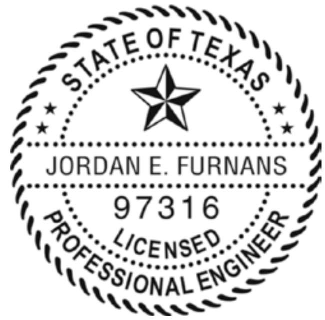
Geoscientist and Engineer Seals

The Texas Water Development Board contracted with LRE Water, LLC, a licensed professional geoscientist firm (Texas License No. 50516) and licensed professional engineering firm (Texas License No. 14368).

This draft report is released to the Texas Water Development Board for review by the following licensed professional geoscientists and licensed professional engineers in the State of Texas:

Jordan Furnans, PhD, PE, PG

Dr. Furnans was the Project Manager for this work, with responsibility for all project tasks.



Signature 2/28/2022 Date

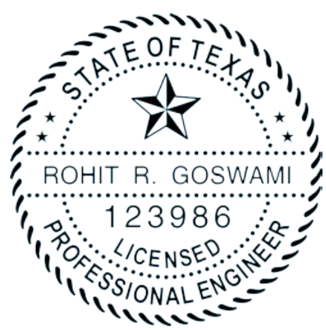
Michael Keester, PG

Mr. Keester was primarily responsible for directing compilation of available data, evaluation of the TWDB Water Use Survey pumping data, and development of a plan to address anomalies in the Water Use Survey data. He was the primary author of the draft Task 1 and Task 2 reports which were the basis for the report sections on these topics.

Signature 2/28/2022 Date

Rohit Goswami, PhD, PE

Dr. Goswami led the WSP, Inc. team in completing the mining assessment effort, and assisted in developing the municipal-surveyed assessments.



Signature 2/28/2022 Date

Table of Contents

Table of Figures

Table of Tables

1 Introduction

An important task of the Texas Water Development Board (TWDB) is the development of numerical groundwater flow models of the major and minor aquifers in Texas. Within these numerical flow models, groundwater production is often an important transient stress on the modeled system and on the calibration of other model parameters. In fact, as shown by Kelley and others (2014), the transient calibration of these numerical groundwater flow models can be highly sensitive to the input pumping rates. Having the most accurate numerical models of the major and minor aquifers is vital to help conservation districts during joint planning as the districts must consider results from the models during development of desired future conditions (Texas Water Code 36.108). Once districts adopt desired future conditions for their managed aquifers, the TWDB then typically utilizes the applicable numerical model to quantify the amount of modeled available groundwater. With the importance of accurate and well-calibrated numerical models, having reasonably accurate estimates of pumping locations, amounts, and timing is essential. It is also essential that these estimates are based on a consistent and defensible process to estimate groundwater pumping. Only with reasonably accurate pumping data can Texans be assured their groundwater availability models are appropriately determining future groundwater availability.

This project involved developing estimates of the volume, location, and timing of groundwater pumpage from the Pecos Valley Aquifer, Edwards-Trinity (Plateau) Aquifer, Trinity (Hill Country) Aquifer, Lipan Aquifer, and Edwards (Balcones Fault Zone) Aquifer (located south of the Colorado River). The study area for this project includes portions of 56 counties (Figure 1), 35 conservation districts (Figure 2), eight groundwater management areas (Figure 3), and five regional water planning areas (Figure 4). One major source of the pumping information is the TWDB Water Use Survey program. This program, initiated in 1955, strives to develop estimates of surface water and groundwater use across the state. Methods used to achieve this objective have evolved over time which can lead to inconsistencies in the resulting datasets. For groundwater pumping, changes in the methodology for determining annual volume used or from which aquifer the estimated use occurred have likely resulted in inconsistent pumping estimates for this project study area and for other areas within Texas. Along with methodology changes, other factors certainly contributed to inconsistencies and fluctuations in the pumping data. Such other factors could include variability in weather patterns, precipitation, and economic drivers (for example crop prices or oil prices). During this project we attempted to understand how such factors may be incorporated in defined processes for estimating pumpage datasets.

The first goal of this project, which is documented in Section 3 of this report, was to develop an automated process to evaluate the TWDB Water Use Survey data from at least 1984 through 2018 and identify missing data or inconsistencies. Following evaluation of the data, the next phase of the project involved development of a plan to address the identified inconsistencies using automated methods and through gathering of additional data from public sources. This plan is included in Section 4 of this report. The final project phase involved preparation of a revised pumpage dataset, and the development of a toolset to seamlessly allow incorporation of the revised data into numerical groundwater flow models using MODFLOW well package. An overall objective of the project was that the processes developed and applied for our study area could be replicated and applied to other study areas in support of other modeling projects undertaken within the TWDB Groundwater Availability Modeling Program.

This report provides our complete set of project deliverables, including 1) our evaluation of the Water Use Survey data from 1984 through 2018 for each county, aquifer, and use, 2) our methodology for revising the Water Use Survey data, 3) a description of the revised data, and 4) a description of the toolbox created for converting the revised pumpage data into a groundwater model MODFLOW well package. All data, computer programs, and program documentation has been provided to TWDB in electronic format on an external hard drive accompanying this report.

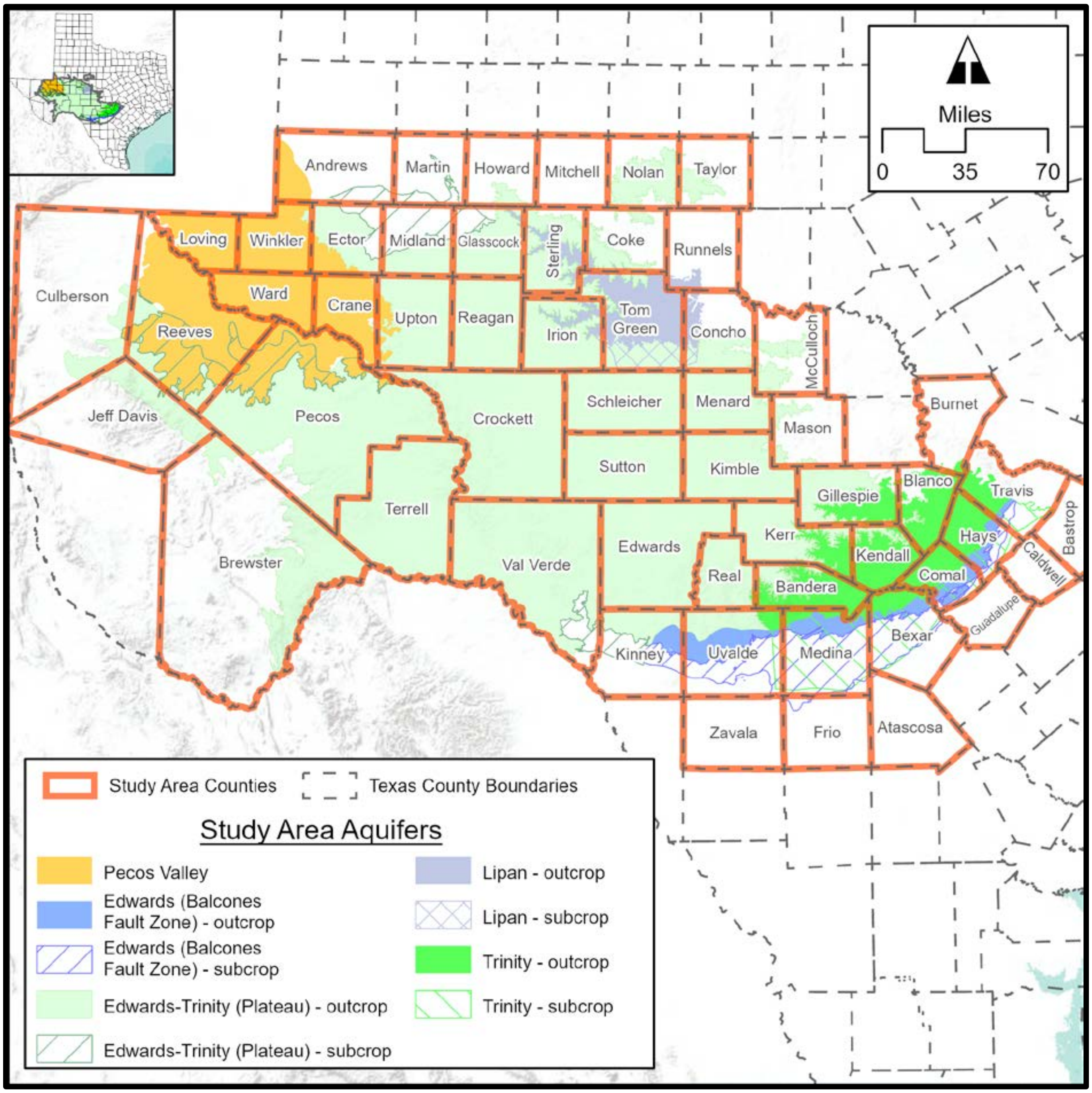


Figure 1. **Study area map illustrating the counties and aquifers included as part of this project. County and aquifer geographic information system files from TWDB (2021).**

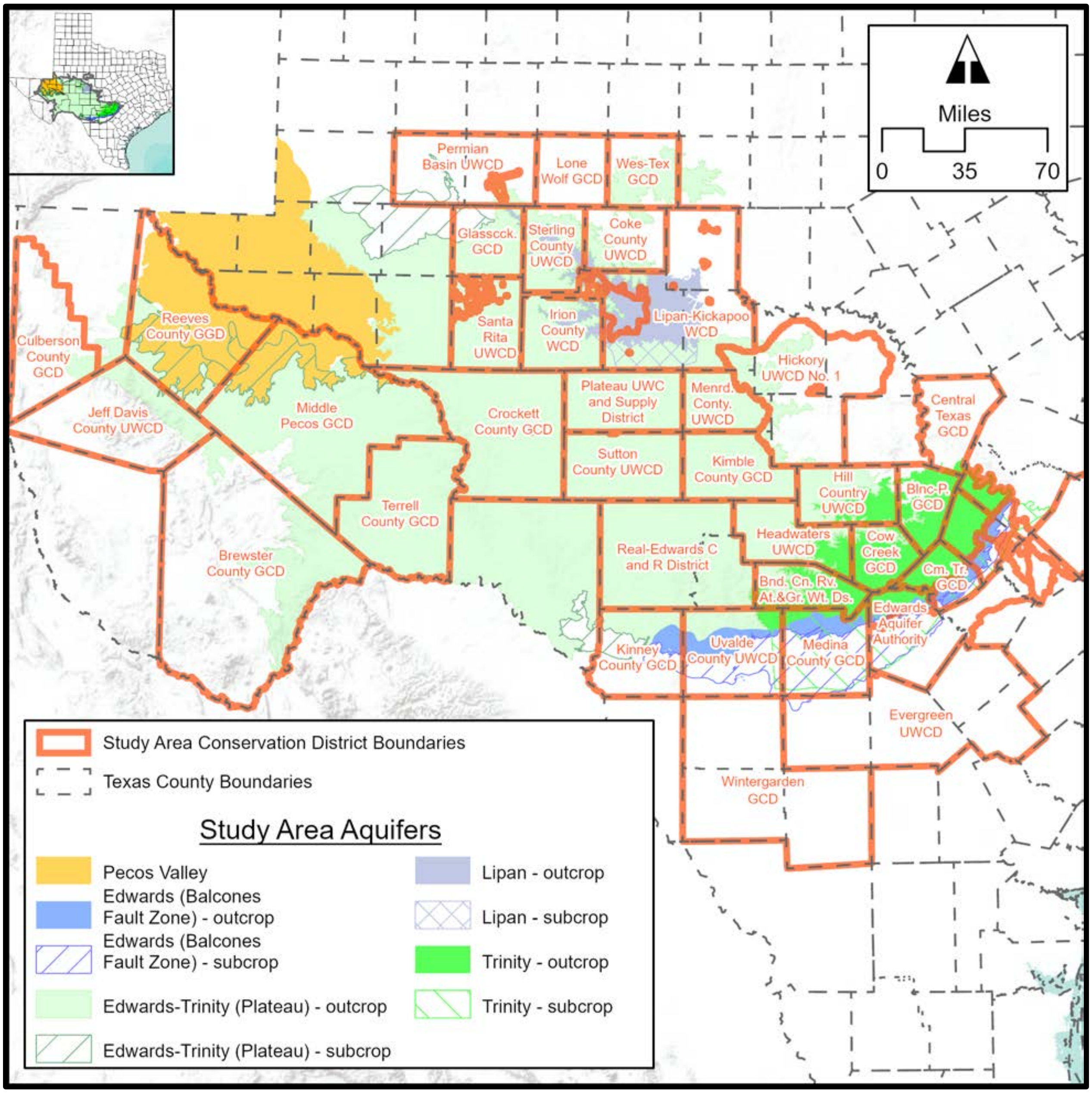


Figure 2. **Study area map illustrating the conservation districts and aquifers included as part of this project. County, conservation district, and aquifer geographic information system files from TWDB (2021). Groundwater conservation districts are abbreviated as, "GCD"; underground water conservation districts are abbreviated as, "UWCD"; and water conservation districts are abbreviated as, "WCD".**

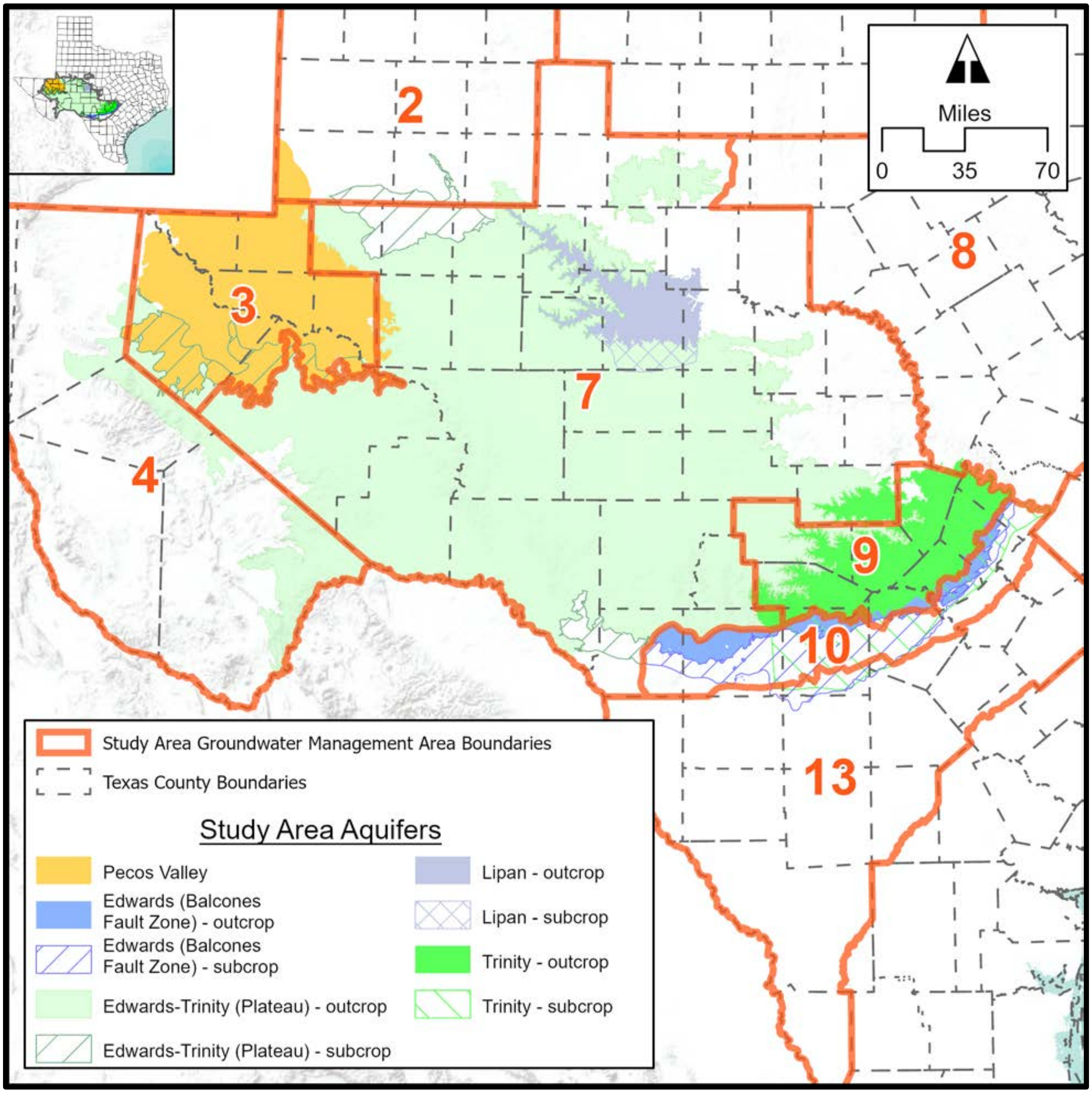


Figure 3. Study area map illustrating the groundwater management areas and aquifers included as part of this project. Numbers correspond to the identification numbers of the groundwater management area. County, groundwater management area, and aquifer geographic information system files from TWDB (2021).

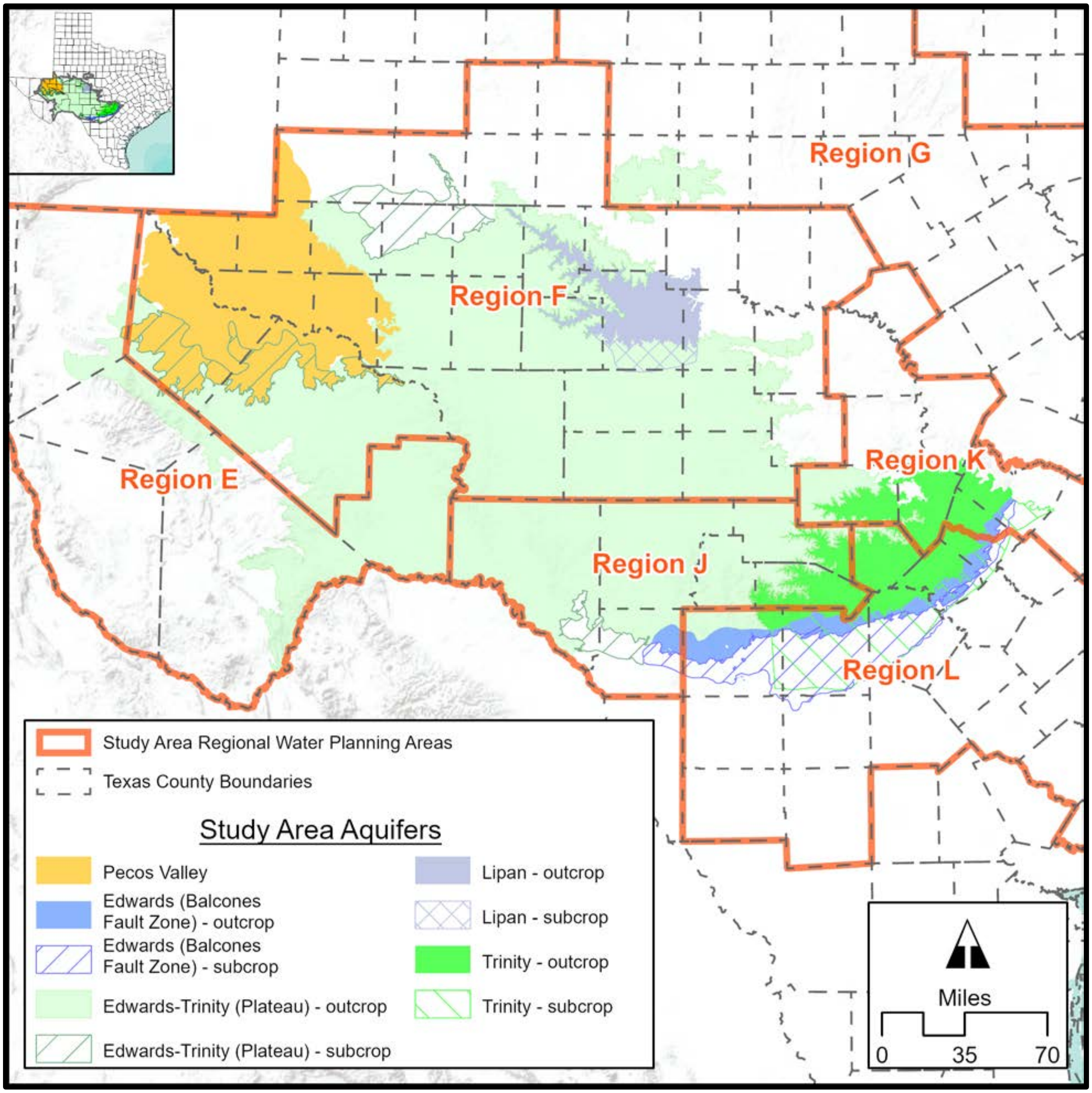


Figure 4. **Study area map illustrating the regional water planning areas and aquifers included as part of this project. County, regional water planning area, and aquifer geographic information system files from TWDB (2021).**

2 Data Compilation

Reliable groundwater production data is important for modeling as pumping can be a significant transient stress on an aquifer system. However, it is also frequently one of the greatest unknowns when developing a groundwater availability model. Developing the estimates of pumping amounts, locations, and timing for the conceptual model of the aquifer system often requires significant effort.

One of the first steps in developing a pumping dataset is to compile existing data from various sources. To compile the available data, we began by searching existing reports for summaries of historical groundwater pumping. We also conducted stakeholder outreach to obtain information from entities that may have data not previously known to TWDB and/or not included within TWDB historical pumping datasets. The following provides a summary of the sources we reviewed while compiling information related to groundwater production within the study area.

2.1 Groundwater Pumping

2.1.1 Historical Data

Through online searches, we compiled groundwater pumping data from various TWDB, U.S. Geological Survey, and Groundwater Conservation District reports. The project team also carried out a comprehensive literature review for every county within the study area to compile historical groundwater pumping information. Our review of historical pumping data included more than 140 sources for the 56-county study area to help inform our understanding of Water Use Survey pumping estimates and for potentially updating the pumping data during subsequent phases of the project. The TWDB reports (TWDB, 2020g) that we reviewed included:

- Groundwater Bulletins: a series of reports from 1950 to 1965 that often cover a county and include information on groundwater resources, well records, water-level measurements, and geology.
- Numbered Reports: a series of reports from 1965 to the present. Older reports often cover a county and include information on groundwater resources while recent reports often cover multiple counties and make use of TWDB Water Use Survey pumpage data.
- Historic Groundwater Reports: a series of reports from 1936 to 1961 attributed to the historic Texas Board of Water Engineers. The reports often cover individual counties and include information on groundwater resources, records of wells, well locations, driller's logs, and water analyses.
- Limited Printed Reports: a series of reports from 1976 to 1995 covering a variety of topics, including groundwater conditions of aquifers in a specific county.
- Other Reports: a compilation of circulars (1962 to 1968), intensive surveys, limited distribution reports, memorandum reports, and miscellaneous reports. The most useful reports for the purpose of this study were the memorandum reports and miscellaneous reports.
- Contracted Reports: a series of reports from 1984 to present covering various water-related technical issues.

- Technical Notes: a series of technical analyses that are each too short to be a formal report but still warrant publication.

We also accessed the U.S. Geological Survey Publications Warehouse (USGS, 2020a) to compile data from the following sources:

- Water-Resource Investigations
- Open-File Reports
- Water Supply Papers
- U.S. Geological Survey Bulletins
- U.S. Geological Survey Reports

We reviewed these sources and developed an annotated source list which is included within the electronic deliverables accompanying this project report (See "4014TDB03 – Pumping Data Research.xlxs"). From our review of these sources, we tabulated the reported pumping information. In some cases, the reported pumping amounts did not reflect an annual volume but rather a monthly or seasonal quantity. In those cases where a pumping estimate did not reflect the annual pumping for a particular year, we used the reported values to estimate annual groundwater production as the sum of individual months or the average of multiple years. For reported pumping that only reflected amounts from specific wells or a locality within a county, we recorded the detailed information for potential use during subsequent phases of this project. These reports of groundwater pumping from specific locations will be useful for subsequent verification of TWDB Water Use Survey countywide pumping amounts. In addition, the historical pumping information will be useful in defining pumping locations and time-series volumes within future groundwater models covering the study area.

We tabulated all the reported historical pumping values by county, aquifer, and use in a manner similar to the Water Use Survey data format. For each reported value we also included the source of the data for quality assurance purposes. In addition, we recorded any comments that may help inform our understanding of the reported values. A table with the reported historical pumping is included in the draft project geodatabase (which accompanies this report as the Task #1 project deliverables).

2.1.2 Stakeholder Outreach

To help obtain additional information beneficial to the project, we conducted an extensive outreach program to raise awareness of this project in the Texas water industry (specifically in the groundwater community), and to gather other lesser-known pumping-related data. We targeted select groups typically involved in groundwater availability modeling discussions, including groundwater conservation districts and regional water planning groups whose membership includes representatives from groundwater management areas, the Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Department of Agriculture, water utilities, educational groups, agricultural interests, environmental interests, private landowners, and industry.

In addition to the entities listed above, we also contacted the Texas Alliance of Groundwater Districts. Lastly, to inform the statewide water community of this study and to seek all possible data sources, we reached out to the Texas Water Conservation Association, the state's primary professional water-industry organization working to promote sound water policy for Texas.

For our outreach effort, our team developed an education and outreach email explaining the purpose of the project and requesting that stakeholders provide all historical pumping data that they had not previously made public. The requested documents may include pumping records or estimates, historical well screen/completion records, local water use surveys, or other information the stakeholder deemed pertinent. On September 23, 2020, we sent the email describing the project and requesting stakeholder participation to representatives of each of the 35 conservation districts and five regional water planning groups within the study area.

In addition to the conservation districts and regional water planning groups, we also attempted to directly notify officials from 70 municipalities within the study. We selected the municipalities based upon them being included as a major water user within the regional water planning areas. We initially contacted officials from each municipality by telephone to obtain an updated water system contact name and email address. We then emailed the project details and data request to the provided contact for each municipality.

To help increase awareness of the project, we contacted the Executive Director of the Texas Alliance of Groundwater Districts, Ms. Leah Martinsson, to request inclusion of information regarding the project in newsletters or on their website. The Texas Alliance of Groundwater Districts consists of conservation districts in Texas with the powers and duties to manage groundwater defined in Chapter 36 of the Texas Water Code. Other associate members of Texas Alliance of Groundwater Districts include organizations and/or consultants that work in areas related to groundwater (TAGD, 2020).

Information regarding the research project was included in the weekly email to the Texas Alliance of Groundwater Districts' members beginning October 2, 2020. Ms. Martinsson also posted a copy of a memorandum discussing the project on the Texas Alliance of Groundwater Districts' website (https://texasgroundwater.org/request-for-pumping-data/) beginning October 1, 2020. In terms of stakeholder outreach for this project, communicating with Texas Alliance of Groundwater Districts and its membership was extremely critical to the success of this study.

We also contacted the Director of Communications, Outreach, and Membership for the Texas Water Conservation Association, Ms. Adeline Fox. The Texas Water Conservation Association is an association of water professionals and organizations in the State of Texas whose membership includes engineers, hydrogeologists, attorneys, government administrators, and numerous other individuals involved in managing Texas' water resources (TWCA, 2020).

We provided Ms. Fox a copy of a memorandum discussing the project and requested the opportunity to inform attendees of the Texas Water Conservation Association Fall Conference regarding the project. During the Texas Water Conservation Association groundwater committee meeting on October 14, 2020, we briefly discussed the project to let the members know the work we were doing in support of the TWDB and to request data that may be pertinent to the project.

Output derived from each of these various outreach efforts largely consisted of local aquifer knowledge and assumptions, provided predominantly by groundwater conservation district staff. This information was incorporated into our data assessment methodologies and workplans.

2.1.3 Groundwater Availability Models

There are several groundwater models covering portions of the study area (see Figure 5). When the authors created these models, the TWDB Water Use Survey dataset was a primary source for estimating the amount of groundwater production during recent years. As such, we did not extract the pumping as represented in the well files for these models, but will include a comparison with of the pumping data in these files with the pumping dataset we develop in subsequent project phases. However, we did utilize the geologic structure data incorporated within these models to help ascertain in which aquifer water wells are likely completed.

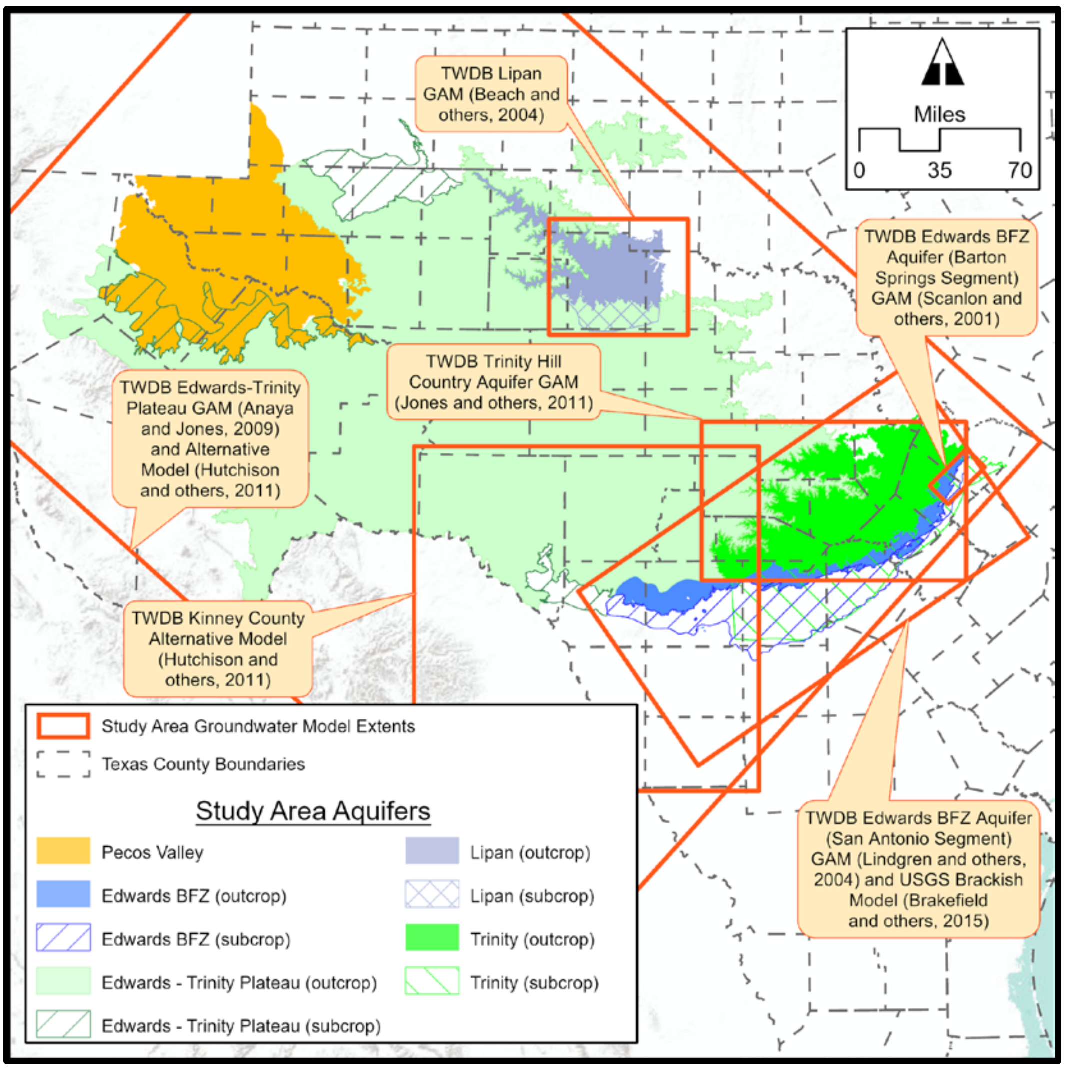


Figure 5. Extents of groundwater flow models completed for the study area aquifers. The Balcones Fault Zone is abbreviated as, "BFZ"; groundwater availability model is abbreviated as, "GAM".

2.1.4 *Water Use Survey Data*

We worked with TWDB staff to obtain Water Use Survey data for each of the counties and aquifers in the study area. In addition to the data provided directly by TWDB staff, we also downloaded (in comma separated format) the Water Use Survey data from the TWDB online report system (TWDB, 2020c; TWDB, 2020a) for quality assurance purposes. We used the data from the TWDB online reports to verify the data provided by TWDB staff. Much of the data matched, although we did identify some minor differences in the data from the online reports compared to the data provided by TWDB staff. Upon investigation, the differences in values were due to the syntax of the database query used to extract the data from the database. Once the query was updated, the data resulting from the query exactly matched that provided within the online reports.

To create an automated method that would be functional for users downloading the Water Use Survey data from the current online report system, we utilized the online reports for our analyses. The data from the online system provides a reliable report of the groundwater pumping estimates by county, aquifer, and use in the Water Use Survey data. Annual survey data are available from 1984 onward, though the methods for estimating the pumping for specific uses have changed over time. Additional information regarding the Water Use Survey program is provided in the Water Use Survey Evaluation section (Section 3).

2.2 Wells

Our primary source for well data were the publicly available statewide databases, namely:

- The TWDB Groundwater database (TWDB, 2020b)
- The Submitted Drillers Report database (TWDB, 2020f)
- The Texas Commission on Environmental Quality Public Water Supply well database (TCEQ, 2020)

We compiled the wells from each of the databases into a single project data table. Each well was assigned a unique well identification number based on their database source for quality assurance purposes. Table 1 provides the assigned well identification values for each database.

Table 1. Assigned well identification values for each database.

Source Database	Database Prefix	Source Database Identification and Modification	Example Well Identification
TWDB Groundwater	T-	State well number + 100,000,000	T106808515
Submitted Drillers Report	S-	Tracking number + 100,000,000	S100535483
Texas Commission on Environmental Quality Public Water Supply well	G-	Water Source Identification value	G0070004B

We filtered out and removed all wells from the project database completed in aquifers or formations other than the study area aquifers. We also filtered out from the project database locations identified as a “Spring.” For wells found in more than one database, we removed the duplicate wells based on matching both state well identification values and completion depths. This removal of duplicate wells will help to avoid overestimating the number of wells completed or in existence during a particular year. For wells from the Submitted Drillers Report database that were not in one of the other databases, we used the completion information along with the aquifer structure from the groundwater availability models to identify in which study area aquifer the well was completed.

Within our project database, we assigned each well to a TWDB use category, describing the intended purpose for the produced water. For wells identified within the Texas Commission on Environmental Quality Public Water Supply well database, we assigned each to municipal water use. Wells in the Submitted Drillers Report and TWDB Groundwater databases have a primary or proposed use specified. In many cases these uses are not associated with groundwater withdrawals. For example, wells identified as an “environmental soil boring” or an “injection well” were not included in our project database. For other specified uses, we assigned a TWDB use category based on our interpretation of the specified use. The assigned use categories are not always consistent with the current TWDB Water Use Survey program classification methodology. For example, program methods classify “commercial” wells as pumping for municipal purposes, and golf courses using groundwater are classified as “irrigation” usage. Table 2 provides the TWDB use category for the various specified uses found in the Submitted Drillers Report and TWDB Groundwater well databases, as included in this report and revised pumpage dataset.

Table 2. Assigned TWDB use category for well uses identified in the Submitted Drillers Report and TWDB Groundwater databases.

Well Use from Database	Applied TWDB Use Category	Use Identification
Domestic	Domestic	RD
Withdrawal of Water	Domestic	RD
Aquaculture	Irrigation	IRR
Irrigation	Irrigation	IRR
Stock	Livestock	LIV
Commercial	Manufacturing	MFG
Industrial	Manufacturing	MFG
Industrial (cooling)	Steam-Electric/Power	PWR
De-watering	Mining	MIN
Extraction	Mining	MIN
Fracking Supply	Mining	MIN
Mining	Mining	MIN
Rig Supply	Mining	MIN
Air Conditioning	Municipal	MUN
Bottling	Municipal	MUN
Fire	Municipal	MUN
Institution	Municipal	MUN
Medicinal	Municipal	MUN
Municipal	Municipal	MUN
Public Supply	Municipal	MUN
Recreation	Municipal	MUN

Each well in the Submitted Drillers Report and TWDB Groundwater databases has a record of the well's completion date; however, the Texas Commission on Environmental Quality Public Water Supply well database only contains each well's drilled date. We extracted the year value from these dates to estimate how many wells were completed and potentially pumping from a specific aquifer each year. For wells without a reported completion date, we assumed the wells were completed during pre-development years and assigned them a completion year of 1800 to distinguish them from those wells with reported completion or drilled dates.

We assumed all wells were continuously active from the date they were completed. We did not account for wells that had been taken out of operation after having been utilized for multiple years. We did exclude from our analyses any wells what were listed as having been capped or plugged immediately after drilling completion.

2.3 Precipitation

We obtained gridded precipitation data for the study area from the PRISM Climate Group (PRISM, 2020). The gridded data provides daily precipitation estimates throughout the study area. The PRISM Climate Group develops the gridded datasets using a variety of modeling techniques that incorporate available site-specific measurements. For purposes of this project, we limited our data collection to precipitation estimates to the study period from January 1, 1984 through present.

The gridded precipitation data from the PRISM Climate Group covers the conterminous United States with a 2.5 arcminute (approximately 4 kilometers or 2.5 miles) resolution. To improve the resolution within our study area, we performed geoprocessing in ArcGIS to clip each dataset to the study area and resample the resulting raster dataset using bilinear interpolation to a 1,000-foot resolution. During geoprocessing we also converted the raster values for precipitation from millimeters to inches.

2.4 Land Use/Land Cover and Aerial Imagery

To evaluate apparent changes in land use we obtained land use data from Land Use Land Cover Modeling projects conducted by the U.S. Geological Survey Earth Resources Observation and Science Center (USGS, 2020b). The available datasets cover a period beginning in 1938 through 1992 (Sohl and others, 2016) with projections extending from 1992 through 2100 (Sohl and others, 2014). The datasets are available in a raster format covering the conterminous United States with a 250-meter (approximately 820 feet) resolution. The gridded datasets identify up to 16 different land uses within the study area. Of particular interest for this project are areas identified as crop as these areas may be considered "potential irrigation areas" that may be irrigated using groundwater. Figure 6 illustrates the 2020 land use in and near the study area.

Initially, we anticipated obtaining aerial imagery for the study area to conduct analyses of potential irrigation areas. However, after investigating potential options for using remote sensing, we determined that it would be most beneficial to utilize the imagery available through Google Earth Engine. During subsequent phases of the project, we anticipate testing and potentially utilizing a technique developed by Deines and others (2019) where they leveraged Google Earth

Engine to map annual irrigation across the Ogallala Aquifer. Applying this methodology will allow us to efficiently utilize a much larger aerial imagery dataset, potentially going back more than forty years (Google, 2020), than would be possible through obtaining the imagery data ourselves.

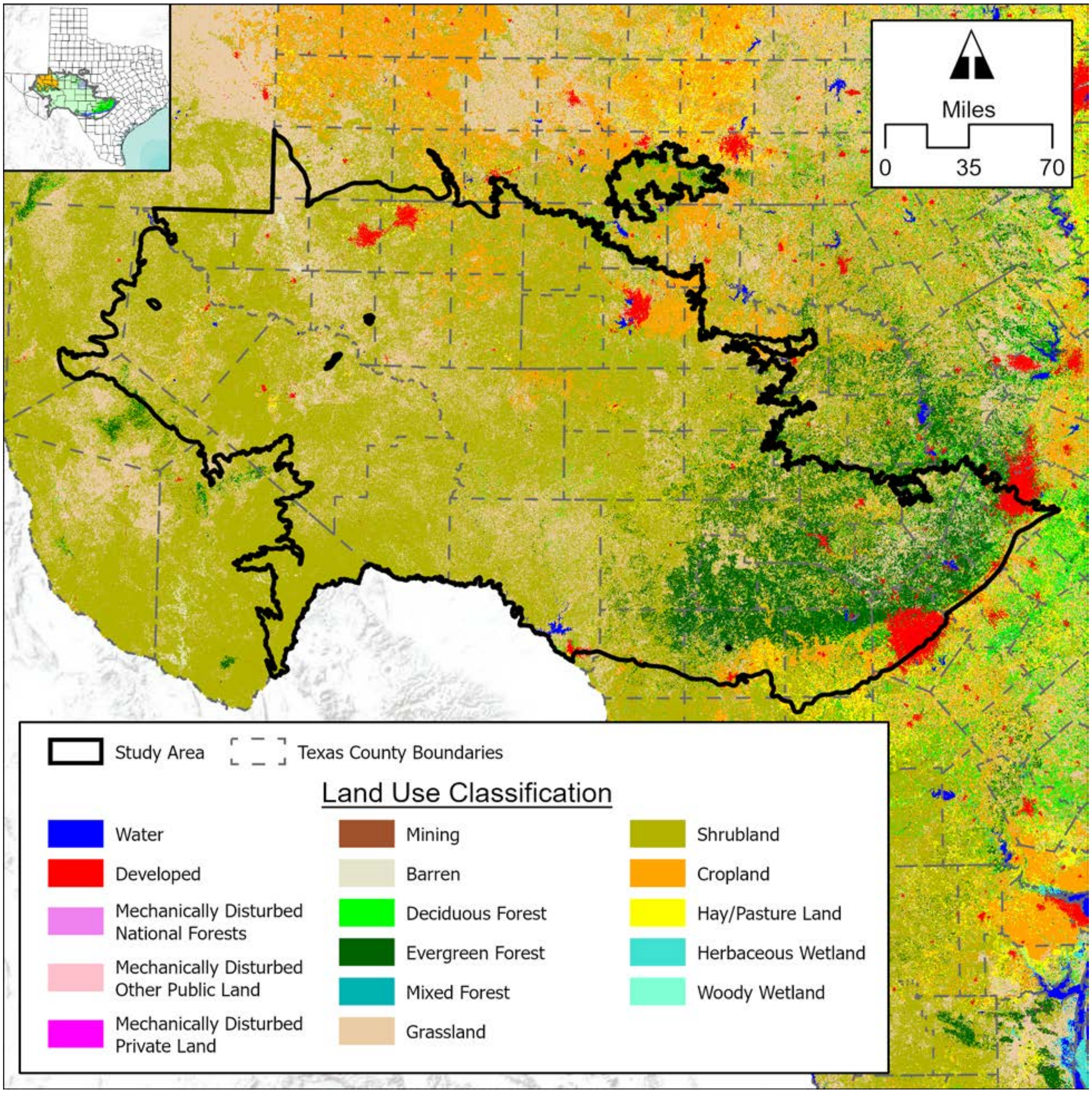


Figure 6. Modeled classification of land use in 2020 (Sohl and others, 2014).

2.5 Agricultural Data

To help us understand estimates of groundwater pumping associated with irrigation and livestock use, we obtained data from the United States Department of Agriculture. For 1997 through 2017, we obtained census data from the National Agricultural Statistics Service's Quick Stats Database (USDA, 2020a). For prior years of the study period, we obtained information from the Census of Agriculture Historical Archive (USDA, 2020b). From these datasets we focused on the following information for each county in the study area:

- The number of irrigated acres
- The inventory of cattle including calves
- The inventory of sheep including lambs
- The inventory of hogs
- The inventory of chickens

Utilizing the Quick Stats Database, we were able to query data for each of the parameters in each county of the study area. However, for data prior to 1997, we had to review digital copies of tables of the data. Upon review of the tables we copied the relevant values for the parameters of interest to our project database for potential use in evaluating irrigation and livestock use estimates of groundwater pumping in subsequent phases. We did not use data from the Quick Stats Database directly in performing the data analyses and evaluations documented within this report.

3 Water Use Survey Evaluation

The TWDB is legislatively directed to provide planning and financial assistance to develop and manage Texas water resources. The Water Use Survey is administered annually to assist in long-term water planning by providing accurate information about current water use in the state. Water use data captured by the Water Use Survey is important in assessing conservation initiatives, addressing limited water supplies and facilities in some areas, and supply-planning for continued population growth. Data from the Water Use Survey are important for improving water planning models. With the importance of accurate and well-calibrated numerical models, having reasonably accurate estimates of pumping locations, amounts, and timing is essential. It is also essential that these estimates are based on a consistent and defensible process to estimate groundwater pumping. Only with reasonably accurate pumping data can Texans be assured their groundwater availability models are appropriately determining future groundwater availability.

Within this section we detail our compilation and review of groundwater pumping data reported within the TWDB Water User Survey database. We obtained data for each of the 56 counties (Figure 1) included in our study area. The survey data obtained for each county identified from which of the five study area aquifers the pumping occurred and to which of the seven usage categories the pumping pertained.

For all our analyses, we limited our focus to data within the period from 1984 through 2018, although we note that the Water Use Survey database does contain earlier data for selected counties and use types. For many of the study area counties the Water Use Survey database identifies some historical pumping as coming from an “Other Aquifer” or “Unknown” aquifer. These aquifer designations reflect pumping that TWDB staff could not definitively assign to a major or minor aquifer at the time of consideration. However, it is possible that with additional analysis we may be able to assign some of the pumping associated with these designations to one of the aquifers included in this study. It is also possible that the “Other Aquifer” designation could refer to local stratigraphic units not included in defined major or minor Texas aquifers. These Other Aquifers could include Quaternary alluvium deposits or various Paleozoic stratigraphic units. For example, as shown on Figure 7, in Irion County there are two study area aquifers underlying the county: the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer. However, the Water Use Survey database does not designate any pumping to the Lipan Aquifer. It is possible that pumping within Irion County attributed to an “Other Aquifer” or an “Unknown Aquifer” was actually produced from the Lipan Aquifer. It is also possible that production occurred from the Dockum Aquifer subcrop, (not shown on Figure 1 and not included in Figure 7 as it is not part of this study), which also underlies the central and western portion of the Irion County. It is also possible that the increase in pumpage from 2008 onward that is attributed to “Other Aquifer” could also be due to a change in methodology used by TWDB for estimating irrigation usage. Through efforts under subsequent project tasks, we will strive to determine the true aquifer source for any pumping attributed to an “Other Aquifer” or an “Unknown Aquifer,” as well as to assess impacts of estimation methodology changes on computed annual usage totals. During completion of this project task, we did not attempt such attributions. Such efforts will become part of our work to address identified anomalies and develop a robust pumping dataset.

In the following sections, we present our understanding of the Water Use Survey data as well as our methods for processing and evaluating the data. Within Section 3.1 we detail the various methods employed by TWDB staff to develop the Water Use Survey data. Section 3.2 contains a detailed description of our methodology for evaluating the pumping data from the Water Use Survey database, as well as our methods for identifying anomalies in the data. Within Section 3.3 we provide a detailed discussion of our evaluations for each of the 52 study area counties for which the Water Use Survey dataset contains pertinent data for this project. Within Section 3.4 we provide a brief discussion of four counties in our study area for which the Water Use Survey dataset does not contain data pertinent to this project.

As detailed in Section 3.3, we focused our county-by-county evaluations on detecting anomalies in the TWDB Water Use Survey data. Detection of an anomaly does not imply that the reported data are erroneous, only that the data warrants further scrutiny. Many of these identified anomalies are likely to be explained by obvious external factors, such as a new well field coming online or the record heat in 2011 causing pumping amounts to abruptly increase. However, for this evaluation we do not address the likelihood or provide potential explanations for any anomalies. We will address these in later phases of the project. Rather, the evaluations presented in Section 3.3 identify the anomalies for which we will develop a plan for investigation during the next phase of the project.

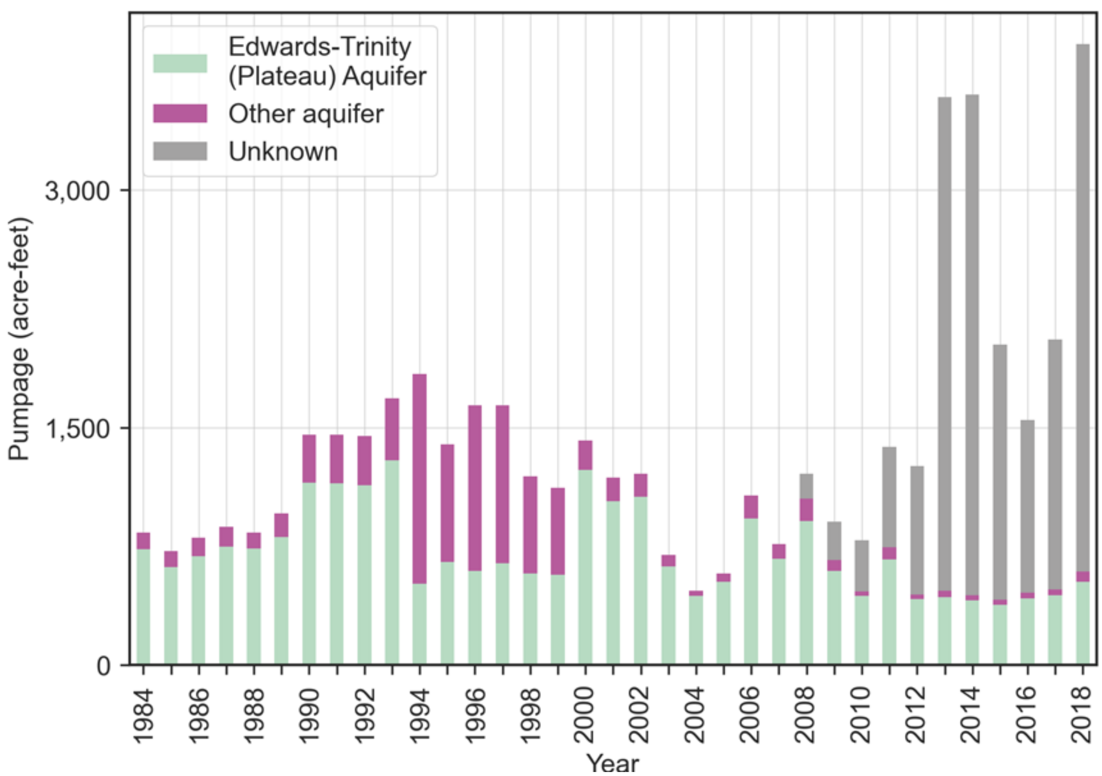


Figure 7. Example of groundwater pumping data for Irion County from the TWDB Water Use Survey database illustrating the total pumping designated to the Edwards-Trinity (Plateau) Aquifer, Other aquifer, and Unknown aquifer.

3.1 Water Use Survey

Development of estimates of water use in the state began in 1955 and has changed significantly since then to aid in development of Regional and State Water Plans. Since 1984, the TWDB has annually summarized survey data and estimated pumpage (TWDB, 2020c). Prior to 1984, TWDB conducted annual surveys and summarized estimated pumpage in conjunction with State Water Plans and reports to legislature. TWDB staff compile the information received from approximately 7,000 annual surveys from public water systems and industrial facilities and estimate water use for irrigation, livestock, mining, and rural domestic purposes to generate historical water use estimates which the TWDB uses for water resources planning (TWDB, 2020c). Table 3 provides a short summary of the different water use categories included in the Water Use Survey dataset. Table 4 provides a brief history of the Water Use Survey identifying some important milestones within the program. Various TWDB program areas are responsible for developing water use estimates in each water use category of the Water Use Survey. The Conservation department develops the irrigation estimates. The non-surveyed livestock and non-surveyed mining water use estimates (including fracking) are developed by the Projections and Socioeconomic Analysis department. Each program area enters information in the Water Use Survey Database. Table 5 summarizes which program area is responsible for providing estimates for each water use category.

Currently, TWDB staff base water use estimates for municipal and industrial (power, manufacturing, and mining) categories on annual surveys of public water suppliers and major manufacturing, non-oil and gas mining, and power producing entities. Estimates for municipal and industrial categories may be supplemented with estimates for non-surveyed entities through special studies (such as for mining) or other approaches. Since September 1, 2001, the Texas Water Code (Section 16.012(m)) and Texas Administrative Code (31 TAC §358.5) has required any entity that receives the survey to complete it and return the information to the TWDB. For other use types, TWDB staff develop non-surveyed estimates.

Mining includes water used in the exploration, development, and extraction of oil, gas, coal, aggregates, and other materials. According to Ridgeway (2014), mining use includes water used in secondary processes for oil and gas recovery. Ridgeway (2014) also indicated that historically TWDB staff have derived livestock water-use estimates from the annual livestock population estimates produced by the National Agricultural Statistics Service and the estimated water use per animal by the Texas A&M AgriLife Extension and various research. Similarly, Ridgeway (2014) stated that TWDB staff used annual crop acreage from the Farm Service Agency as well as potential evapotranspiration rates to derive irrigation water-use estimates.

For non-surveyed municipal use estimates (previously referred to as "rural domestic"), Billingsley (2019) indicates that TWDB staff use census population data. TWDB (2021) indicated that historically they derived the used volume by multiplying the number of connections reported in the municipal survey by a factor (such as 3.5) representing the average number of people per connection. They then subtracted this estimated population (served by surveyed-municipal sources) from the total number of people in the county per the census. They assigned the remaining persons to county-other non-surveyed municipal. If the number of persons from the connection analysis was greater than the county-wide census information, then the number of persons applied to county-other was zero. However, for estimating non-surveyed municipal pumping for the modeling program, TWDB (2021) assumed pumping occurred in every county. Using census block data for areas outside of cities, they assigned the average gallons per capita use for Texas per year to derive a volume for each census block.

Table 3. Current TWDB Water Use Survey categories and summary description.

Water Use Category	Summary Description
Surveyed Municipal	Self-reported municipal water use by active community public water systems.
Non-Surveyed Municipal	Estimated from non-system population and rural gallons per capita per day.
Mining	Self-reported and estimated water use by various entities.
Manufacturing	Self-reported water use for entities involved in manufacturing.
Power	Self-reported water use by power generation operations.
Irrigation	Estimated from crop histories, land use and water used per crop. Adjustments for rainfall and other considerations were incorporated in estimations since 2001.
Livestock	Estimated from annual livestock population and water used per animal.
Unknown	Water used that was not included in any of the main water use categories.

Municipal entities include all active public water systems that are a community water system type as defined by the Texas Commission on Environmental Quality (TWDB, 2020a). It includes city-owned utilities, districts, water supply corporations, or private utilities supplying residential, commercial (non-goods-producing businesses), and institutional (schools, governmental operations) entities (TWDB, 2020a). Rural domestic water use consists of all other municipal water use not included in the municipal annual surveys. Estimates of rural domestic are the product of non-system population estimates within each county, not served by a surveyed water system, and the average rural statewide gallons per capita per day water use for Water Supply Corporations and Investor-Owned Utilities (Ridgeway, 2020). Data review indicated that the non-surveyed municipal use, which includes rural domestic use, was not included in the Water Use Survey data prior to 2000. Table 6 summarizes a timeline of the Water Use Survey derivation methods for non-surveyed municipal pumpage.

Surveyed industrial entities are water users that annually use more than 10 million gallons of water or use a significant volume of water for the industrial sector for a particular area of the state. Within the industrial category, we can find three main categories: manufacturing, power, and mining. Water used for manufacturing is the sum of water use for large manufacturing firms reporting to the TWDB. This category includes cogeneration plants that generate power for manufacturing or mining processes. Water use for power is a combination of reports and calculations of consumed water based on self-reported consumptive use volume percent data. Note that it includes all electric power generating plants regardless of volume pumped but only those power generation plants that sell power on the open market (TWDB, 2020a).

Mining water use refers to water used in the mining of oil, gas, coal, sand, gravel, and other materials. It is a combination of reported water use by various entities and additional estimates based on prior years research (TWDB, 2020a). Table 7 summarizes a timeline of the Water Use Survey estimates for mining (Billingsley, 2019). Estimated oil and gas water use for fracking activities have been based on water use volumes collected through the FracFocus database since 2012.

Table 4. Timeline of Water Use Survey milestones. Modified from Kluge (2014) and Billingsley (2019).

Year	Water Use Survey Milestone
1955	Surveying of total annual self-supplied groundwater volumes began (mostly specific study areas).
1960	Surveying of monthly water pumping volumes began.
1971	Water Use Survey was expanded to include self-supplied and purchased groundwater, surface water, saline water and treated effluent.
1974 - 1977	County-level summaries were estimated statewide.
1977	Water Use Survey data began being entered electronically.
1981 - 1983	Irrigation values were calculated using linear regression, yet summaries were not developed.
1984	TWDB began developing annual summaries.
1985	Water Use Survey team created groundwater pumpage estimates by aquifer with cooperation of TWDB staff geologists.
1994	Methodology for assigning non-surveyed estimates to aquifer changed where multiple aquifers exist.
1997	Senate Bill 1 Regional Water Planning was instituted.
1999	Water Use Survey became mandatory; non-respondents cannot receive TWDB funding and are ineligible to obtain permits, permit amendments or permit renewals from the Texas Commission on Environmental Quality under Chapter 11 of the Texas Water Code.
2002	For survey of water use for year 2001, began to survey the volume of metered sales for water use categories rather than percentages of total metered sales and the number of connections inside and outside the city limits.
2003	TWDB began collecting survey data online in addition to paper surveys for survey year 2002.
2005	For survey year 2004, municipal short form surveys were mailed for mobile home communities and municipal facilities, in addition to the traditional municipal surveys and separate industrial surveys sent to large and small facilities. TWDB began to survey for monthly volumes of metered sales and the number of connections by water use category, direct and indirect reuse volumes, and volumes of saline water use.
2012	Senate Bill 181 (2011) added the collection of the amount of connections and water use volumes for industrial, agricultural, commercial, and institutional sectors served by municipal water utilities.
2019	TWDB developed a statewide public water system service area mapping application called the Texas Water Service Boundary Viewer through a grant from the U.S. Geological Survey Water Availability and Use Science Program.

Table 5. Summary of water use categories and the TWDB program area that is responsible for providing estimates.

Water Use Category	Surveyed?	Estimated by TWDB staff? + responsible program area
Municipal: PWS	**Yes**	
Municipal: non-system (domestic) use		**Yes** – by Water Supply & Infrastructure - Water Supply Planning division - Water Use and Planning Data department
Irrigation		**Yes** – by Water Science & Conservation -Conservation & Innovative Water Technologies division - Conservation department
Livestock	**Yes** (fish hatcheries only)	**Yes** – by Water Supply & Infrastructure - Water Supply Planning division - Projections & Socioeconomic Analysis department
Manufacturing	**Yes**	
Mining	**Yes** (aggregate/surface mining facilities)	**Yes** – by Water Supply & Infrastructure -Water Supply Planning division - Projections & Socioeconomic Analysis department (oil and gas only)
Steam-Electric	**Yes**	

Table 6. Timeline of Water Use Survey derivation methods for non-surveyed municipal pumpage (Billingsley, 2019).

Year	Non-surveyed Municipal Water Use Milestone
Historical - 2010	County-wide number of total connections reported by water systems compared to the county population growth estimated by the Texas State Data Center. The growth in the number of connections served by the water systems within a county determine the county’s non-system population growth.
2010 - present	The non-system population estimate began being estimated with the block-level census data and the Statewide Water System Map delineating the boundaries of community water systems.

Table 7. Timeline of Water Use Survey derivation methods for mining pumpage (Billingsley, 2019).

Year	Mining Water Use Milestone
1984 - 2005	Survey of facilities, inclusion of water-use estimates from a mid-1990 Railroad Commission report on water-flood activities, and other historical estimates.
2006 - 2008	Only volumes from surveyed facilities are included (sand and gravel/ aggregate facilities and coal facilities)
2009	From the 2011 University of Texas Bureau of Economic Geology report (Nicot and others, 2011), used the average between the 2008 water use estimates and the projected 2010 water use volumes. This included all categories of mining (fracking, coal, sand and gravel, water flood, etc.).
2010	Projected water uses volumes from the University of Texas Bureau of Economic Geology report (Nicot and others, 2011).
2011	A composite of surveyed water use volumes and non-surveyed water use estimates from a 2011 University of Texas Bureau of Economic Geology report (Nicot and others, 2011) and a 2012 update report focusing on hydraulic fracturing use (Nicot and others, 2012).
2012 - present	A combination of reported water use by various entities and hydraulic fracturing use estimates from FracFocus database.

Texas ranks first in the nation for total number of farms, accounting for 127 million acres of agricultural land which represents 74 percent of the state's land and a $25 billion contribution to the economy (USDA, 2019). However, the TWDB does not have the authority to require agricultural producers to report actual irrigation water use volumes, and must thus aggregate information from various sources to develop irrigation water use estimates (TWDB, 2020d). Since 1985, the TWDB has annually estimated water use for irrigation. Every five years, the National Resource Conservation Service helped develop county-level irrigation surveys. Until 2000, TWDB staff adjusted those county-level estimates based on data from the National Agricultural Statistics Service (Turner, 2015). In 2003, the TWDB began collaborating with the U.S. Department of Agriculture-Farm Service Agency for irrigated crop acreage data and the Texas Commission on Environmental Quality for surface water irrigation diversions data to determine a more accurate water use distribution between surface water and groundwater. Additionally, TWDB staff began accounting for surface water delivery system losses not previously considered. According to the TWDB, "the historical on-farm irrigation estimates developed between 1985 and 2002 may not be comparable with estimates developed in and after 2003 in counties with surface-water irrigation" (Turner, 2015).

The historical irrigation water use estimates have practically been "developed from four different sources of information and methodologies" creating a significant variation in annual irrigation use for some counties. In particular, the derivation method for water used to irrigate crops changed often between 1994 and 2007 (Turner, 2020). Table 8 presents a summarized timeline of the irrigation water use derivation methods used in the Water Use Survey from 1958 to today.

TWDB staff derive livestock water use estimates from annual livestock population estimates produced by the National Agricultural Statistics Service. Estimated water use per animal unit is based on research conducted by the Texas A&M AgriLife Extension and other researchers (Ridgeway, 2020).

Table 8. Timeline of Water Use Survey derivation methods for irrigation pumpage (TWDB, 2020e; Turner, 2020).

Year	Irrigation Water Use Milestone
1958 - 2000	TWDB staff developed annual estimates of agricultural irrigation water use for every county in the state with assistance from the Natural Resources Conservation Service who developed county-level irrigation surveys every five years. TWDB staff adjusted annual estimates using data from the Texas National Agricultural Statistics Service (TASS) and compiled these estimates from 1985 through 2000. Where there were gaps in the TASS county data, TWDB staff referred to the most recent 5-year NRCS on-farm irrigation survey.
1994	Detailed irrigation surveys for 1994 were provided exclusively by the United States Department of Agriculture - Natural Resources Conservation Service. Each local county office of Natural Resources Conservation Service compiled information on the irrigated acreage of crops and the average representative value of irrigation water applied to that crop during that specific year.
1995 -1999	The National Agricultural Statistics Service estimated irrigated acreages for major crop types and Natural Resources Conservation Service provided estimates of irrigation water use by crop type in each county. For crops not included in these data, TWDB relied on data from the most recent Natural Resources Conservation Service detailed survey. The distribution of resulting irrigation water use was divided into groundwater and surface water based on estimates from the most recent detailed survey.
2000	Detailed irrigation surveys for 2000 were provided exclusively by the United States Department of Agriculture - Natural Resources Conservation Service using a similar method to the one used for development of the 1994 surveys.
2001 - 2002	The Natural Resources Conservation Service no longer provided irrigation data. TWDB continued using the National Agricultural Statistics Service major crop acreage data along with data from the 2000 Natural Resources Conservation Service on-farm irrigation survey. Estimated irrigation water use was based on the historic data and adjusted, if necessary, for rainfall conditions in 2001 and 2002.
2003 - 2009	The United States Department of Agriculture's Farm Service Agency (FSA) provided data of irrigated crop acreages for each county. The Texas Commission on Environmental Quality provided annual reported surface water irrigation water use to distribute water use between groundwater and surface water. TWDB staff began accounting for conveyance loss, wastewater reuse, and included more non-traditional crop types. In some regions, TWDB staff estimated irrigation application rates based on evapotranspiration data from weather stations maintained by the Texas A&M AgriLife Extension Service. TWDB staff requested that Texas groundwater conservation districts review and comment on annual draft irrigation estimates. To the extent possible, TWDB uses the comments and proposed revisions in the final version of the annual irrigation water use estimates.
2010 - Present	Expanding on the 2003-2009 methodology, staff began utilizing geographic information systems to refine irrigation rates based on quantitative adjustment factors derived from gridded climatological data. Remote sensing is also used to improve geographic allocation of reported surface water diversions and irrigated acres. Annual irrigation estimates are compared to an increasing number external sources of data as they become readily available including the United States Department of Agriculture's National Agricultural Statistics Service, Agricultural Census, Farm and Ranch Irrigation Surveys, and the United States Geological Survey irrigation water use reports. Comments and revisions of the irrigation estimates by qualified local irrigation water experts and groundwater conservation districts are encouraged by TWDB staff.

According to Billingsley (2019), even though the survey response rate between 2011 and 2017 have oscillated from 78 to 84 percent, "the total volume of water use represented by returned surveys is greater than 90%." Understanding how the Water Use Survey data was derived for each water use category is an essential step in assessing the identified data anomalies in subsequent project phases. While evaluating the identified inconsistencies in the dataset for groundwater pumping for irrigation, reviewers may place higher confidence in pumping for irrigation estimated in 1994 and 2000 when United States Department of Agriculture – Natural Resources Conservation Service staff carried out detailed irrigation surveys to estimate groundwater production.

3.2 Data Evaluation and Anomaly Detection Methodology

We began our evaluation of the Water Use Survey data by reviewing the reported volume of groundwater produced from each of the study area aquifers for each defined use and county. We organized and plotted the pumping data by county, aquifer, and use to show the annual pumping for the 1984-2018 period. Figure 8 is an example of the plotted pumping data for Medina County from the Trinity (Hill Country) Aquifer for livestock use.

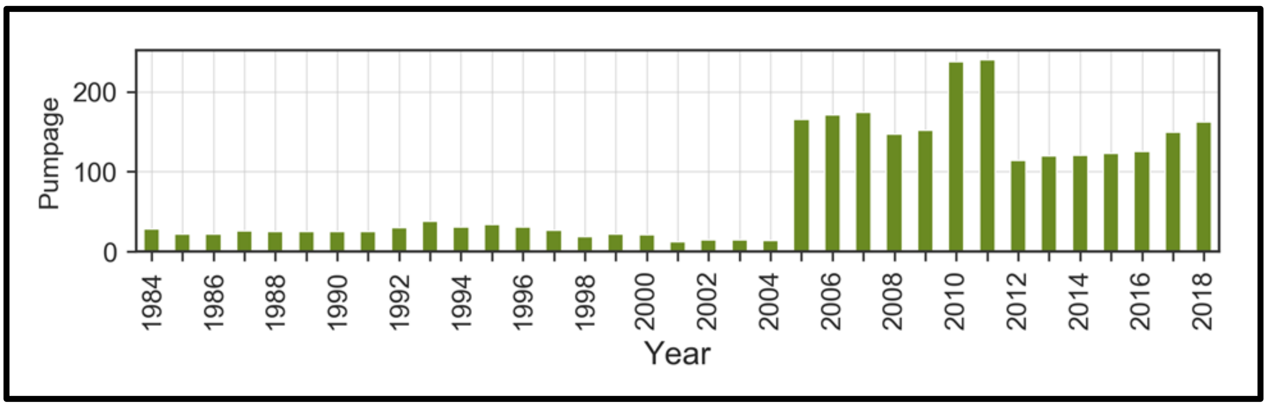


Figure 8. Example of groundwater pumping data from the TWDB Water Use Survey database showing acre-feet of groundwater pumped from the Trinity Hill County Aquifer for livestock use in Medina County.

Using the plots of annual pumping, we identified years in which the reported pumping volumes appear anomalous and which may warrant further review. In addition, we conducted initial evaluations, which will be expanded during subsequent project tasks, of the correlation of the data with other datasets and trends in the pumping data (such as annual precipitation). Our primary objective for this evaluation was to identify potential data anomalies for further review and possible revision in subsequent project tasks.

We evaluated multiple methods for identifying anomalies in the Water Use Survey groundwater pumping data. Upon review of the results from each method, we selected three methods which were most useful for application to all of data across the study area. We applied each of the three methods to improve our ability to identify all anomalous years of pumping data within the Water Use Survey database. It is important to recognize that our analysis method does not imply that identified anomalies are incorrect, rather only that the reported data is sufficiently different than "expected" to warrant further investigation. The three methods we selected for detection of anomalies are:

- Manual review and professional judgement
- Year-to-year change analysis
- Statistical analysis using a standard deviation criterion

In general, each method identifies anomalies as abrupt changes in pumping amount, recognizing that gradual changes are less likely to be indicative of potentially erroneous data. Note that any non-reported pumpage values or pumpage reported as zero are automatically flagged as anomalies in the statistical analysis and year-to-year change methods. Anomalies identified using each of the methods are tabulated for each county, aquifer, and use.

Importantly, the methods utilized are only meant to identify anomalies in the data. They are not meant to indicate any pumping values are incorrect. Through the application of these evaluation methods, we strove to identify years for which additional investigation may be warranted.

3.2.1 Manual Review and Professional Judgement

As a first step in our data review, we manually scrutinized and visually identified years with anomalous pumping amounts. During manual review, each reviewer visually observed data trends to assess anomalies. During this review, we did not consider factors that could influence the water usage in any given year. Individual reviewers applied professional judgement to identify anomalies with multiple professionals from the project team reviewing each county dataset for quality assurance.

As an example of the manual review process and results, in Figure 8 we observe abrupt changes in 2005, 2010, and 2012. These three years of pumping data appear to be anomalous pumping amounts based on the preceding year's amount. In general, our project team flagged an annual pumping volume for review if it represented an apparently significant deviation from visually observable trends within the data time-series. For example, we flagged the year 2005 because it suggested significantly larger pumping than the amounts from 1984 to 2004. However, we did not flag 2006 because pumping in that year was similar to that from 2005 and 2007. Similarly, we flagged 2010 because its pumping value was significantly larger than the previous five years, but we flagged 2012 because it was significantly lower than the amounts in 2010 or 2011.

Due to the size of the datasets for each county, it was not difficult to perform manual review of the groundwater pumping estimates from the Water Use Survey data. The manual review was also beneficial for familiarizing our project team members with the data and information available for each county in the study area. However, our manual review and professional judgement was not necessarily consistent amongst the project team members. That is, reviewers did not necessarily identify the same years of pumping as anomalous. As a quantitative quality check on our manual review, we applied two analytical methods which evaluated the data based on the annual changes and short-term data trends. However, these analytical methods were not able to identify the first reported year as anomalous. For the first year of data only our manual review was applicable.

3.2.2 Year-to-Year Change Analysis

For reviewing the year-to-year change in pumping, we used a comparison of the range of annual pumping values (from 1984 through 2018) to year-to-year differences in pumping for each county, aquifer, and use dataset. By comparing the year-to-year differences against a specified percentage of the data range, we were able to identify if an annual pumping amount was anomalous. Our application of the method included the following process, which Figure 9 illustrates:

1. Compute the average Water Use Survey annual groundwater production per county, aquifer, and use.
2. Compute the range of Water Use Survey annual groundwater production per county, aquifer, and use (that is, the maximum minus the minimum for the period from 1984-2018) (Figure 9-a).
3. Assign a threshold percentage per county, aquifer, and use
    a. For a range greater than one-half the average, use a 15 percent range threshold
    b. For a range less than or equal to one-half the average, use a 35 percent range threshold
4. Compute the year-to-year difference in Water Use Survey annual groundwater production per county, aquifer, and use (Figure 9-b).
5. Divide the year-to-year difference by the range per county, aquifer, and use (Figure 9-c).
6. If the resulting quotient exceeds the applicable range threshold, the data for the given year and the one previous are flagged as anomalous (Figure 9-d)

This method allows for gradual change over time within the pumping dataset yet identifies periods of rapid change as anomalous. By using the assigned threshold values, we were able to apply a consistent evaluation method to all the data. However, we based the thresholds themselves on our professional judgement upon data review. While we found our selected thresholds were reasonably applicable across the study area, they may not be equally applicable within other portions of Texas. Adjustment of the thresholds may be justified for specific areas with relatively low pumping amounts to address potential sensitivity to relatively small changes in pumping. In applying thresholds to any given area, some manual review and professional judgement will be required in order to ensure that all anomalous data is identified. Thresholds of 15 percent and 35 percent should be used as an “initial” pass within the data analysis, followed by a rapid manual review to identify if any obvious data anomalies were missed. If anomalies were missed, the thresholds should be adjusted and the year-to-year change analysis re-applied. For this project, we did not need to refine our thresholds from the 15 percent and 35 percent values.

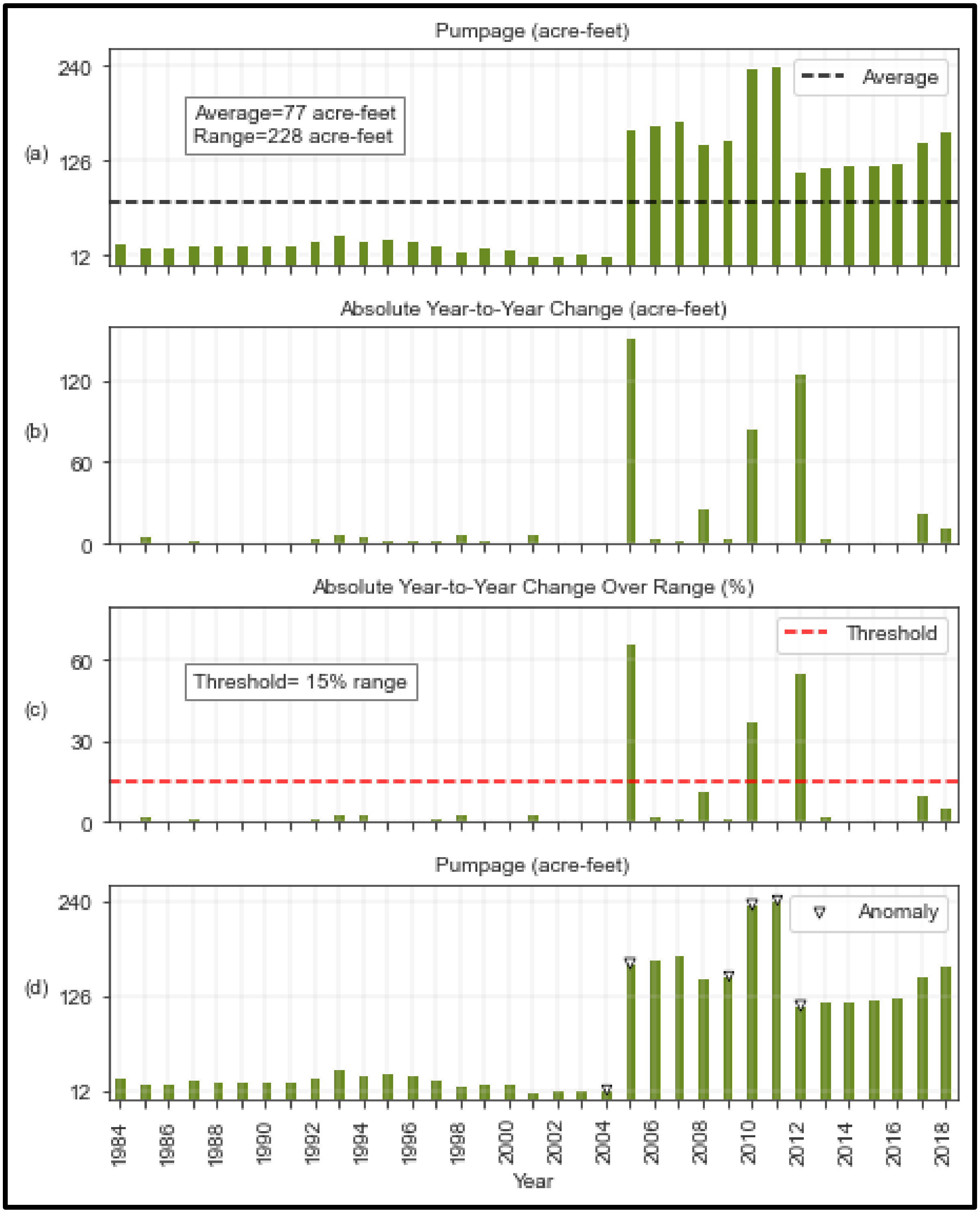


Figure 9. Example application of the year-to-year change analysis: (a) raw survey data with average pumping, range and applicable threshold indicated, (b) year-to-year change in pumping, (c) year to year change as a fraction of the range, and (d) raw data with anomalous years flagged.

3.2.3 Statistical Analysis using a Standard Deviation criterion

As an additional quantitative analysis, we applied a simple standard deviation criterion to each county, aquifer, and use dataset. The method we applied is a generalization of the Chauvenet (1863) method which essentially states that a data value outside of a certain number of standard deviations from the mean is anomalous. While Barnett and Lewis (1994) provide valid criticisms for the simplicity of the method, it serves well for the purpose of our evaluation to identify anomalies in the Water Use Survey data. Our application of the method included the following process, which Figure 10 illustrates:

1. Compute the average of groundwater pumping for the three years prior to each annual data point (Figure 10-a). For the first three years of data, we set the three-year average equal to the average of the first three years.
2. Compute the difference (that is, residual) between the three-year average and the annual groundwater pumping value for a given year (Figure 10-b).
3. Compute the average and standard deviation of the set of residuals computed during the previous step.
4. Flag as anomalous any year where the residual from the previous three-year average (calculated during Step #2) exceeds 1.5 standard deviations from the average of the set of residuals (calculated during Step #3) (Figure 10-c)

Some benefits of the standard deviation method are that: 1) we could automate the method which resulted in rapid detection of anomalies, and 2) the method is not subjective and will not result in differing data interpretations when applied by individual reviewers. However, our application of the method does require the selection of the standard deviation coefficient value used to identify anomalies. After testing standard deviation coefficient values ranging from 1.0 to 2.0, we selected the value of 1.5 for our evaluations as it appeared to provide a more consistent match with anomalies identified during our manual review.

Another potential limitation of the method is the use of the average from the previous three-year period for each year considered. As shown in Figure 10-c, applying the standard deviation criterion identified pumping amounts in 2006 and 2013 as anomalies despite the pumping value in 2006 being similar to that from 2005 and the value in 2013 being similar to 2012. These flags occur because the three-year average includes significantly different values than the year under consideration which affects the three-year average used for comparison. Nonetheless, this potential limitation is also a strength of the method due to its incorporation of the apparent trend in pumping leading up to the year under consideration.

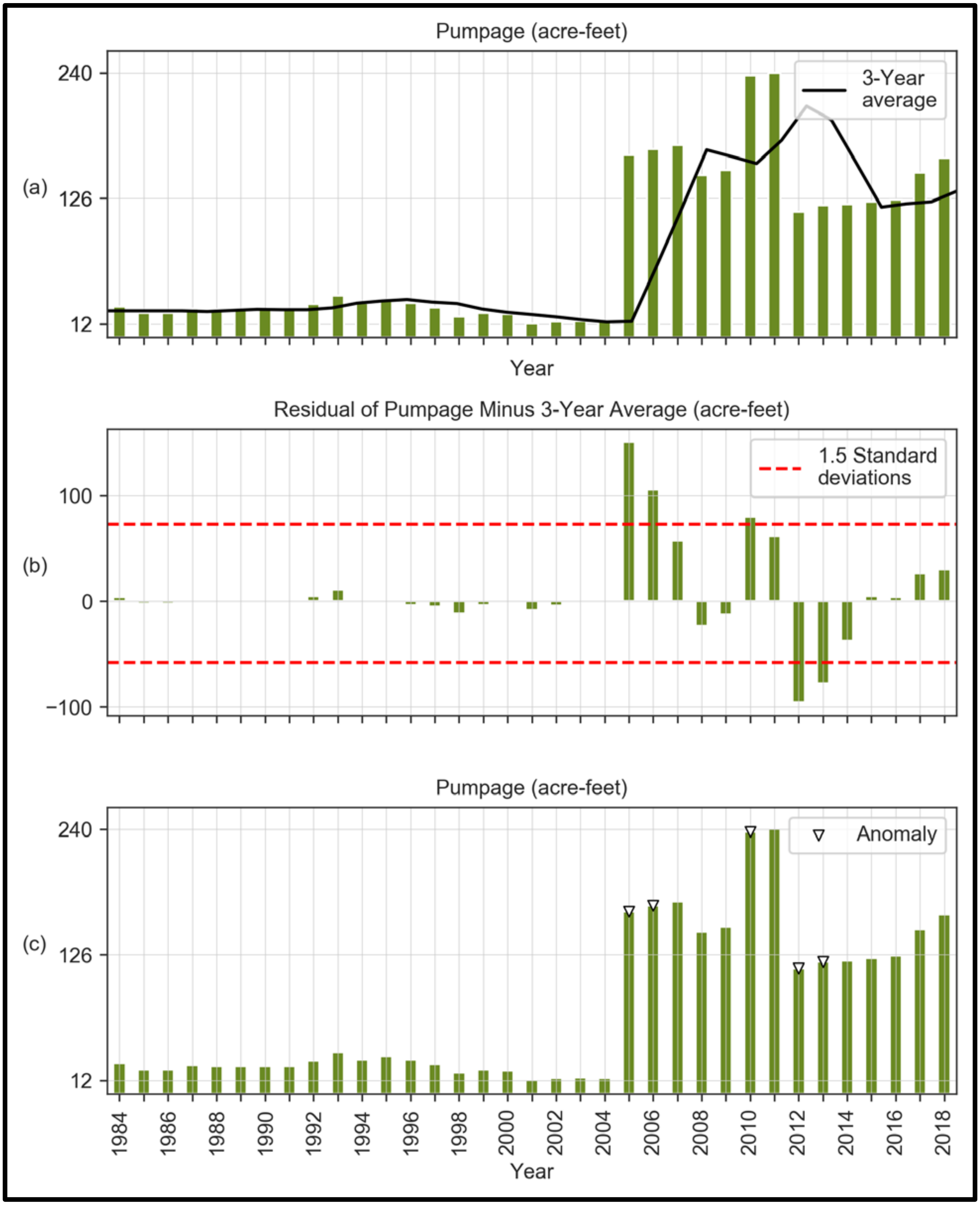


Figure 10. Example application of the standard deviation criterion: (a) raw pumping data with a computed 3 prior-year average, (b) yearly residual results compared against 1.5 standard deviations of the residual dataset, (c) raw pumping data with anomalous years flagged.

3.2.4 Other Data Evaluations

In addition to the three primary evaluations discussed above, we also explored several other methods of assessing the Water Use Survey data. The evaluations included:

- Comparison and correlation of groundwater pumpage with precipitation and land use
- Comparison of the apparent number of wells completed in an aquifer for a particular use and the amount of pumping for that use
- Separation of non-surveyed municipal and surveyed municipal water use

While some of these evaluations are informative, they did not prove universally beneficial for our analyses. Specifically, our comparisons did not yield consistent or highly-correlated relationships between the subject datasets. Some comparisons were so poorly correlated that we did not discuss the results or provide a graphic of the correlations within our county-by-county anomaly analysis (See Section 3.3) Our final pumpage dataset, as detailed in Section 5, was created without reliance on these other data evaluation methods, although it did include separate investigations of surveyed and non-surveyed municipal usage. In Section 3.3, we identified some counties for which the above listed evaluation methods provided beneficial insight. In our description of the data for each county we include a brief discussion of any insight gained through application of these other data evaluation methods. The following provides a summary of these other data evaluation methods.

Precipitation and Land Use Data

We compared two parameters derived from modeling and remote sensing techniques to the Water Use Survey groundwater production volumes for irrigation, namely, precipitation occurring over the aquifer and potentially irrigated land area. We prepared these comparisons because one would typically expect irrigation to decrease during relatively wet years and increase during relatively dry years. We note that when comparing groundwater irrigation to land use, we are not factoring in irrigation associated with surface water. As such, this approach may be more applicable in West Texas where groundwater is more prominently used for irrigation than Central to East Texas.

For the comparison, we calculated precipitation volumes over the aquifer using data collected as described in Section 2.3. We then plotted the time-series precipitation volumes with the Water Use Survey pumping data, and prepared a cross-plot and a linear regression model of the precipitation volume versus irrigation pumping for each county and aquifer combination in the study area.

Figure 11 is an example of the time-series precipitation volumes plotted with the Water Use Survey data. As expected, we observe relatively higher groundwater pumping for irrigation during dry years such as 2006, 2008, and 2011 (Figure 11). Figure 12 is an example of the time-series precipitation and pumping data as a cross-plot with a linear regression model and 95 percent confidence interval for that regression.

The linear regression model on the cross-plot of irrigation pumping and precipitation (Figure 12) shows a linear correlation coefficient ("*r*" value) of -0.41. Evans (1996) indicates that this "*r*" value suggests a moderate negative correlation with precipitation falling on the aquifer in the county (see Table 9 for the strength of the correlation associated with a particular *"r"* value). Since the *"r"* value is negative, the correlation is what we would expect with higher precipitation being associated with lower irrigation pumping. When we observe a positive *"r"* value in the dataset, it may indicate that the irrigation pumping dataset warrants further review.

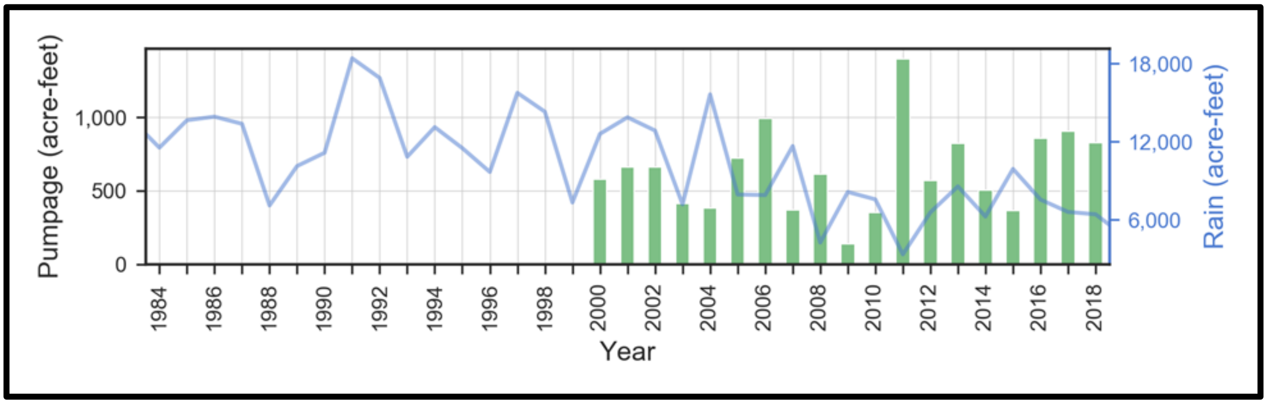


Figure 11. Travis County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

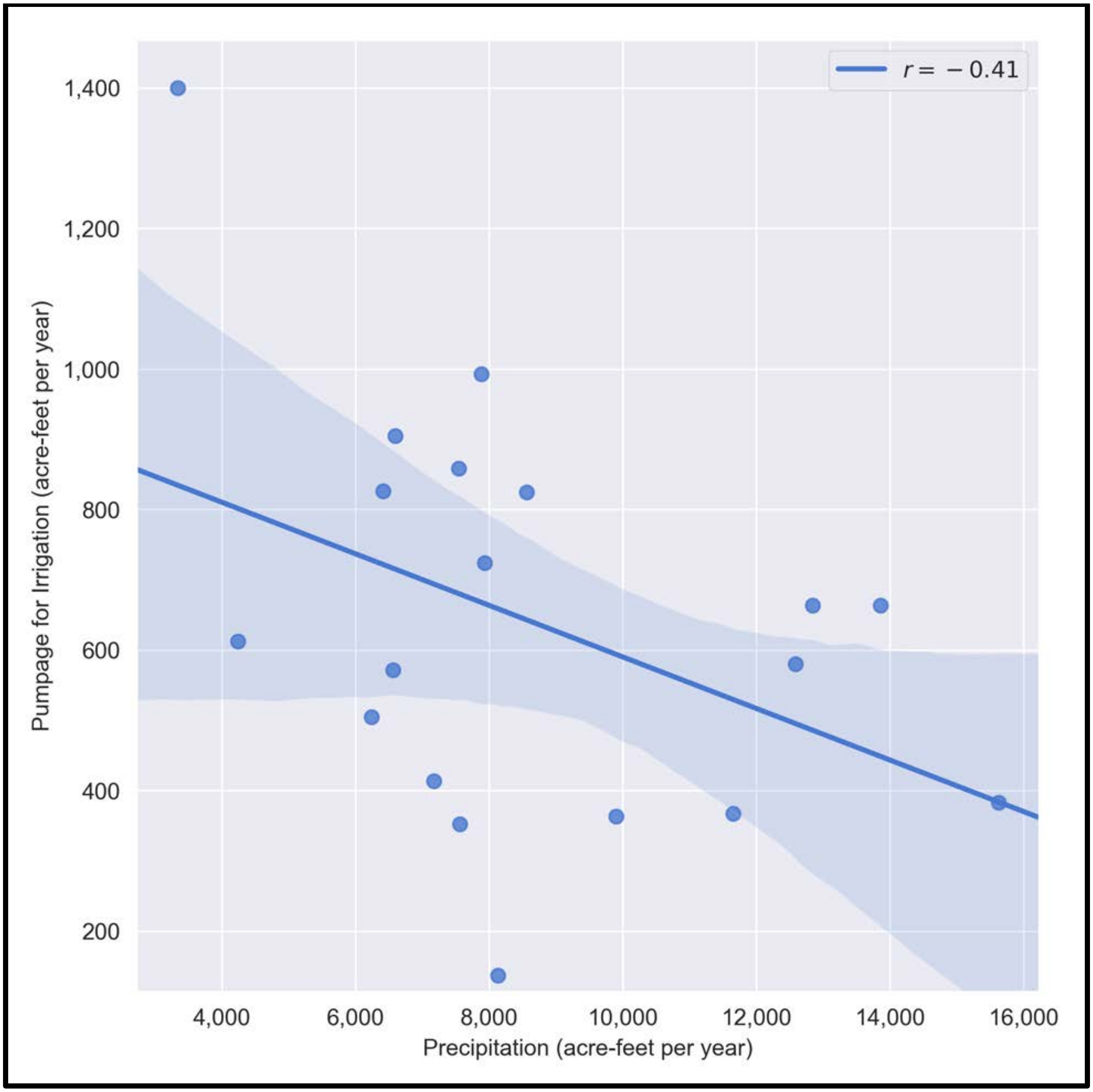


Figure 12. Travis County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

Table 9. Range in the absolute correlation value (*r*) and corresponding strength of the correlation (Evans, 1996).

Magnitude of correlation value, r	Strength of correlation
0.01 – 0.19	Very weak
0.20 – 0.39	Weak
0.40 – 0.59	Moderate
0.60 – 0.79	Strong
0.80 – 1.00	Very Strong

We performed a similar analysis by comparing the Water Use Survey irrigation pumping data with the potentially irrigated land area derived from the U.S. Geological Survey Land Use Land Cover Modeling Program (Sohl and others, 2014; Sohl and others, 2016). We prepared these comparisons because one would typically expect irrigation to increase with an increase in potentially irrigated land. For the comparison, we plotted the time-series Water Use Survey irrigation pumping data with the acres of crop, hay, and pasture land (that is, potentially irrigated land) derived from the land use datasets. We then prepared a cross-plot and a linear regression model of the potentially irrigated land versus irrigation pumping for each county and aquifer combination in the study area. Figure 13 is an example of the cross-plot and linear correlation model of the Water Use Survey irrigation pumping data and the potentially irrigated land area. A correlation value of 0.73 suggests a strong positive correlation of pumping for irrigation and potentially irrigated land area in Bandera County. Since the *"r"* value is positive, the correlation is what we would expect with greater areas of potentially irrigated lands associated with higher irrigation pumping. When we observe a negative *"r"* value in the dataset, it may indicate that the irrigation pumping dataset warrants further review.

For the purpose of this project phase, we analyzed any correlations classified as moderate to very strong for both precipitation and potentially irrigated land area (see Table 9). The correlations determined using this method do not establish causation of pumping for irrigation but rather provide hints as to what to consider for determining causation during future phases of the project.

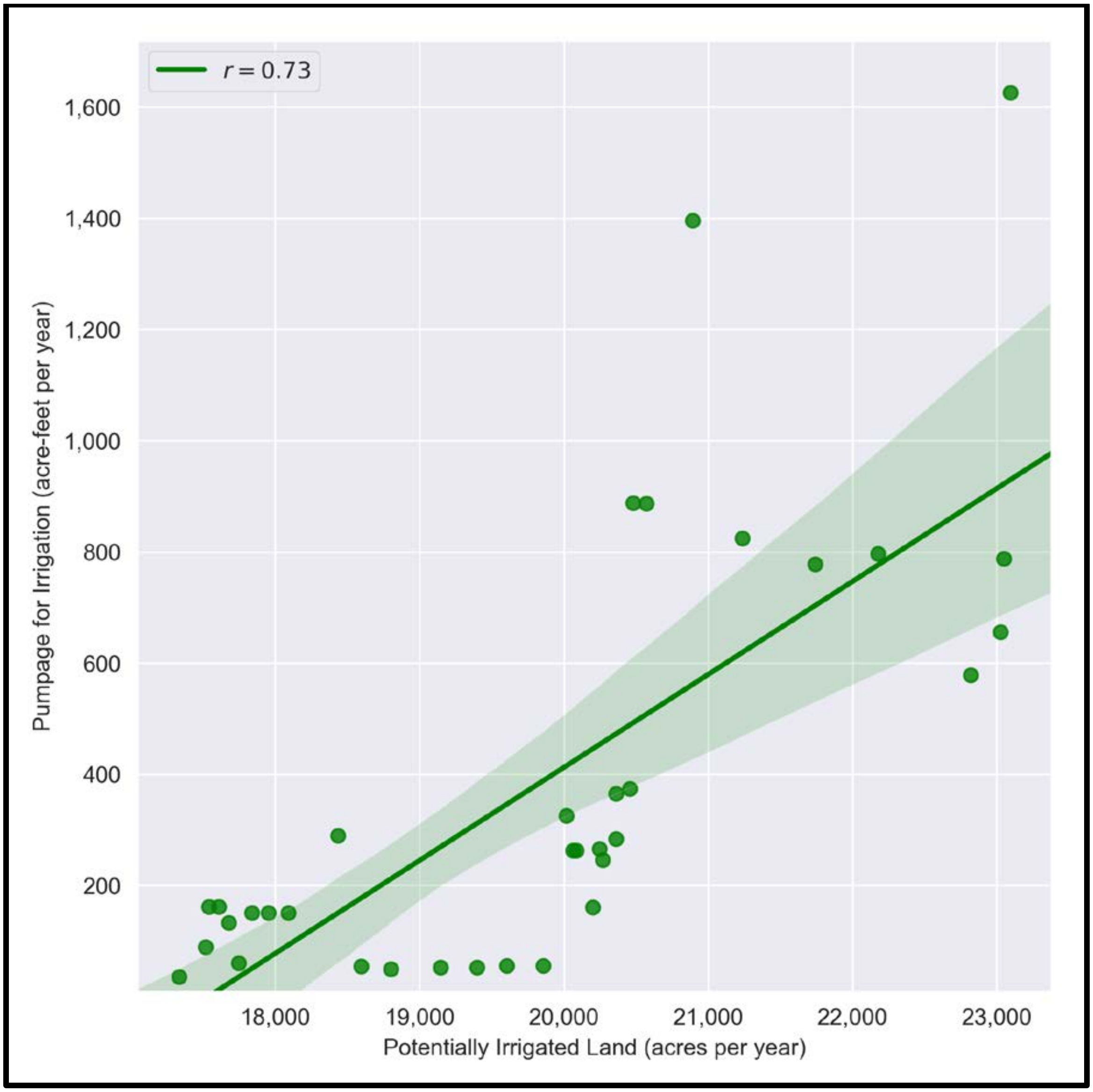


Figure 13. Bandera County Trinity (Hill Country) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Well Completions

In general, we expect an increase in the number of wells would correlate to an increase in groundwater pumping. To review the trend in well completions and the Water Use Survey groundwater pumpage data, we plotted the cumulative total number of wells completed each year with the Water Use Survey pumping data for each county, aquifer, and use combination in the study area. If the apparent trend in the number of wells in an aquifer for a particular use was significantly dissimilar from the trend in pumping, then we noted the Water Use Survey data as anomalous. We note that when comparing groundwater irrigation to well completions, we are not factoring in irrigation associated with surface water. As such, this approach may be more applicable in West Texas where groundwater is more prominently used for irrigation than Central to East Texas.

Figure 14 is an example illustrating the number of well completions and the Water Use Survey data for the Lipan Aquifer in Tom Green County. Upon review of the information shown on Figure 14, we observe the addition of several irrigation and municipal wells since 2015 but groundwater pumping for those uses did not appear to increase correspondingly. The addition of wells without a corresponding increase in pumping suggests the Water Use Survey data is anomalous and may warrant further review.

We included rural domestic wells on the plot with the total number of wells and total pumping (Figure 14-f). For this report, we did not include them as part of the municipal wells despite rural domestic pumping being included in the non-surveyed municipal use amounts. Rather, we only included public supply wells with the municipal pumping as these wells typically produce at a much higher rate than a domestic well and the trend of public supply wells is generally a better indicator of an anomaly in the Water Use Survey Data for municipal use. In subsequent project phases, we will evaluate the rural domestic amount of water use, utilizing information regarding the wells completed for domestic use, separately from the surveyed municipal use.

During our analysis, we are cognizant of potential limitations with the comparison. For example, since the comparison is strictly between well completions and pumping, it does not consider transitions to alternative water supplies. In addition, we assume that all the wells completed in the aquifer continued production in perpetuity following completion and that any well without a completion date record, was completed and pumping prior to 1984. Despite these limitations, the evaluation provided an additional means for identifying anomalous data.

Surveyed and Non-Surveyed Municipal Water Use

As discussed in Section 3.1, the TWDB Water Use Survey Program includes rural domestic pumping estimates as part of the non-surveyed municipal data (Billingsley, 2019). While the non-surveyed municipal use may contain some amounts for users that did not respond to the Water Use Survey, it some cases it appears to primarily represent just the rural domestic use. To illustrate the relative amounts of non-surveyed municipal use and surveyed municipal use, we plotted the values separately beginning in survey year 2000.

Figure 15 illustrates a case where the non-surveyed municipal use represents all the municipal use after 2000. As stated in Section 0, prior to 2000 non-surveyed municipal use was not included in the Water Use Survey data; however, Figure 15 presents an example where we should focus future analysis of anomalies on the rural domestic use. Figure 16 is an example of the opposite case where the non-surveyed municipal use is insignificant and would likely not warrant significant investigation of any anomalies. As these examples illustrate, while the difference between the non-surveyed and surveyed municipal use amounts can be significant, we limited our evaluation of the difference to manual review and maintained the combined surveyed and non-surveyed municipal use for the year-to-year change and standard deviation analyses.

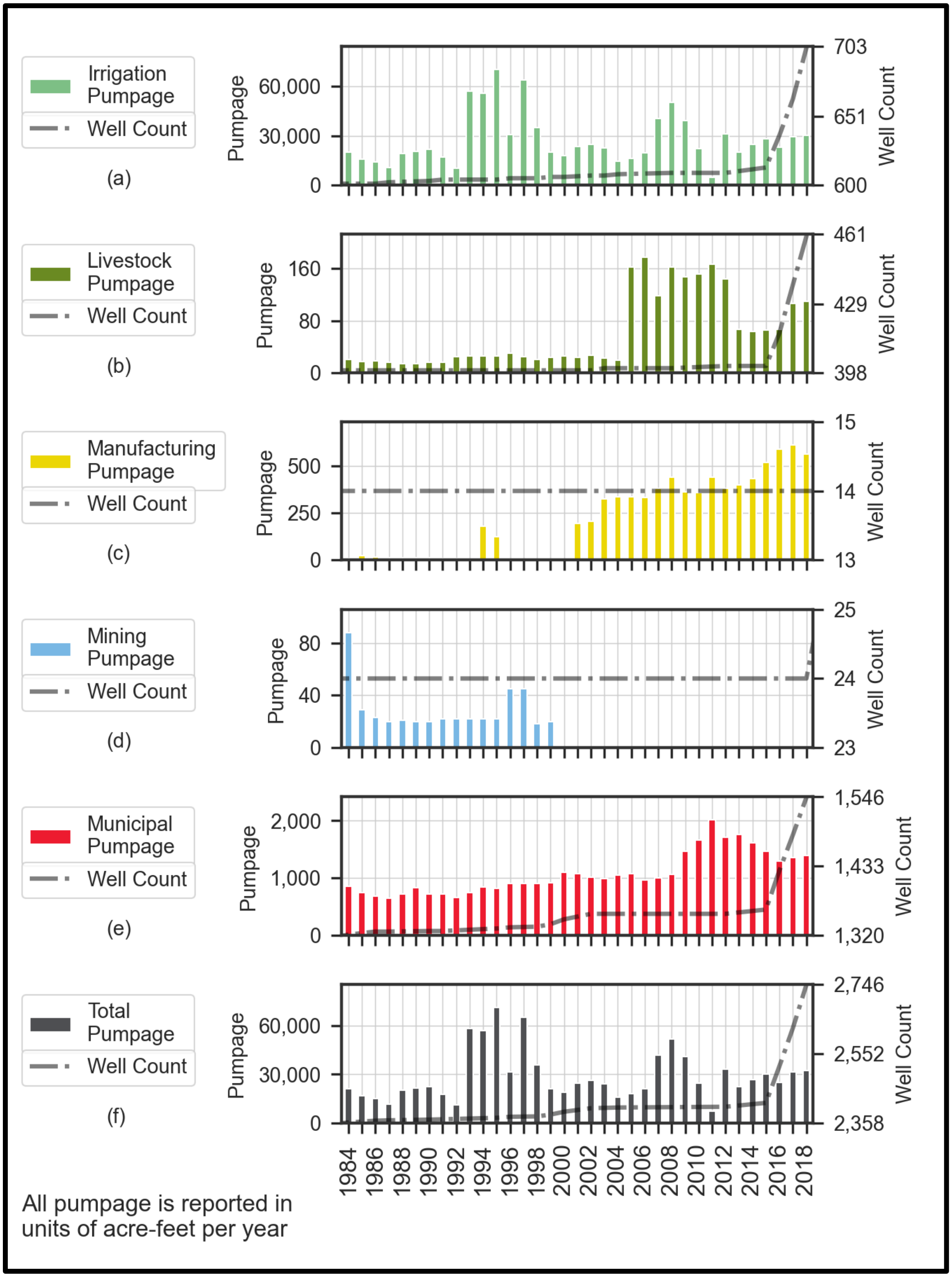


Figure 14. **Tom Green County Lipan Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer as recorded in publicly available databases.**

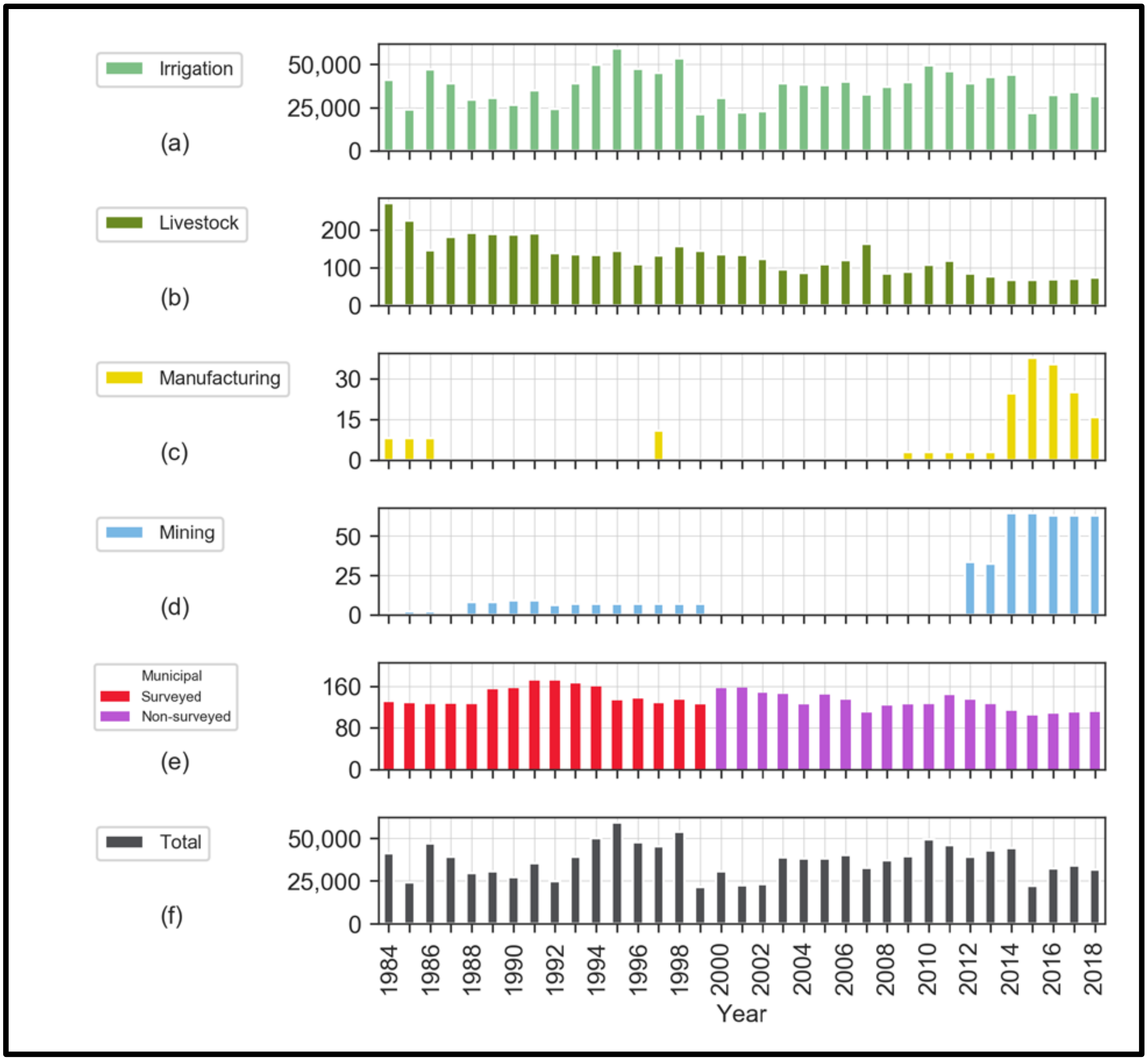


Figure 15. **Glasscock County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

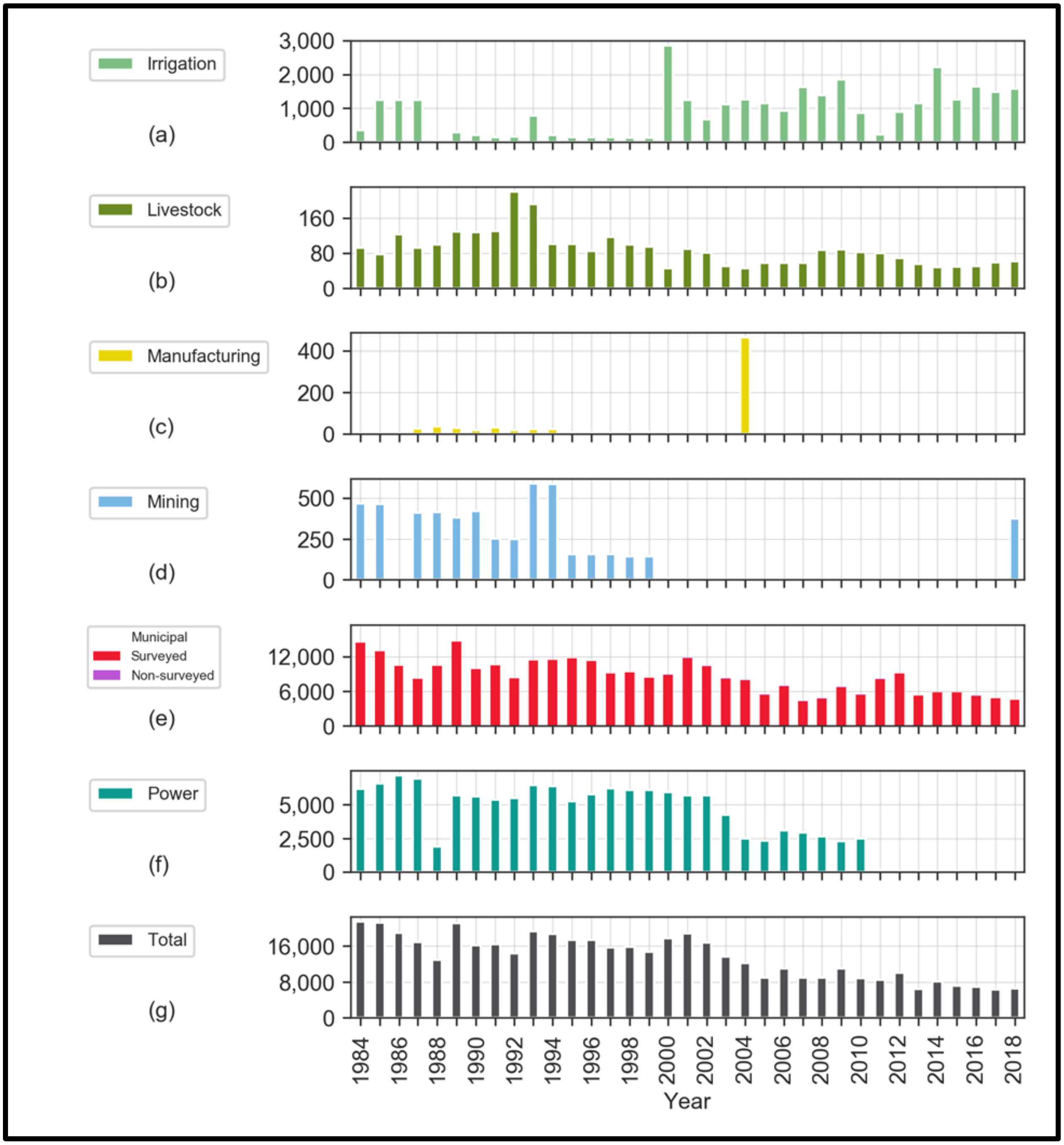


Figure 16. **Ward County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

3.3 County Evaluations

The following sections provide a brief discussion of the results of our evaluations of the TWDB Water Use Survey data. We summarize the information for counties with no pumping in the study area in Section 3.4.

3.3.1 Andrews County

A portion of the Edwards-Trinity (Plateau) Aquifer is present in the southern portion of Andrews County (underlying about 11 percent of the county by area). The Pecos Valley Aquifer underlies the western portion of the county, spanning approximately 18 percent of the county area. In total, our project study area encompasses approximately 29 percent of Andrews County. Figure 17 illustrates the extent of the study area aquifers in Andrews County.

Groundwater pumping estimates from the Water Use Survey indicate that total pumping from the Edwards-Trinity (Plateau) Aquifer reaches up to approximately 400 acre-feet per year (Figure 18). The only reported groundwater uses from this aquifer are for livestock, mining, and municipal needs, with water usage for mining in 1985 through 1988 being approximately 20 times larger than for livestock and municipal purposes. There is not any surveyed municipal use after 2000 for the Edwards-Trinity (Plateau) Aquifer in Andrews County and only a relatively small amount of non-surveyed use. It is also notable that mining usage has not been reported since 1988, and municipal usage has not been reported since 2005.

The year-to-year change analysis (Figure 19) and standard deviation analysis (Figure 20) flagged many anomalies in the data for the Edward-Trinity (Plateau) Aquifer. However, due to the low amounts of production, significant additional review may not be warranted. The primary anomaly of interest for the Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer pumping data is the unreported values for mining and municipal use.

Groundwater pumping estimates from the Water Use Survey indicate that total pumping from the Pecos Valley Aquifer is greater than that from the Edwards-Trinity (Plateau) Aquifer being up to 2,000 acre-feet per year (Figure 21). Like the Edwards-Trinity (Plateau) Aquifer, livestock, mining, and municipal are the three reported uses of groundwater from the Pecos Valley Aquifer. Data review indicates pumping for livestock use declined from approximately 50 acre-feet per year in 2000 to about five acre-feet per year in 2001. There is also an abrupt increase in municipal pumping from 1999 to 2000, of similar magnitude as the change in livestock use. In 2000, the first reported value for non-surveyed municipal use is more than 50 acre-feet and it continues through 2018 as the largest component of the total municipal use from the Pecos Valley Aquifer in Andrews County. A final observation is that the Pecos Valley Aquifer pumping for mining use showed an abrupt decline in pumping from nearly 2,000 acre-feet in 1984 to an average of less than 100 acre-feet per year in subsequent years.

The year-to-year change analysis (Figure 22) and standard deviation analysis (Figure 23) flagged many anomalies in the data for the Pecos Valley Aquifer. Table 10 details the years identified as having anomalous pumping amounts for Andrews County for both the Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer.

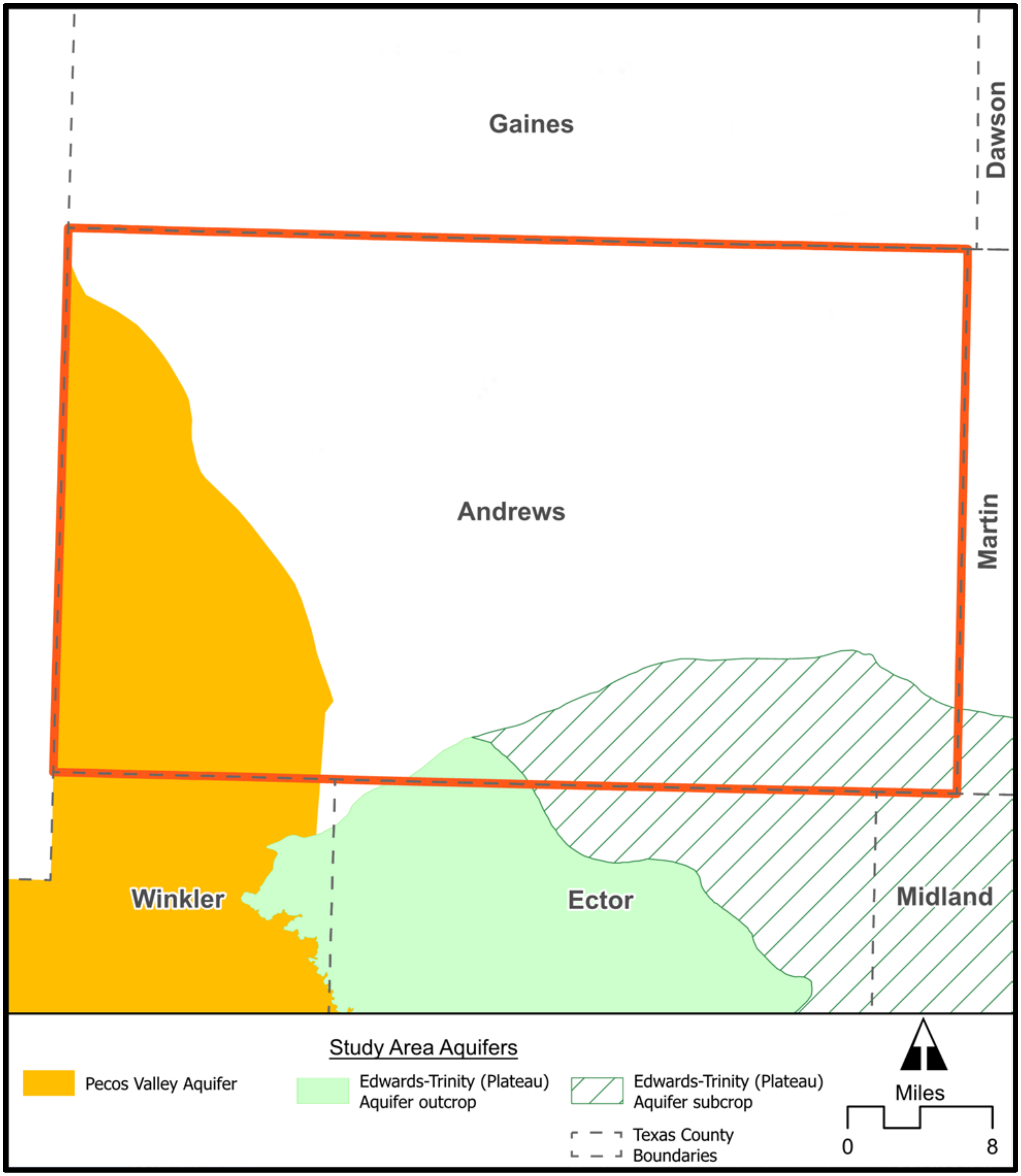


Figure 17. Andrews County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer.

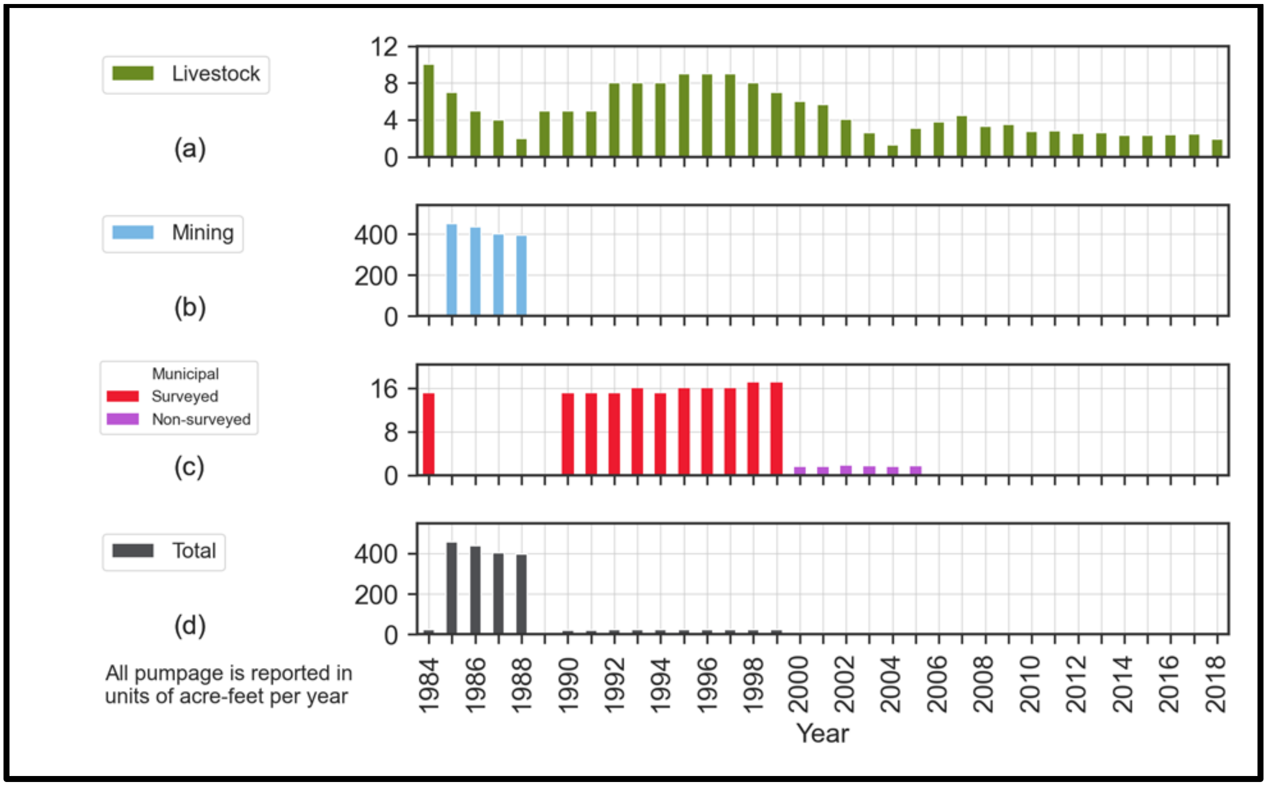


Figure 18. **Andrews County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

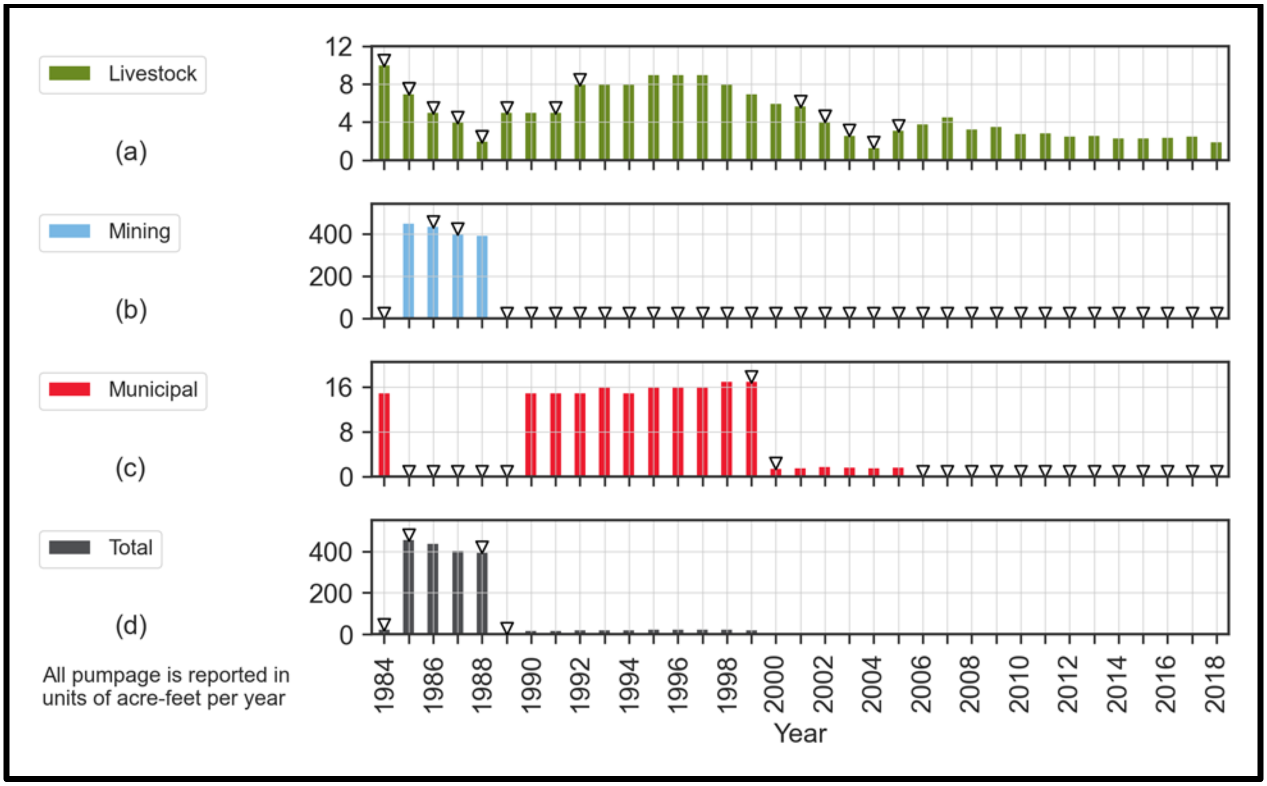


Figure 19. **Andrews County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

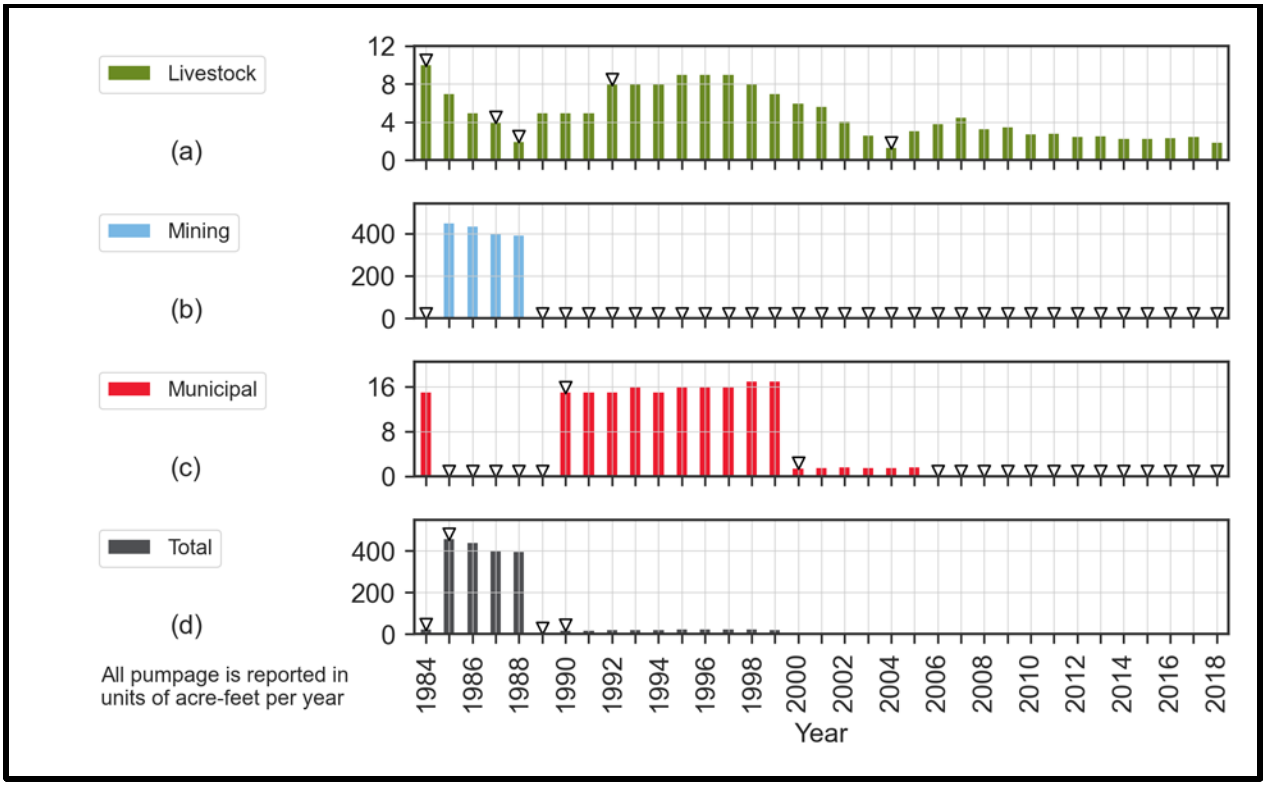


Figure 20. Andrews County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

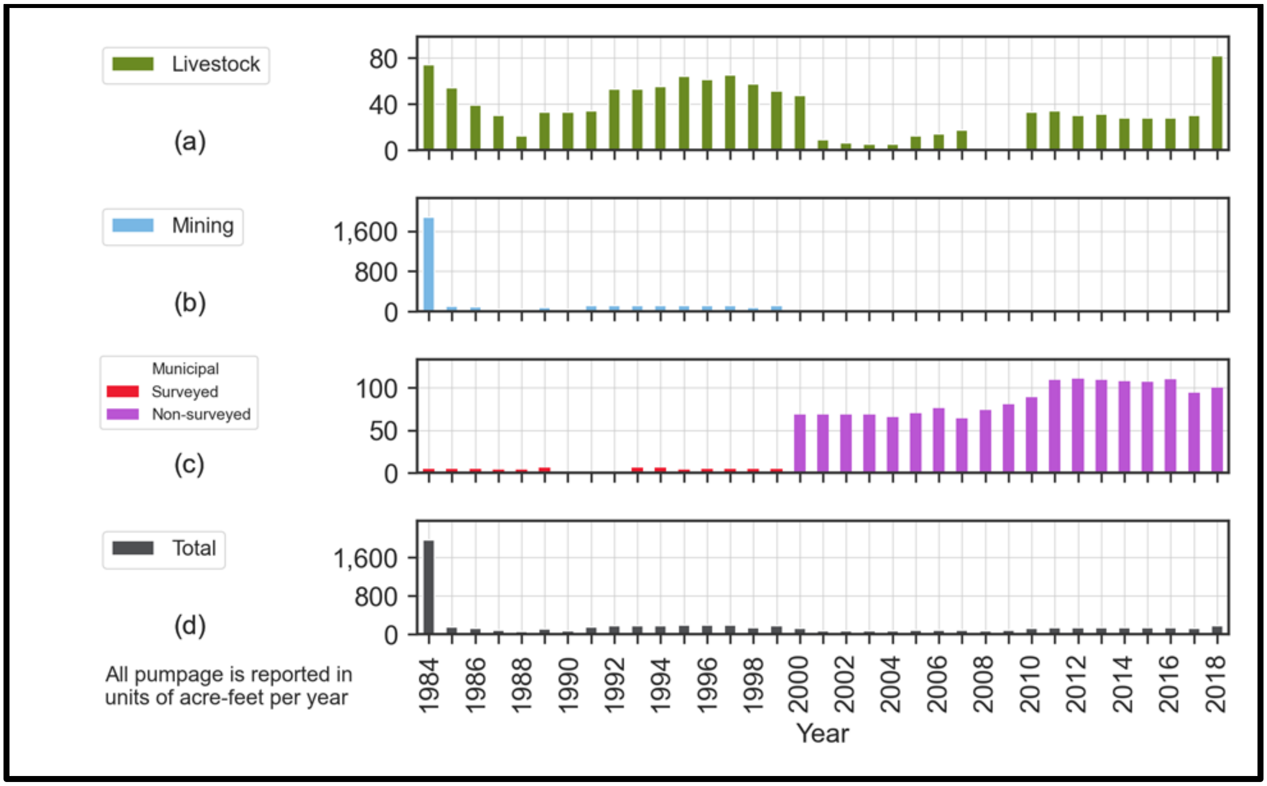


Figure 21. Andrews County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

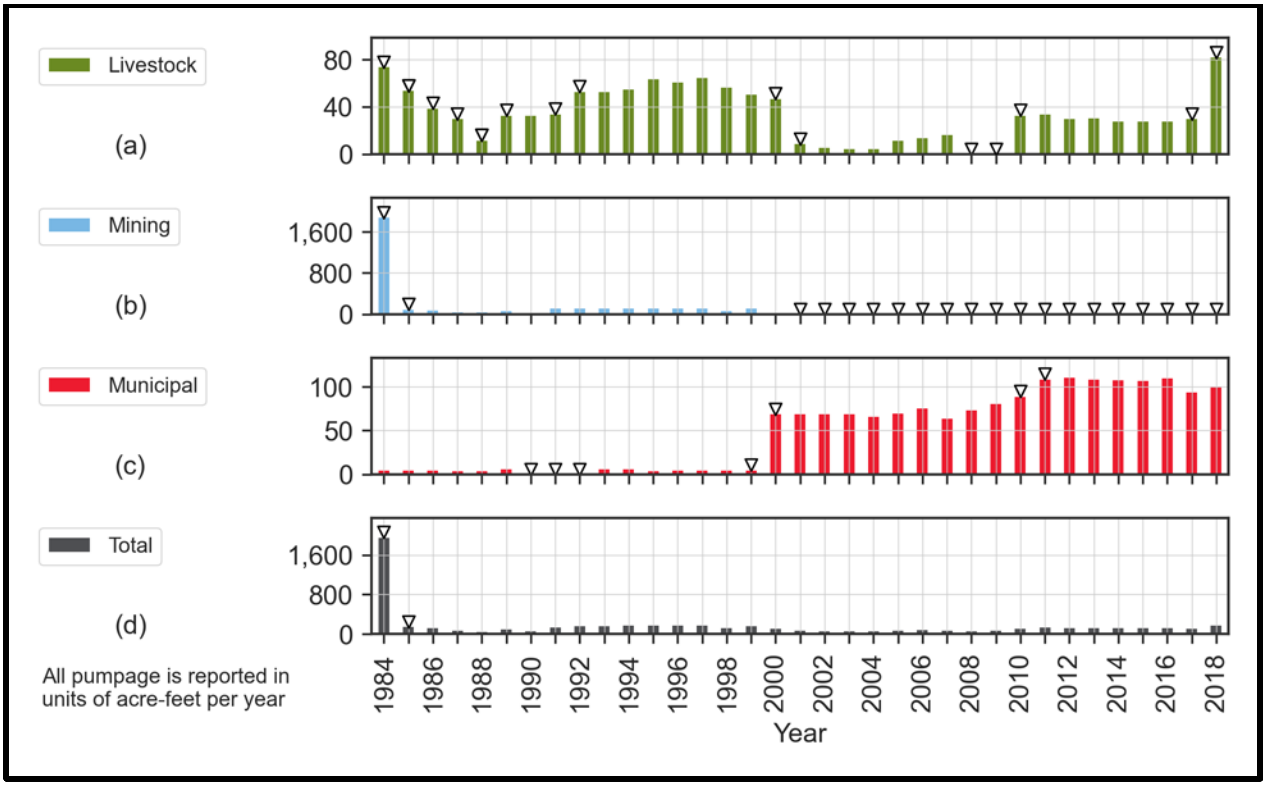


Figure 22. Andrews County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

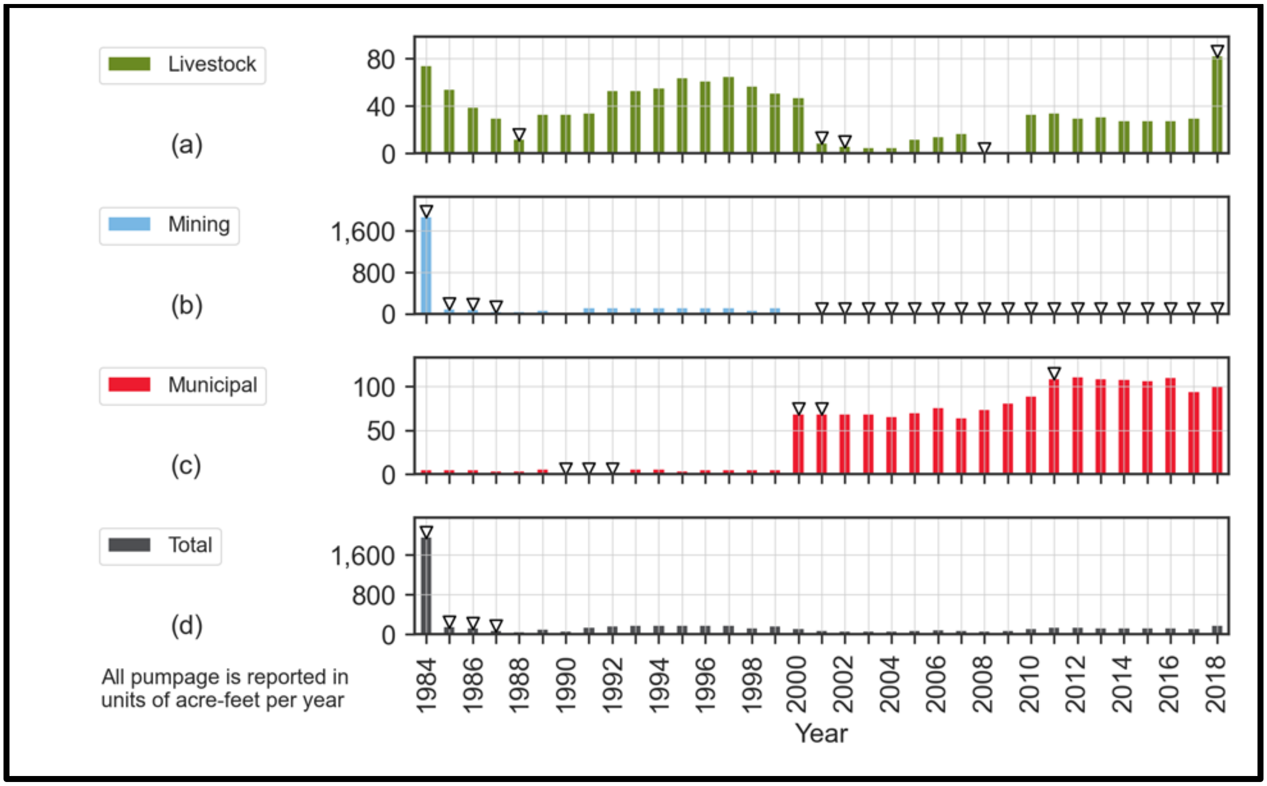


Figure 23. Andrews County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 10. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Andrews County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	None	1984-1986, 1988, 1989, 1992,2002, 2003, 2005	1984, 1987, 1988, 1992, 2004
	Mining	1984, 1989-2018	1984, 1985, 1987, 1989-2018	1984, 1989-2018
	Municipal	1985-1989, 2000, 2006-2018	1984-1990, 2000, 2006-2018	1985-1990, 2000, 2006-2018
Pecos Valley	Livestock	2008, 2009	1984-1986, 1988, 1989, 1992, 2001, 2008, 2010, 2018	1988, 2001, 2002, 2008, 2009, 2018
	Mining	1985, 2000-2018	1984, 1985, 2001-2018	1984-1987, 2001-2018
	Municipal	1990-1992, 2000	1990-1992, 2000, 2011	1990-1992, 2000, 2001, 2011

3.3.2 Atascosa County

Only a small portion of the subcrop area of the Trinity (Hill Country) and overlying Edwards (Balcones Fault Zone) aquifers are present in the northwestern corner of Atascosa County (see Figure 24). The Carrizo Sand is the principal aquifer in the county with three other aquifers not included in this study (the Wilcox Group, Queen City Sand, and Sparta Sand) supplying smaller amounts of groundwater (Alexander, Jr. and White, 1966). Groundwater pumping estimates from the TWDB Water Use Survey database indicate that there is not any production from the Trinity (Hill Country) Aquifer. However, as shown on Figure 25, total pumping from the Edwards (Balcones Fault Zone) Aquifer is estimated to be up to approximately 2,000 acre-feet per year.

As shown in Figure 25, irrigation and municipal are the only two uses of Edwards (Balcones Fault Zone) Aquifer groundwater identified in the Water Use Survey data. Irrigation use was first reported in 1994 and then ranged from approximately 1,000 to 1,500 acre-feet between 1994 through 2002. In 2003 the estimated irrigation pumping declined by nearly 1,000 acre-feet and subsequently rarely exceeded 500 acre-feet per year through 2018.

Pumping from the Edwards (Balcones Fault Zone) Aquifer for municipal use appears relatively consistent from 1984 through 2010. During this period, reported municipal use ranged from approximately 400 to 600 acre-feet per year. However, for two years during this period (2006 and 2007) and for 2011 through 2018, there was not any reported pumping. Municipal water use in the county is almost entirely surveyed, there is only a relatively small amount of non-surveyed municipal use from 2000 to 2005.

The year-to-year change analysis (Figure 26) and standard deviation analysis (Figure 27) identified many of the same potential data anomalies as identified in our manual review. The year-to-year change analysis identifies some years for review that our manual review and standard deviation analysis did not flag (for example, 2012 irrigation pumping). Table 11 provides the years identified as having anomalous pumping amounts for Atascosa County.

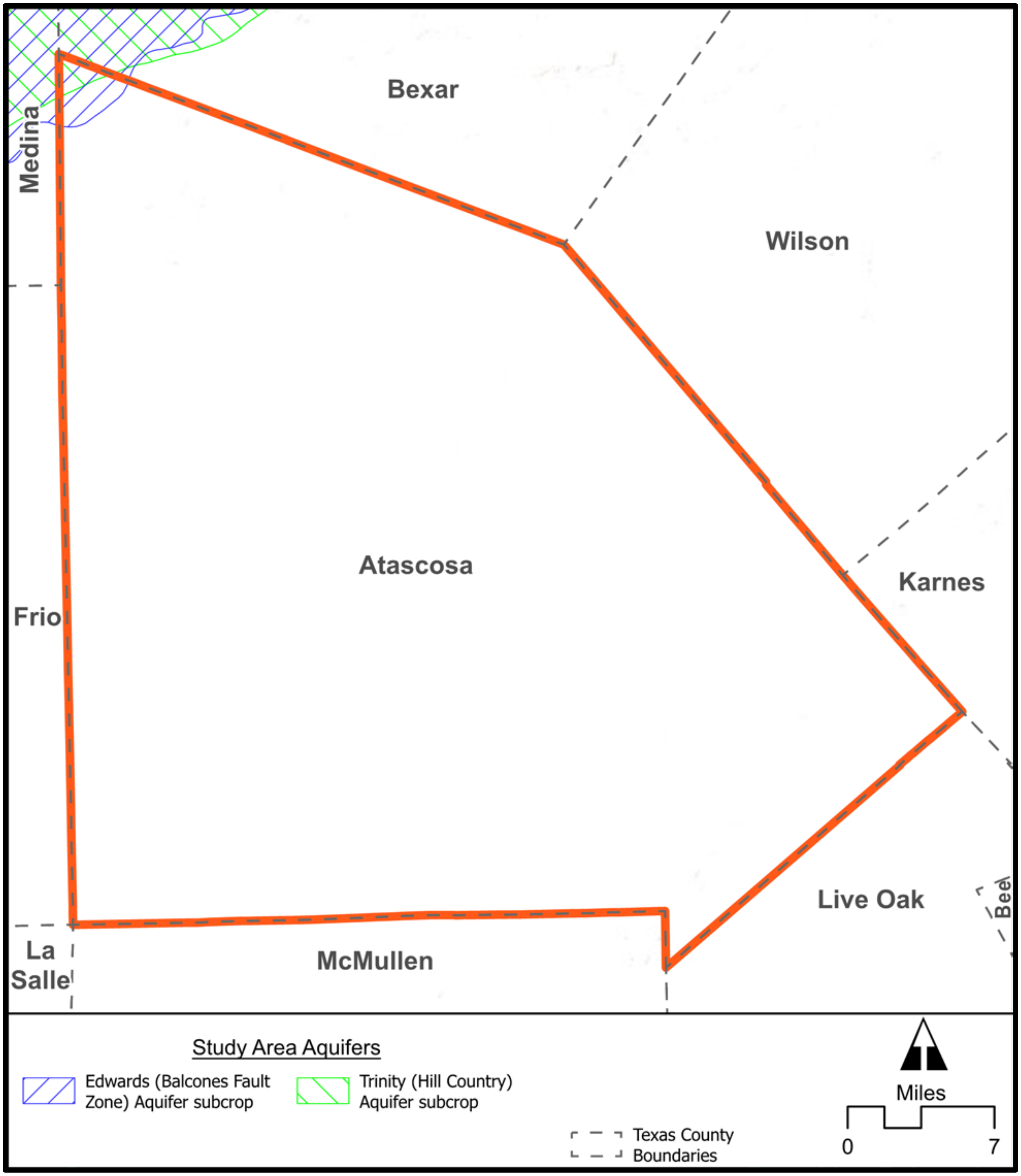


Figure 24. Atascosa County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

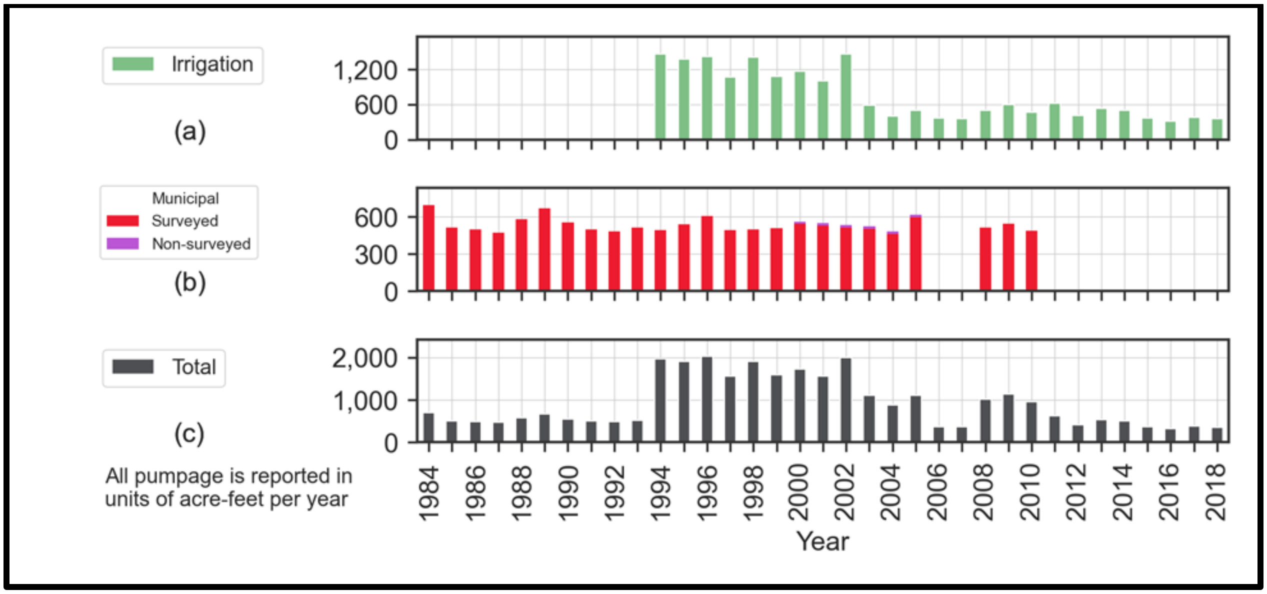


Figure 25. **Atascosa County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

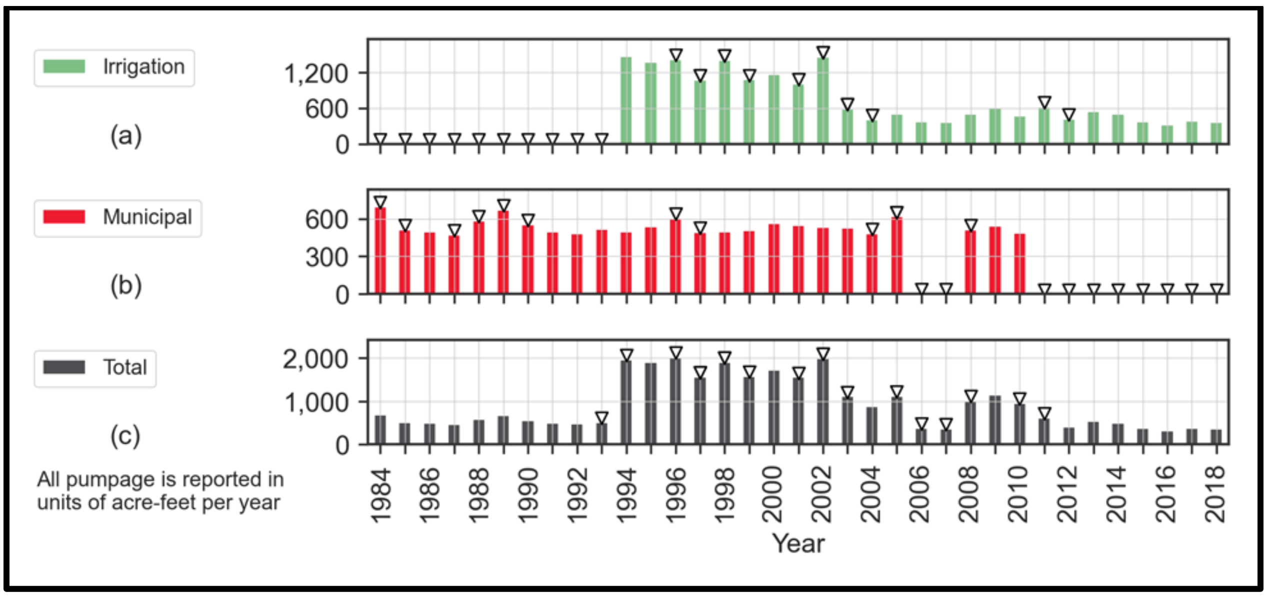


Figure 26. **Atascosa County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

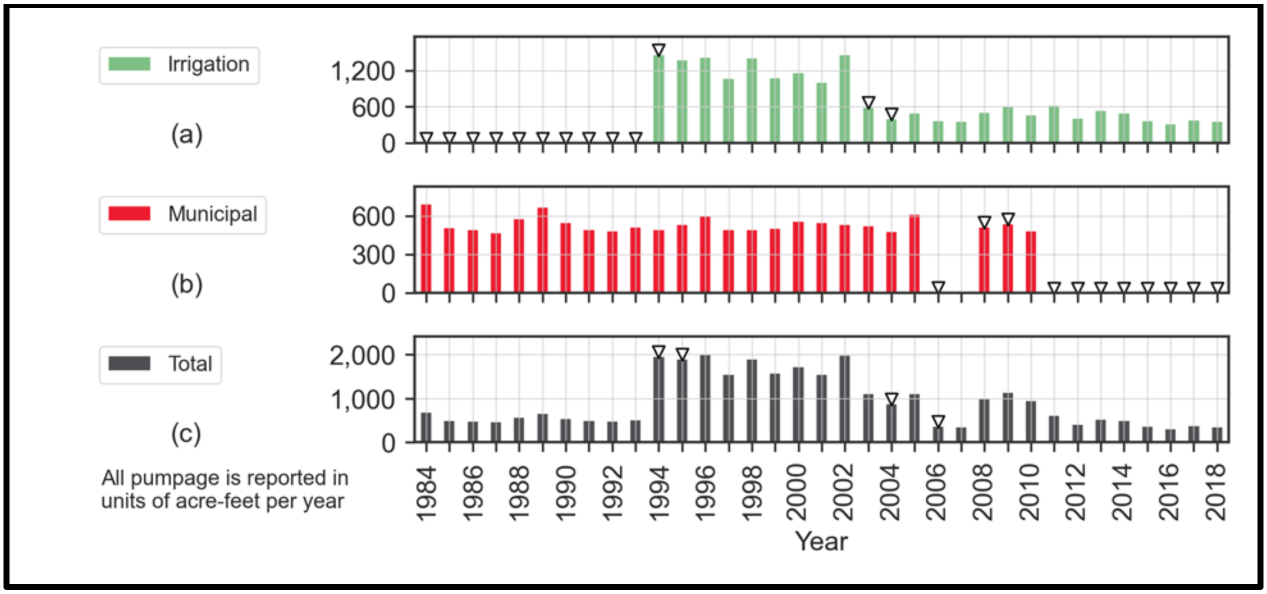


Figure 27. **Atascosa County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 11. **Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Atascosa County.**

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	1984-1993, 2003	1984-1994, 1997-1999, 2002-2004, 2012	1984-1994, 2003, 2004
	Municipal	2006, 2007, 2011-2018	1984, 1985, 1988, 1990, 1997, 2005, 2006, 2008, 2011-2018	2006, 2008, 2009, 2011-2018

3.3.3 Bandera County

The Edwards-Trinity (Plateau) Aquifer is present in the northwestern portion of Bandera County and spans approximately 26 percent of the county area. The remaining 74 percent of the county area consists of outcrop of the Trinity (Hill Country) Aquifer. Figure 28 illustrates the extent of the study area aquifers in the county.

Groundwater pumping estimates from the Water Use Survey database indicate that maximum total pumping from the Edwards-Trinity (Plateau) Aquifer was approximately 200 acre-feet per year during the study period (Figure 29). As shown on Figure 29, municipal and livestock uses are the only reported uses of groundwater from the Edwards-Trinity (Plateau) Aquifer within Bandera County. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, surveyed municipal use for the Edwards-Trinity (Plateau) Aquifer decreased and non-surveyed use constituted most of the municipal water use.

The year-to-year change analysis (Figure 30) and standard deviation analysis (Figure 31) flagged anomalies in the pumpage data for the Edwards-Trinity (Plateau) Aquifer in Bandera County. Specifically, the analyses flagged pumping data for livestock use in 2004 through 2006 as data indicated a large increase with respect to prior year pumping. Municipal pumping also increased notably after 2000, peaking in 2005 and then decreasing annually through 2018, with multiple years flagged as anomalies over this period.

Groundwater pumping estimates from the Water Use Survey database indicate that the maximum total pumping within Bandera County from the Trinity (Hill Country) Aquifer was approximately 4,000 acre-feet per year in 2011 (Figure 32). As shown on Figure 32, irrigation, livestock, manufacturing, mining, and municipal use are the primary uses of groundwater from the Trinity (Hill Country) Aquifer within Bandera County, with the majority of water pumped for municipal use. Since 2000, surveyed municipal use for the Trinity (Hill Country) Aquifer decreased and non-surveyed use constituted most of the municipal water use.

The year-to-year change analysis (Figure 33) and standard deviation analysis (Figure 34) flagged many anomalies in the Bandera County pumping data for the Trinity (Hill Country) Aquifer. These analyses identified anomalies in irrigation use data in 2009, 2011, 2012, and 2018. The automated analyses also flagged anomalies in both livestock and municipal use data, yet our manual review did not identify many of these same potential data anomalies.

Potentially irrigated land in Bandera County over the Trinity (Hill Country) Aquifer correlates linearly to groundwater pumpage from the Trinity (Hill Country) Aquifer for irrigation use. Figure 35 indicates that as the area of potentially irrigated land over the Trinity (Hill Country) Aquifer increased in the county, reported pumpage for irrigation also increased. Figure 36 indicates a linear correlation value (“r”) of 0.73 between potentially irrigated land area over the Trinity (Hill Country) Aquifer and groundwater pumpage for irrigation use. This strong positive correlation reinforces the observation that pumpage from the Trinity (Hill Country) Aquifer for irrigation in Bandera County has tended to increase as potentially irrigated land located over Trinity (Hill Country) Aquifer has increased.

Table 12 provides the years identified as having anomalous pumping amounts for Bandera County, from both the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer.

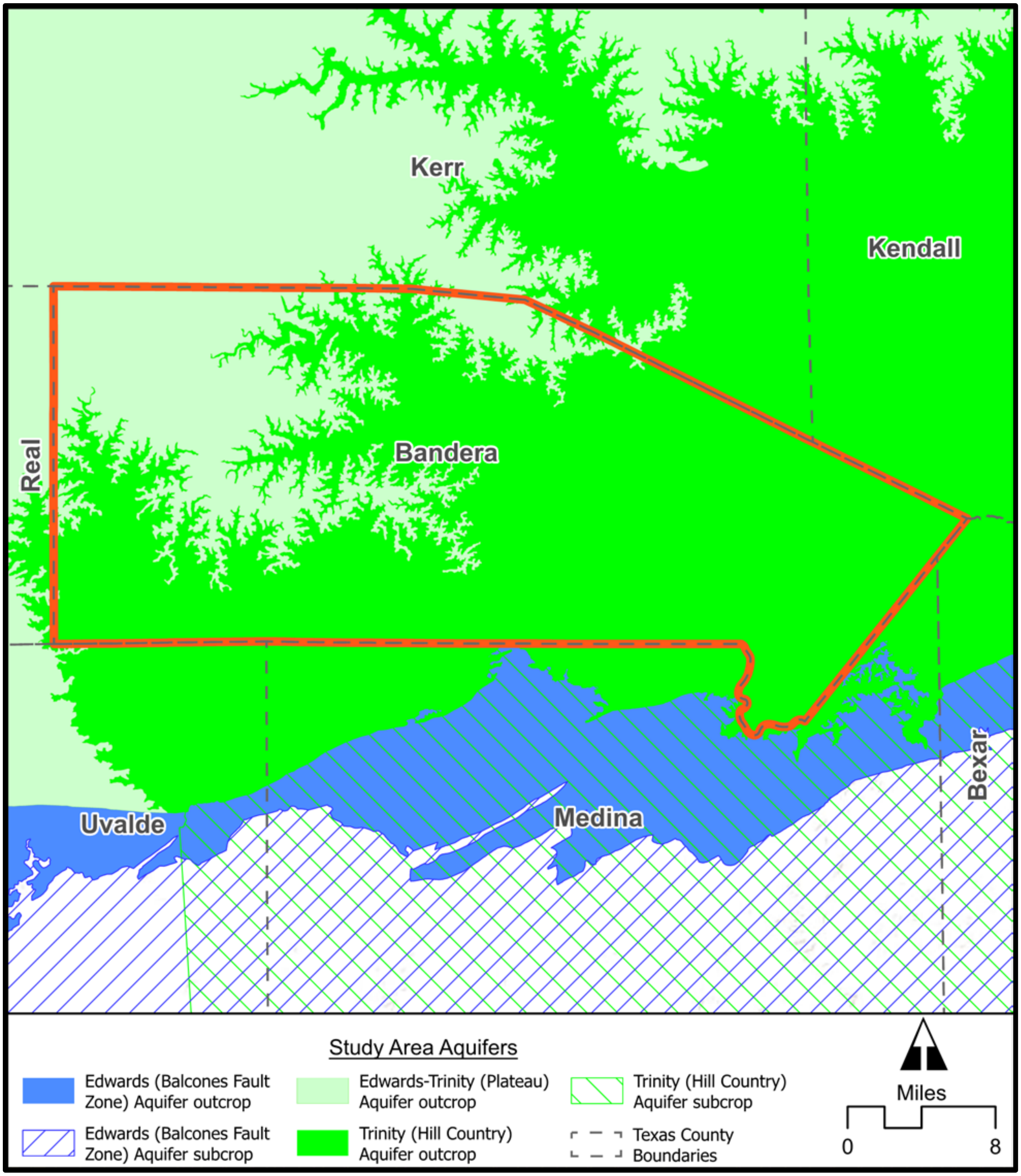


Figure 28. Bandera County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer.

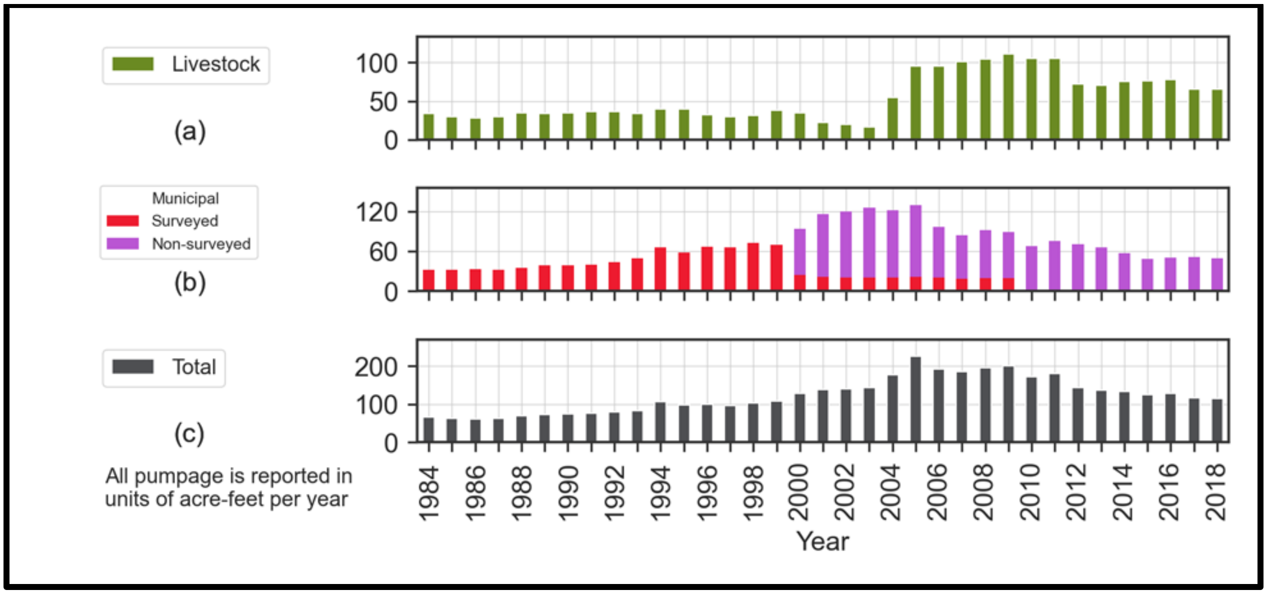


Figure 29. **Bandera County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

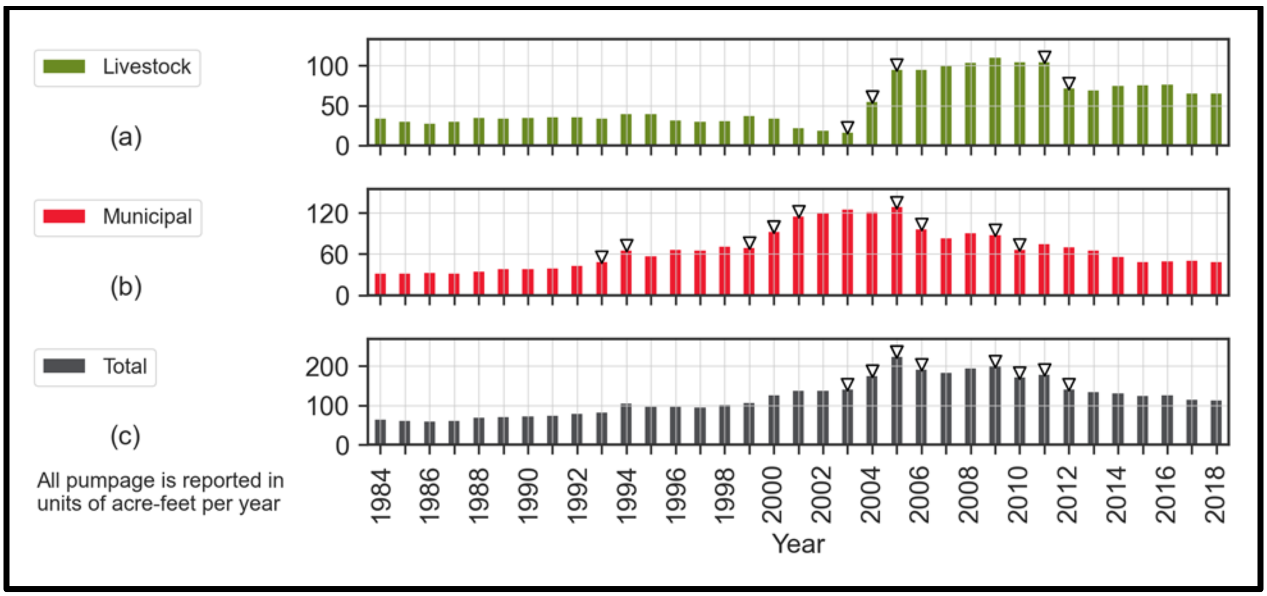


Figure 30. **Bandera County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

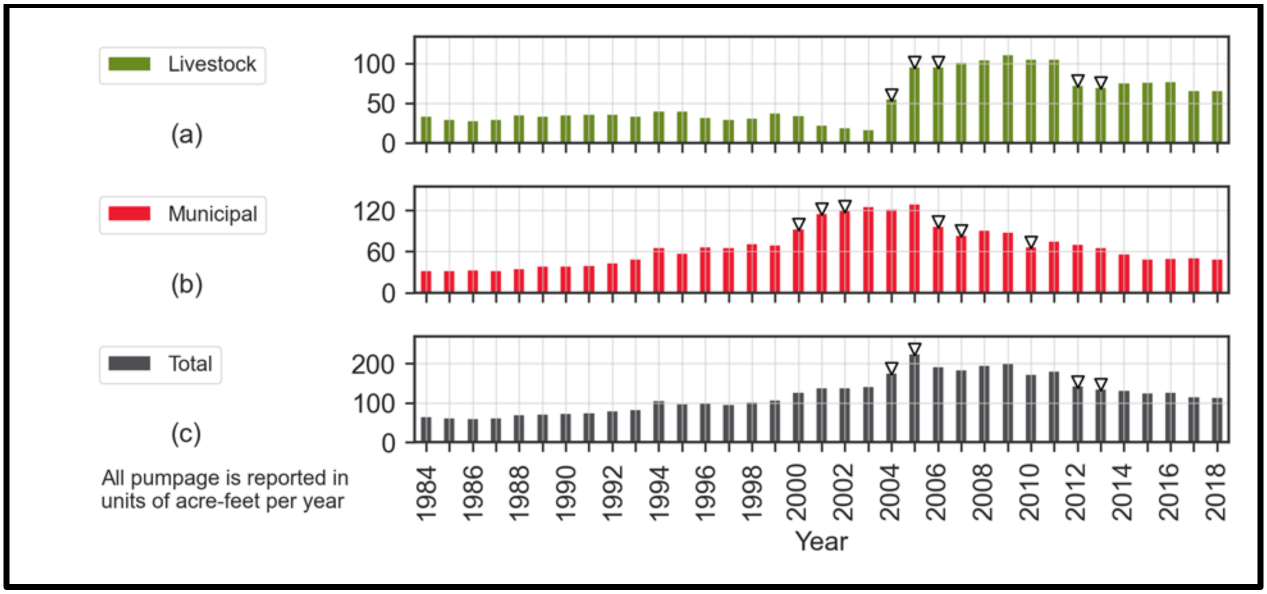


Figure 31. Bandera County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

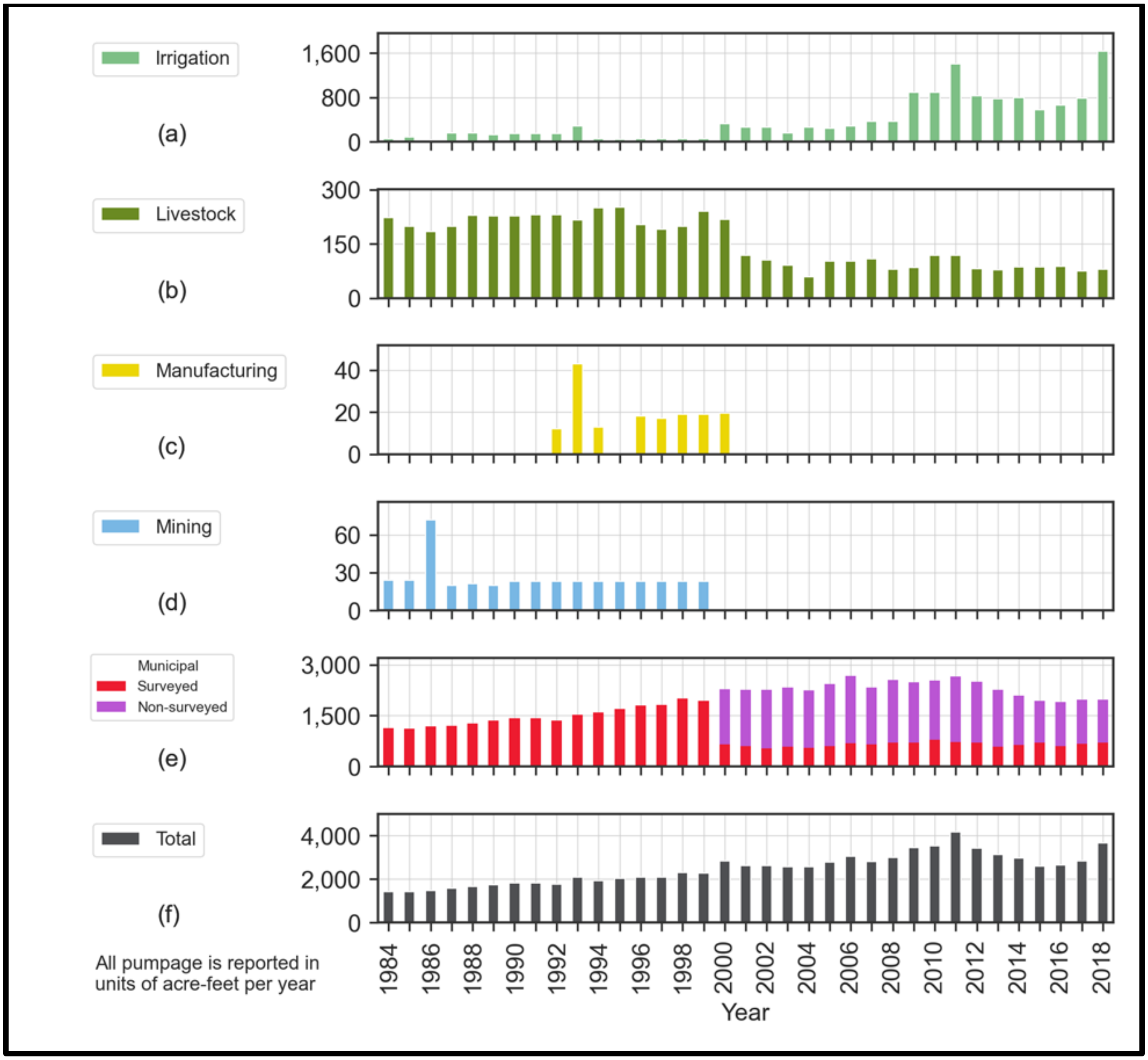


Figure 32. Bandera County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

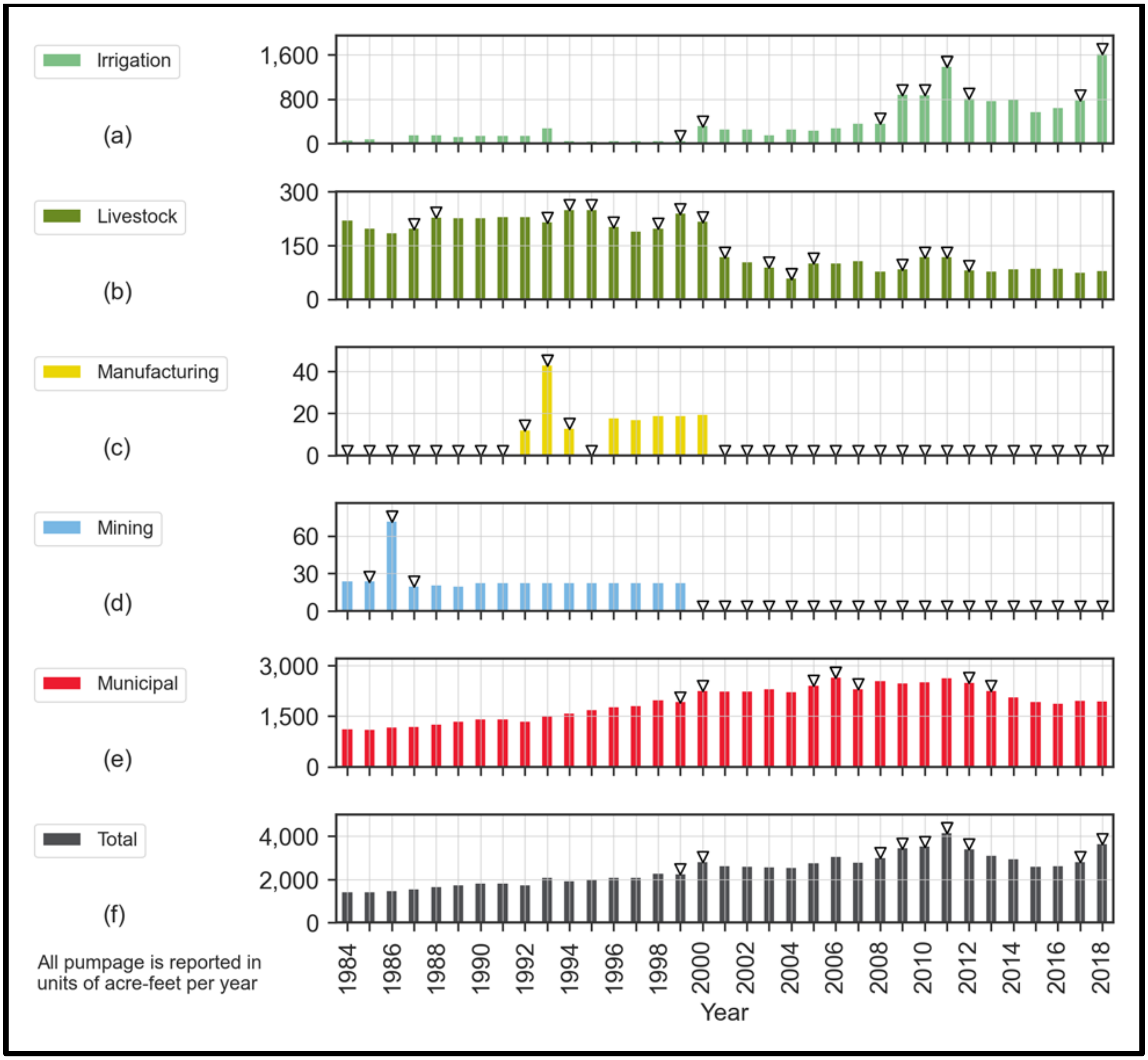


Figure 33. **Bandera County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

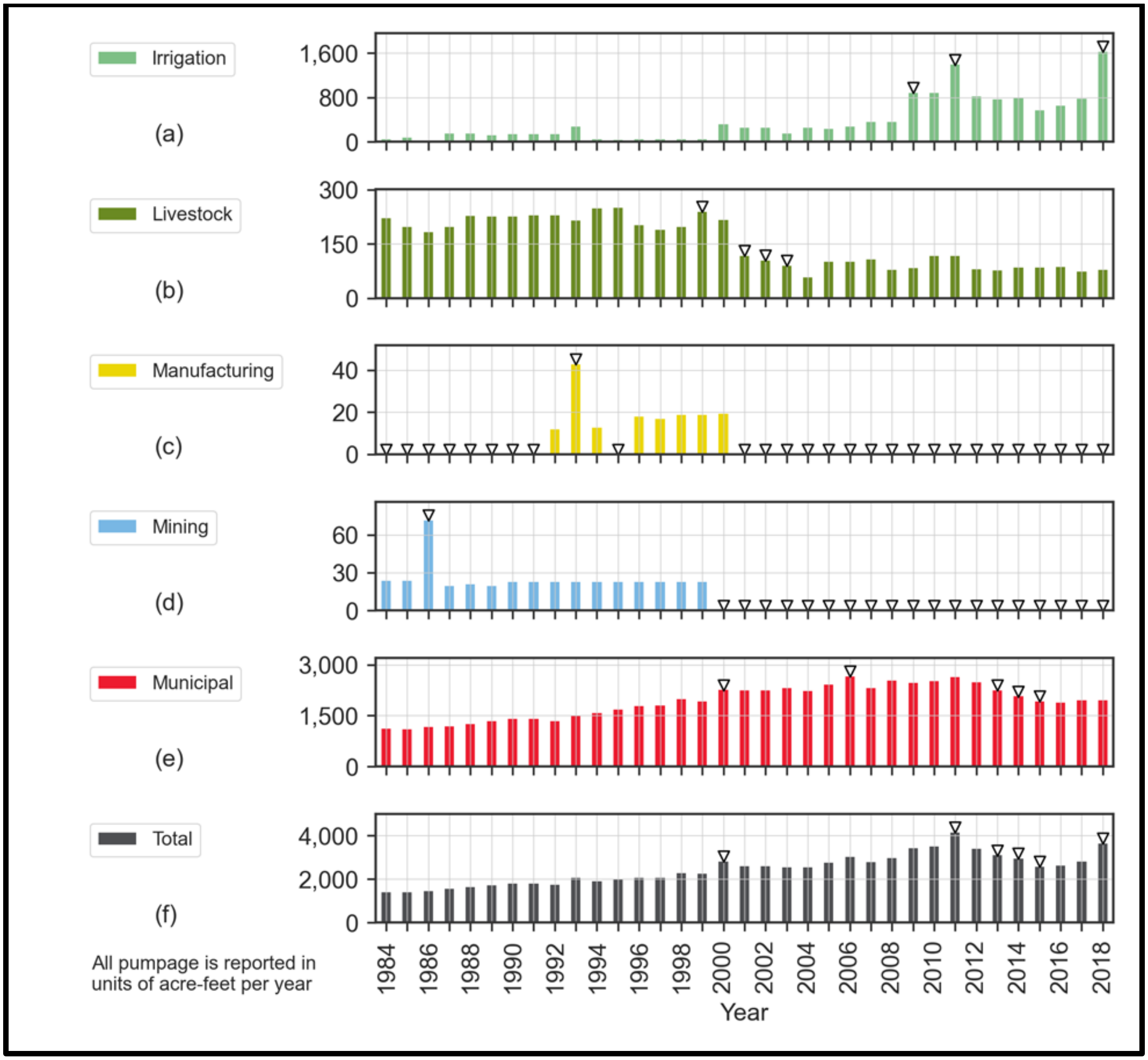


Figure 34. **Bandera County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

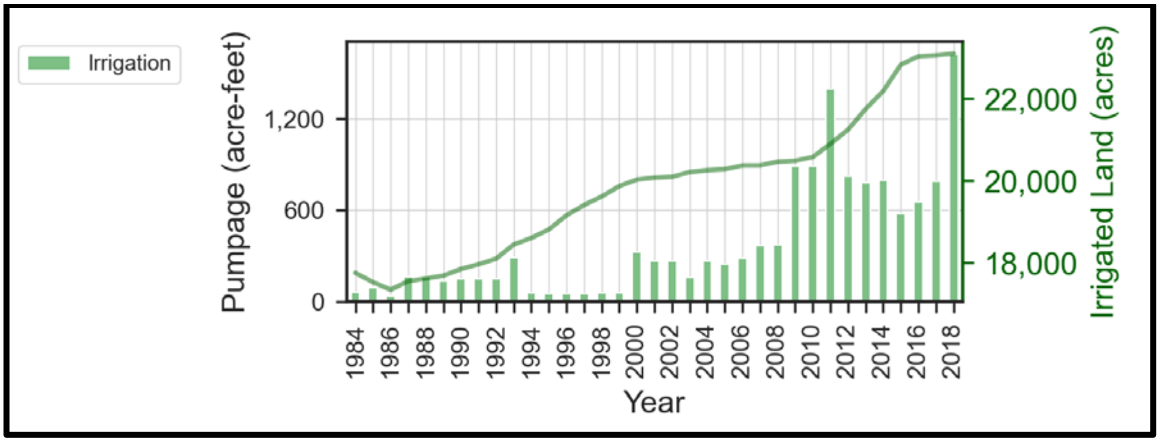


Figure 35. **Bandera County Trinity (Hill Country) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.**

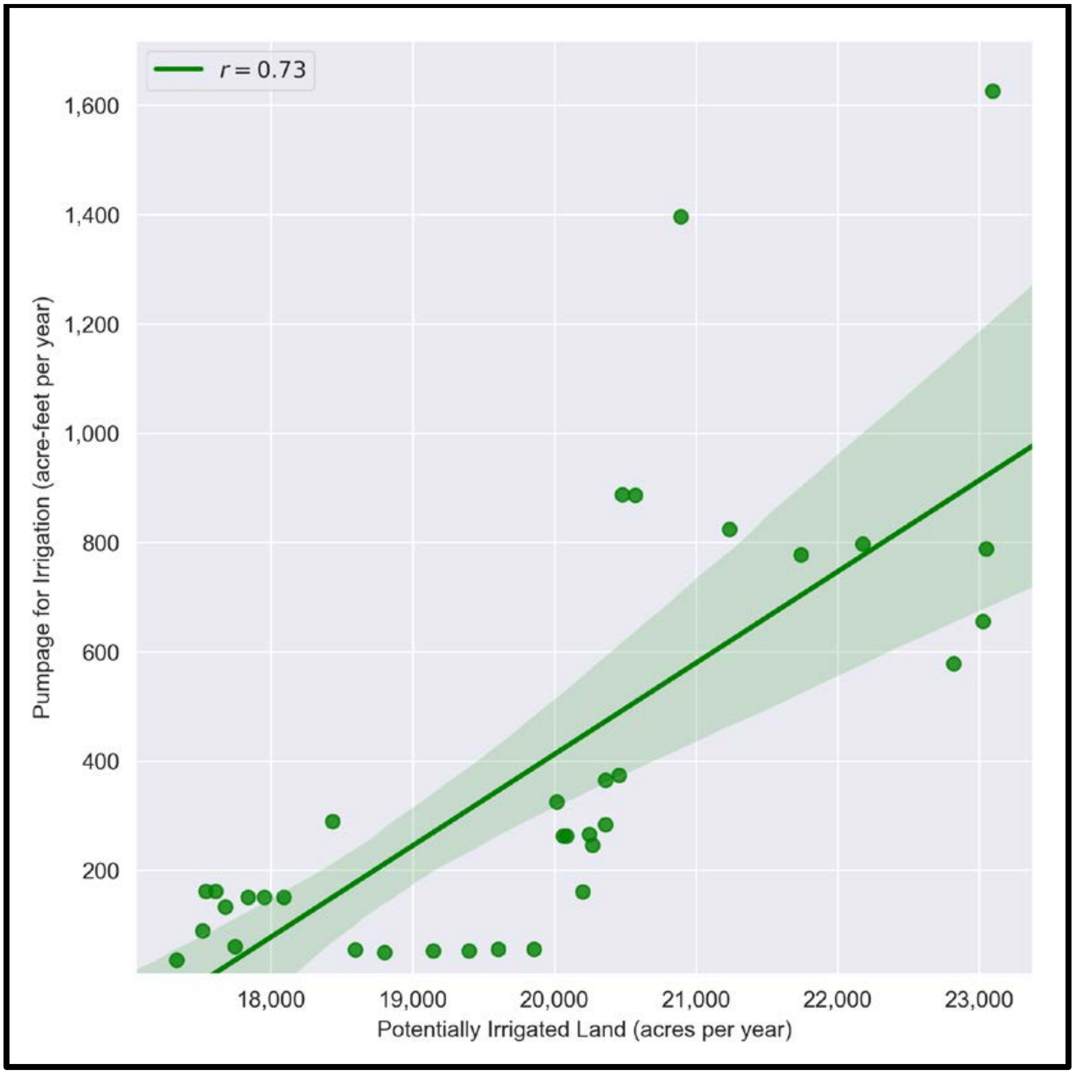


Figure 36. Bandera County Trinity (Hill Country) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 12. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Bandera County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	2004	2004, 2005, 2012	2004-2006, 2012, 2013
	Municipal	None	1994, 2000, 2001, 2006, 2010	2000-2002, 2006, 2007-2009
Trinity (Hill Country)	Irrigation	2011, 2018	2000, 2009, 2011, 2012, 2018	2009, 2011, 2018
	Livestock	2001	1988, 1994, 1996, 1999, 2001, 2004, 2005, 2010, 2012	1999, 2001-2003
	Manufacturing	1992, 1995, 2001-2018	1984-1996, 2001-2018	1984-1991, 1993, 1995, 2001-2018
	Mining	2000-2018	1986, 1987, 2000-2018	1986, 2000-2018
	Municipal	None	2000, 2006, 2007, 2013	2000, 2006, 2013-2015

3.3.4 Bexar County

The Edwards (Balcones Fault Zone) Aquifer is present in the northwestern portion of Bexar County and spans approximately 48 percent of the county area. The Trinity (Hill Country) Aquifer is also in the northwestern portion of Bexar County and comprises about 61 percent of the area, including some areas where the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer overlap. Figure 37 illustrates the extent of the study area aquifers in Bexar County.

Groundwater pumping estimates from the Water Use Survey database indicate that maximum total pumping from the Edwards (Balcones Fault Zone) was just under 300,000 acre-feet per year (Figure 38). As shown on Figure 38, Edwards (Balcones Fault Zone) Aquifer water uses within Bexar County have included irrigation, livestock, manufacturing, mining, municipal, power, and "unknown" with the majority of usage for municipal purposes. The TWDB Water Use Survey database includes non-surveyed municipal water use from the Edwards (Balcones Fault Zone) Aquifer in Bexar since 2000 but the amount is small in comparison to the surveyed municipal water use.

The year-to-year change analysis (Figure 39) and standard deviation analysis (Figure 40) flagged numerous anomalies in the Bexar County data for the Edwards (Balcones Fault Zone) Aquifer. We identified data anomalies for all water use categories which were often associated with rapid fluctuations in pumpage. Examination of individual entity pumping records during subsequent project phases may reveal explanations for many of the industry-related anomalies (for manufacturing, mining, and power use).

Groundwater pumping estimates from the Water Use Survey dataset indicate that maximum total pumping within Bexar County from the Trinity (Hill Country) Aquifer was approximately 40,000 acre-feet per year (Figure 41), which occurred in 2016. As shown on Figure 41, the Water Use Survey dataset records irrigation, municipal, livestock, mining, and manufacturing uses from the Trinity (Hill Country) Aquifer. The TWDB Water Use Survey database includes non-surveyed municipal water use from the Trinity (Hill Country) Aquifer in Bexar County since 2006 but the amount is small in comparison to the surveyed municipal water use.

The year-to-year change analysis (Figure 42) and standard deviation analysis (Figure 43) flagged many anomalies in the Bexar County Water Use Survey data for the Trinity (Hill Country) Aquifer. These anomalies included a large increase in municipal usage after 2014, as well as an increase and decline in water usage for mining from 2009 onward.

Potentially irrigated land in Bexar County over the Edwards (Balcones Fault Zone) Aquifer correlates linearly to groundwater pumpage from the Edwards (Balcones Fault Zone) Aquifer for irrigation use. Figure 44 indicates that as the area of potentially irrigated land over the Edwards (Balcones Fault Zone) Aquifer decreased in the county, so has the reported Edwards (Balcones Fault Zone) Aquifer pumpage for irrigation. Figure 45 indicates a linear correlation value ("*r*") of 0.60 between the potentially irrigated land area and groundwater pumpage for irrigation. This strong positive correlation suggests that pumpage for irrigation in Bexar County from the Edwards (Balcones Fault Zone) Aquifer matches the trend in potentially irrigated land overlying the aquifer.

Table 13 provides the years identified as having anomalous pumping amounts for Bexar County from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer.

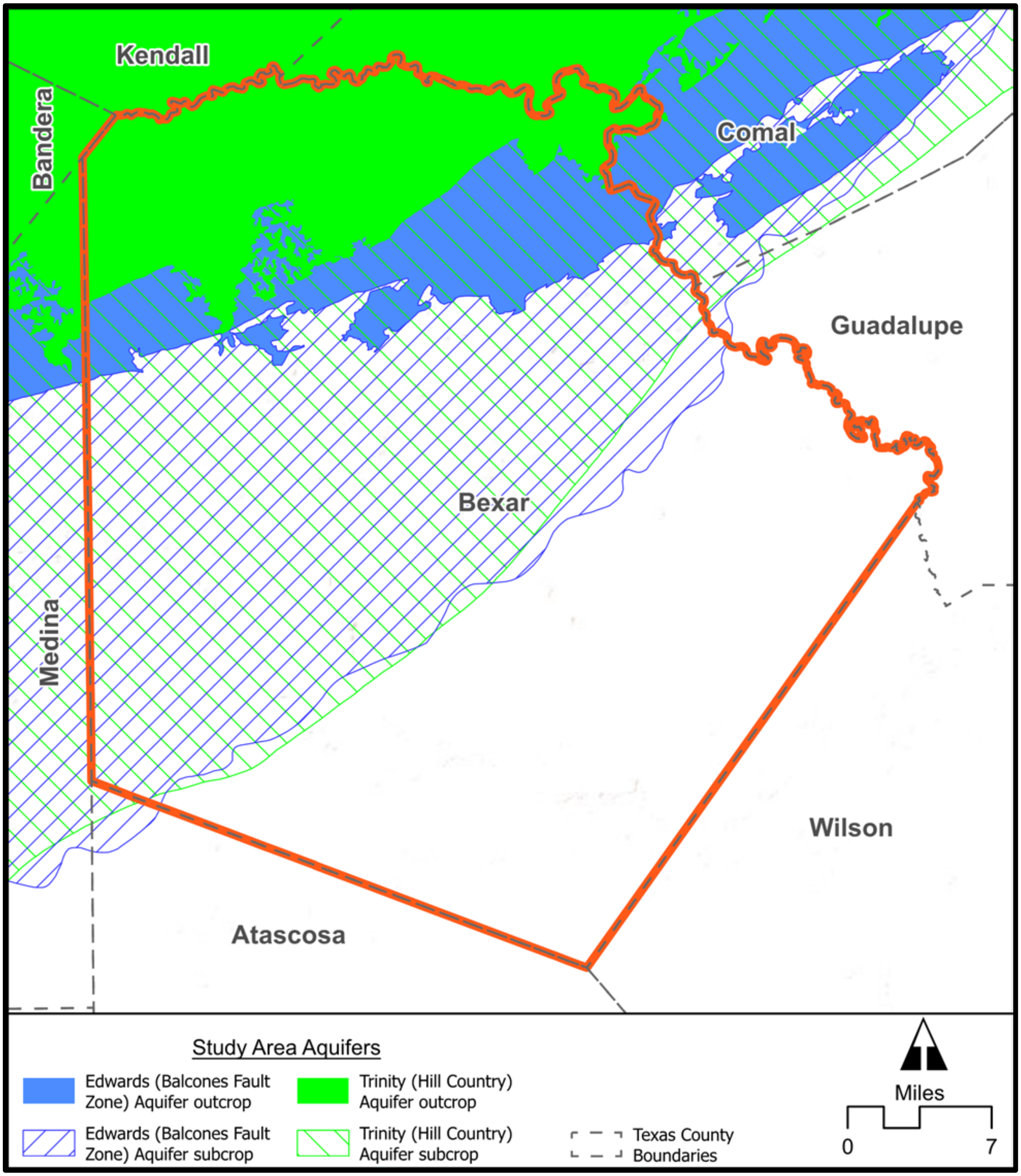


Figure 37. Bexar County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

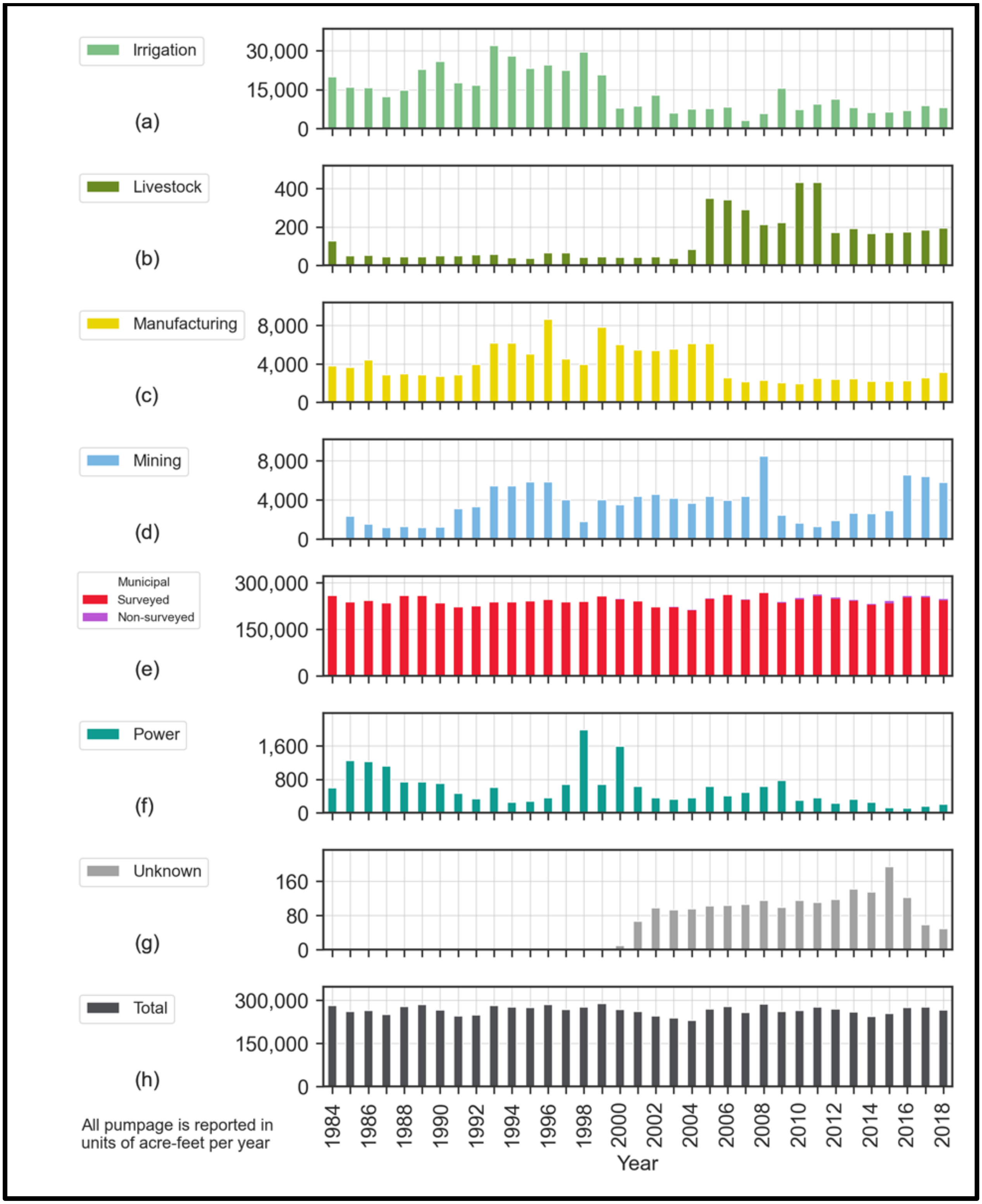


Figure 38. Bexar County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Figure 39. Bexar County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 40. **Bexar County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Figure 41. **Bexar County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

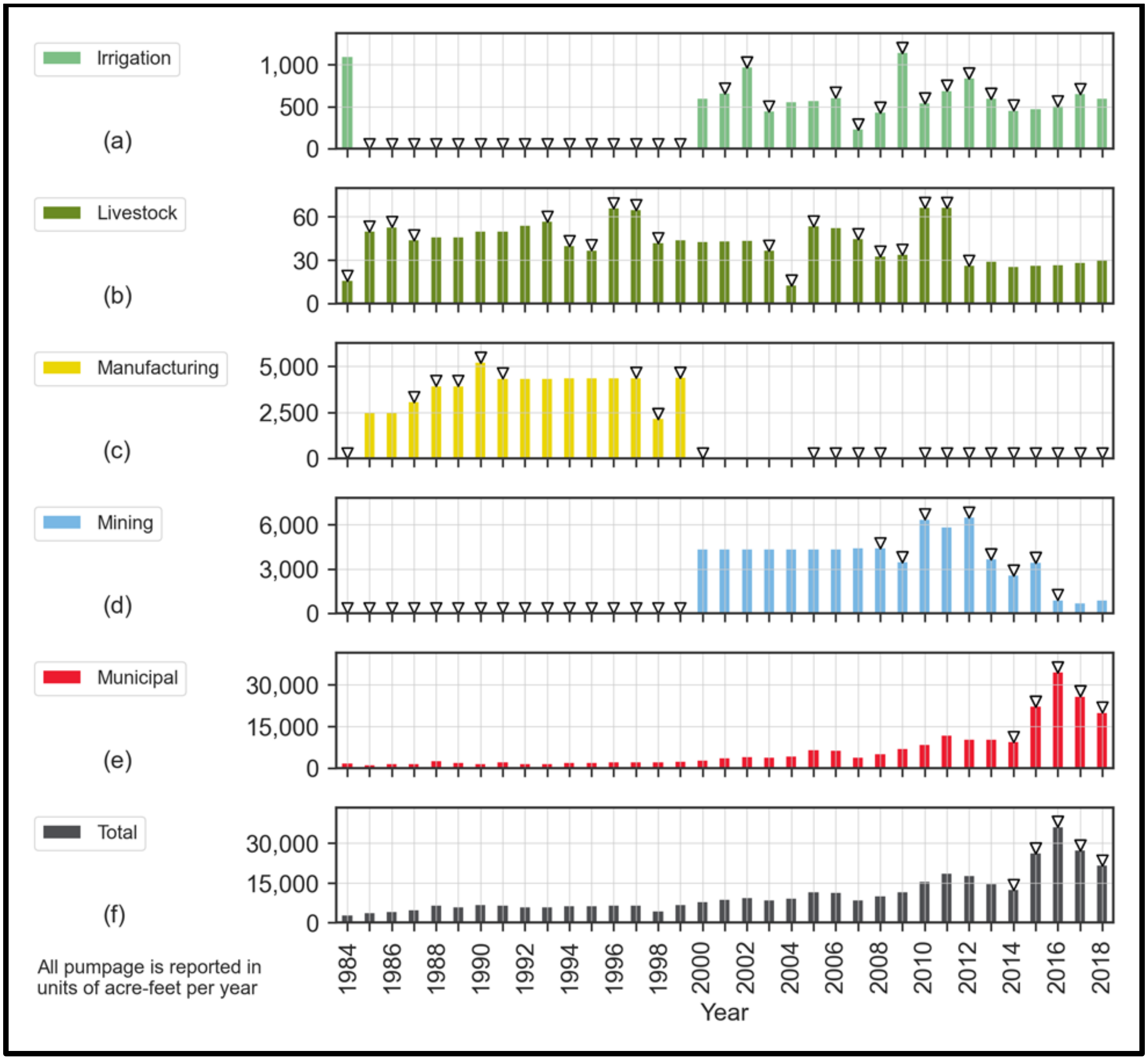


Figure 42. **Bexar County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

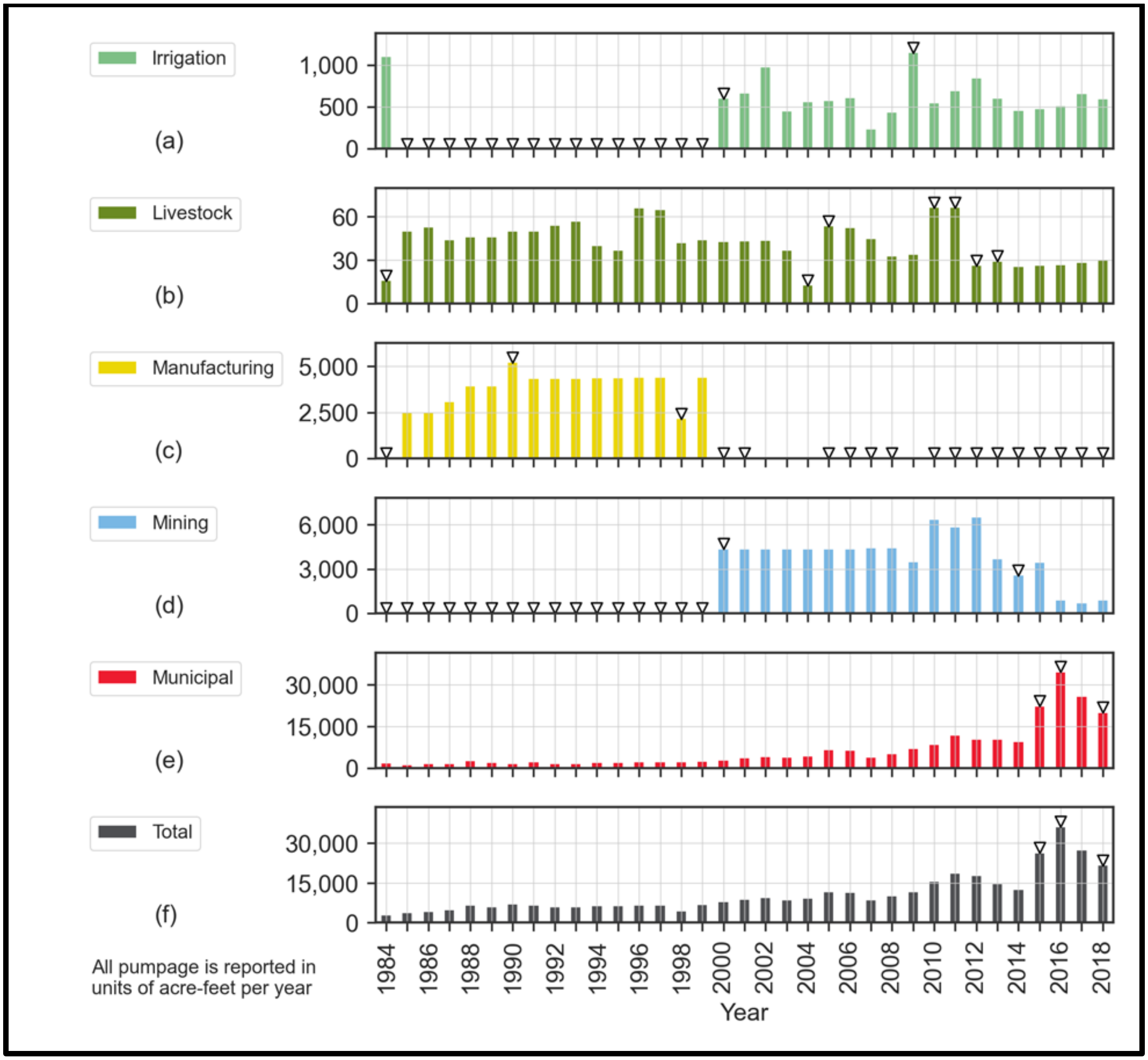


Figure 43. Bexar County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

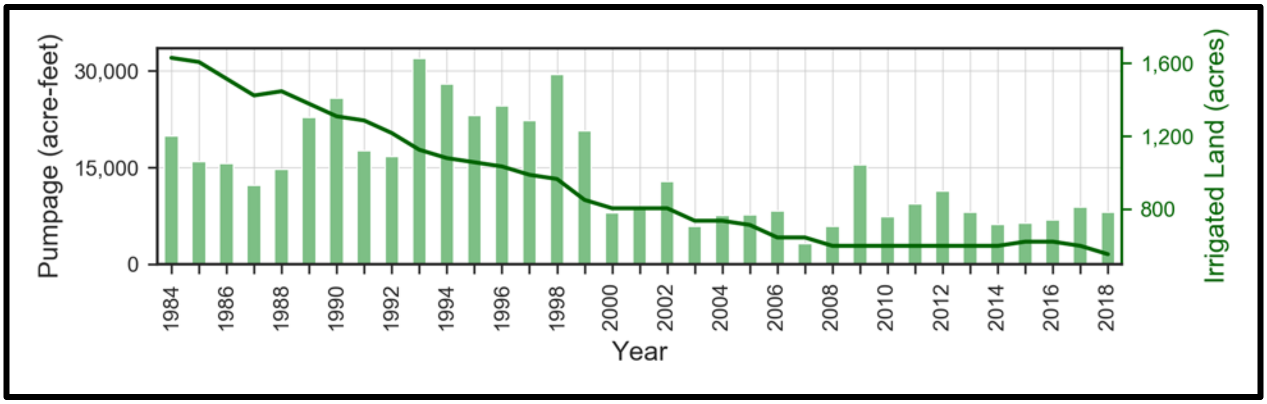


Figure 44. Bexar County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

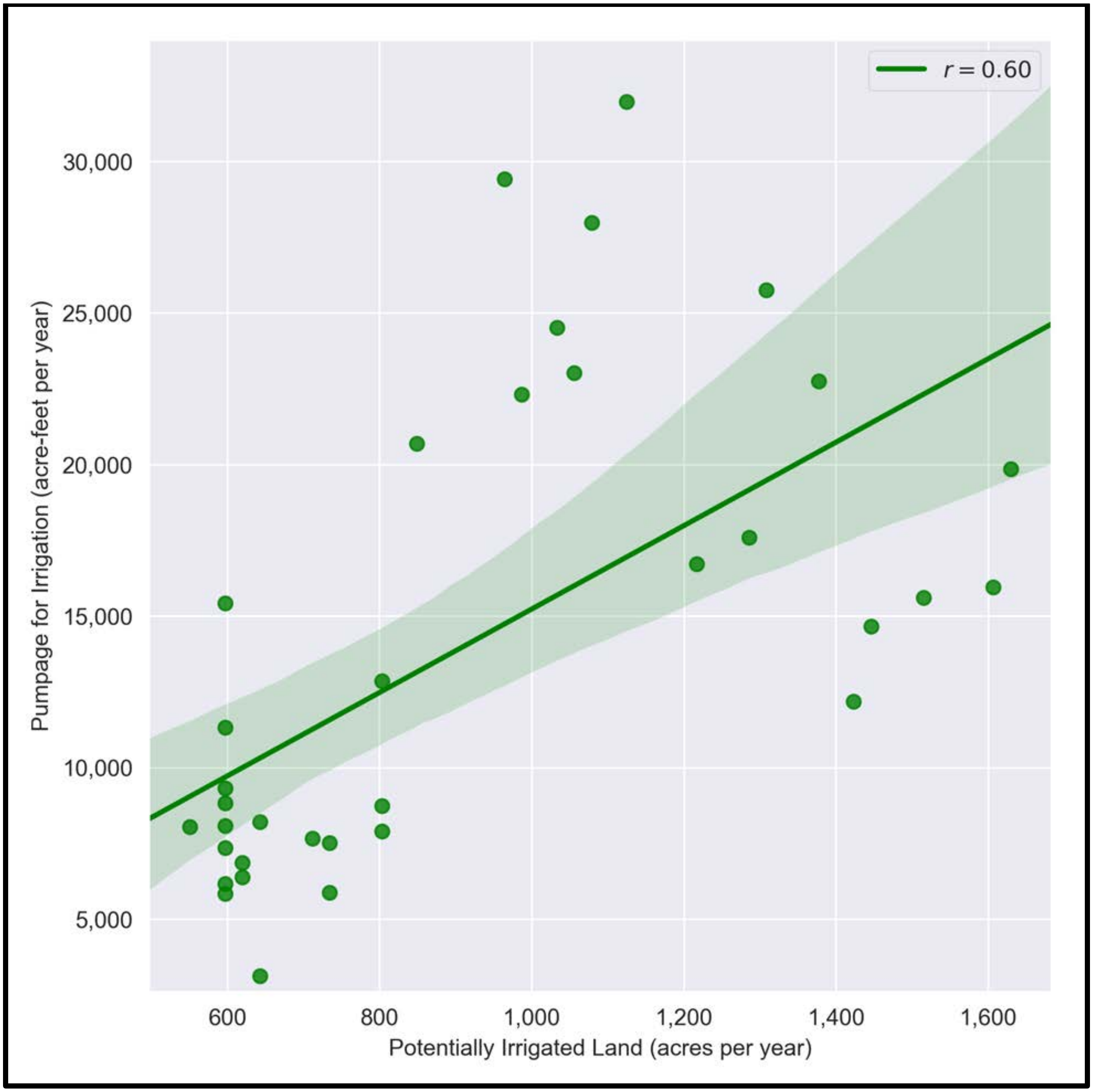


Figure 45. Bexar County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 13. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Bexar County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	2000	1989, 1991, 1993, 1995, 1998-2000, 2003, 2007, 2009, 2010	1989, 1990, 1993, 2000, 2001, 2009
	Livestock	2005, 2010-2011	1984, 1985, 2005, 2008, 2010, 2012	2005, 2006, 2010-2013
	Manufacturing	1993, 2006	1987, 1992, 1993, 1995-1997, 1999, 2000, 2006	1993, 1996-1999, 2006, 2007
	Mining	1984, 2008, 2016	1984, 1985, 1991, 1993, 1997-1999, 2008, 2009, 2016	1984, 1993, 1998, 2008-2011, 2016
	Municipal	None	1984, 1985, 1988, 1990, 2005, 2008, 2009	1991, 2002, 2005, 2006
	Power	1998, 2000	1984, 1985, 1988, 1994, 1997-2001, 2010	1998, 2001
	Unknown	1984-1999, 2015	1984-1999, 2001, 2002, 2015-2017	1984-1999, 2017, 2018
Trinity (Hill Country)	Irrigation	1985-1999	1984-2000, 2002, 2003, 2007-2014, 2017	1985-2000, 2009
	Livestock	1984, 2004, 2010-2011	1984, 1985, 1987, 1994, 1996, 1998, 2004, 2005, 2008, 2010, 2012	1984, 2004, 2005, 2010-2013
	Manufacturing	1984, 2000-2018	1984, 1985, 1988, 1990, 1991, 1998-2000, 2005-2008, 2010-2018	1984, 1990, 1998, 2000, 2001, 2005-2008, 2010-2018
	Mining	1984-1999	1984-2000, 2009, 2010, 2013-2016	1984-2000, 2014-2016
	Municipal	2016	2015-2018	2015, 2016, 2018

3.3.5 Blanco County

A small amount of the Edwards-Trinity (Plateau) Aquifer is present in the western portion of Blanco County (about 3 percent of the county area). Approximately 80 percent of Blanco County overlies the Trinity (Hill Country) Aquifer. Figure 46 illustrates the extent of the study area aquifers in the county.

Groundwater pumping estimates from the Water Use Survey database indicate that maximum total pumping from the Edwards-Trinity (Plateau) Aquifer within Blanco County was just over three acre-feet per year (Figure 47). As shown on Figure 47, all Water Use Survey reported water pumpage was for livestock use.

The year-to-year change analysis (Figure 48) and standard deviation analysis (Figure 49) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer. However, due to the low amounts of production, additional review of these anomalies may not be warranted.

Groundwater pumping estimates from the Water Use Survey database indicate that maximum total pumping from the Trinity (Hill Country) within Blanco County was approximately 2,000 acre-feet, which occurred in 2014 (Figure 50). As shown on Figure 50, the Water Use Survey reports pumping for mining, livestock, municipal, and irrigation use. Non-surveyed municipal water use constitutes most of the municipal water use from 2000 through 2003 and 2006 through 2008 but becomes small relative to the surveyed municipal water use after 2008.

The year-to-year change analysis (Figure 51) and standard deviation analysis (Figure 52) flagged many anomalies in the Blanco County data for the Trinity (Hill Country) Aquifer. The abrupt increase in irrigation pumping after 2011 indicates an anomaly in the dataset, as well as the increase and decrease in municipal pumping after 2007. Fluctuations in pumpage for livestock also yielded some data anomalies. Table 14 provides the years identified as having anomalous pumping amounts for Blanco County for the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer.

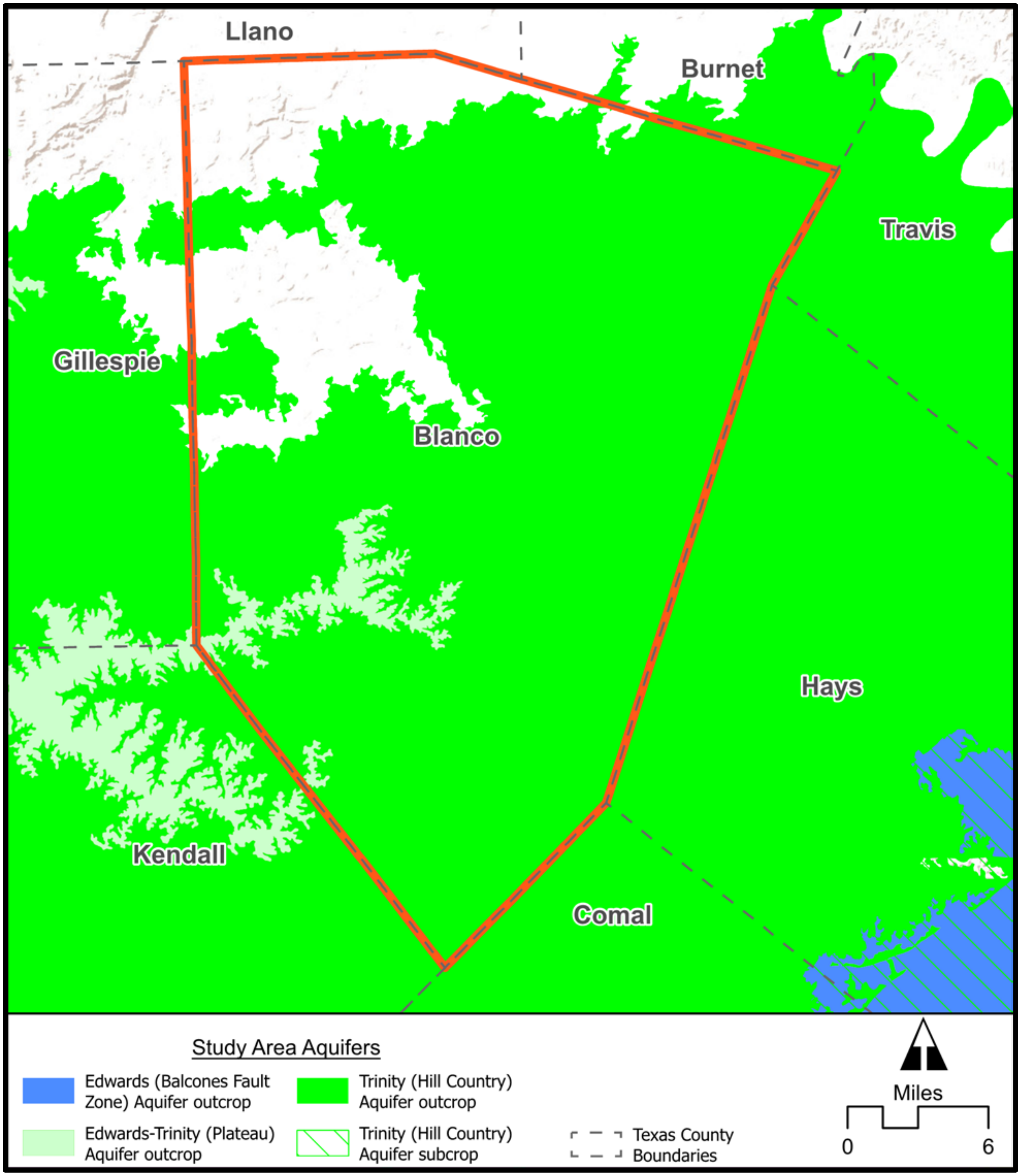


Figure 46. **Blanco County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer.**

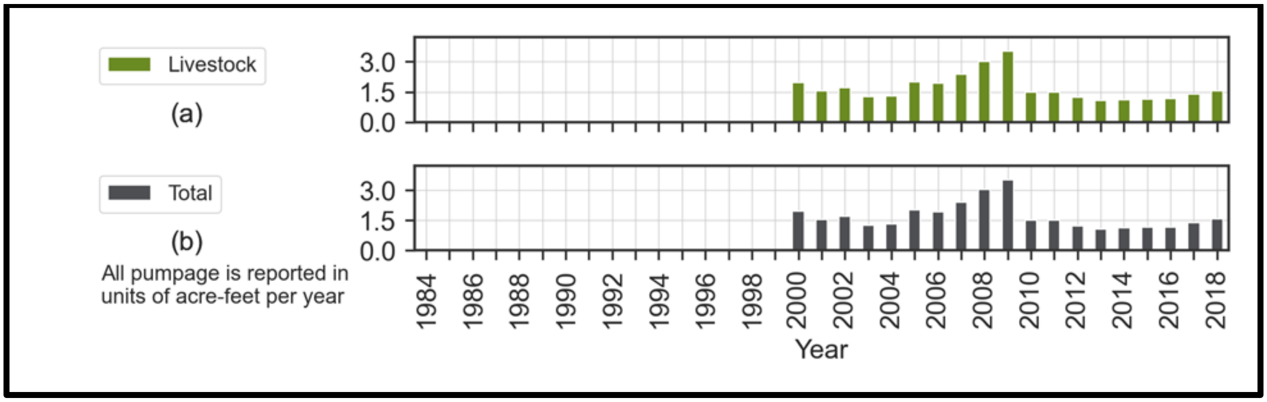


Figure 47. Blanco County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

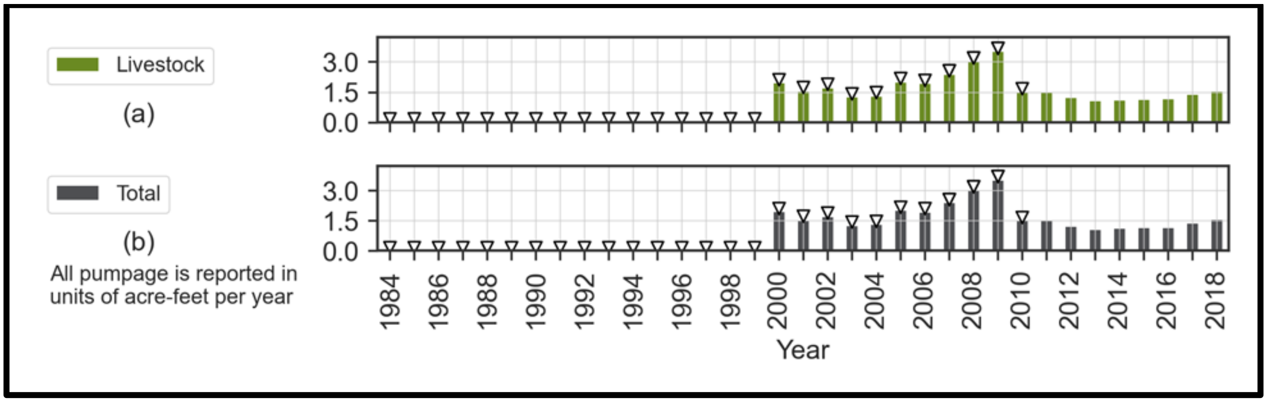


Figure 48. Blanco County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

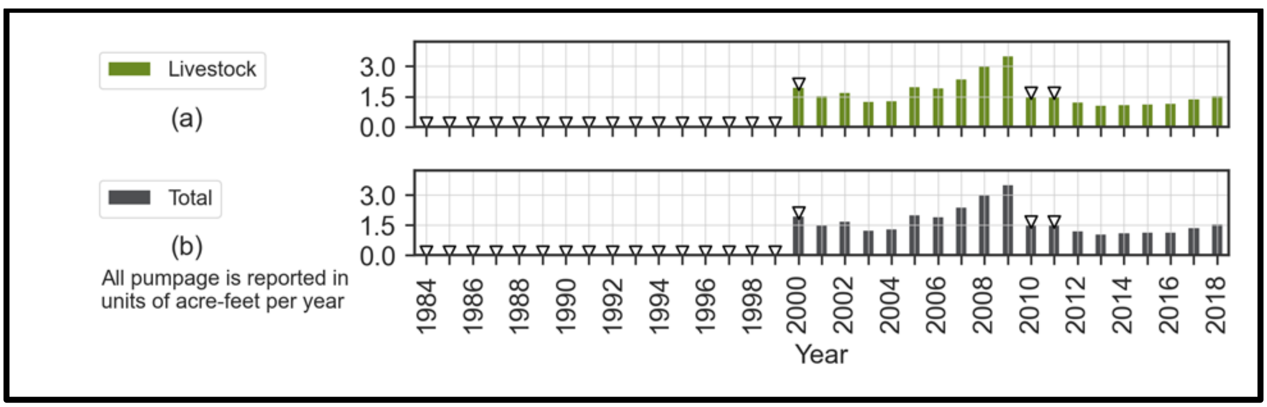


Figure 49. Blanco County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

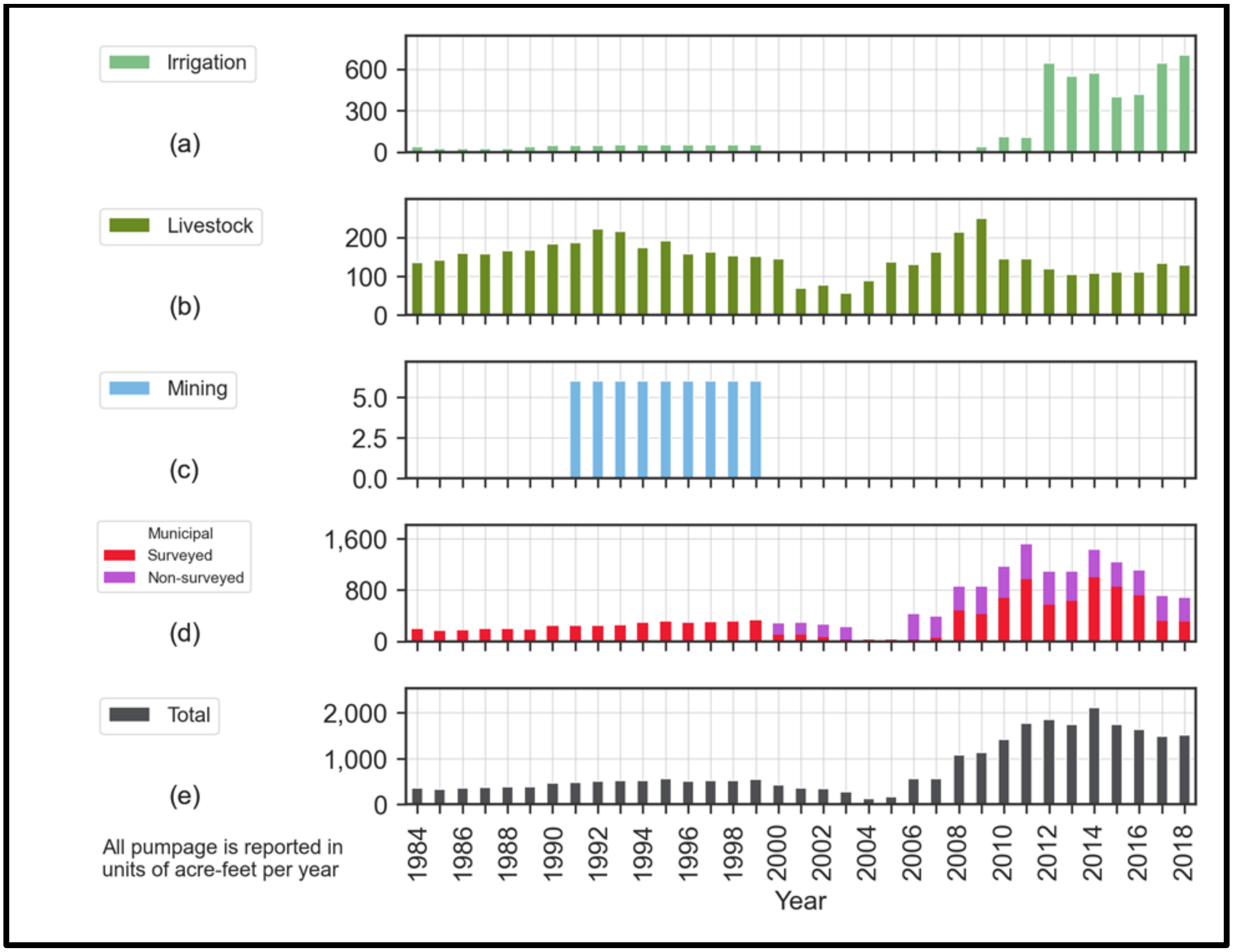


Figure 50. Blanco County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

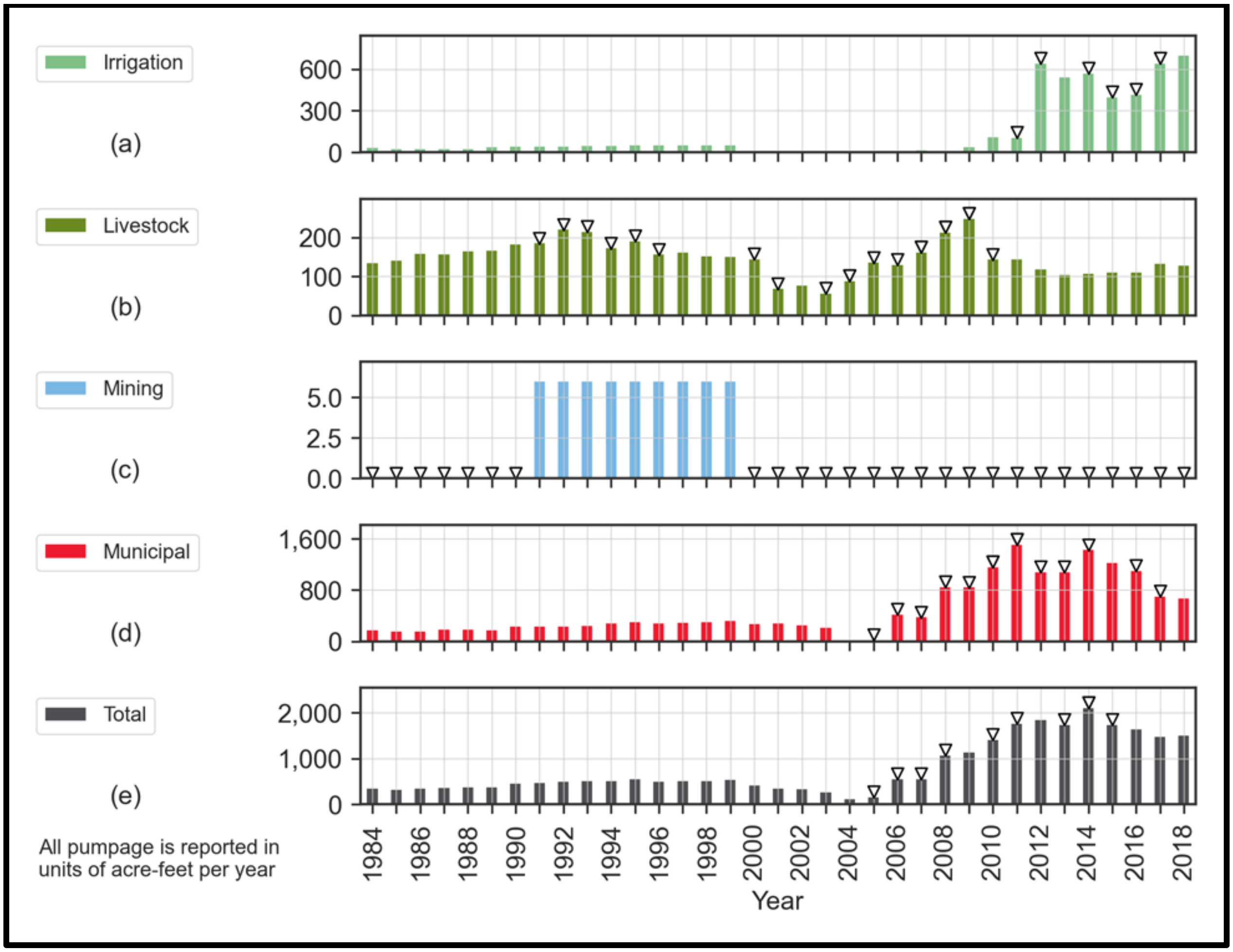


Figure 51. **Blanco County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

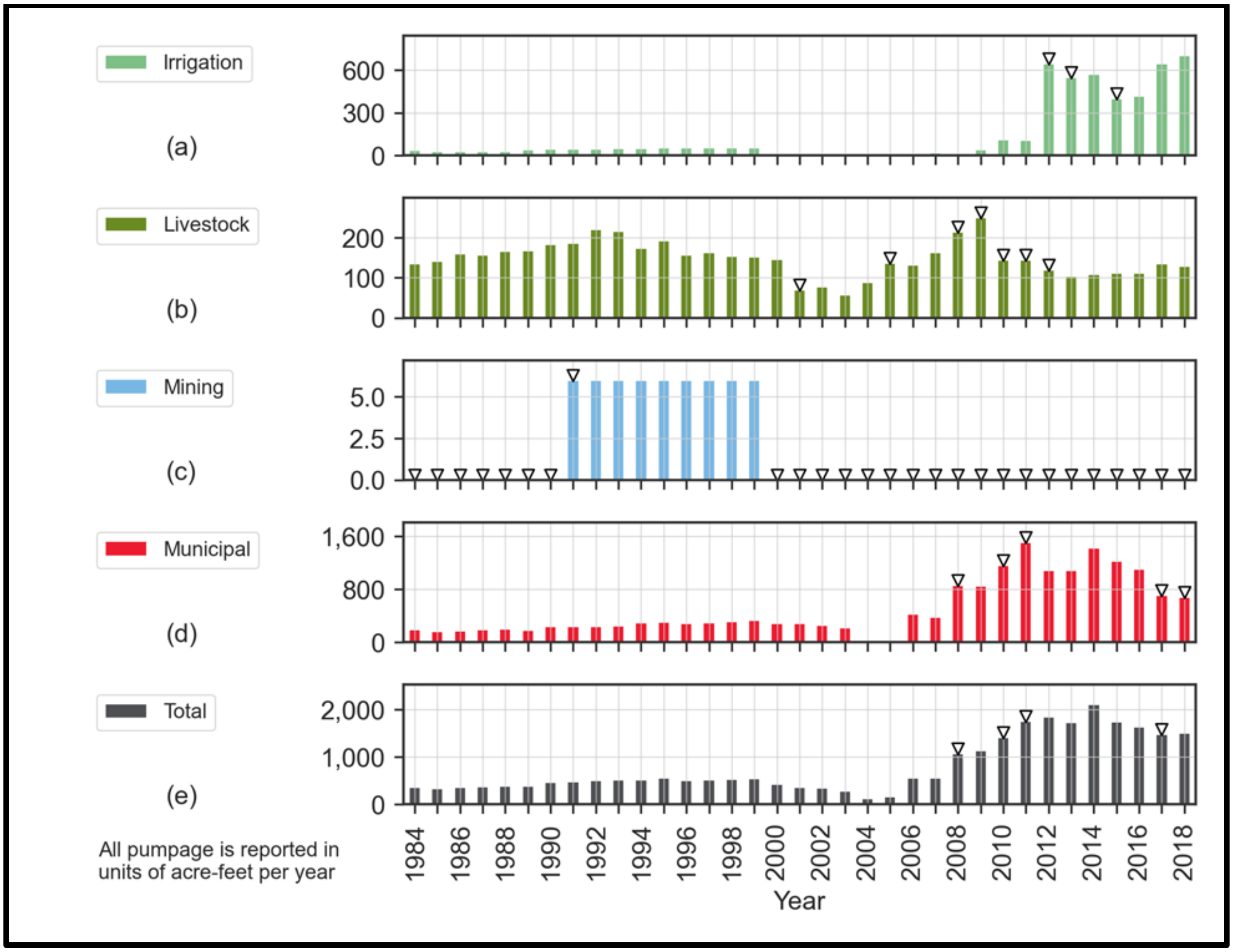


Figure 52. **Blanco County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 14. **Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Blanco County.**

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	1984-1999, 2010	2000, 2001, 2003, 2005, 2007-2010	2009-2011-2013
Trinity (Hill Country)	Irrigation	2012-2018	2012, 2015, 2017	2012, 2013, 2015
	Livestock	None	1992, 1994, 1996, 2001, 2004, 2005, 2007-2010	2001, 2005, 2008-2012
	Mining	1984-1991, 2000-2018	1984-1990, 2000-2018	1984-1991, 2000-2018
	Municipal	2004-2005	2006, 2008, 2010-2012, 2014, 2017	2008, 2010, 2011, 2017, 2018

3.3.6 Brewster County

The outcrop area of the Edwards-Trinity (Plateau) Aquifer covers about 25 percent of Brewster County, as is predominantly along the eastern portion of the county (see Figure 53). As shown on Figure 54, the TWDB Water Use Survey indicates total pumping from the Edwards-Trinity (Plateau) Aquifer in Brewster County to be up to approximately 1,600 acre-feet per year in the late 1980's, but is significantly less from 2000 onward. Most of the pumping is for livestock and municipal use, yet mining use was also prevalent before 1989. Since 2000, when inclusion of non-surveyed municipal use in the TWDB Water Use Survey database began, it represents most of the total municipal use.

The year-to-year analysis (Figure 55) and standard deviation analysis (Figure 56) indicate that pumping data for the Edwards-Trinity (Plateau) Aquifer for irrigation is missing from the years 2000-2018. Manufacturing data and mining data are absent from the database after 1988. Furthermore, there is a sharp decrease in municipal and livestock use beginning in 2000. Overall, the TWDB Water Use Survey data suggests total groundwater production from the aquifer is relatively low (compared to aquifer production from other counties), but there are some years of data that may warrant further investigation. Table 15 provides the years identified as having anomalous pumping amounts for Edwards-Trinity (Plateau) Aquifer Brewster County.

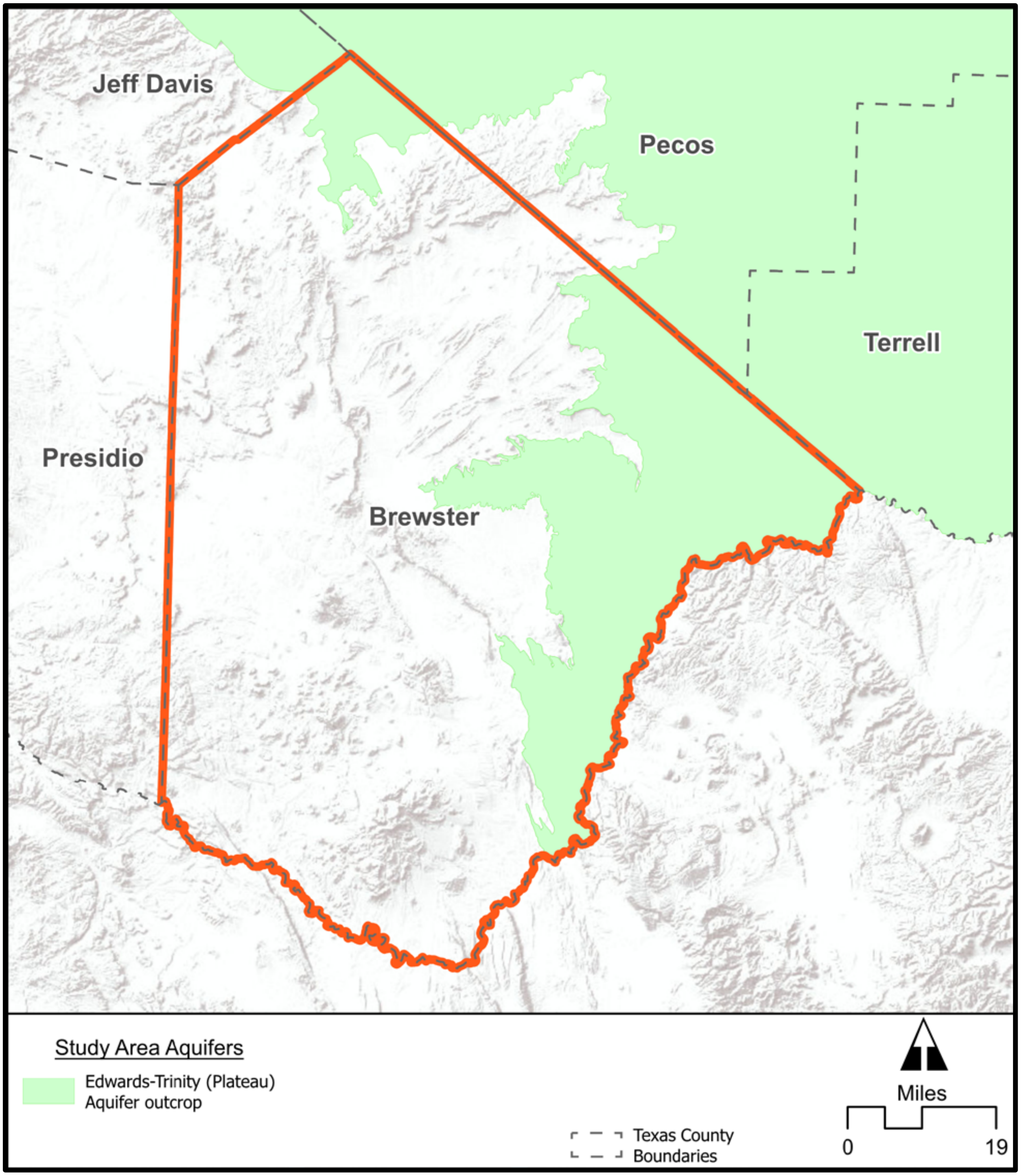


Figure 53. Brewster County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

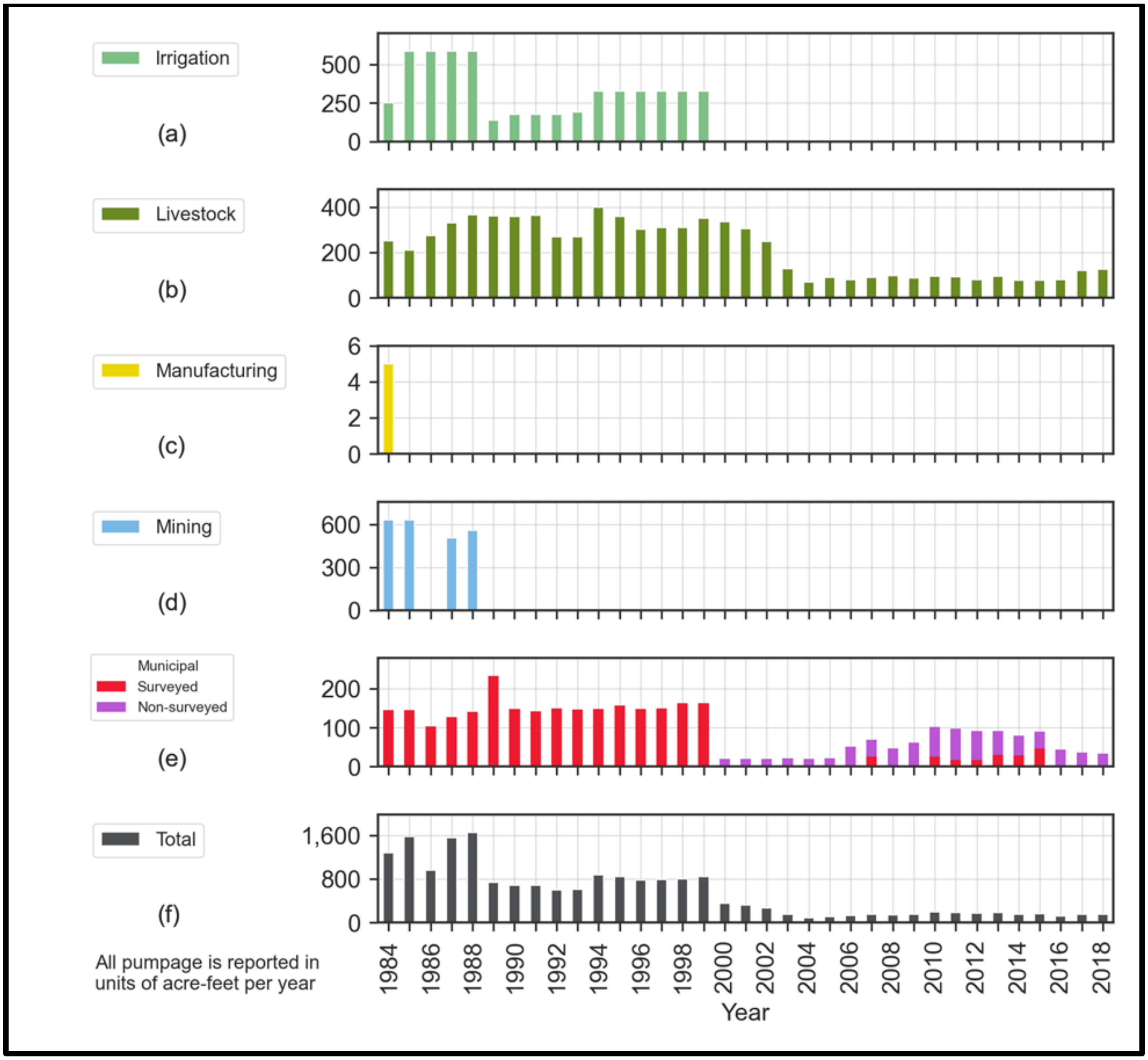


Figure 54. **Brewster County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

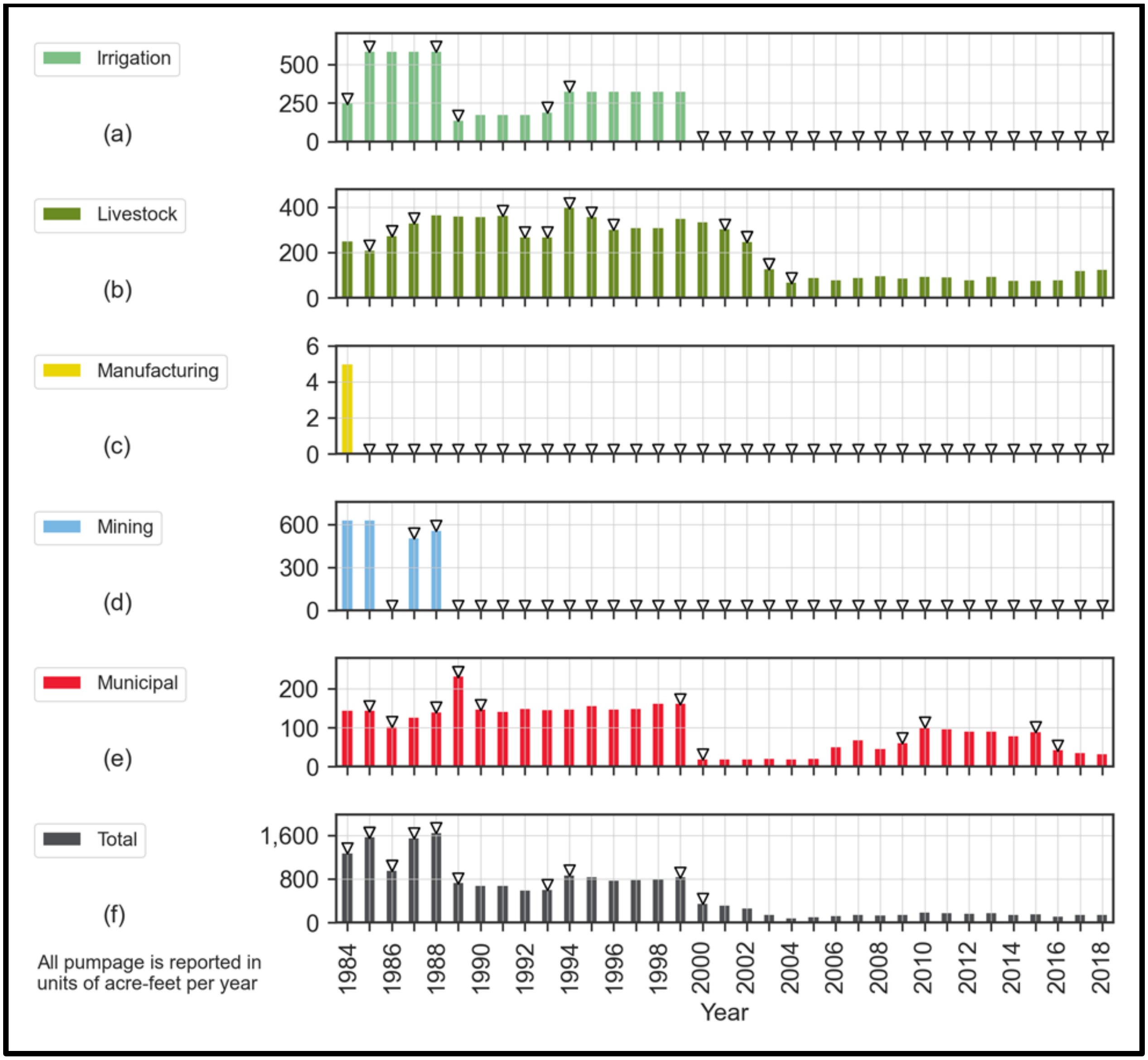


Figure 55. Brewster County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

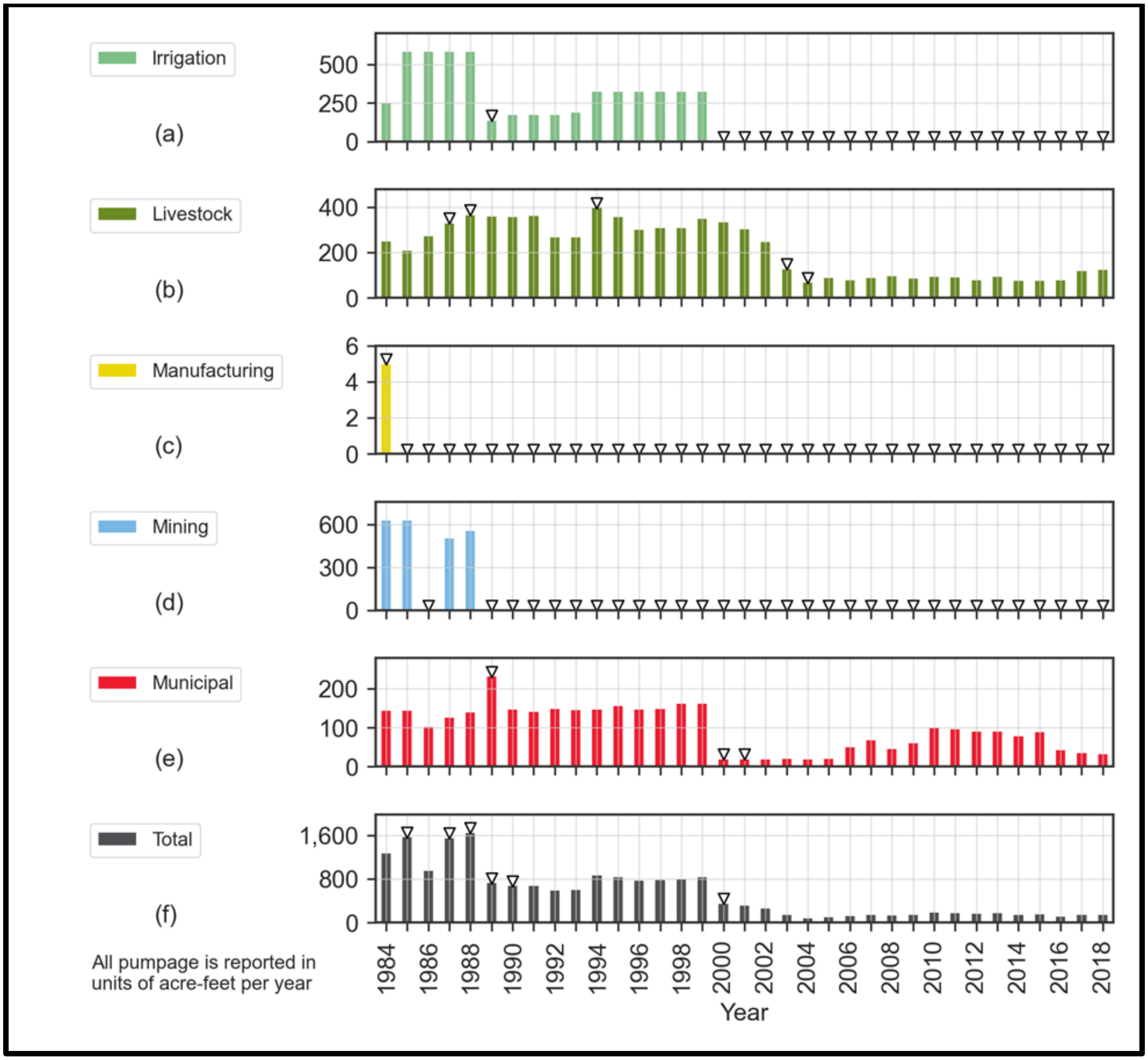


Figure 56. **Brewster County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 15. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Brewster County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	2000-2018	1984, 1985, 1989, 1994, 2000-2018	1989, 2000-2018
	Livestock	2003-2018	1986, 1987, 1992, 1994, 1996, 2002-2004	1987, 1988, 1994, 2003, 2004
	Manufacturing	1985-2018	1985-2018	1984-2018
	Mining	1986, 1989-2018	1986-2018	1986, 1989-2018
	Municipal	1989, 2000	1986, 1989, 1990, 2000, 2010, 2016	1989, 2000, 2001

3.3.7 Burnet County

The Trinity (Hill Country) Aquifer outcrop is present in the southern portion of Burnet County and covers about three percent of the county area (see Figure 57). Estimated total pumping from the Trinity (Hill Country) Aquifer was typically around 1,000 acre-feet per year and ranged up to a little more than 2,000 acre-feet per year (Figure 58).

Groundwater pumping values from the TWDB Water Use Survey data indicate a small amount of pumping within Burnet County from both the Edwards (Balcones Fault Zone) Aquifer and the Edwards-Trinity (Plateau) Aquifer. However, the TWDB delineation of these aquifers does not show them as present within the county. We have flagged these data for further review and verification within subsequent phases of this project.

As shown in Figure 58, the TWDB Water Use Survey reports irrigation, livestock, manufacturing, mining, and municipal use of groundwater from the Trinity (Hill Country) Aquifer. Pumping for irrigation typically ranges from 50 to 200 acre-feet per year. In the years 2010 through 2012, pumping for irrigation abruptly increased to over 400 acre-feet per year, followed by an abrupt decrease and then relatively consistent levels from 2013 through 2018. As seen on the year-to-year (Figure 59) and standard deviation (Figure 60) anomaly detection plots, this variation in reported production is anomalous and warrants further scrutiny.

Pumping for livestock typically ranged from 100 to 300 acre-feet per year. In 2008 and 2009, livestock pumping decreased to less than 50 acre-feet per year. In 2018, pumping for livestock increased to 700 acre-feet per year. Groundwater use for manufacturing ranged from 1 to 15 acre-feet per year from 1984-2011, in increased to between 50 and 60 acre-feet per year through 2018. Pumping for mining typically averaged approximately 13 acre-feet per year from 1984 through 1997. From 1998 to 2011 mining water usage was reportedly low, yet from 2012 through 2018 was significantly higher than in all previous years. Compared to the other uses, pumping for municipal use was relatively consistent from 1984 through 2018, typically ranging from 500 to 1,000 acre-feet per year. Since 2000, when inclusion of non-surveyed municipal use in the TWDB Water Use Survey database began, it represents most of the total reported municipal use. The main anomaly identified for Burnet County is the assignment of pumping to aquifers that the TWDB does not define as present in the county. Table 16 provides the years identified as having anomalous pumping amounts from the Trinity (Hill Country) Aquifer for Burnet County based on our manual review, year-to-year change (Figure 59), and standard deviation (Figure 60) analyses. In addition, we will review the assignment of municipal use pumping to the Edwards-Trinity (Plateau) Aquifer in 2004, and the assignment of municipal and/or mining pumping to the Edwards (Balcones Fault Zone) Aquifer in 2000 through 2015.

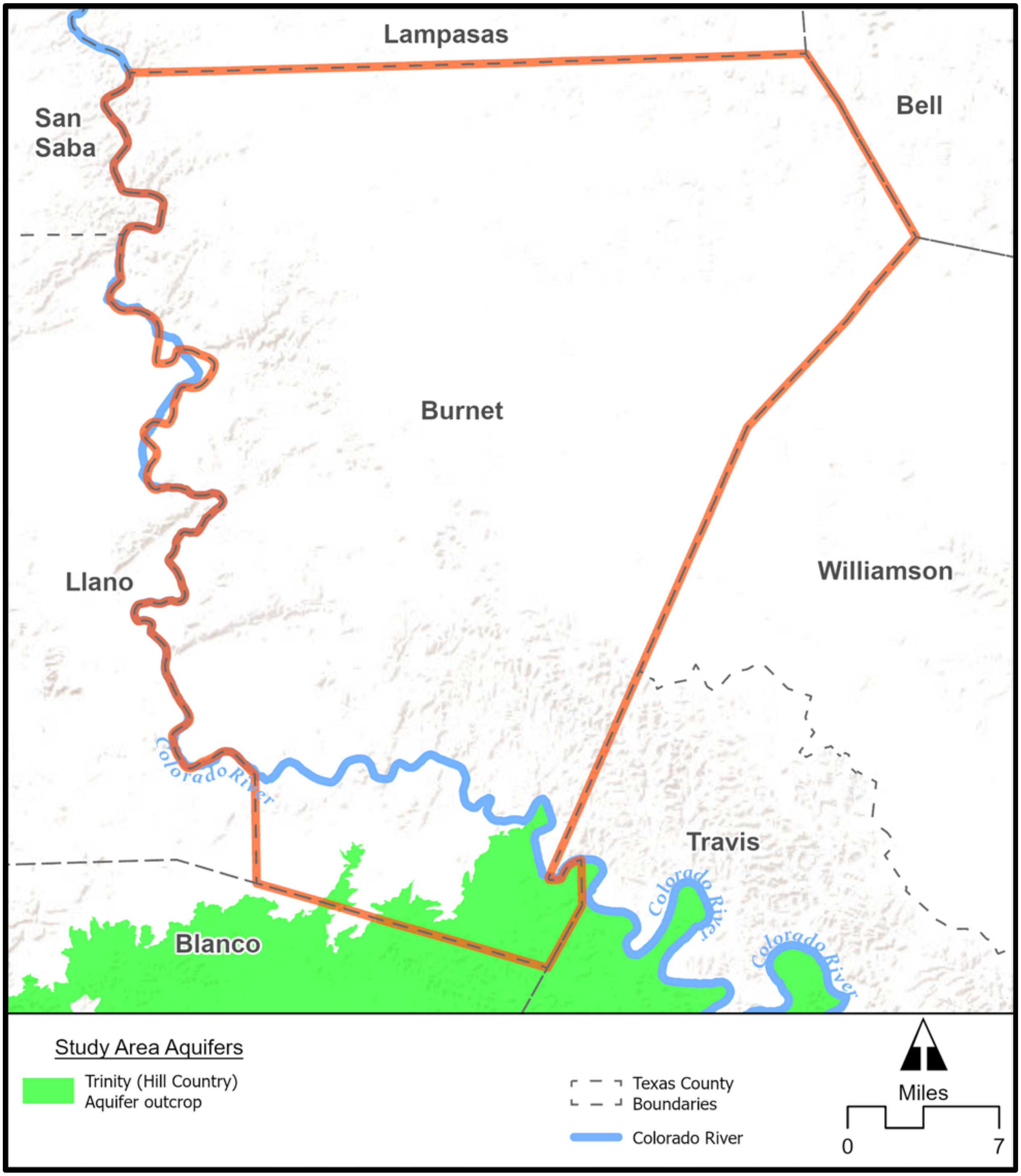


Figure 57. Burnet County showing the extent of the Trinity (Hill Country) Aquifer within the study area.

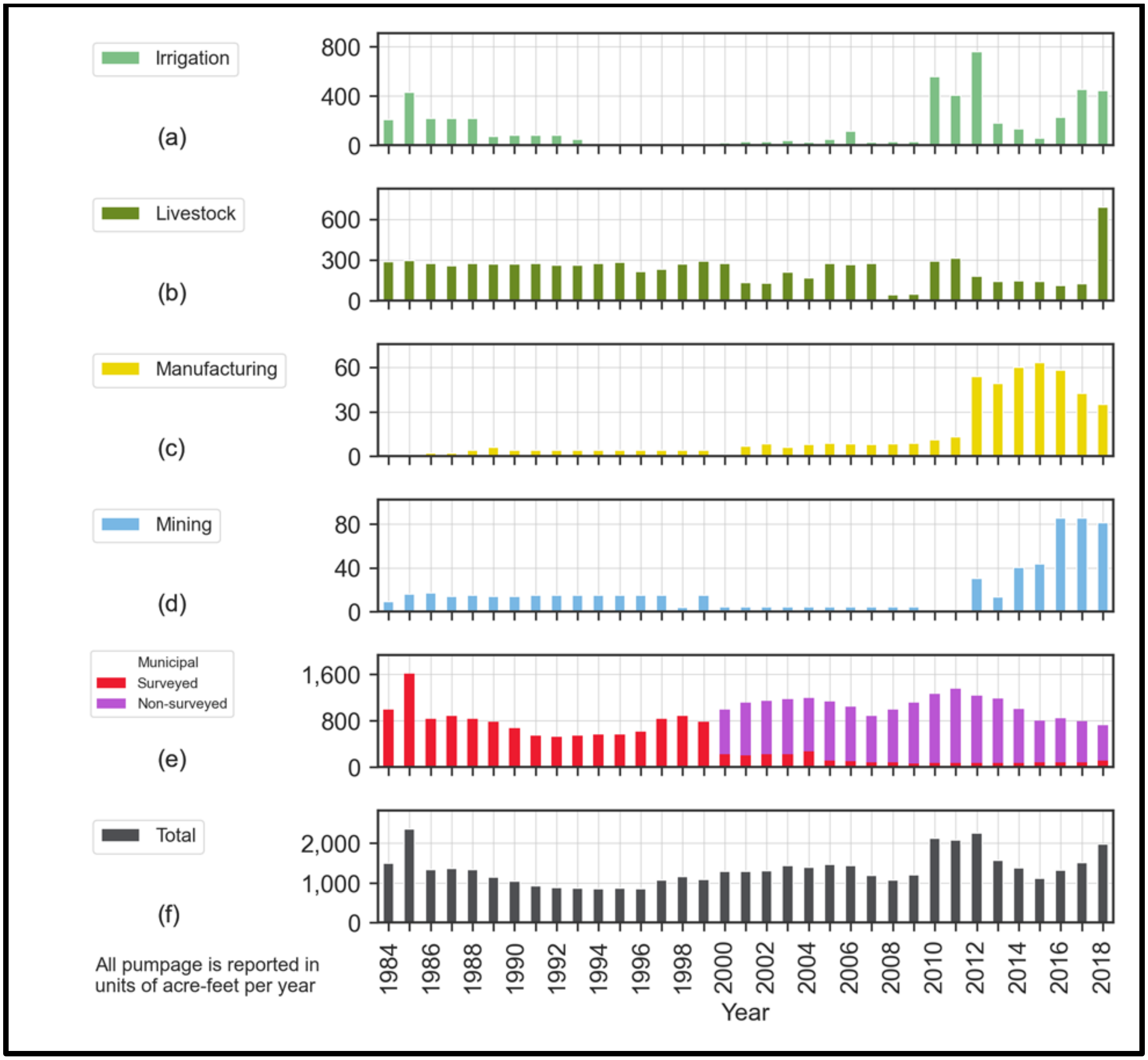


Figure 58. Burnet County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

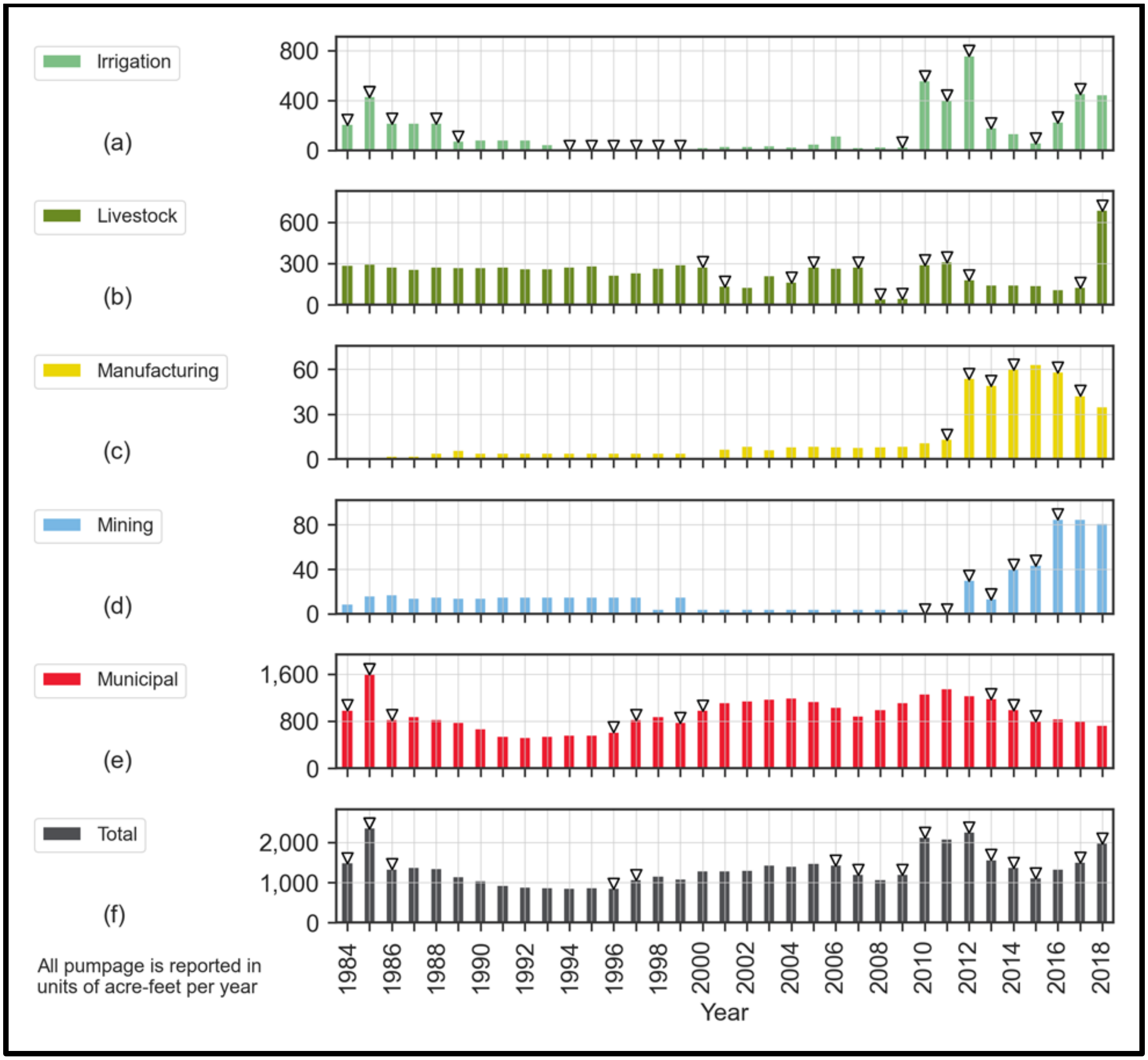


Figure 59. Burnet County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

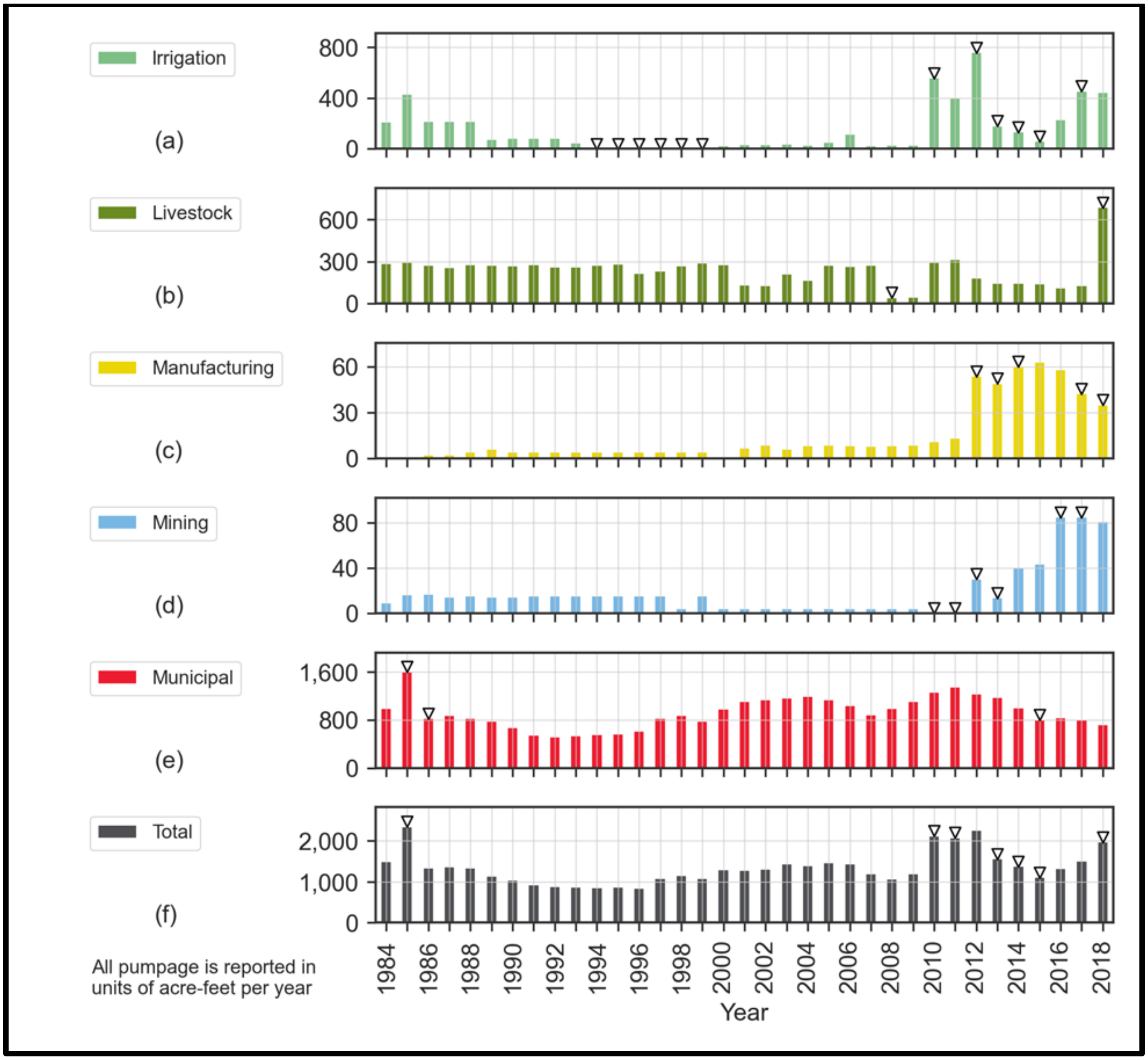


Figure 60. Burnet County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 16. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Burnet County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Trinity (Hill Country)	Irrigation	2010-2012	1984-1986, 1989, 1994-1999, 2010-2013, 2016, 2017	1994-1999, 2010, 2012-2015, 2017
	Livestock	2008-2009, 2018	2001, 2005, 2008, 2010, 2012, 2018	2008, 2018
	Manufacturing	2012	2012, 2014, 2017	2012-2014, 2017, 2018
	Mining	2012, 2013, 2016	2010-2014, 2016	2010-2013, 2016, 2017
	Municipal	1985	1984-1986, 1997, 2000, 2014, 2015	1985, 1986, 2015
Edwards (Balcones Fault Zone)	All	Not present in county		
Edwards-Trinity (Plateau)	All	Not present in county		

3.3.8 Caldwell County

Only a small portion of the subcrop area of the Trinity (Hill Country) Aquifer is present in the western corner of Caldwell County (see Figure 61). However, TWDB Water Use Survey data indicates pumping of about 10 acre-feet per year is occurring from the Edwards (Balcones Fault Zone) Aquifer (Figure 62). While the formations comprising the aquifer certainly extend beyond the defined aquifer footprint, the assignment of pumping to the aquifer is in itself anomalous and warrants further review.

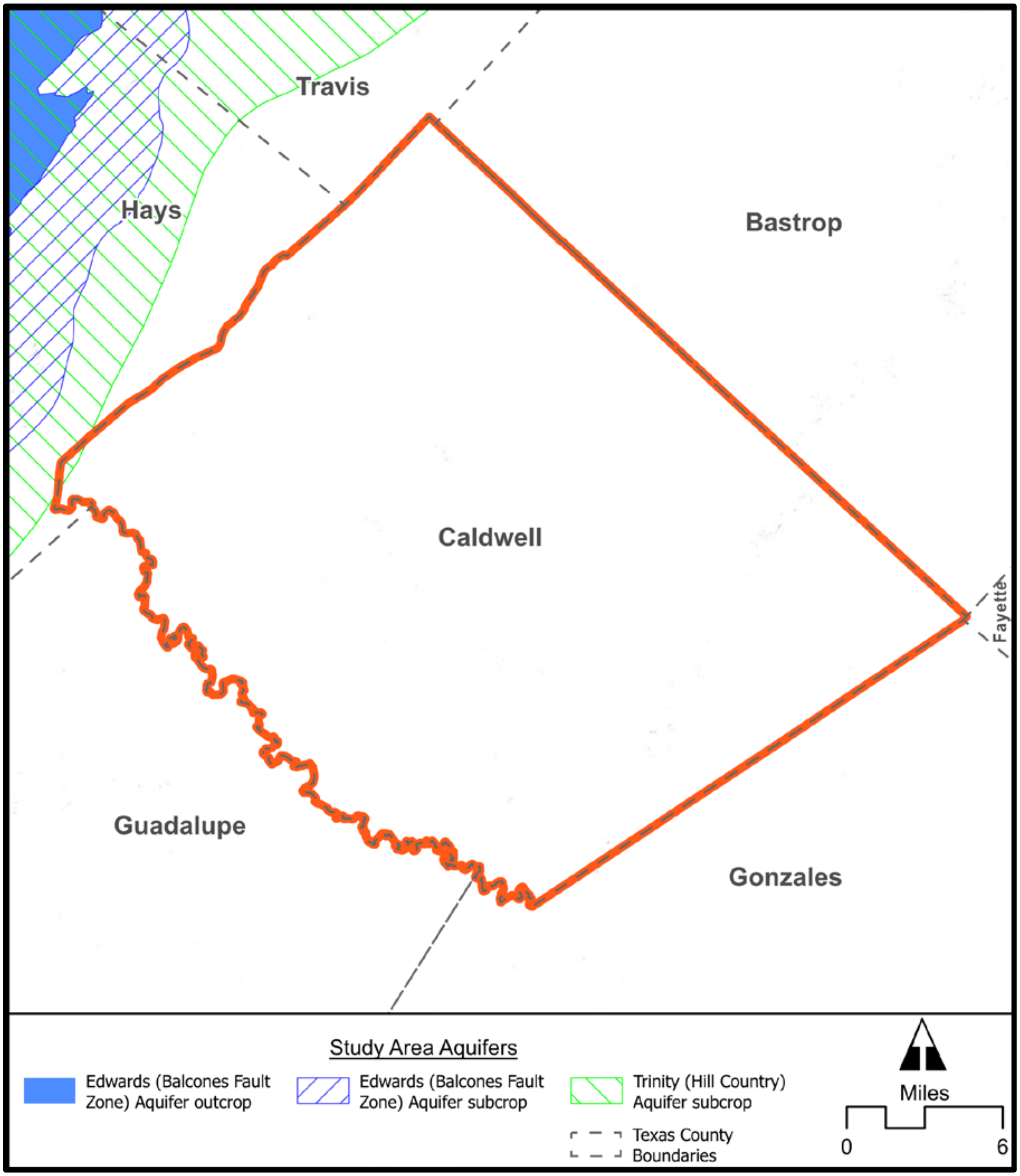


Figure 61. Caldwell County showing the extent of the Trinity (Hill County) Aquifer.

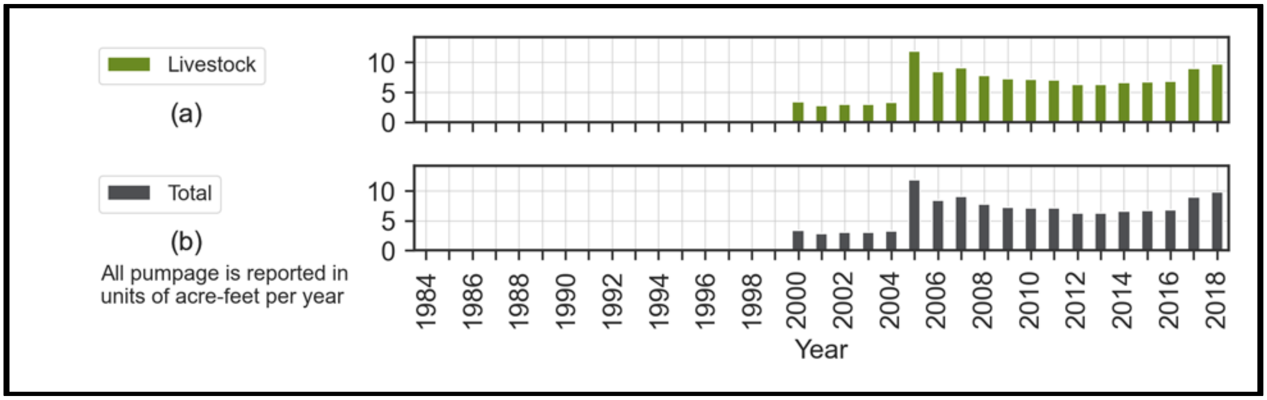


Figure 62. Caldwell County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

3.3.9 Coke County

The Edwards-Trinity (Plateau) Aquifer is present in the northern and southern portions of Coke County covering about 31 percent of the county area. Portions of the Lipan Aquifer are also present within southern and southwestern Coke County. Figure 63 illustrates the extent of the study area aquifers in Coke County.

With respect to the Edwards-Trinity (Plateau) Aquifer within Coke County, groundwater pumping estimates from the Water Use Survey database indicate that maximum total pumping was approximately 200 acre-feet per year (Figure 64). As shown on Figure 64, the TWDB Water Use Survey database reports pumping from the aquifer in the county for manufacturing, livestock, irrigation, and municipal use, with roughly equal volumes used for irrigation, livestock, and municipal after 2004. There is not any surveyed municipal use from 2000 through 2010, 2016, or 2017 and only a relatively small amount of non-surveyed use from 2011 through 2015.

The year-to-year change analysis (Figure 65) and standard deviation analysis (Figure 66) flagged many anomalies in the Coke County data for the Edwards-Trinity (Plateau) Aquifer. In addition to pumping from the Edwards-Trinity (Plateau) Aquifer in Coke County, the TWDB Water Use Survey database also reports pumping from an “Other” aquifer for municipal use. Due to the small footprint of the Lipan Aquifer in the county, we do not expect much pumping from the Lipan Aquifer within Coke County but will investigate if pumping should be included for the aquifer in subsequent project phases.

We expect groundwater pumping for irrigation in Coke County to correlate negatively to precipitation such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 67 indicates that as precipitation increased in the county after 2000, the reported pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer tended to decrease. Similarly, for years with lower rainfall, irrigation pumpage totals were larger. Figure 68 indicates a correlation value (“*r*”) of -0.51 between precipitation and groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer in Coke County. This moderate negative correlation suggests that the reported pumpage for irrigation in Coke County after 2000 inversely follows the trend in precipitation.

We expect a positive linear correlation between the land potentially used for irrigation overlying the Edwards-Trinity (Plateau) Aquifer in Coke County and groundwater pumpage for irrigation use from the aquifer. However, although the acres of potentially irrigated land overlying the aquifer appear to be increasing in the county, the reported pumping from the aquifer for irrigation has reportedly decreased (see Figure 69). Figure 70 indicates a linear correlation value (“*r*”) of -0.58 between the potentially irrigated land area overlying the aquifer within the county and reported groundwater pumpage for irrigation. This moderate negative correlation suggests that pumpage from the aquifer for irrigation in the county inversely follows trends in land use. This inverse trend could indicate that the irrigation pumpage data is in error or be due to another factor, such as, irrigators growing crops with lower water demands per acre or using irrigation methods are more efficient. Nonetheless, further research into the relationship between land use and irrigation pumpage in the county could provide insight into the validity of reported irrigation pumpage from the Edwards-Trinity (Plateau) Aquifer in Coke County.

Table 17 provides the years identified as having anomalous pumping amounts for Coke County based on our manual review, year-to-year change (Figure 65), and standard deviation (Figure 66) analyses within Coke County for the Edwards-Trinity (Plateau) Aquifer.

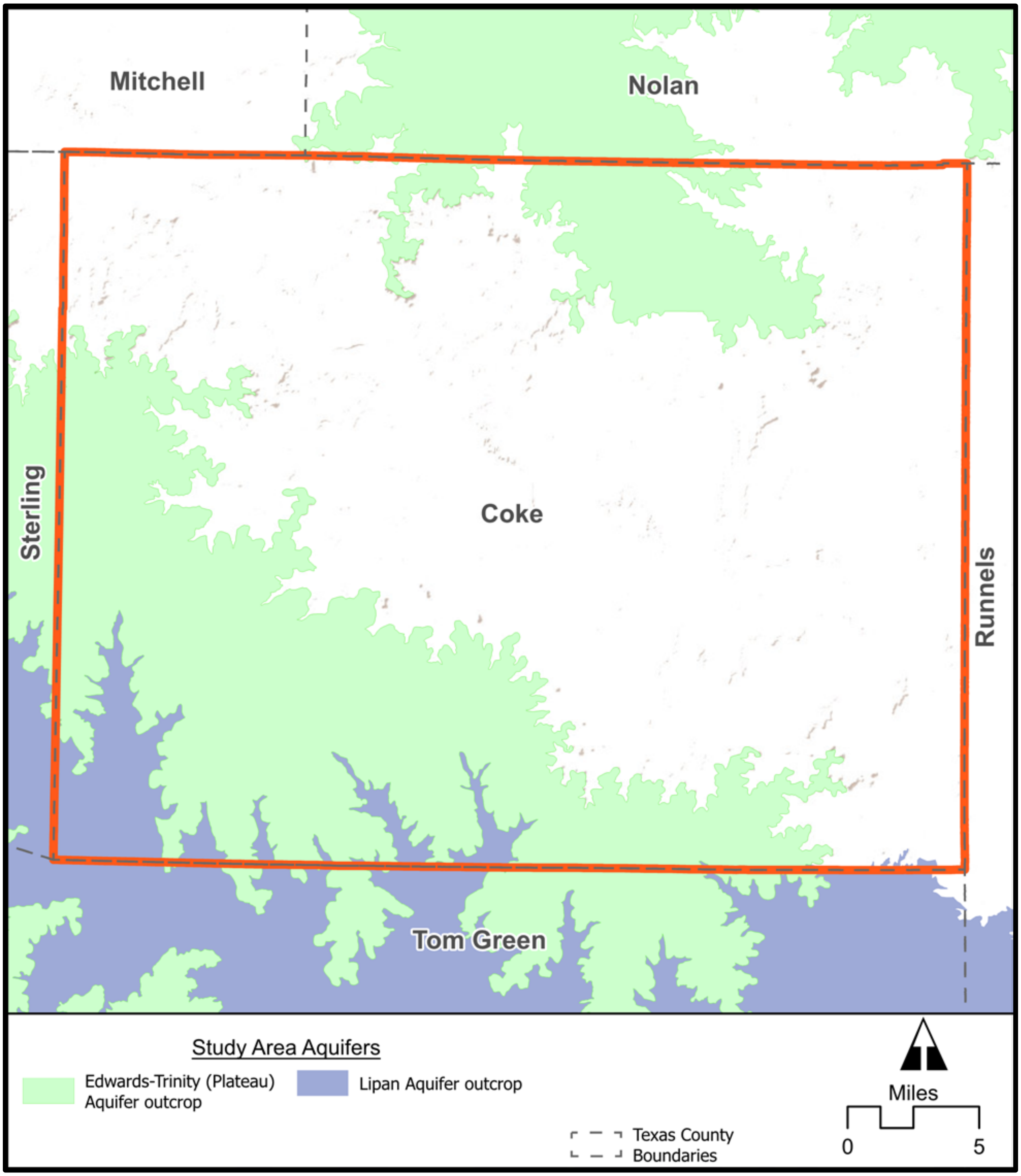


Figure 63. **Coke County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer.**

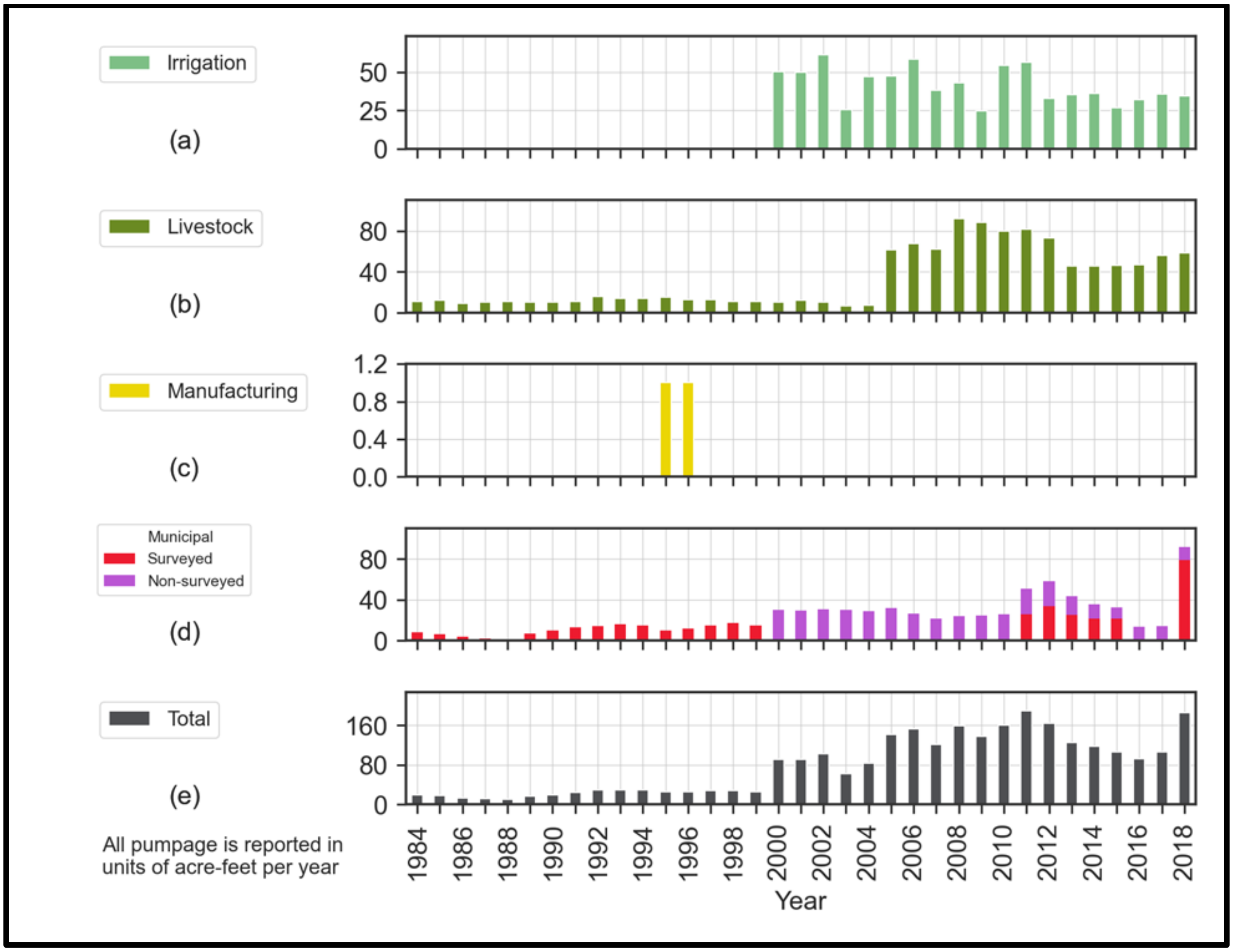


Figure 64. **Coke County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

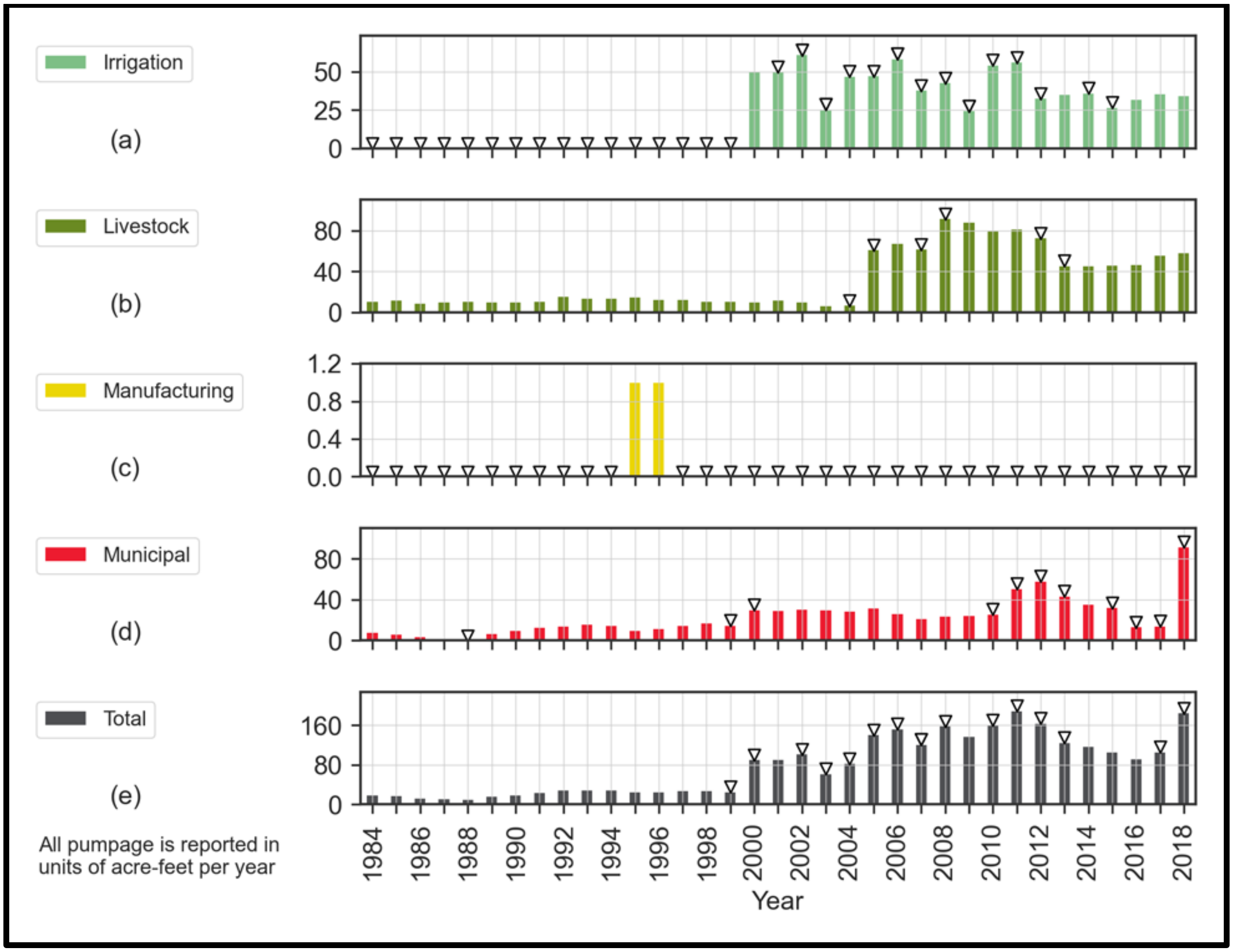


Figure 65. **Coke County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

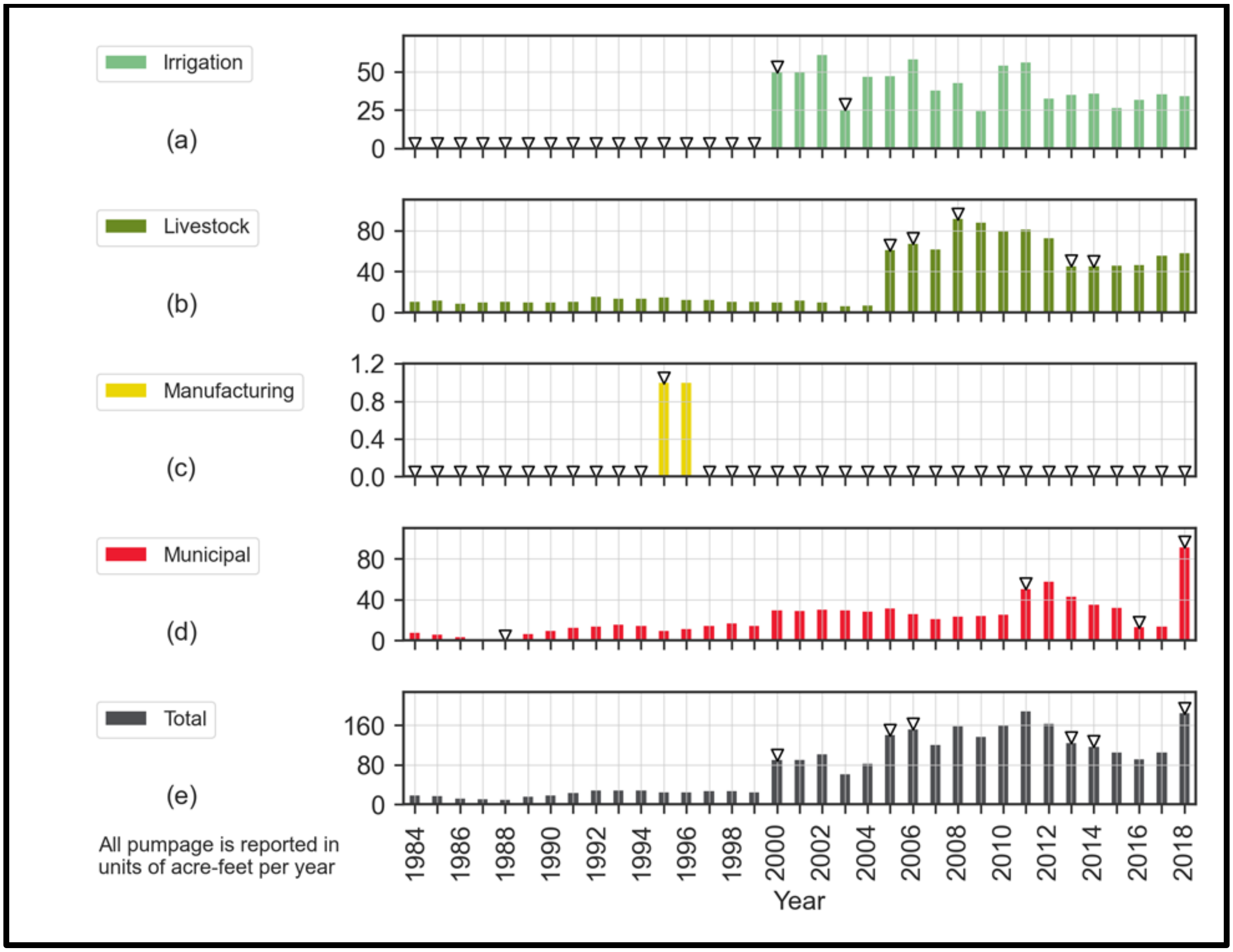


Figure 66. **Coke County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

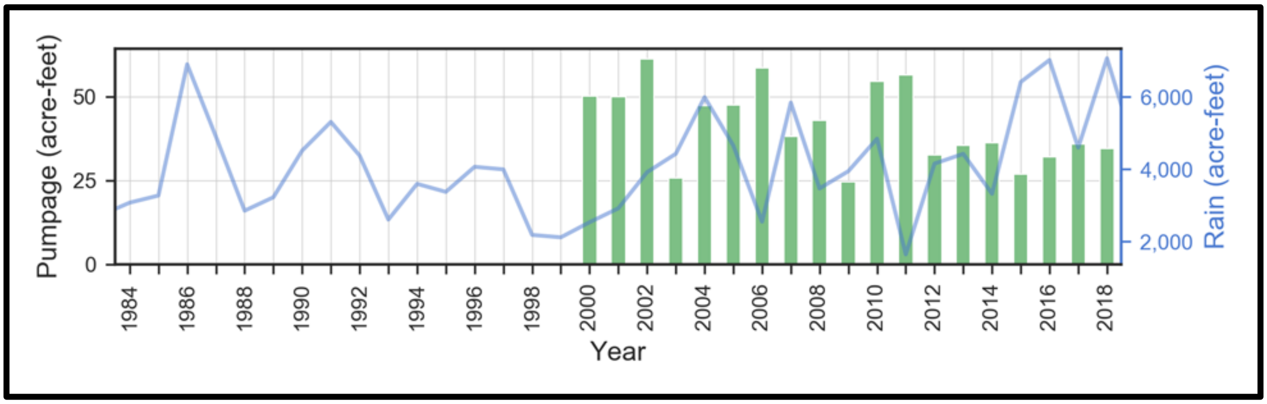


Figure 67. Coke County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

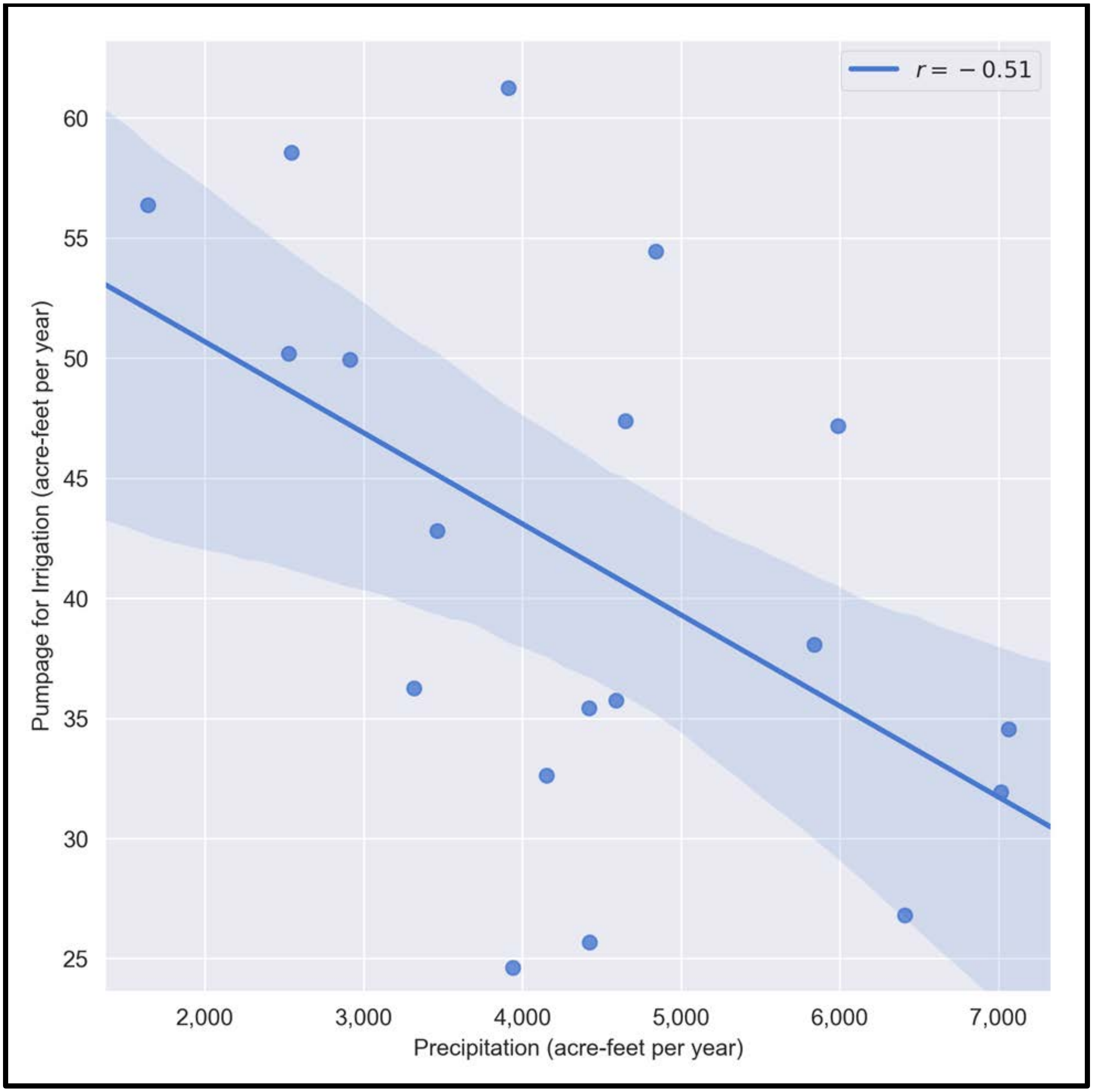


Figure 68. Coke County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

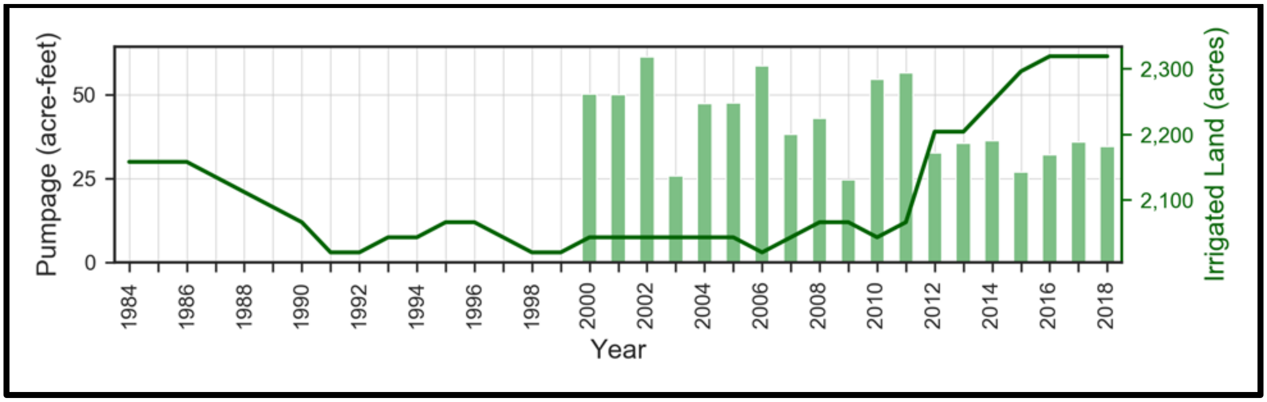


Figure 69. **Coke County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.**

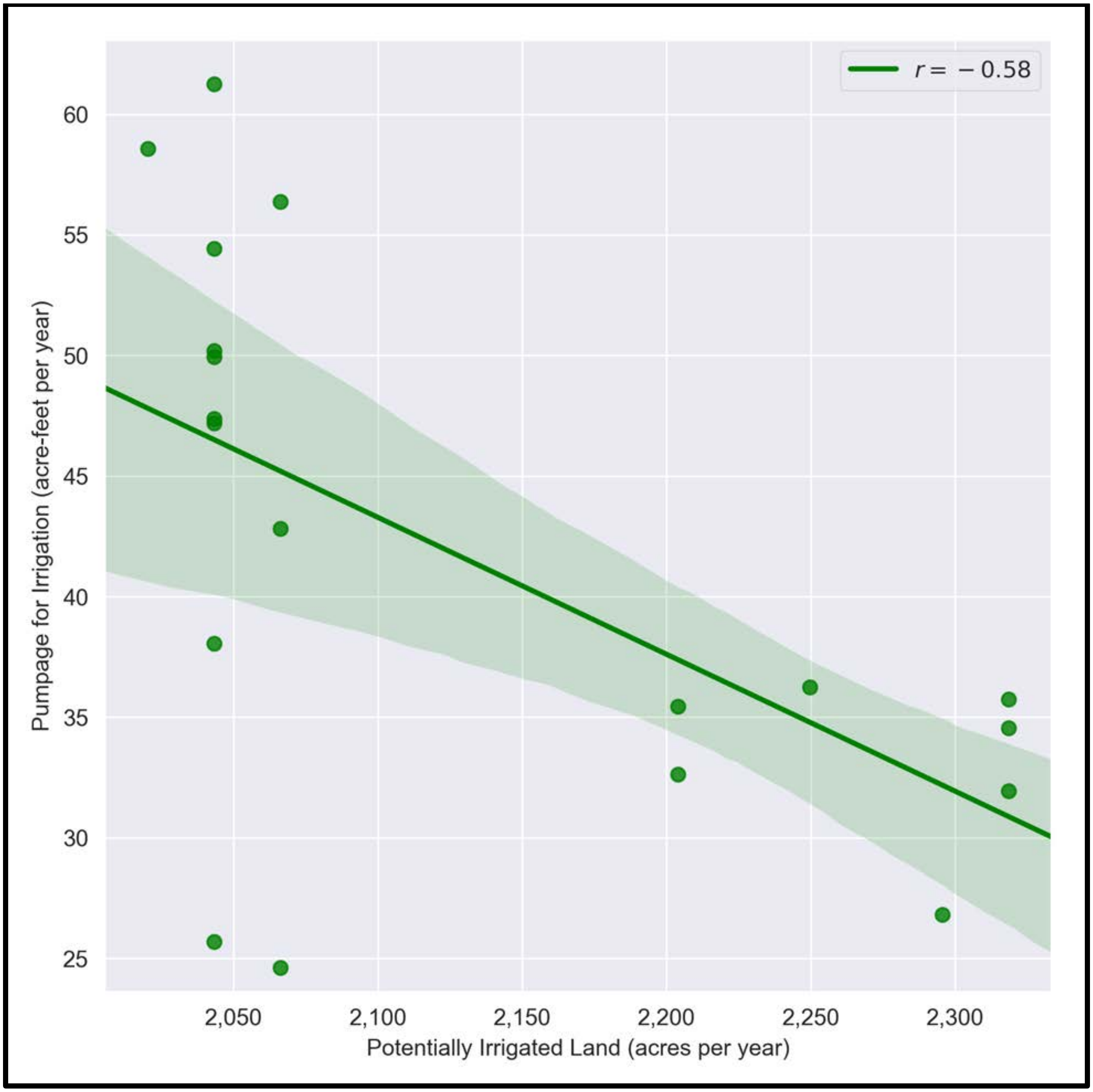


Figure 70. Coke County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 17. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Coke County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1984-1999, 2003, 2009	1984-2000, 2002-2004, 2006, 2007, 2009, 2010, 2012, 2015	1984-2000, 2003
	Livestock	2005	2005, 2008, 2013	2005, 2006, 2008, 2013, 2014
	Manufacturing	1995-1996	1984-1994, 1997-2018	1984-1995, 1997-2018
	Municipal	2000, 2011, 2018	1988, 2000, 2011, 2013, 2016, 2018	1988, 2011, 2016, 2018

3.3.10 Comal County

The Edwards (Balcones Fault Zone) Aquifer is present in the central portion of Comal County and covers about 37 percent of the county area. Approximately 98 percent of Comal County contains the Trinity (Hill Country) Aquifer. Figure 71 illustrates the extent of the study area aquifers in the county.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards (Balcones Fault Zone) within Comal County was approximately 20,000 acre-feet, which occurred in 1996 and 1999. (Figure 72). As shown on Figure 72, irrigation, municipal, mining, livestock, and manufacturing are the recorded uses of groundwater from the Edwards (Balcones Fault Zone) Aquifer within Comal County. There is non-surveyed municipal use reported after 2000 but it represents a small portion of the total municipal use. Water usage for manufacturing, mining, and municipal use were often 10 to 20 times larger than usage for irrigation, and 100 to 200 times larger than reported livestock use.

The year-to-year change analysis (Figure 73) and standard deviation analysis (Figure 74) flagged numerous anomalies in the Comal County data for the Edwards (Balcones Fault Zone) Aquifer. Year-to-year fluctuations in pumpage flagged many of the anomalies. However, the irrigation, livestock, and manufacturing datasets each contained periods of low and nearly constant pumpage bracketed by higher and variable pumpage which could indicate that pumpage was consistently under-reported during the years of low reporting. Other explanations are also possible and the anomalies warrant further investigation.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Trinity (Hill Country) Aquifer in Comal County was been approximately 9,000 acre-feet, which occurred in 2018 (Figure 75). As shown in Figure 75, the Water Use Survey data includes pumping from the Trinity (Hill Country) Aquifer in Comal County for mining, manufacturing, livestock, municipal, and irrigation use. Since 2000, the TWDB Water Use Survey database includes non-surveyed municipal use but it represents a small amount compared to the surveyed use. Manual review of Figure 75 indicates sporadic large changes in year-to-year pumping for municipal and irrigation use. Reported Water Use Survey data are insufficient for manufacturing and mining use to assess data trends and fluctuations. Water for livestock use decreased from 1998 through 2004 and then stabilized at relatively low pumping levels through 2018.

The year-to-year change analysis (Figure 76) and standard deviation analysis (Figure 77) flagged numerous anomalies in the Comal County data for the Trinity (Hill Country) Aquifer. However, due to the low amounts of production, significant additional review may not be warranted for the irrigation and livestock uses. The primary anomaly of interest for the Water Use Survey Trinity (Hill Country) Aquifer pumping data are the large changes in mining and manufacturing pumping, as well as the missing data within these datasets.

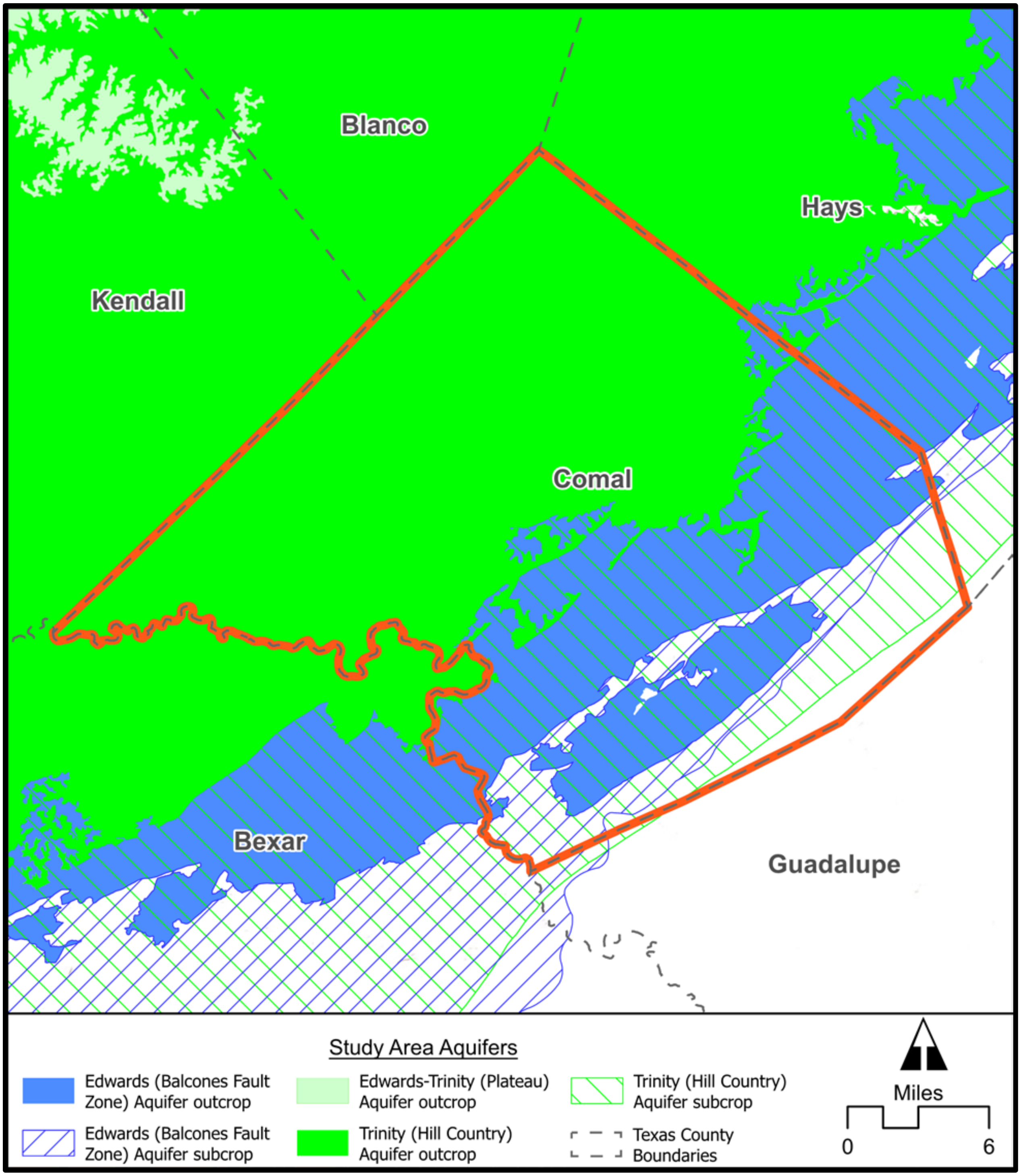


Figure 71. Comal County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

With respect to the Trinity (Hill Country) Aquifer and its footprint area, land used for potential irrigation in Comal county negatively correlates to groundwater pumpage from the Trinity (Hill Country) Aquifer for irrigation use. Figure 78 indicates that although the acres of potentially irrigated land overlying the Trinity (Hill Country) Aquifer in the county have decreased since 1992, the reported pumpage for irrigation use has increased. Figure 79 indicates a linear correlation value of -0.49 between potentially irrigated land area and groundwater pumpage for irrigation. The observed moderate negative correlation inversely follows trends in land use. This inverse trend could indicate that the irrigation pumpage data is in error or be due to another factor, such as, irrigators growing crops with lower water demands per acre or using irrigation methods are more efficient. Nonetheless, further research into the relationship between land use and irrigation pumpage in the county could provide insight into the validity of reported irrigation pumpage from the Trinity (Hill Country) Aquifer in Comal County.

Table 18 provides the years identified as having anomalous pumping data for Comal County for the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

Figure 72. Comal County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

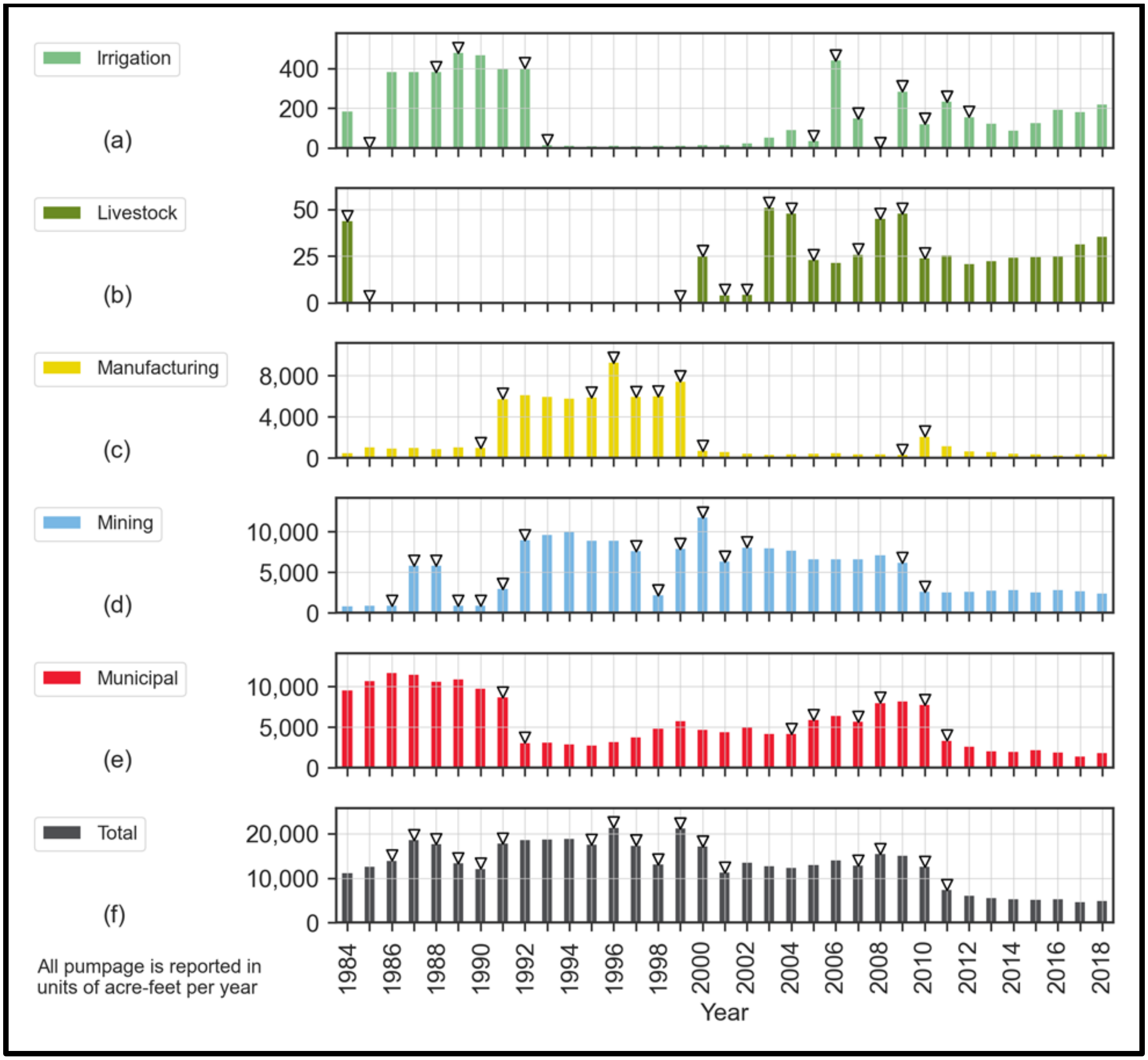


Figure 73. Comal County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

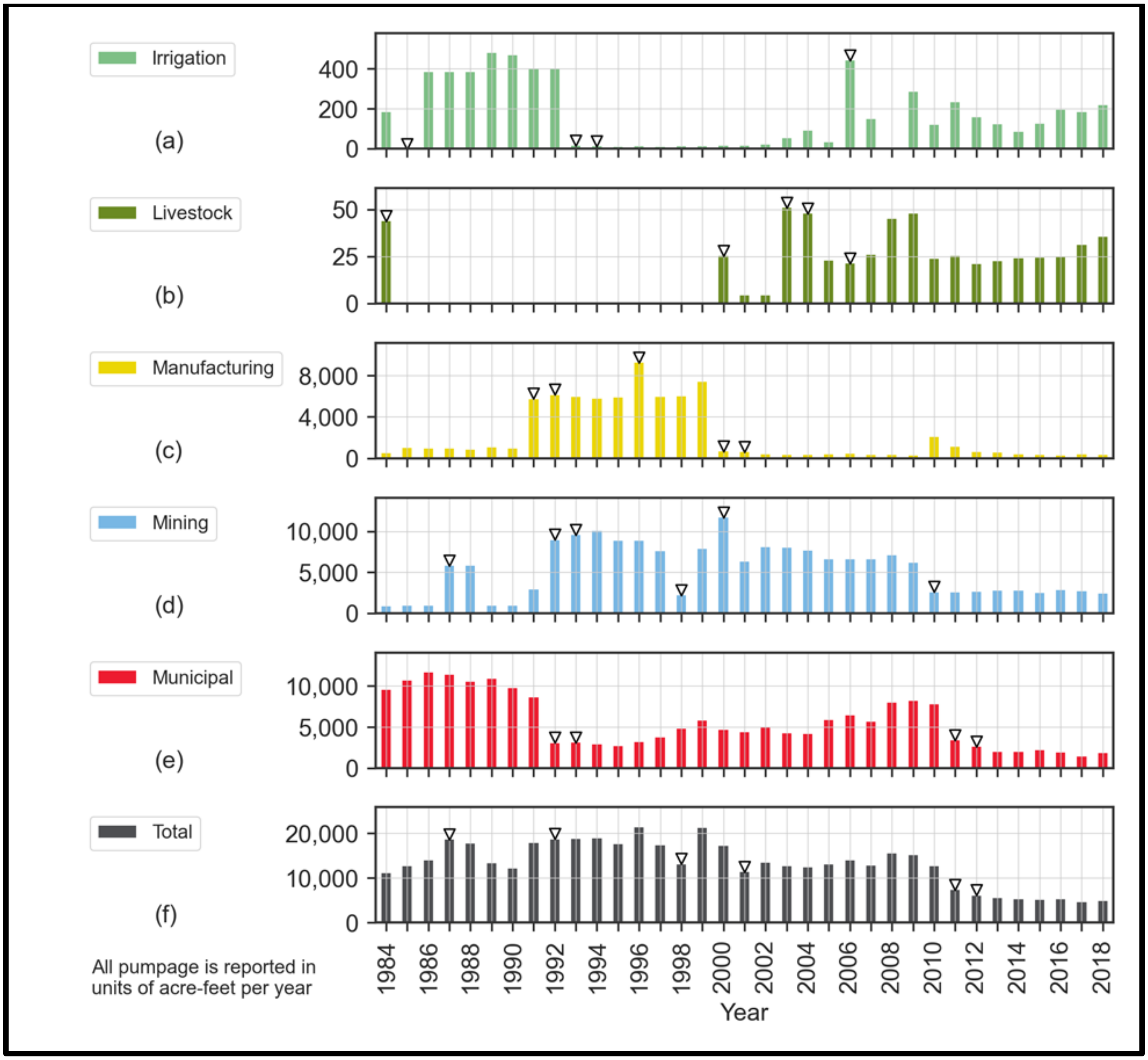


Figure 74. Comal County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

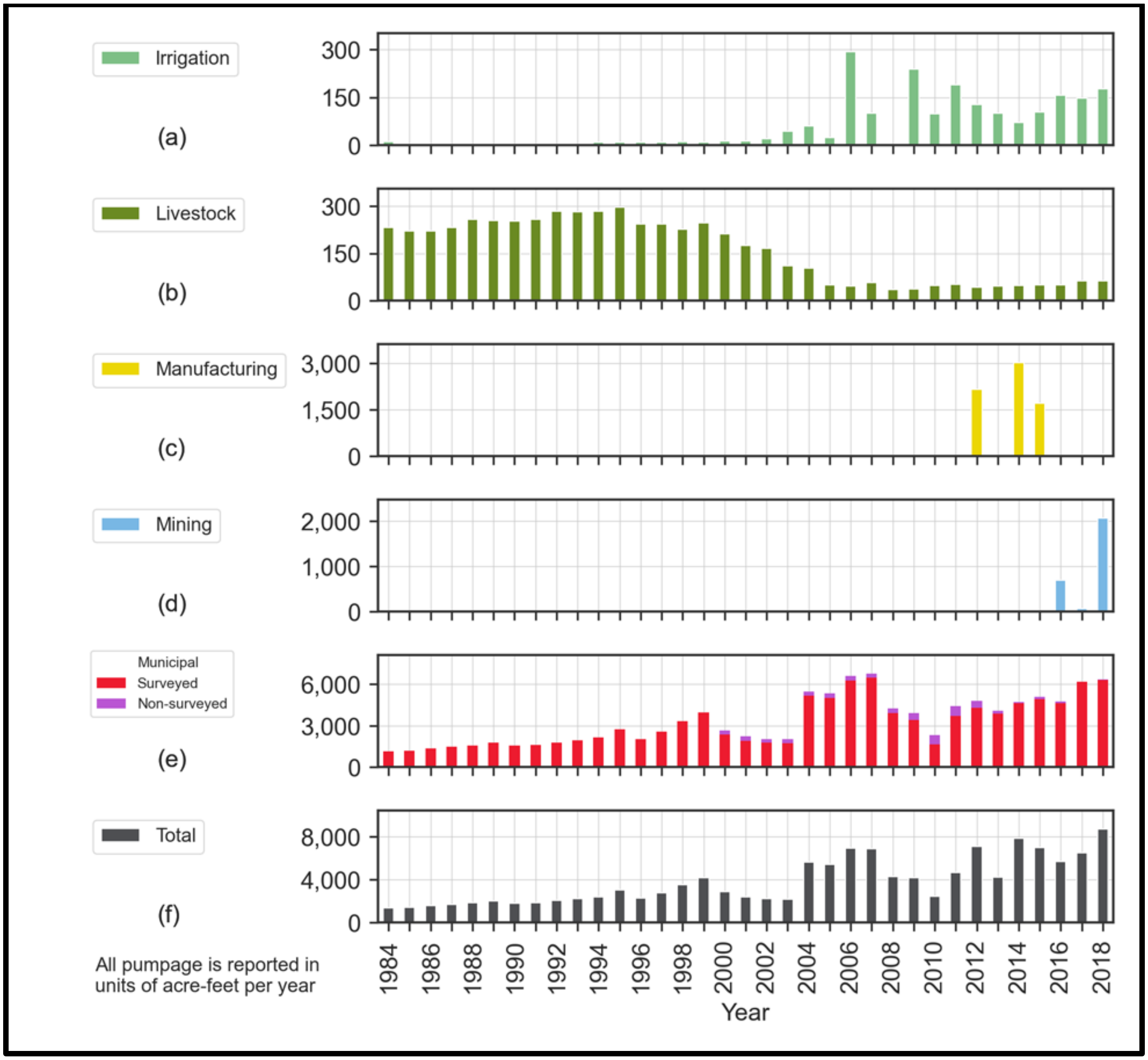


Figure 75. **Comal County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

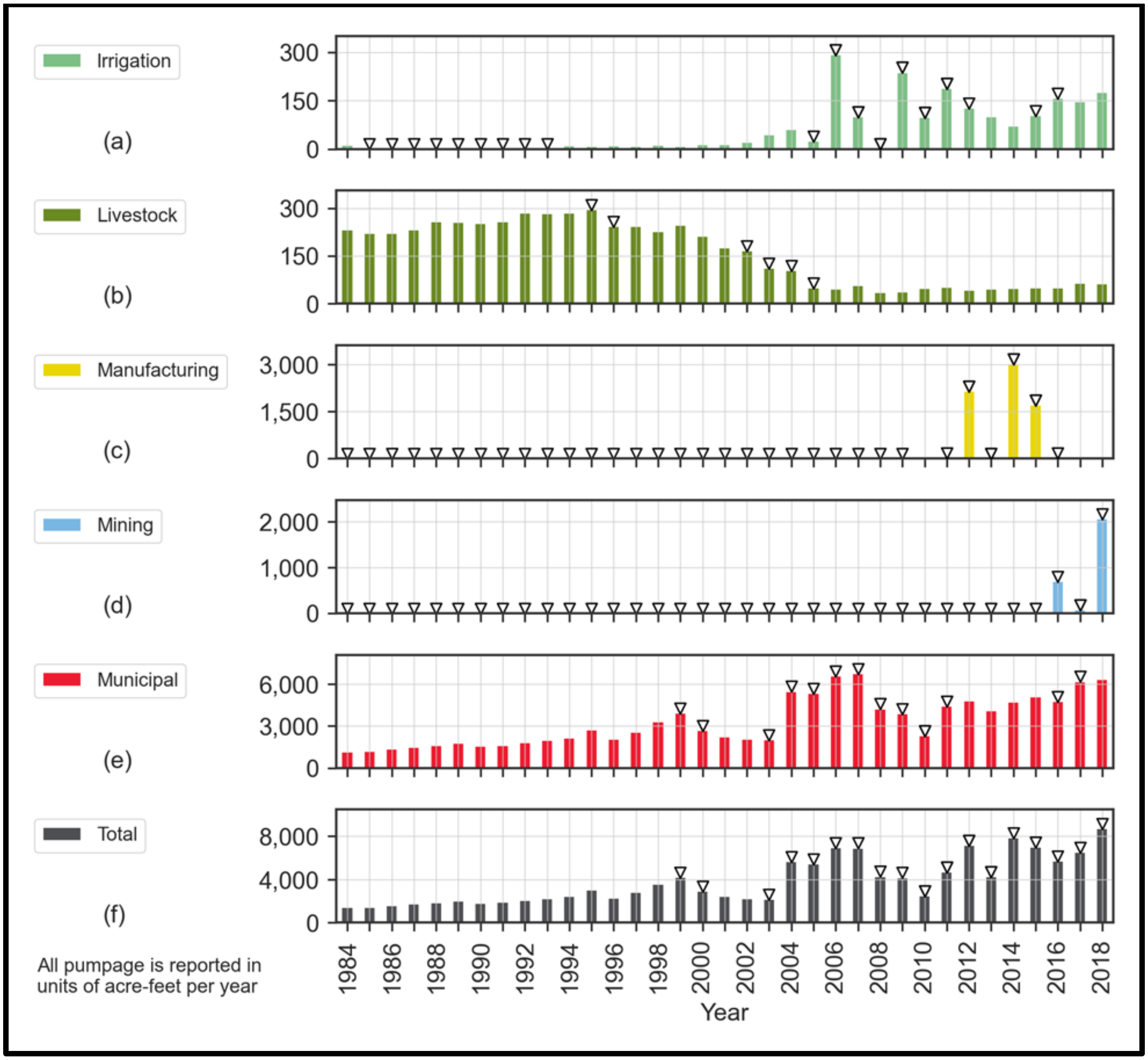


Figure 76. **Comal County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

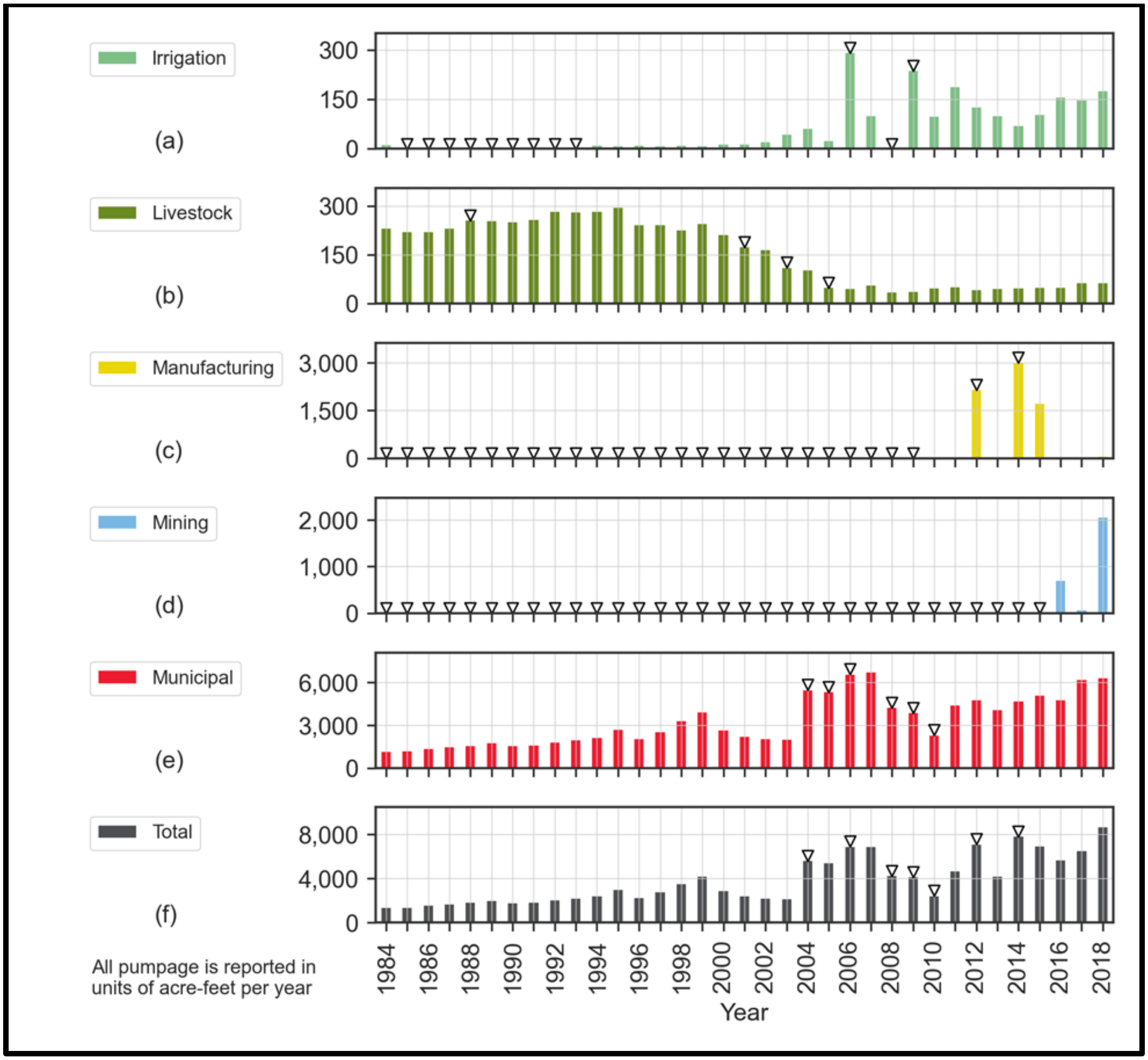


Figure 77. Comal County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

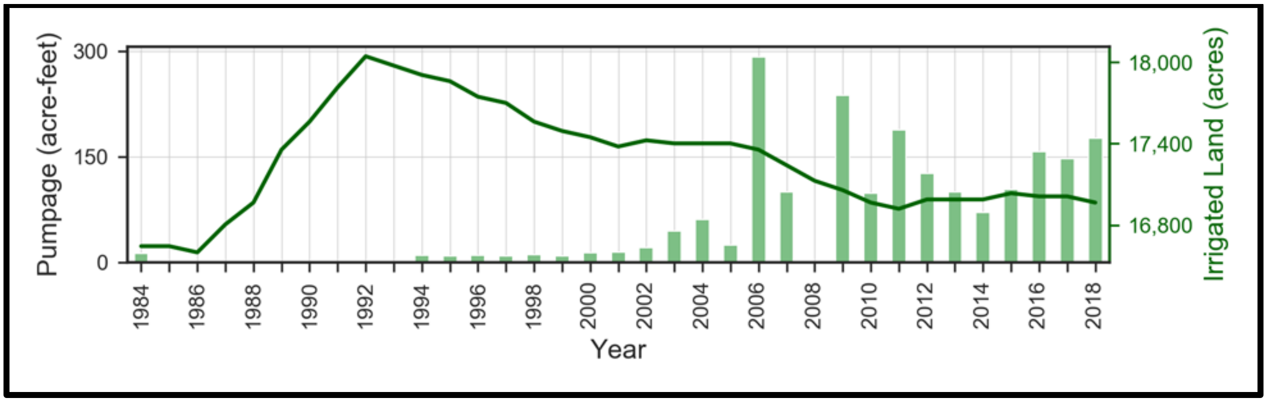


Figure 78. Comal County Trinity (Hill Country) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, of overlying the aquifer.

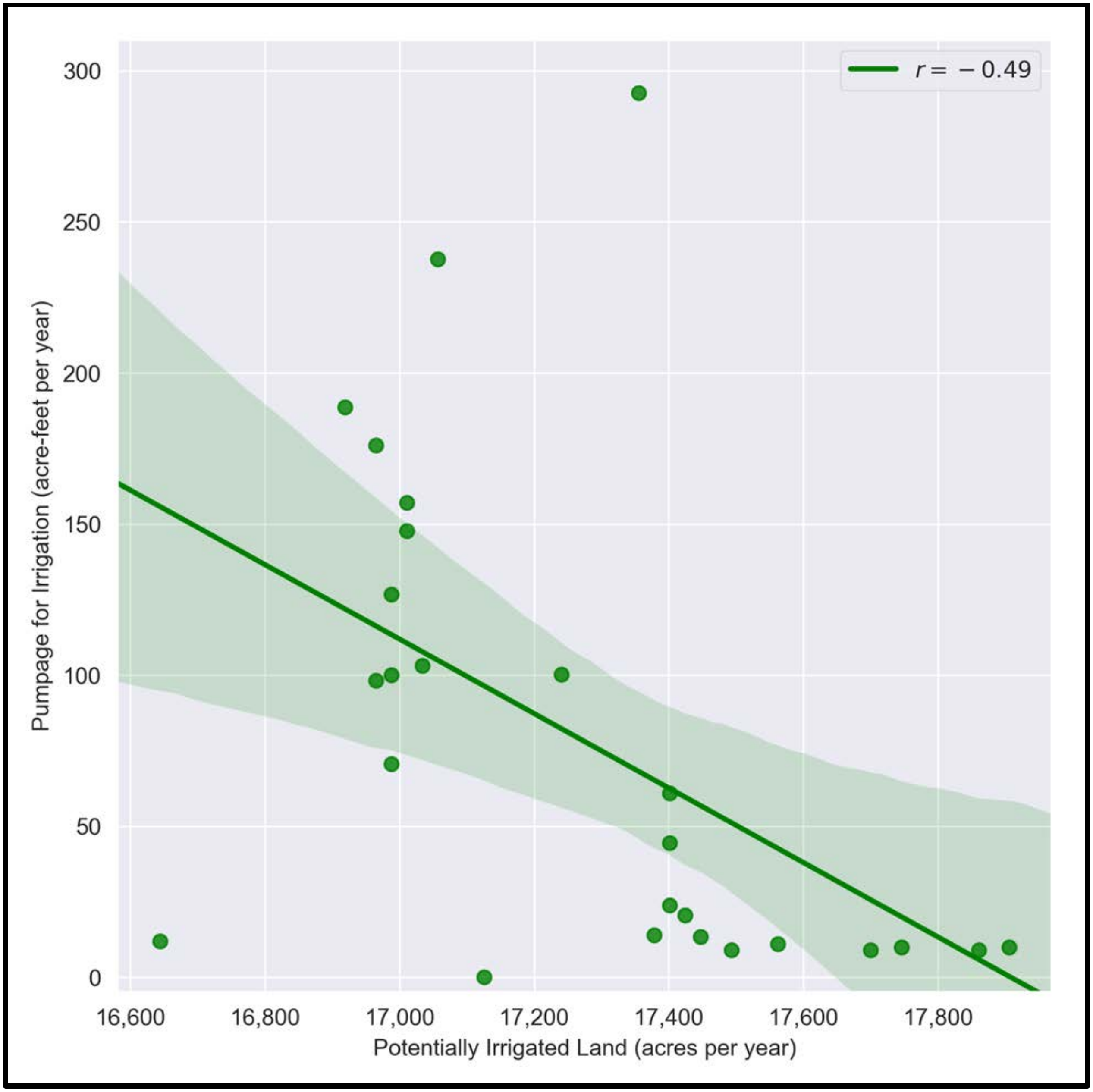


Figure 79. Comal County Trinity (Hill Country) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 18. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Comal County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	1985, 1993-2005, 2008	1984-1986, 1989, 1993, 2006-2012	1985, 1993, 1994, 2006, 2008
	Livestock	1985-1998, 2001-2002	1984, 1985, 2000, 2001, 2003, 2005, 2008, 2010	1984, 2000, 2003, 2004, 2006
	Manufacturing	1991, 2000	1991, 1996, 1997, 1999, 2000, 2010	1991, 1992, 1996, 2000, 2001
	Mining	1984-1986, 1989-19901998, 2010	1987, 1989, 1991, 1992, 1998-2002, 2010	1987, 1992, 1993, 1998, 2000, 2010
	Municipal	1992, 2011	1992, 2005, 2008, 2011	1992, 1993, 2011, 2012
Trinity (Hill Country)	Irrigation	2006, 2010	1985-1993, 2006-2012, 2016	1985-1993, 2006, 2008, 2009
	Livestock	None	1996, 2003, 2005	1988, 2001, 2003, 2005
	Manufacturing	2012, 2014, 2015	1984-2009, 2012-2016	1984-2009, 2012, 2014
	Mining	1984-2015, 2018	1984-2018	1984-2015
	Municipal	2004	2000, 2004, 2006, 2008, 2010, 2011, 2017	2004-2006, 2008-2010

3.3.11 Concho County

The Edwards-Trinity (Plateau) Aquifer is present in the southern portion of Concho County, and covers approximately 37 percent of the county area. The Lipan Aquifer underlies the western portion of Concho County and spans about 20 percent of the county area. Figure 80 illustrates the extent of the study area aquifers in Concho County.

With regard to the Edwards-Trinity (Plateau) Aquifer within Concho County, groundwater pumping estimates from the Water Use Survey dataset indicate that maximum total pumping was approximately 600 acre-feet, which occurred in 1984 (Figure 81). As shown on Figure 81, the Water Use Survey dataset reports pumpage for livestock and municipal uses only. Manual review of the pumping data suggests that 1984, 2001, and 2017 are anomalous data-years with respect to livestock use, and both 1984 and 2018 are anomalous years with respect to municipal use.

The year-to-year change analysis (Figure 82) and standard deviation analysis (Figure 83) flagged numerous anomalies in the data for the Edwards-Trinity (Plateau) Aquifer in Concho County. Flagged anomalies included years of missing data and years where reported pumping differed sufficiently with respect to that from nearby years within the dataset.

For the Lipan Aquifer within Concho County, groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping was approximately 6,000 acre-feet, which occurred in 1993 and 2008 (Figure 84). As shown on Figure 84, the Water Use Survey database only included pumpage for irrigation and municipal uses for the aquifer within the county. Manual review of pumpage data suggests numerous anomalies within the irrigation dataset. Within the municipal dataset, the 2018 value appears anomalous, yet the reported pumpage is small compared to the irrigation usage. Municipal use data is not available prior to 2006. The year-to-year change analysis (Figure 85) and standard deviation analysis (Figure 86) flagged many anomalies in the data for the Lipan Aquifer within Concho County.

Table 19 provides the years identified as having anomalous pumping amounts for Concho County for the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer.

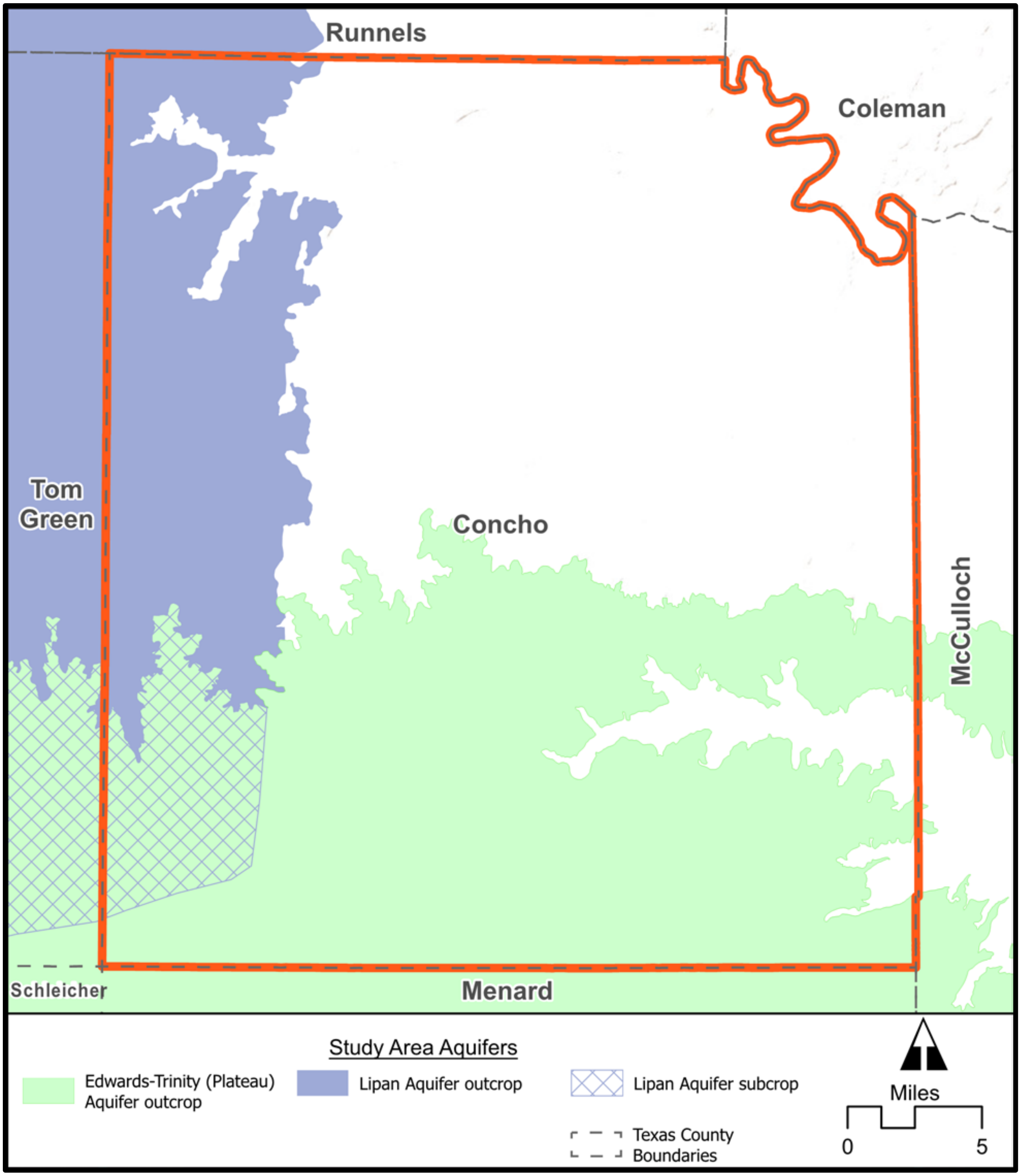


Figure 80. Concho County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer.

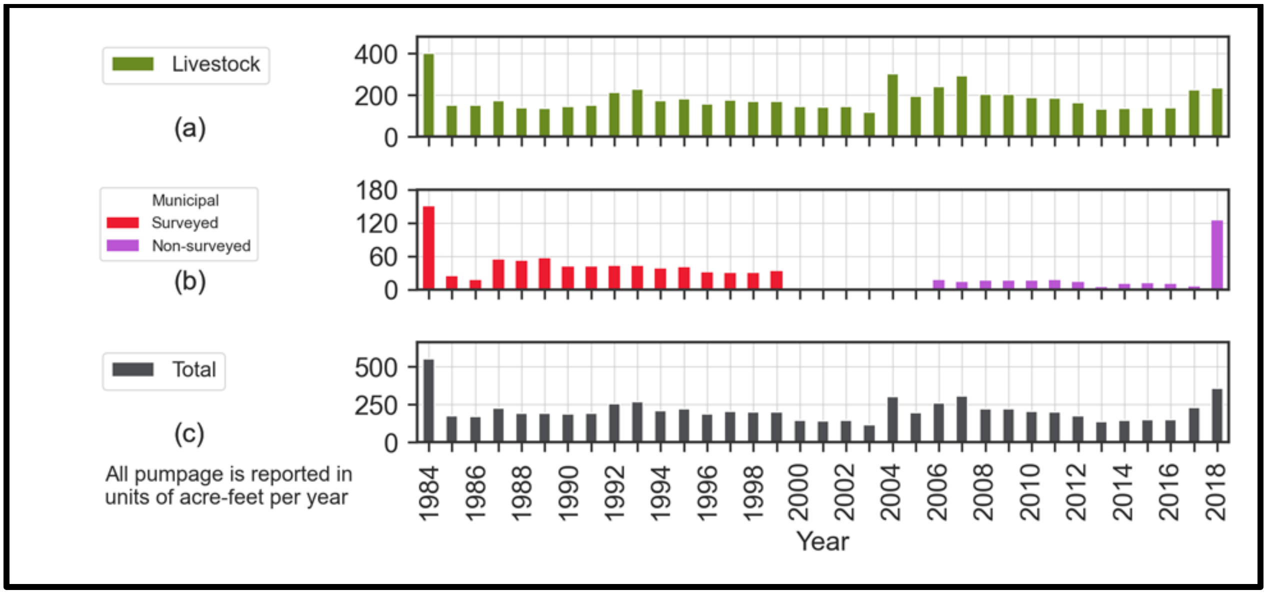


Figure 81. Concho County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

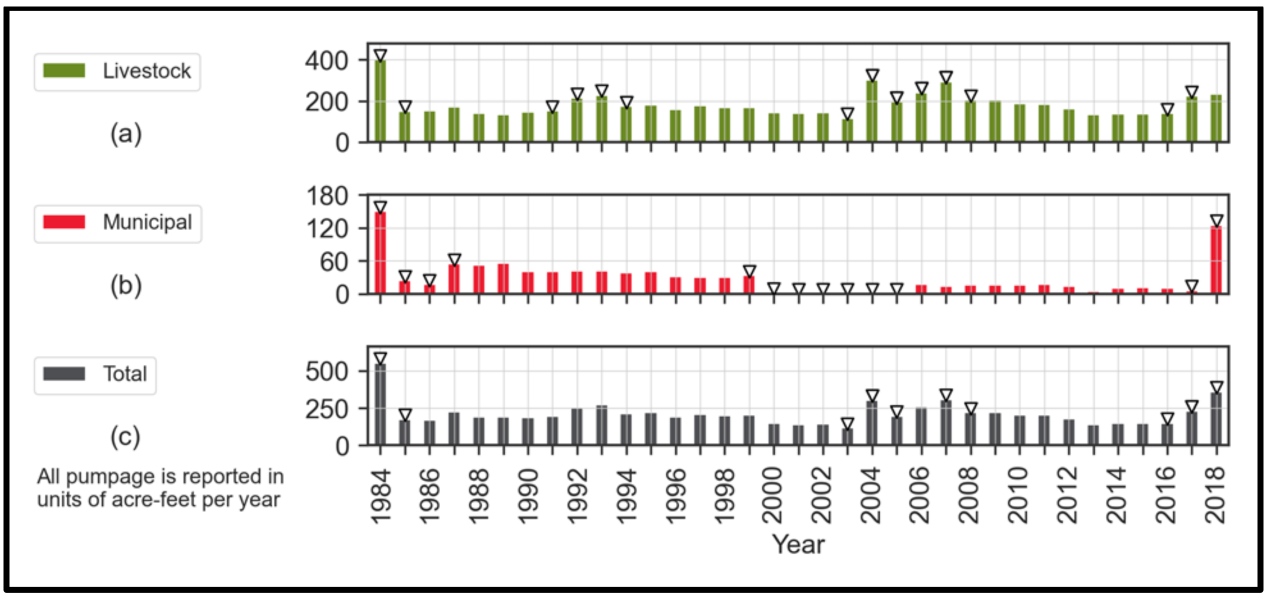


Figure 82. Concho County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

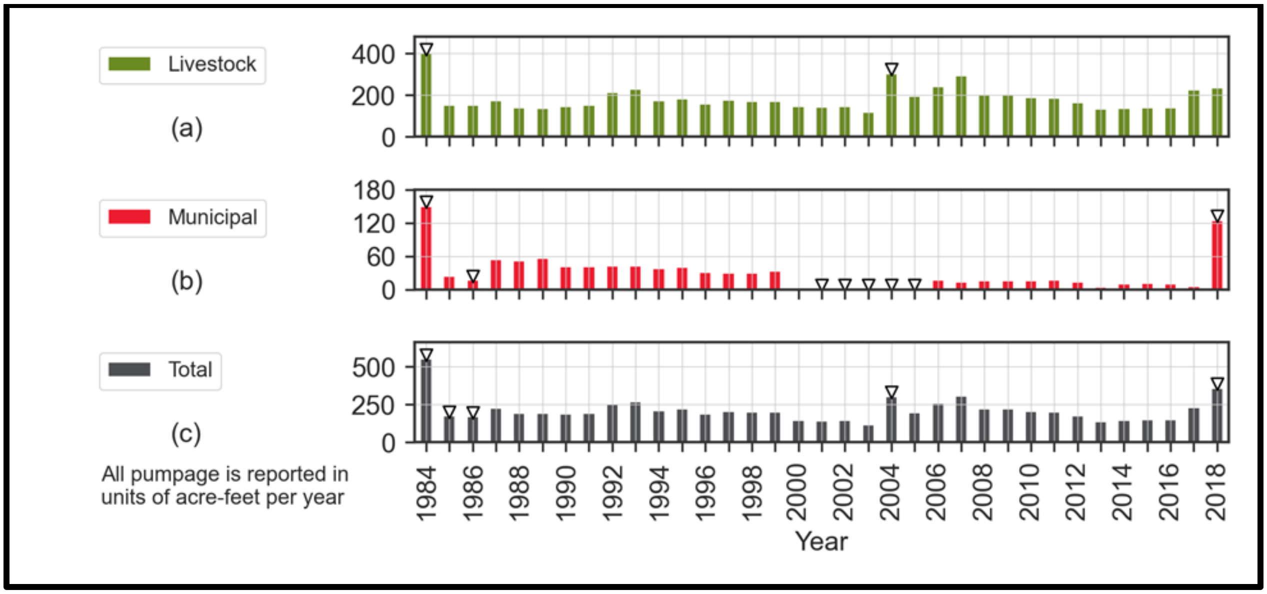


Figure 83. **Concho County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

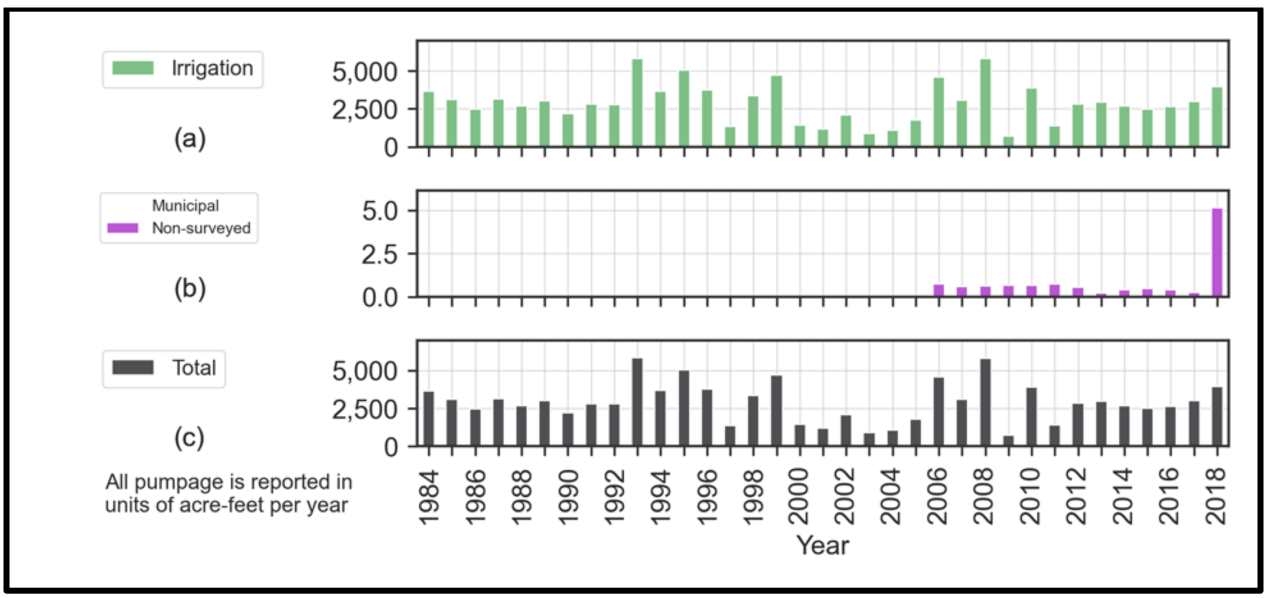


Figure 84. **Concho County Lipan Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

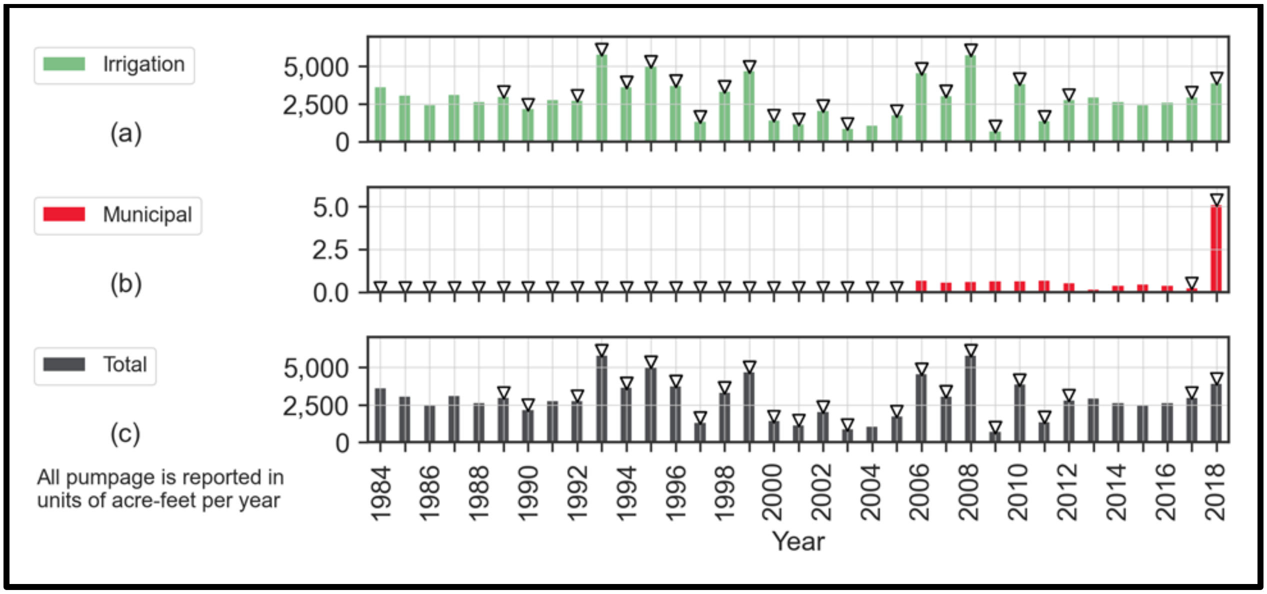


Figure 85. Concho County Lipan Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

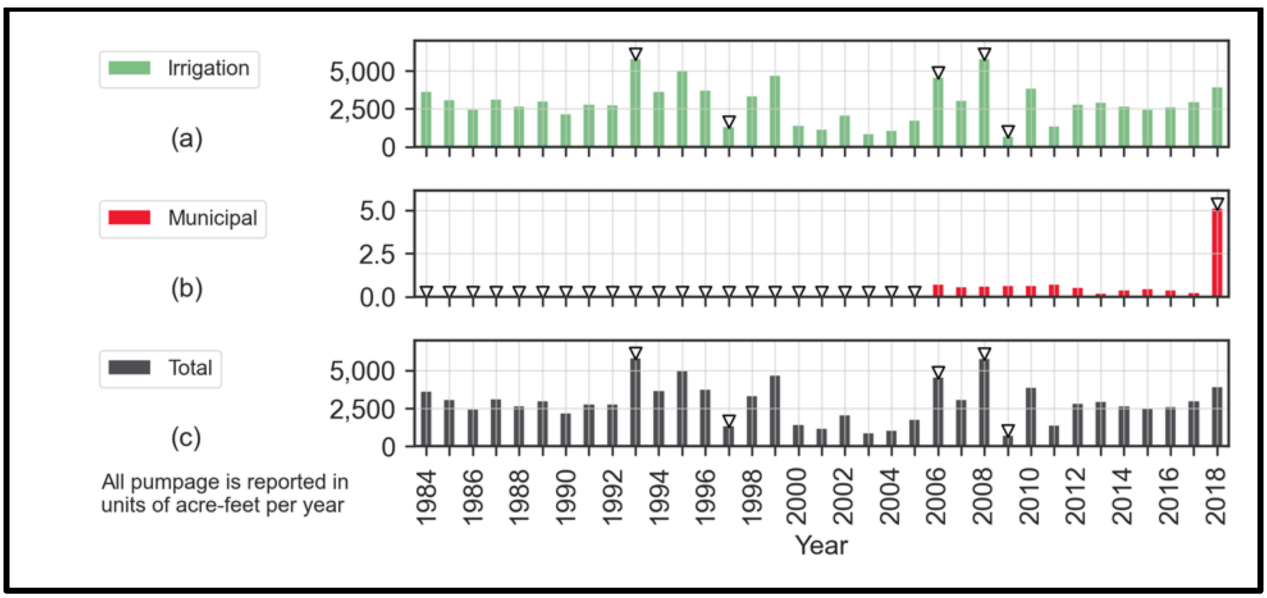


Figure 86. Concho County Lipan Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 19. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Concho County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	1984	1984, 1985, 1992, 1994, 2004-2008, 2017	1984, 2004
	Municipal	1984, 2000-2005, 2018	1984, 1985, 1987, 2000-2005, 2018	1984, 1986, 2001-2005, 2018
Lipan	Irrigation	1993	1990, 1993-2000, 2002, 2003, 2006-2012, 2018	1993, 1997, 2006, 2008, 2009
	Municipal	2018	1984-2005, 2018	1984-2005, 2018

3.3.12 Crane County

The Pecos Valley Aquifer is present in almost all (about 95 percent) of Crane County (see Figure 87). Within relatively small portions of the county the Edwards-Trinity (Plateau) Aquifer is also present, however there is not any reported pumping from this aquifer in the TWDB Water Use Survey database. Groundwater pumping estimates from the TWDB Water Use Survey indicates total pumping from the Pecos Valley Aquifer was more than 4,000 acre-feet per year in 1984, but is generally less than 2,000 acre-feet per year from 2000 onward (see Figure 88). The largest quantities of water pumped within Crane County from the Pecos Valley Aquifer were for mining use prior to 2000. After this time, municipal is the largest water use category.

Pumping for irrigation use typically ranged from 10 to 100 acre-feet per year from 1984 through 1996. An abrupt increase in irrigation pumping occurred in 1997 and continued for three years. After this period, the TWDB Water Use Survey database does not contain irrigation pumping data the Pecos Valley Aquifer within Crane County.

Pumping for livestock use ranged from approximately 50 to 150 acre-feet per year from 1984 through 2018. There is an abrupt drop in pumping from 2009 to 2010 with the previous three years showing an increasing trend. We also observe an anomaly in manufacturing pumping in 1988 with a reported total volume of about 400 acre-feet per year which is higher than the approximately 150 acre-feet per year reported in years 2000 through 2018. Pumping for mining use averaged approximately 1,500 acre-feet per year from 1984 to 1999, with no reported pumping for mining use after 1999. Pumping for municipal use averages about 1,250 acre-feet per year from 1984 through 2018. Since 2000, when inclusion of non-surveyed municipal use in the TWDB Water Use Survey database began, it represents most of the total reported municipal use.

The year-to-year change analysis shown on Figure 89 suggests several data anomalies for livestock and municipal use than we determined from the manual review or the standard deviation analysis (Figure 90). For the municipal pumping estimates, the year-to-year change analysis flagged what appear to be relatively minor changes (for example, 1998 to 1999). Similarly, the standard deviation evaluation flagged the year 1992 (for municipal use), which was not indicated from our manual review.

Table 20 provides the years identified as having anomalous pumping amounts for Crane County based on our manual review, year-to-year change (Figure 89), and standard deviation (Figure 90) analyses.

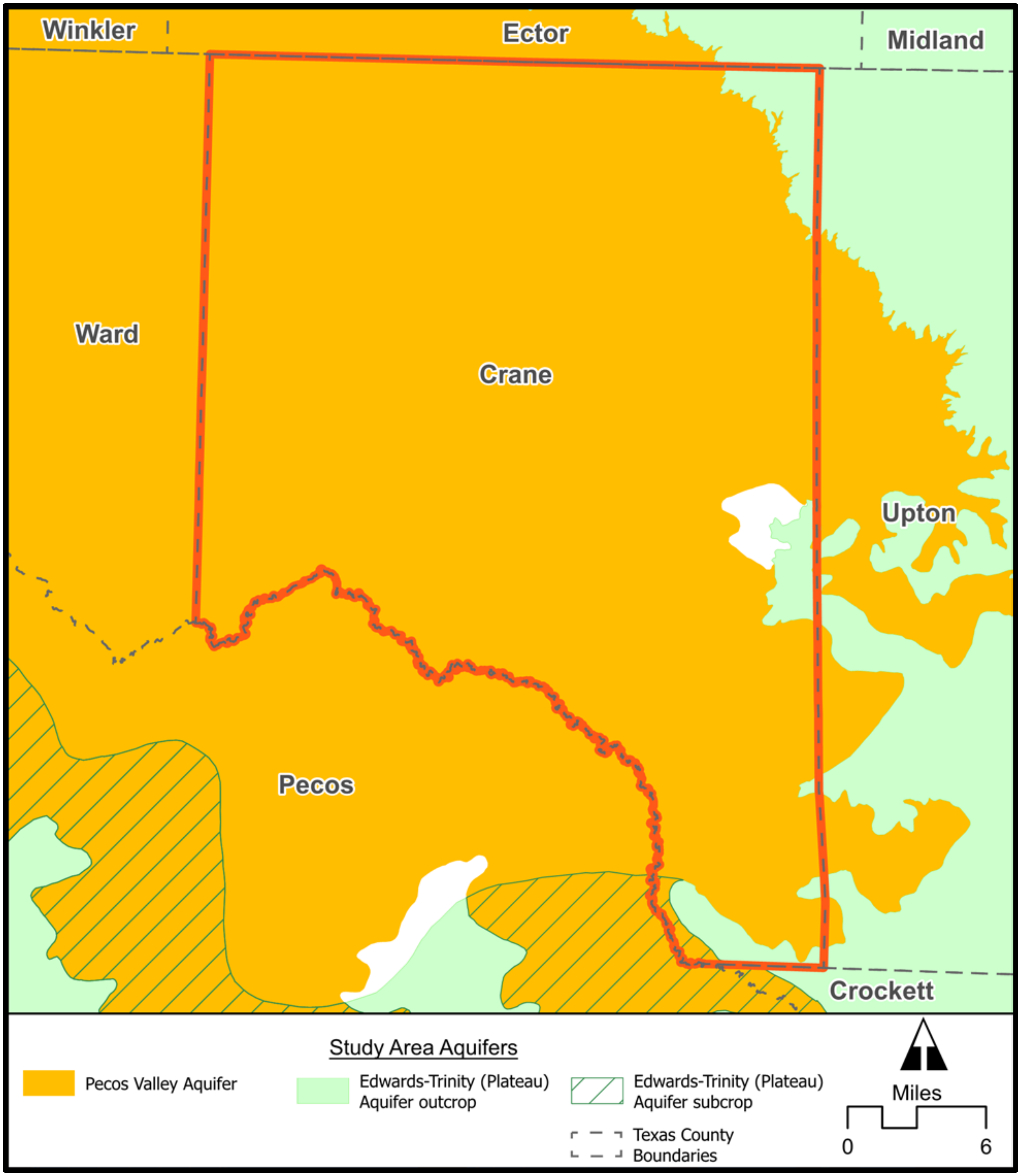


Figure 87. Crane County showing the extent of the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer.

Figure 88. **Crane County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

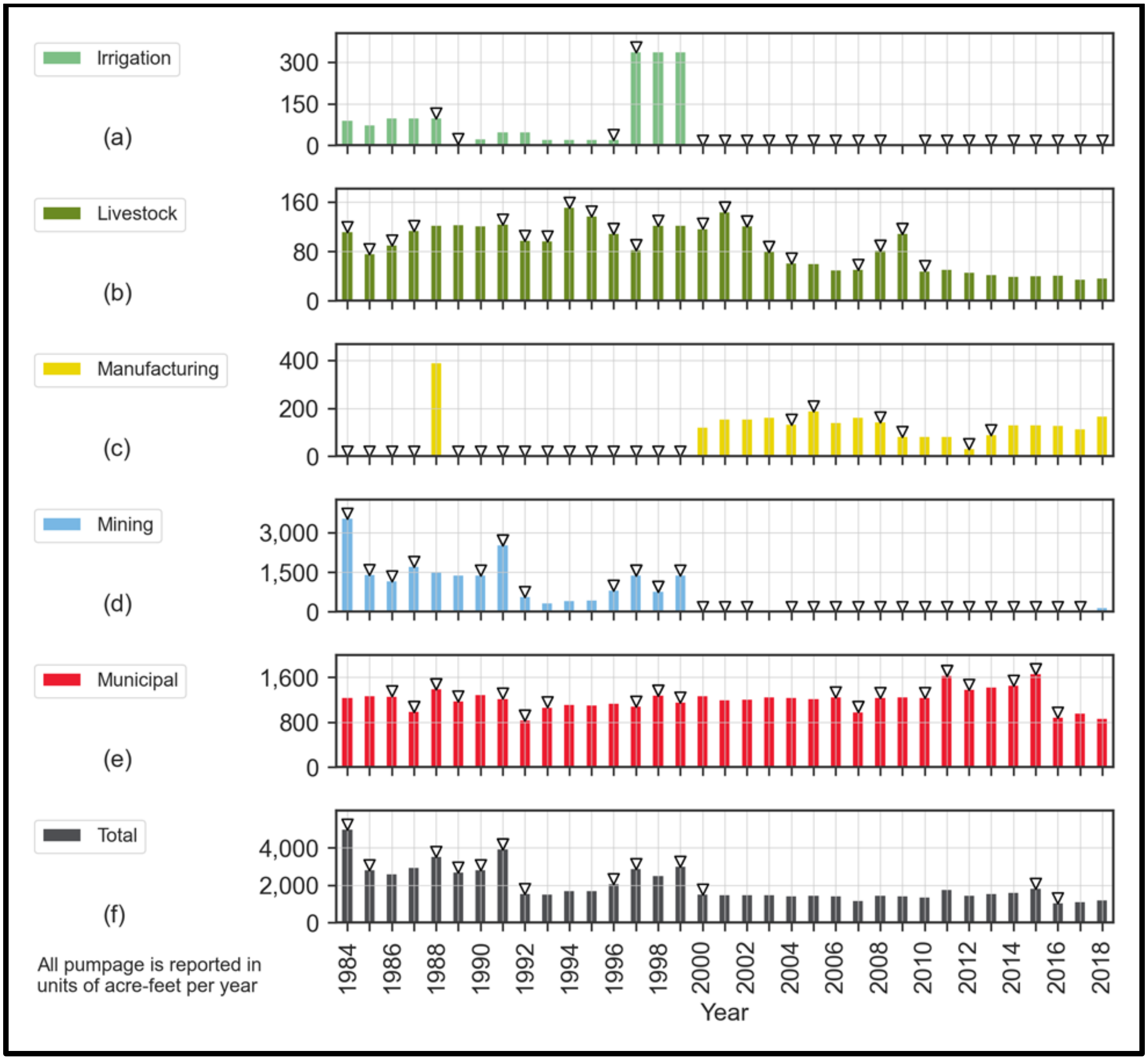


Figure 89. Crane County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 90. **Crane County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 20. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Crane County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Pecos Valley	Irrigation	1997-1999, 2000-2018	1989, 1997, 2000-2008, 2010-2018	1997, 1998, 2000-2018
	Livestock	2010	1984, 1985, 1987, 1992, 1994, 1996-1998, 2001-2004, 2008-2010	1994, 1997, 2003, 2004, 2009
	Manufacturing	1984-1999	1984-2000, 2005, 2009, 2013	1984-1999
	Mining	2000-2018	1984, 1985, 1987, 1991, 1992, 1997-2002, 2004-2017	1984, 1991, 2000-2002, 2004-2017
	Municipal	2016	1987-1989, 1992, 1993, 1998, 1999, 2007, 2008, 2011, 2012, 2015, 2016	1992, 2011, 2016, 2017

3.3.13 Crockett County

The Edwards-Trinity (Plateau) Aquifer is present across the entirety of Crockett County. The Pecos Valley Aquifer is present in the narrow strip of land along a portion of the border between Pecos County and Crockett County. The footprint of the Pecos Valley Aquifer within Crockett County is negligibly small and groundwater use from this aquifer is not reported within Crockett County. Figure 91 illustrates the extent of the study area aquifers in Crockett County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer in Crockett County was approximately 3,000 acre-feet per year, which occurred in 1984, 1985, and 1998 (Figure 92). As shown on Figure 92, reported uses of water within Crockett County from the Edwards-Trinity (Plateau) Aquifer include irrigation, livestock, manufacturing, mining, municipal, and power. Municipal water usage is the largest use category followed by livestock and irrigation. Reported usage for power in 2005 through 2007 is extremely small and may not be accurate. Manual review of Figure 92 indicates anomalies for irrigation use in 1998 and 1999 as well as for the period after 2012 where irrigation data is negligible or not in the Water Use Survey dataset. We also note the large decrease in mining use from 1991 onward as a data anomaly.

The year-to-year change analysis (Figure 93) and standard deviation analysis (Figure 94) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer in Crockett County. Identified anomalies include the large changes in year-to-year irrigation reported for 1997 and 1998 and then for 1999 and 2000, as well as similar abrupt changes in mining usage. We also identified anomalies within the municipal use dataset, yet the identified year-to-year pumping changes did not identify as anomalous through the manual review. The primary potential anomaly of interest for the Water Use Survey Edwards-Trinity (Plateau) Aquifer pumping data are the irrigation use spikes.

We expect groundwater pumping for irrigation in Crockett County to correlate negatively to precipitation such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 95 indicates that as precipitation increases over the Edwards-Trinity (Plateau) Aquifer in the county, the reported pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer decreases. Figure 96 indicates a correlation value (*"r"*) of -0.57 between precipitation over the Edwards-Trinity (Plateau) Aquifer in Crockett County and groundwater pumpage for irrigation from the aquifer within Crockett County. This moderate negative correlation suggests that the reported pumpage from the aquifer for irrigation in Crockett County inversely follows the trend in precipitation over the aquifer. However, based on Figure 96, we believe the correlation will become stronger if it turns out the high-irrigation usage years identified in 1998 and 1999 were incorrectly estimated and that actual pumpage during those years was more consistent with pumpage from the rest of the data time series. We plan to revise Figure 96 and recalculate the correlation coefficient after researching Crockett County irrigation data in subsequent project tasks.

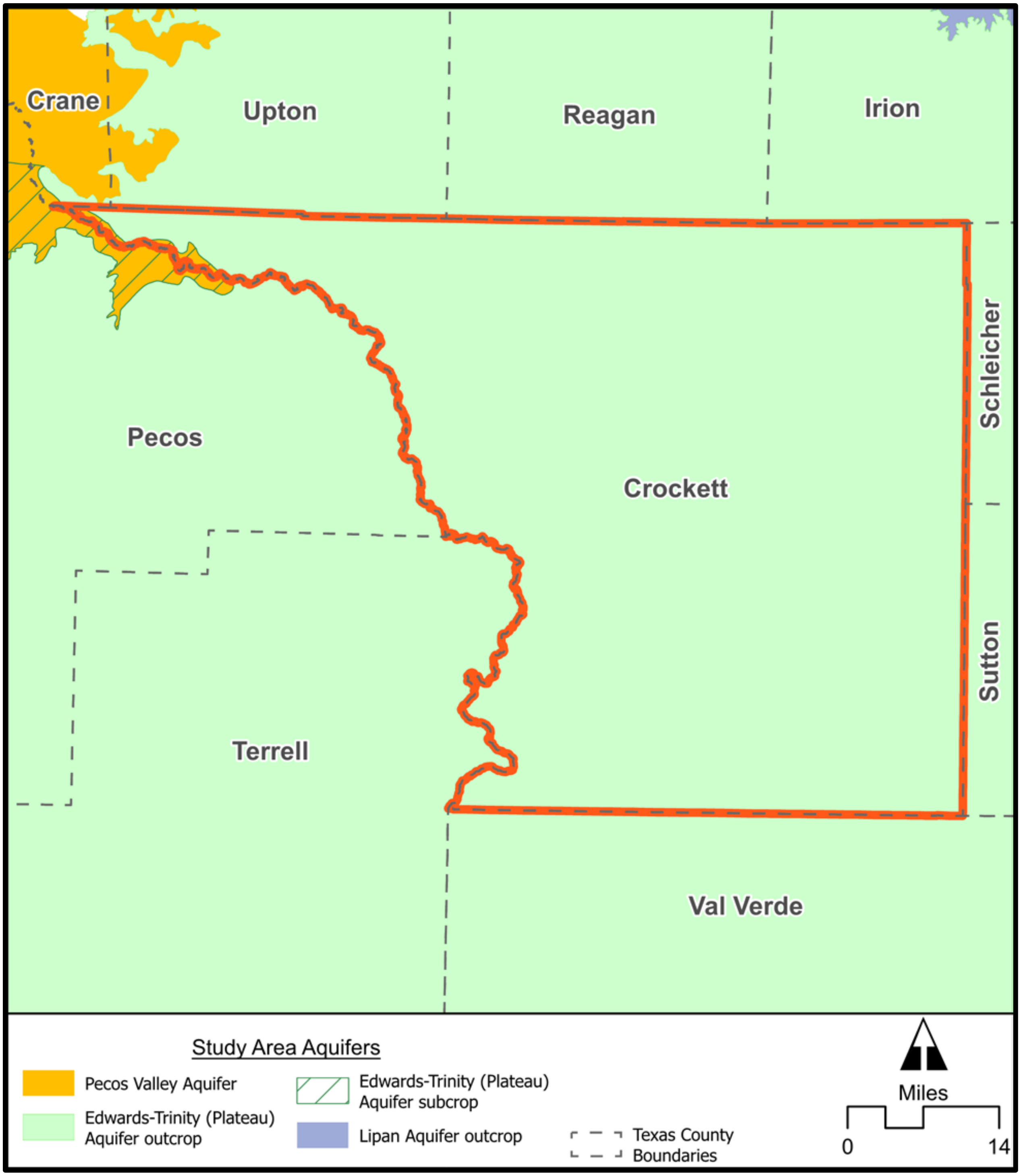


Figure 91. Crockett County showing the extent of the Edwards-Trinity (Plateau) Aquifers.

Land used for potential irrigation in Crockett County negatively correlates to groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation use. Figure 97 indicates that although the area of potentially irrigated land overlying the aquifer has increased by almost 50,000 acres since 1992 in Crockett County, the reported pumpage for irrigation use has decreased. Figure 98 indicates a linear correlation value ("*r*") of -0.50 between potentially irrigated land area and groundwater pumpage for irrigation. One interpretation of Figure 98 is that pumpage data for irrigation in Crockett County is incorrect. Other potential explanations include changing of irrigated crops to less water-demanding species, improved irrigation water delivery mechanisms, and other factors. We plan to revise Figure 98 after we have researched Crockett County irrigation data, land use, and farming practices in subsequent project tasks

Table 21 provides the years identified as having anomalous pumping amounts from the Edwards-Trinity (Plateau) Aquifer within Crockett County.

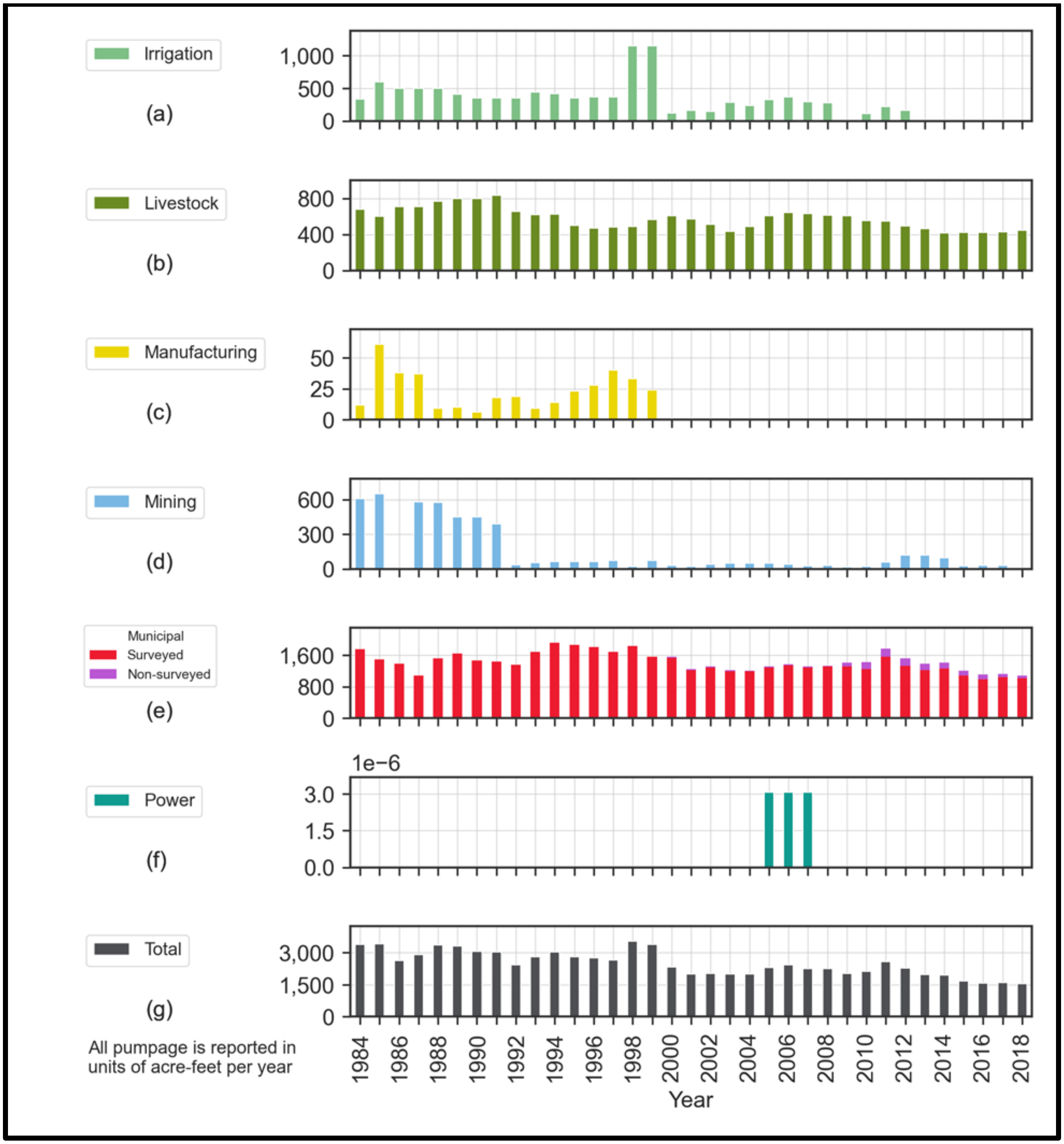


Figure 92. Crockett County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Figure 93. Crockett County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

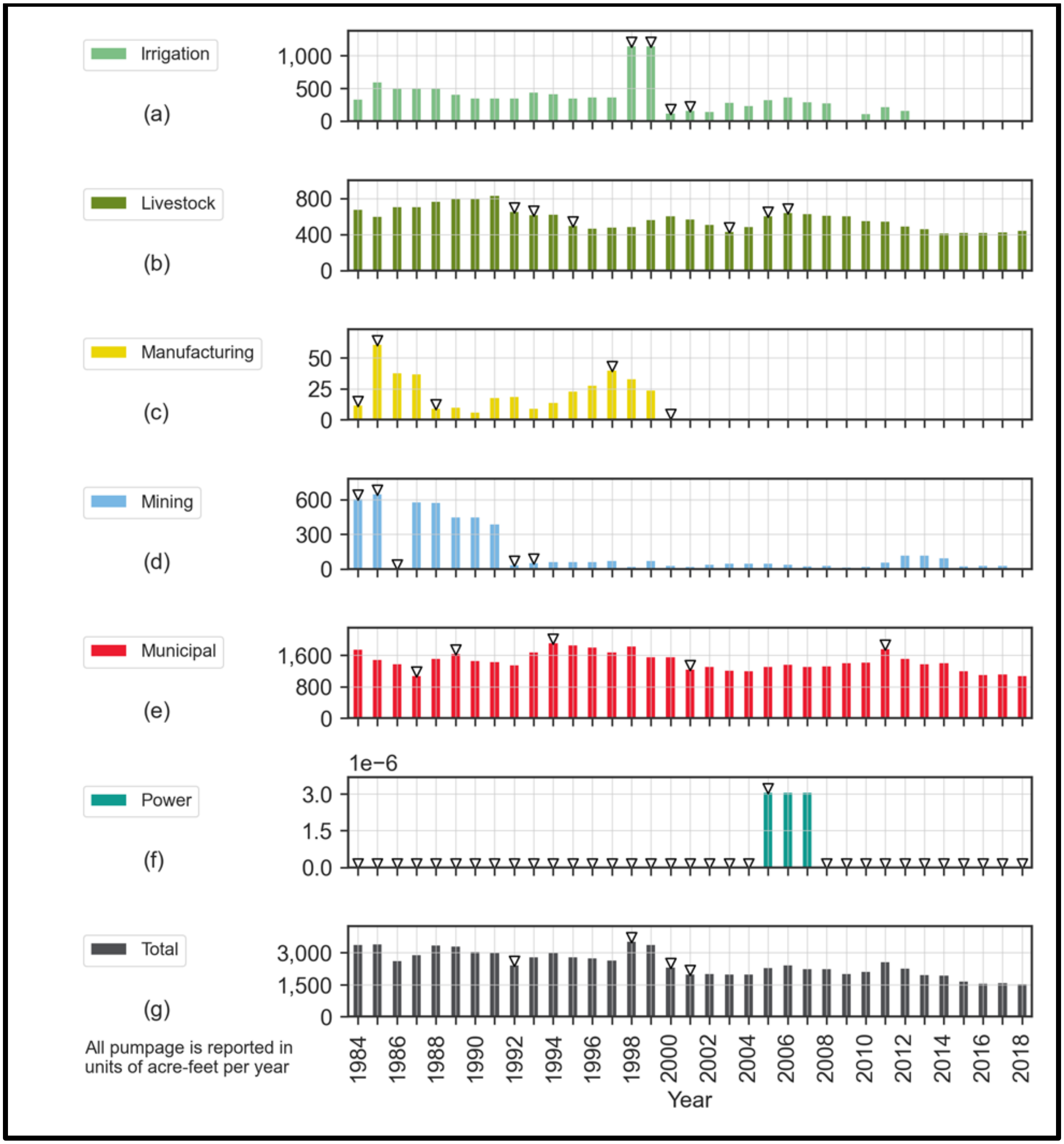


Figure 94. Crockett County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

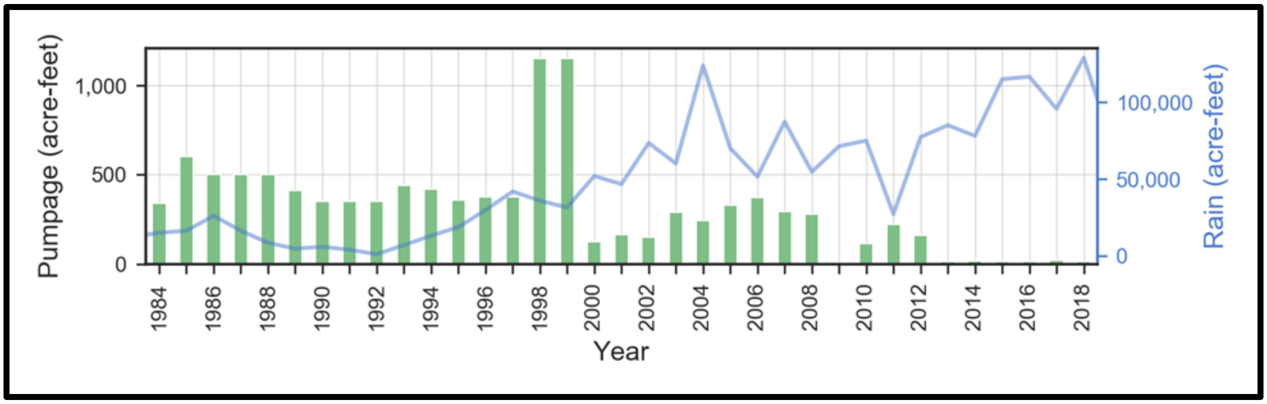


Figure 95. Crockett County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

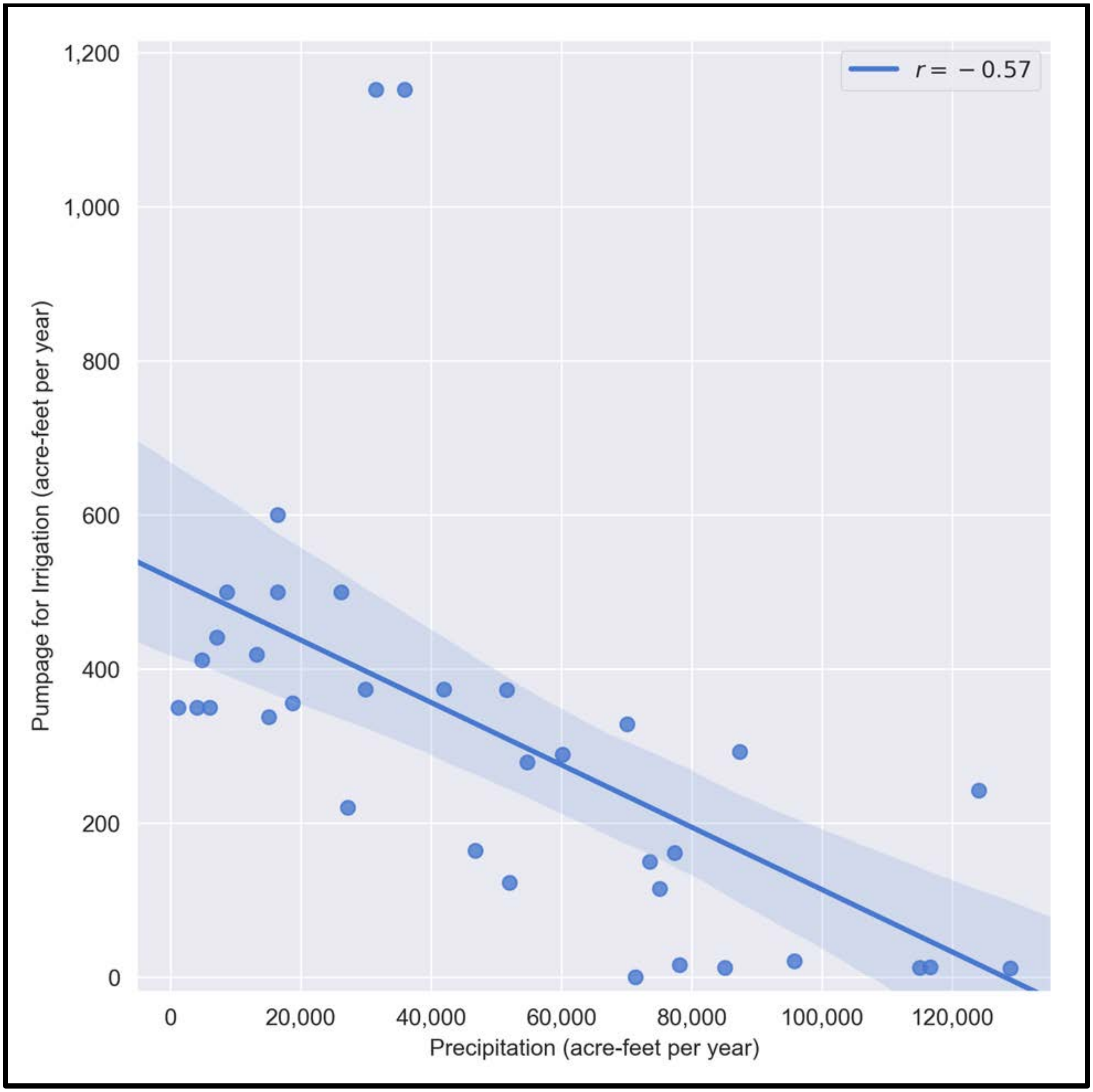


Figure 96. Crockett County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

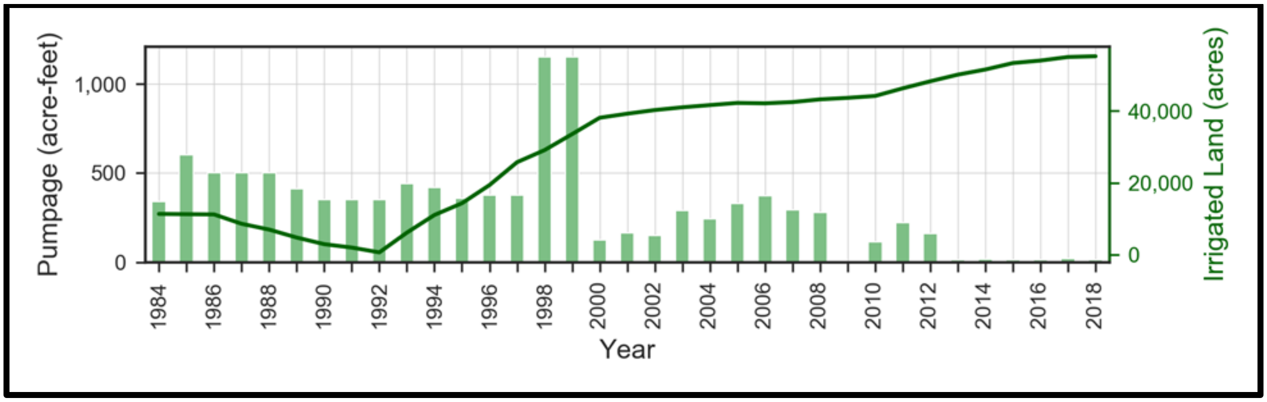


Figure 97. Crockett County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data overlying the aquifer, in acres per year.

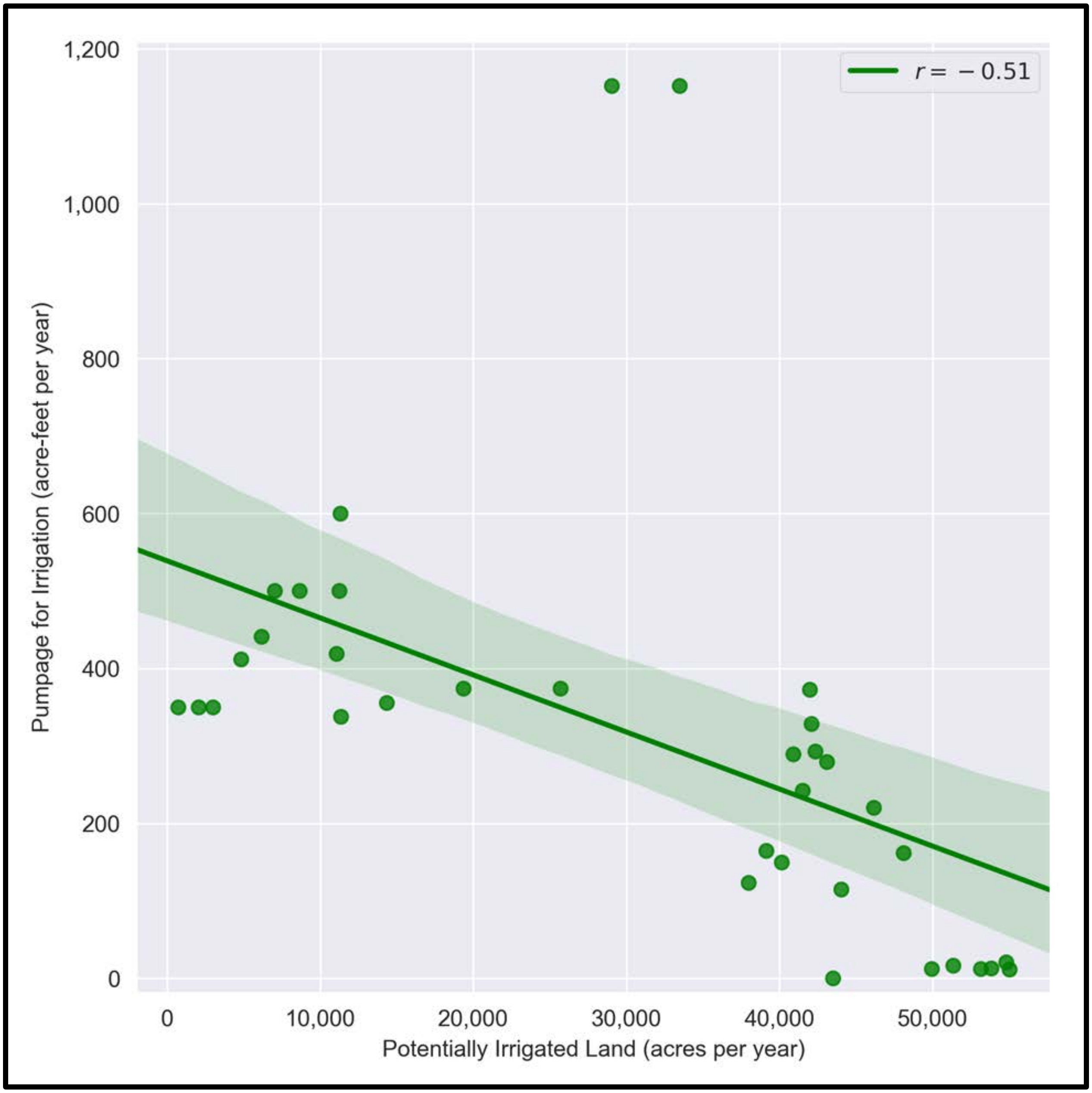


Figure 98. Crockett County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 21. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Crockett County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1998-1999, 2013-2018	1984, 1985, 1998, 2000, 2009	1998-2001, 2009
	Livestock	None	1984-1986, 1992, 1995, 1999, 2003, 2005	1992, 1993, 1995, 2003, 2005, 2006
	Manufacturing	2000-2018	1984-1986, 1988, 1991, 1993, 1997, 2000	1984, 1985, 1988, 1997, 2000
	Mining	1986, 1992	1986, 1987, 1989, 1992	1984-1986, 1992, 1993, 2018
	Municipal	None	1984, 1985, 1987-1990, 1993, 1994, 1997-1999, 2001, 2011-2013, 2015	1987, 1989, 1994, 2001, 2011
	Power	None	1984-2018	1984-2005, 2008-2018

3.3.14 Culberson County

The Edwards-Trinity (Plateau) Aquifer underlies about 10 percent of Culberson County, and is located within the southeastern portion along the borders with Reeves and Jeff Davis counties (see Figure 99). Within relatively small portion of the county the Pecos Valley Aquifer is also present, however there is not any reported pumping from this aquifer in the TWDB Water Use Survey database. Groundwater pumping estimates from the Water Use Survey indicate total pumping from the Edwards-Trinity (Plateau) Aquifer is up to approximately 1,000 acre-feet per year (Figure 100). Pumping from the Edwards-Trinity (Plateau) Aquifer in Culberson County is primarily for irrigation use; however, there is not any reported pumping for irrigation from 1984 through 1999. From 2000 through 2018, pumping for irrigation averaged about 600 acre-feet per year with a reportedly high volume of approximately 1,000 acre-feet in 2012.

Reported pumping for livestock and municipal use is relatively small compared to irrigation. Pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use averaged about 25 acre-feet per year. Reported pumping for municipal use ranges from less than 1 to more than six acre-feet per year. For 1994, the TWDB Water Use Survey database does not contain pumping data and for 2000 through 2005 reported pumping is minimal. There is not any surveyed municipal use after 2000 from the Edwards-Trinity (Plateau) Aquifer, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began.

The year-to-year (Figure 101) and standard deviation (Figure 102) analyses flagged several anomalies in the data. However, due the relatively low pumping amounts for municipal and livestock use (compared to pumping amounts reported for other counties), significant effort for further investigation may not be warranted. Table 22 provides the years identified as having anomalous pumping amounts for Culberson County based on our manual review, year-to-year change (Figure 101), and standard deviation (Figure 102) analyses.

Potentially irrigated land in Culberson County correlates linearly to groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation use. Figure 103 indicates that as the area of potentially irrigated land increased in the county, the reported pumpage for irrigation also increased. Figure 104 indicates a linear correlation value (“*r*”) of 0.83 between potentially irrigated land area and groundwater pumpage for irrigation use. This very strong positive correlation suggests that pumpage for irrigation in Culberson County matches the trend in potentially irrigated land.

We expect groundwater pumping for irrigation in Culberson County to correlate negatively to precipitation such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. However, Figure 105 indicates that as precipitation increased in the county, the reported pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer in Culberson County increased as well. Figure 106 indicates positive correlation value (“*r*”) of 0.73 between precipitation and groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer in Culberson County. This strong positive correlation suggests that the reported pumpage for irrigation in Culberson County follows the trend in precipitation and is anomalous.

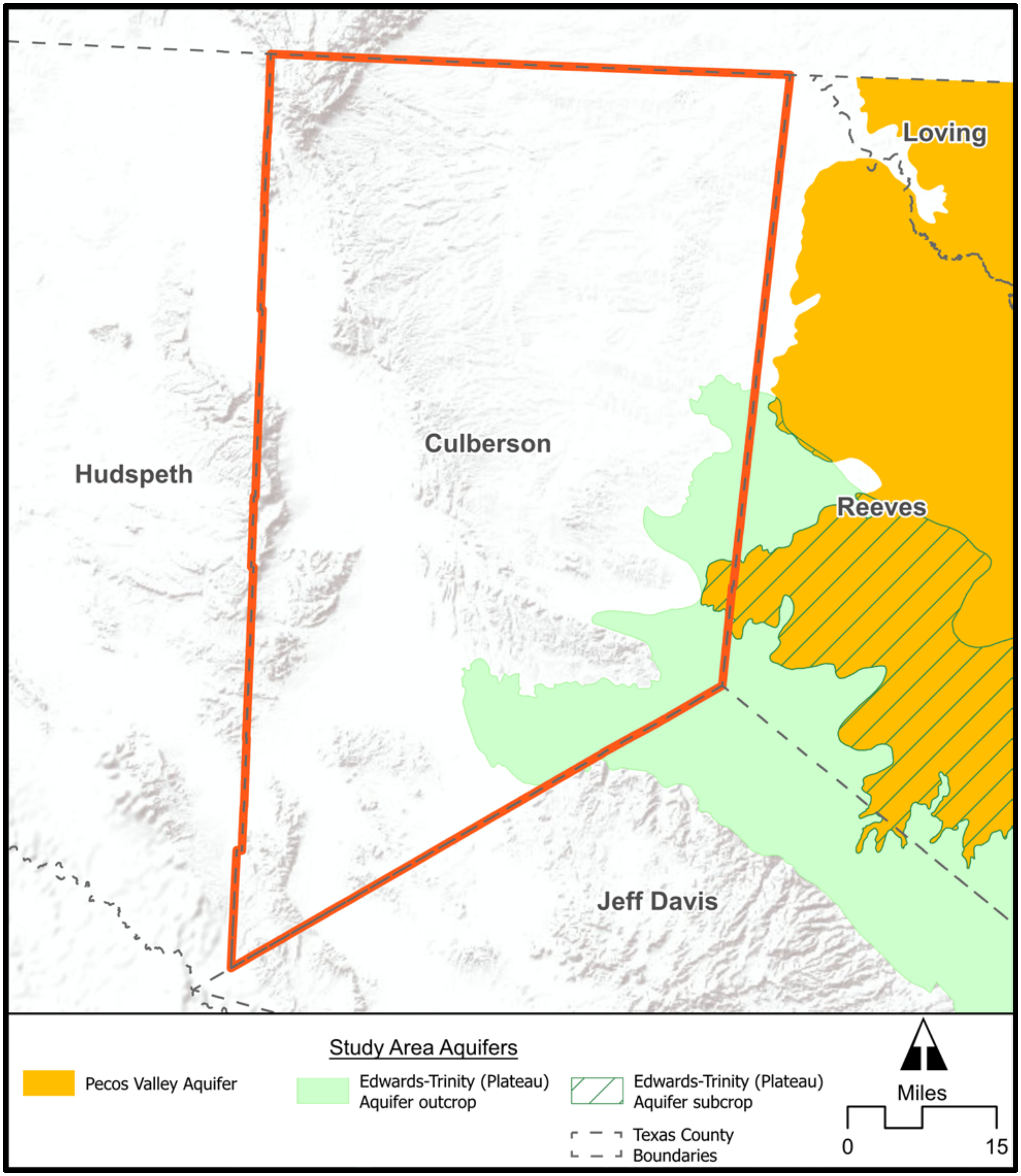


Figure 99. Culberson County showing the extent of the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer.

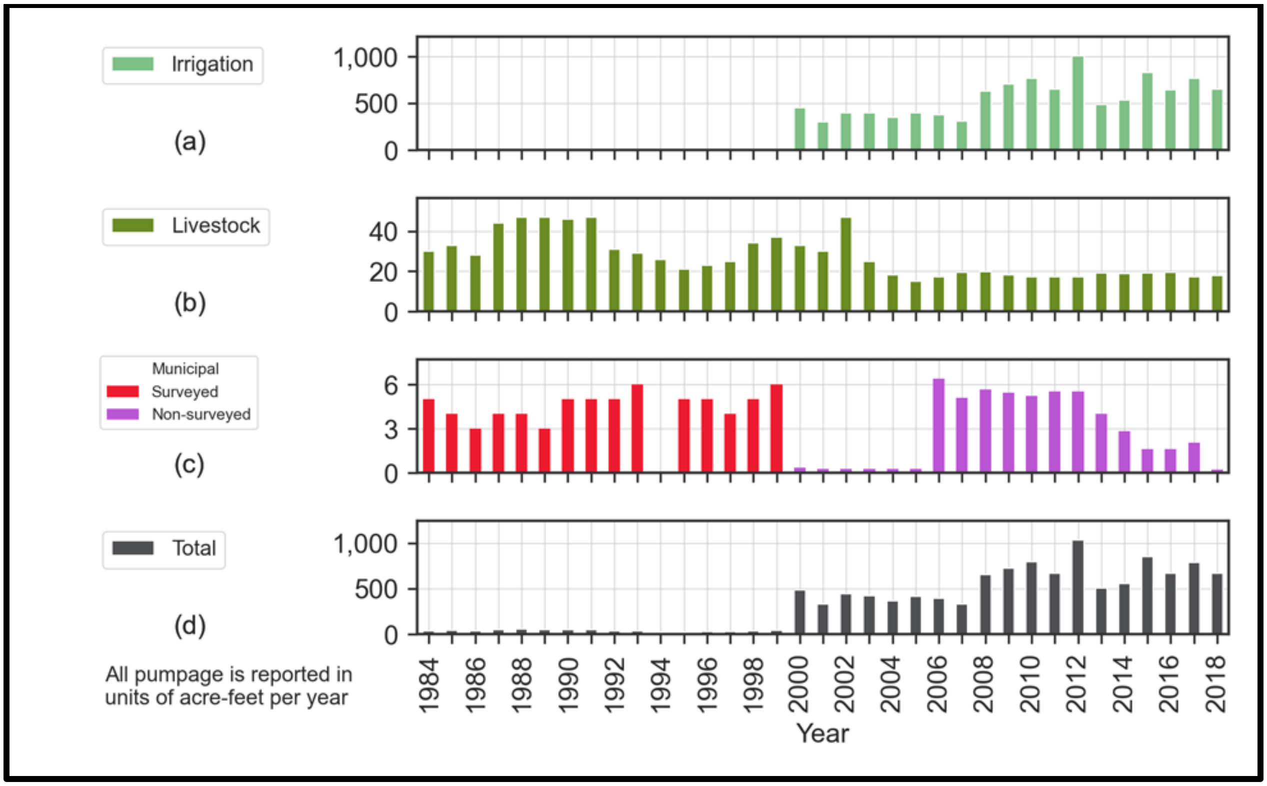


Figure 100. Culberson County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

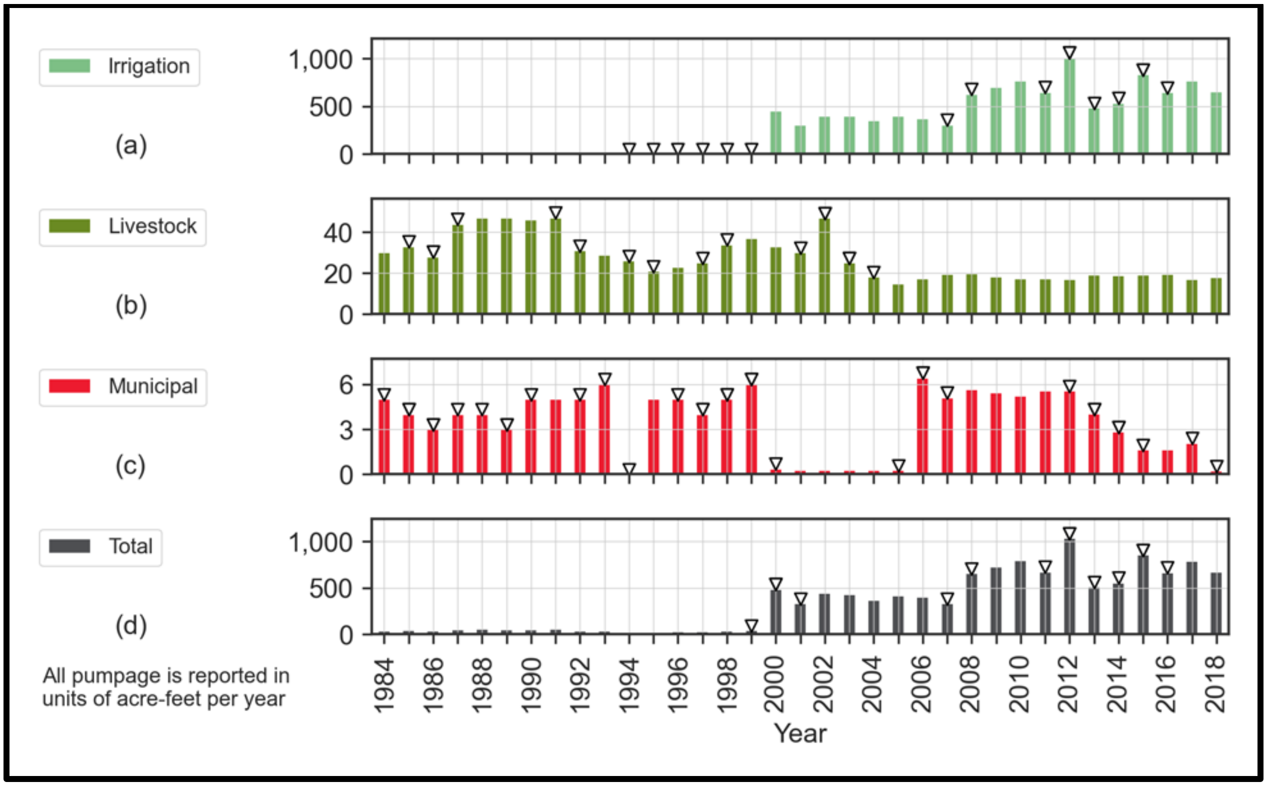


Figure 101. Culberson County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

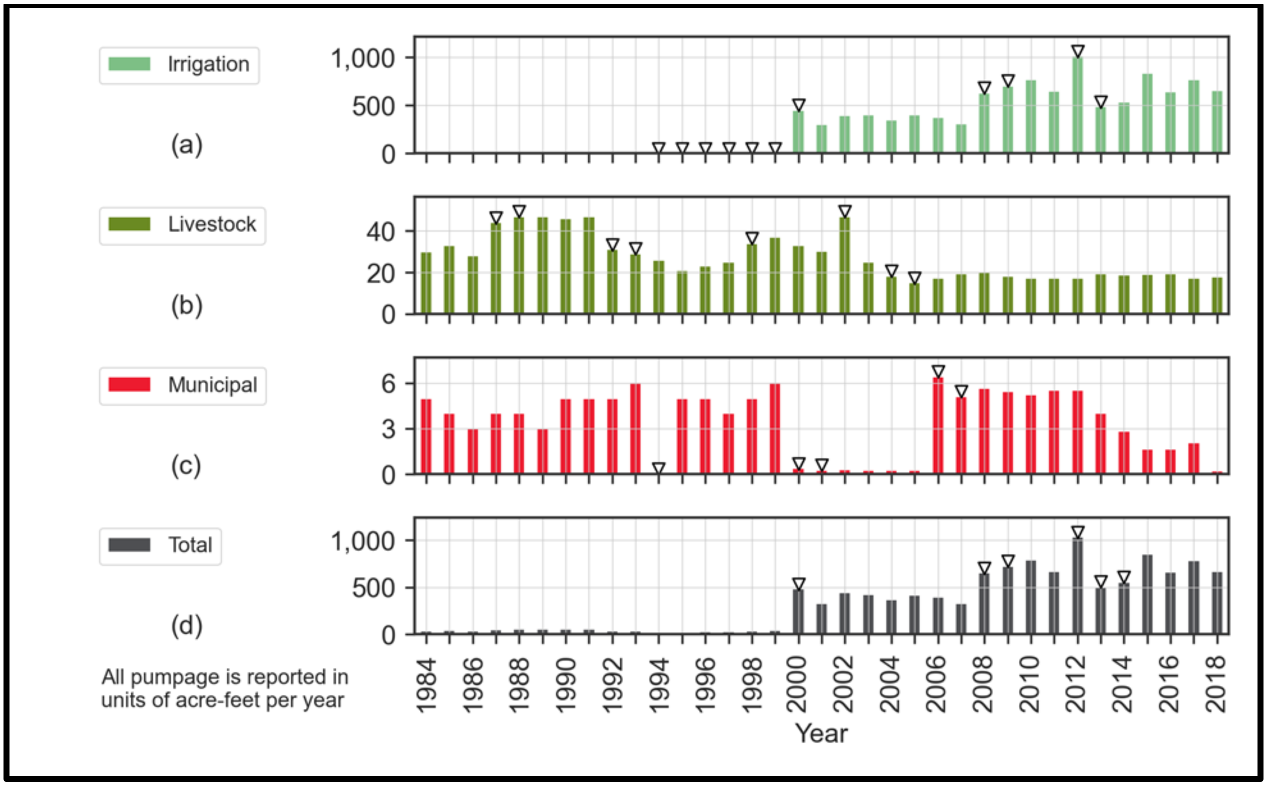


Figure 102. Culberson County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

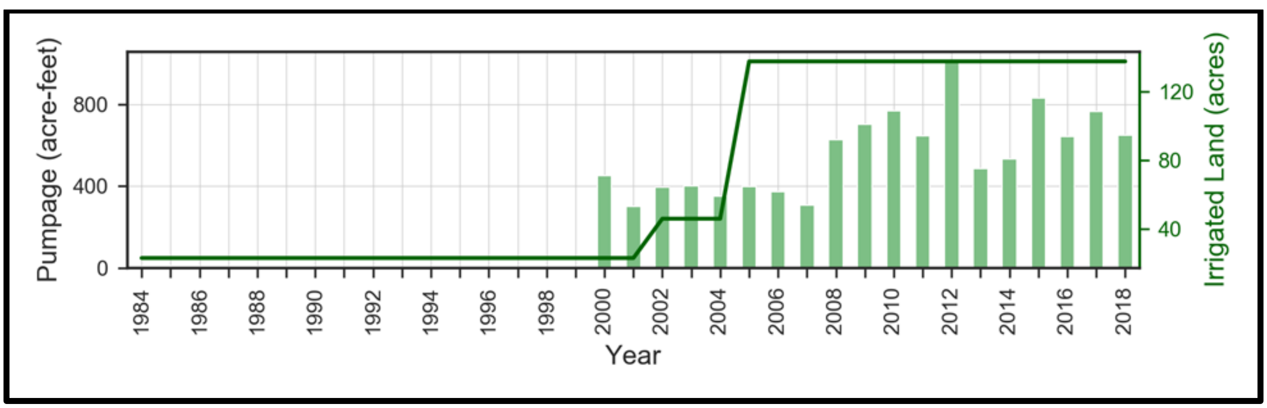


Figure 103. Culberson County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation in acre-feet per year as reported in the TWDB Water Use Survey data and acres of potentially irrigated land area in acres per year (according to land use data) overlying the aquifer.

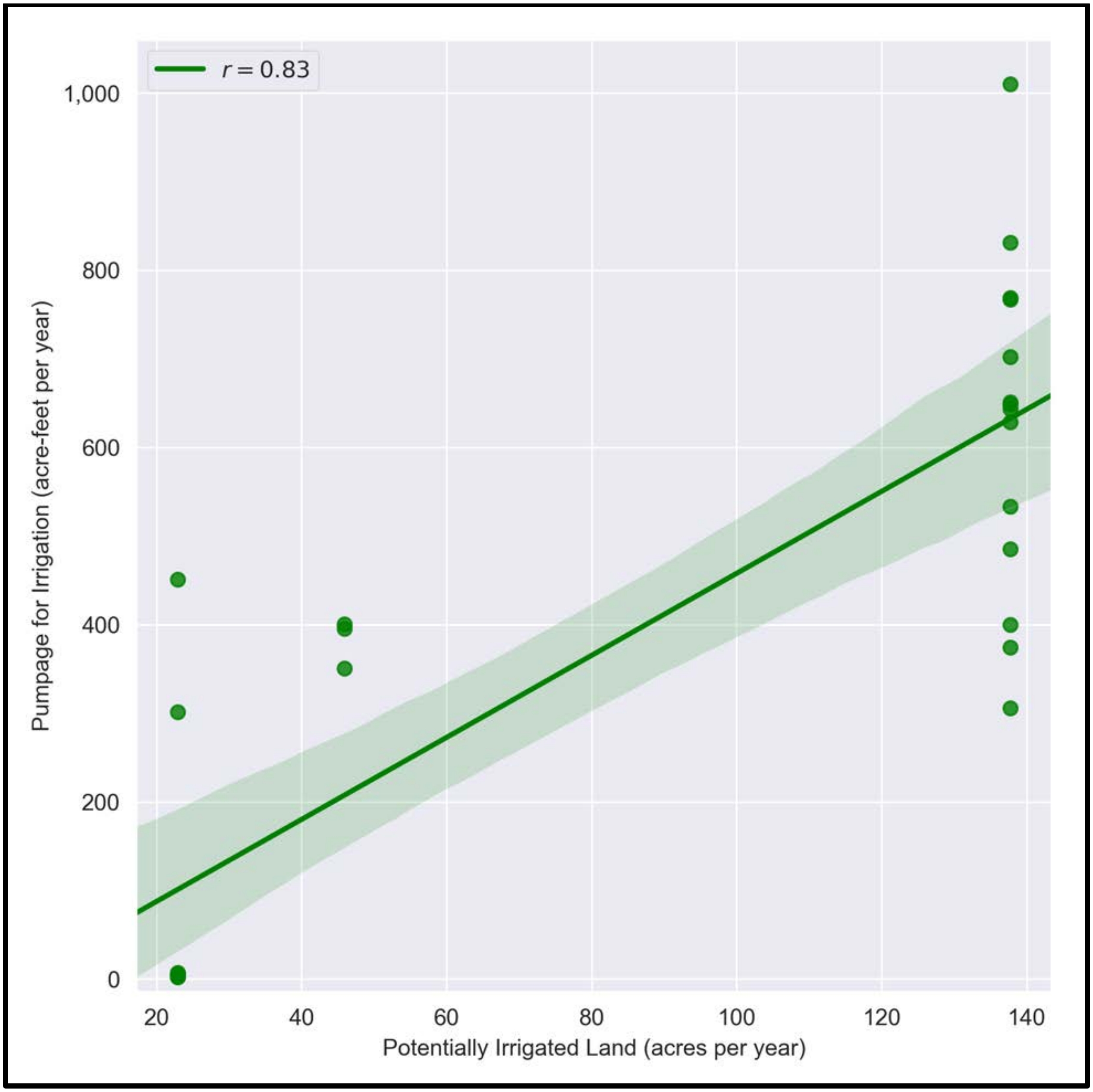


Figure 104. Culberson County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 22. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Culberson County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1984-1999	1994-2000, 2008, 2012, 2013, 2015, 2016	1994-2000, 2008, 2009, 2012, 2013
	Livestock	2002	1986, 1987, 1992, 1995, 1998, 2002-2004	1987, 1988, 1992, 1993, 1998, 2002, 2004, 2005
	Municipal	1994, 2000-2005, 2018	1984-1987, 1989, 1990, 1993-1995, 1997-2000, 2006, 2007, 2013-2015, 2018	1994, 2000, 2001, 2006, 2007

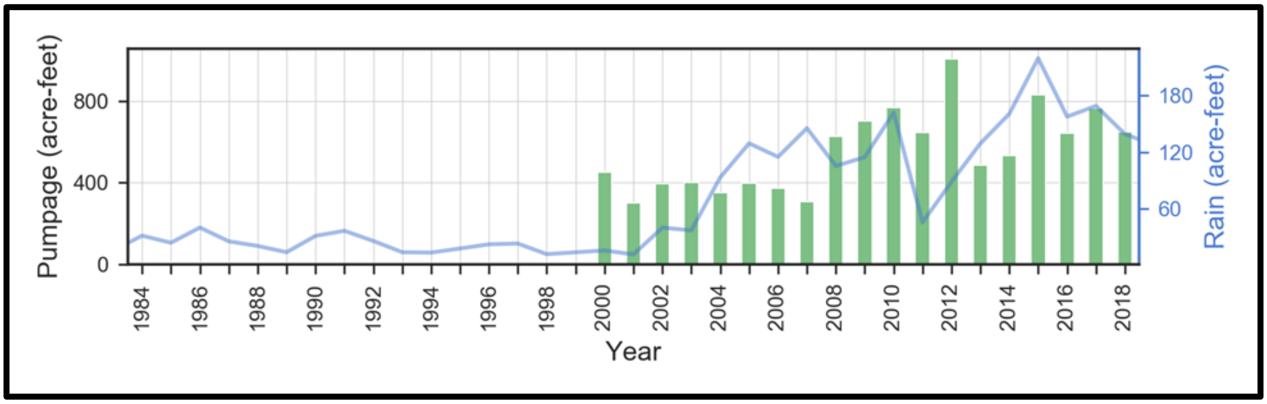


Figure 105. Culberson County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

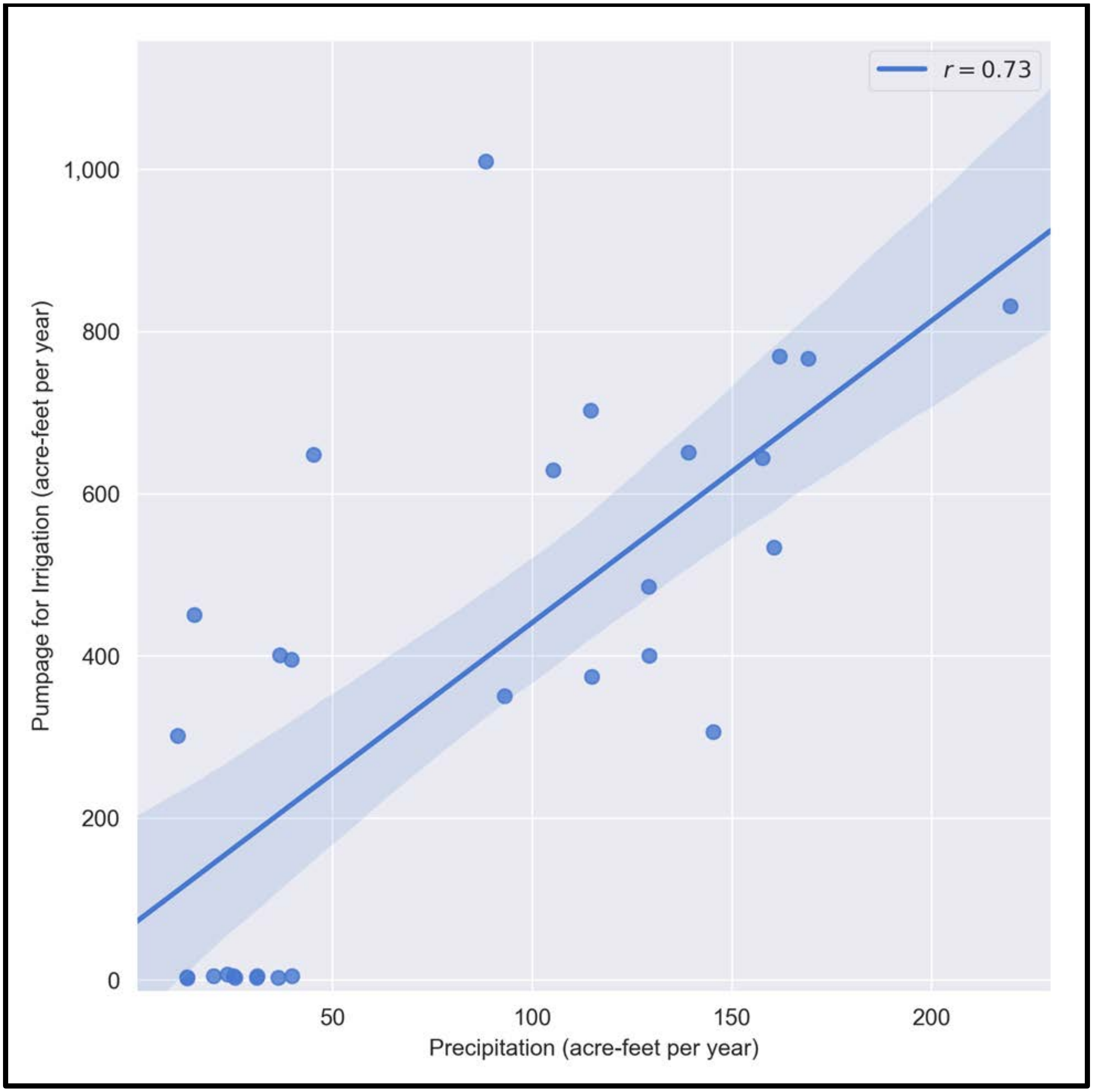


Figure 106. Culberson County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

3.3.15 Ector County

The Edwards-Trinity (Plateau) Aquifer is present across most of Ector County (Figure 107). The Pecos Valley Aquifer covers the southwestern portion of the county. Together, these two study area aquifers cover all but the northwestern tip of the county. Despite the widespread presence of these aquifers within the county, compared to that from adjacent and other nearby counties.

According to the TWDB Water Use Survey, recent pumping from the Pecos Valley Aquifer is nearly non-existent. Historically, consistent pumping from the Pecos Valley Aquifer was primarily for livestock use, though there are periods where irrigation pumping and municipal pumping are dominant (Figure 108).

There are a few anomalies in the reported data for the Pecos Valley Aquifer in Ector County. We observe large gaps in the reported data from the Water Use Survey for irrigation, livestock, manufacturing, mining, and municipal use. There is an abrupt increase in the reported pumping volumes for both mining and municipal use in the year 2000 (Figure 108). There is not any surveyed municipal use after 2000 from the Pecos Valley Aquifer, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began. However, there is a relatively large amount of non-surveyed use from 2000 through 2005 compared to the total reported municipal use prior to 2000. Beginning in 2006, there is not any municipal use from the Pecos Valley Aquifer in Ector County reported. In addition, there are several anomalies noted on the year-to-year and standard deviation plots (Figure 109 and Figure 110, respectively).

The Water Use Survey data has pumping beginning in 2007 for municipal and manufacturing use assigned to the Trinity (Hill Country) Aquifer in Ector County (Figure 111). However, the assignment appears to be anomalous as the TWDB delineation of the footprint of the Trinity (Hill Country) Aquifer does not extend to Ector County. The pumping assigned to this aquifer is more likely coming from the Edwards-Trinity (Plateau) Aquifer and we will further investigate the source in subsequent project phases. Total reported volumes from the Edwards-Trinity (Plateau) Aquifer are near 12,000 acre-feet per year from 1984 through 1993, and show declines from 1994 to 2018 (Figure 112).

We noted several anomalies in the reported Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Ector County. Reported pumping for irrigation use from 1993 to 1994 declined from high a volume (more than 4,000 acre-feet) to a low volume (less than 1,000 acre-feet). Pumping for livestock varied over the study period, with two apparent cycles of declining pumpage followed by a return to previously average pumping levels (Figure 113). There are some low pumping volumes in the reported manufacturing use category and a decline in the reported volumes from 2004 to 2005. For the mining category, there is an abrupt increase in the reported volume from year 1996 to 1997, followed by nearly non-existent reported pumping after the year 1999. Since 2000, surveyed municipal use for the Edwards-Trinity (Plateau) Aquifer in Ector County decreased and non-surveyed use constituted most of the municipal water use. The only anomalies identified within the datasets for the remaining use categories, power and unknown, are large gaps in the reported data.

Table 23 provides the years identified as having anomalous pumping amounts for Ector County based on our manual review, year-to-year change (Figure 109 and Figure 113), and standard deviation (Figure 110 and Figure 114) analyses.

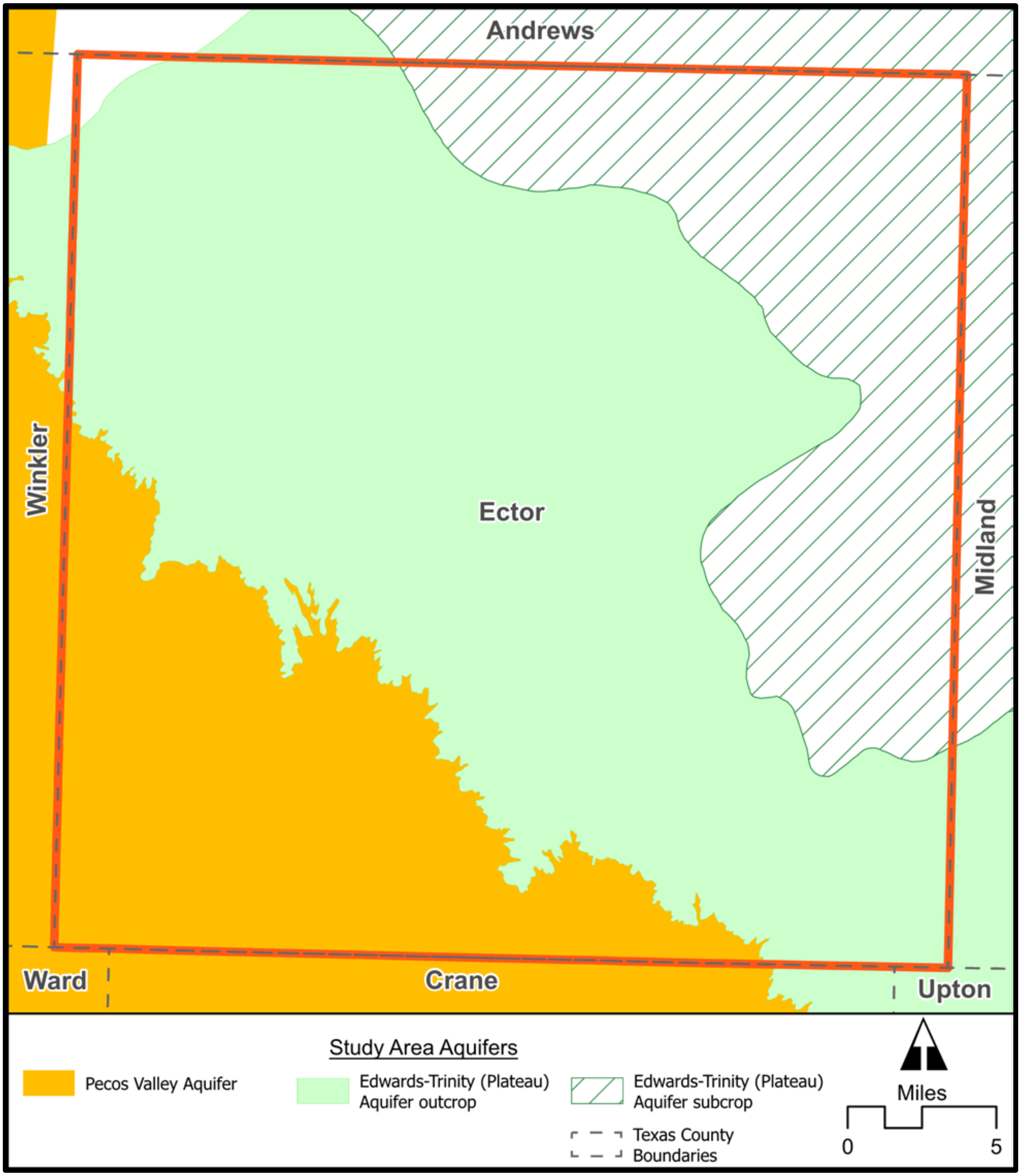


Figure 107. Ector County showing the extent of the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer.

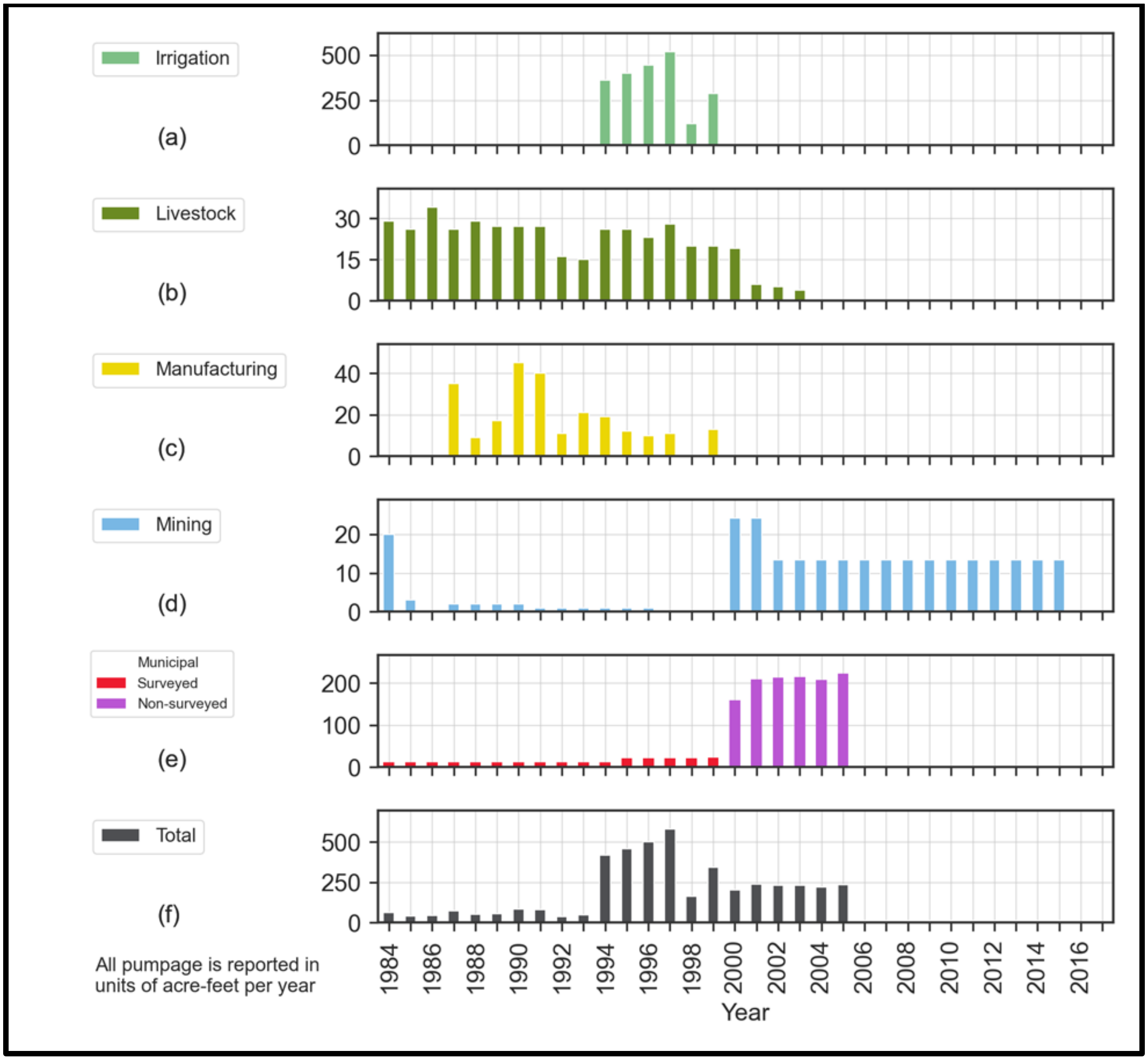


Figure 108. Ector County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

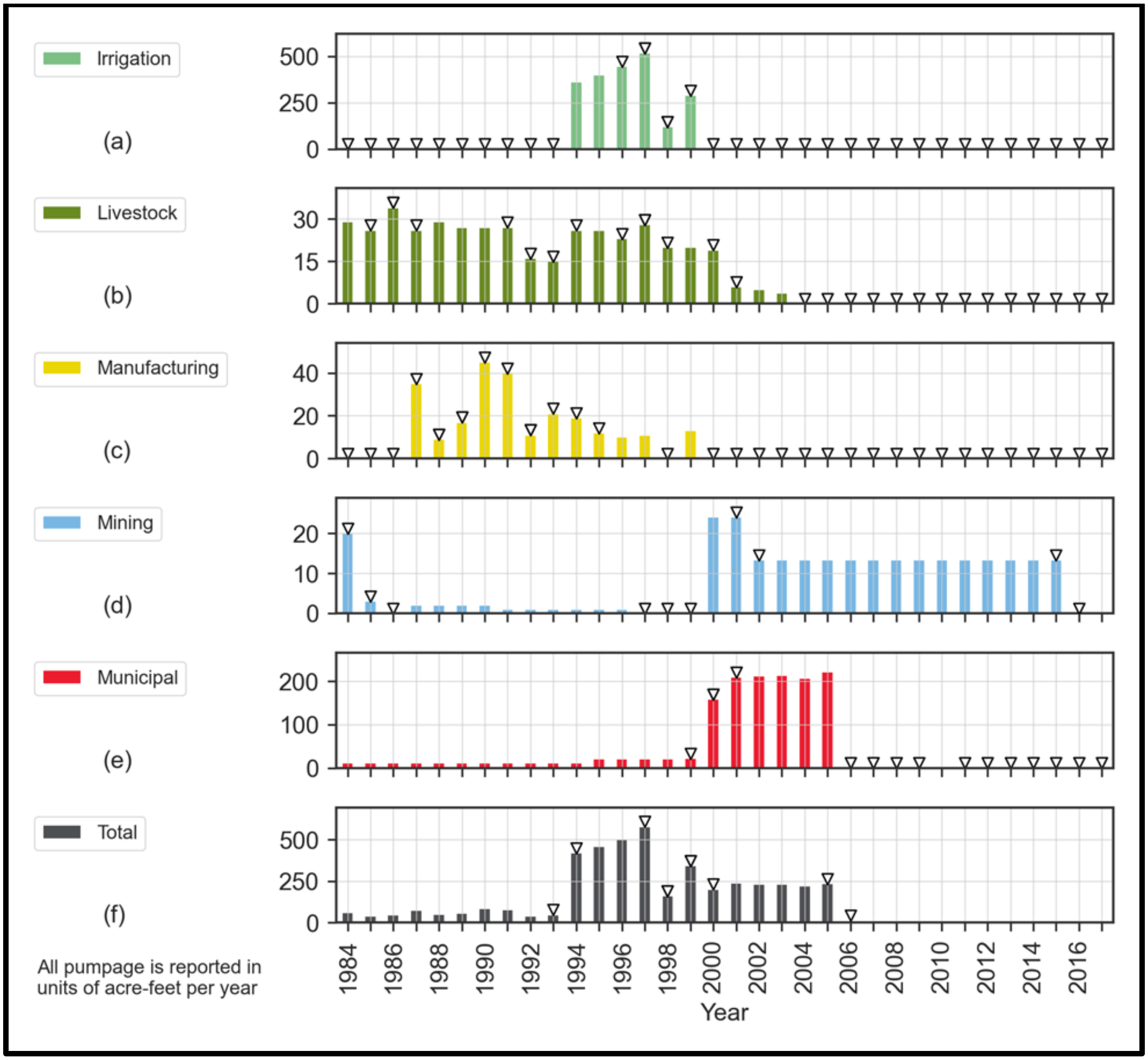


Figure 109. Ector County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

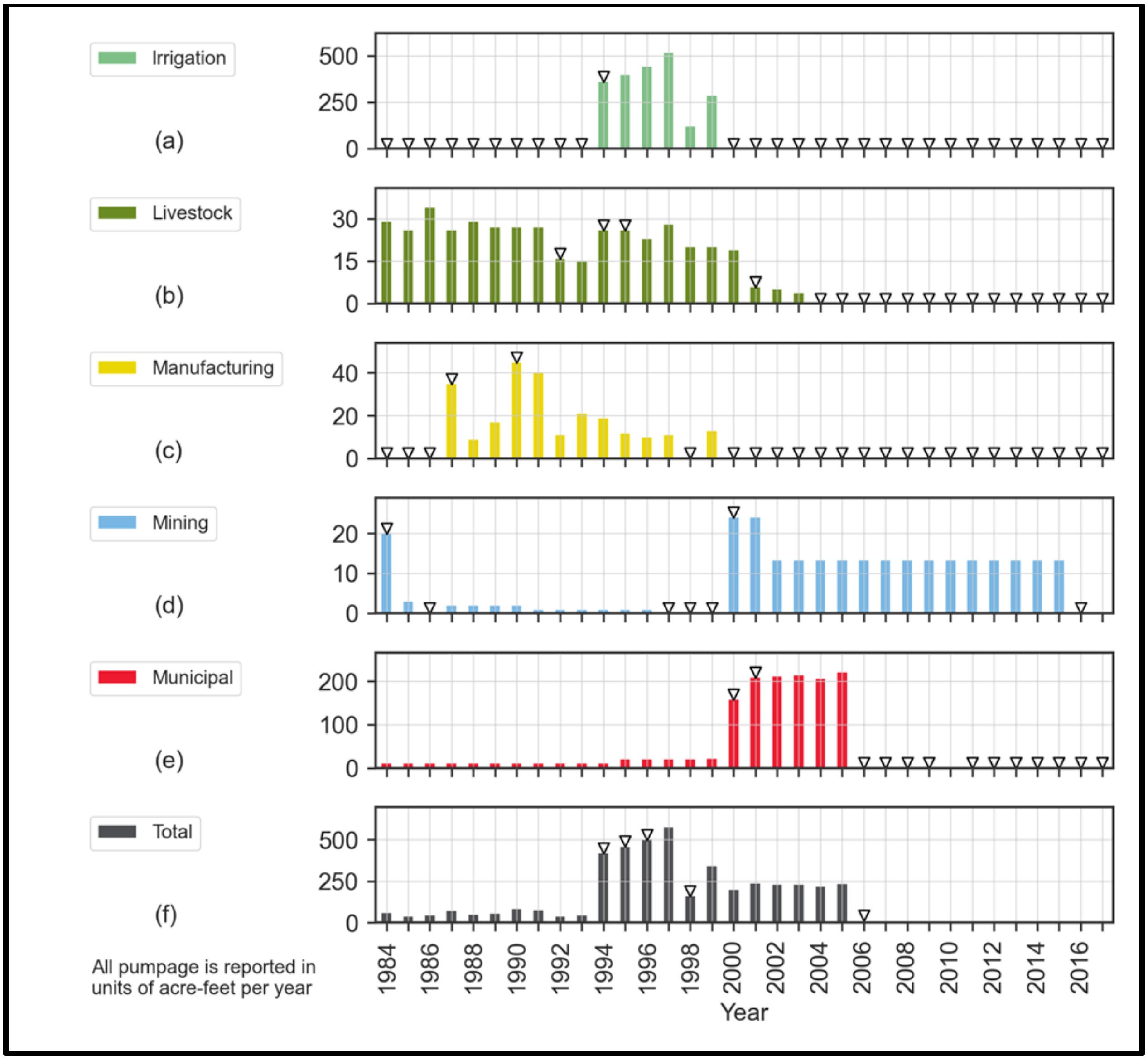


Figure 110. Ector County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

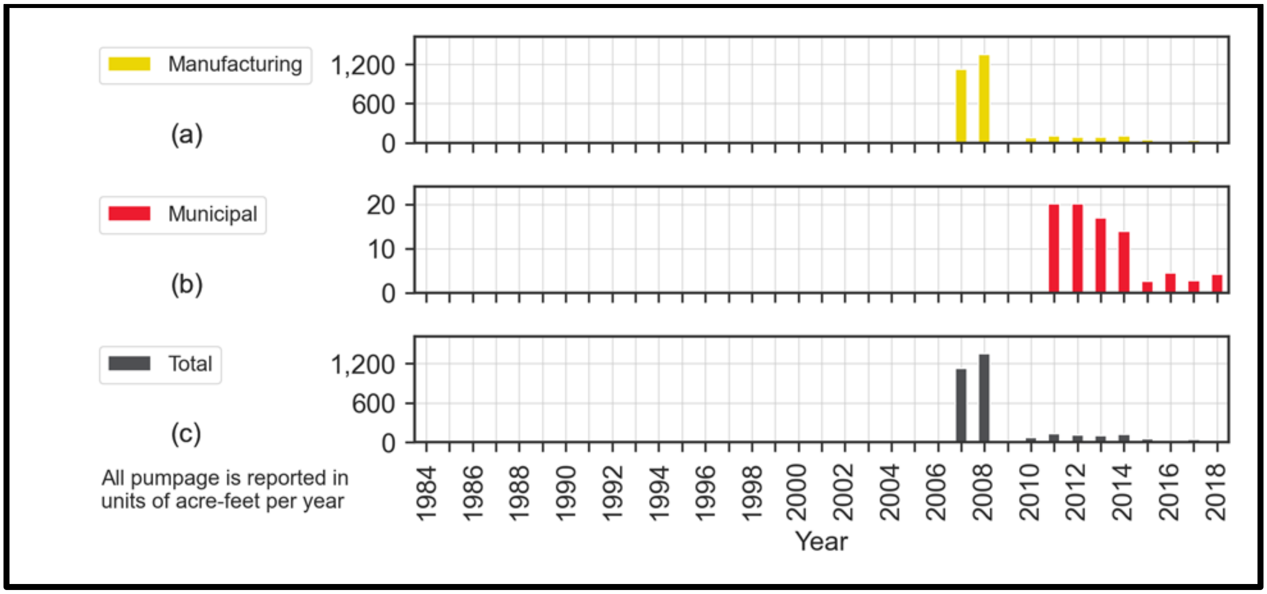


Figure 111. Ector County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

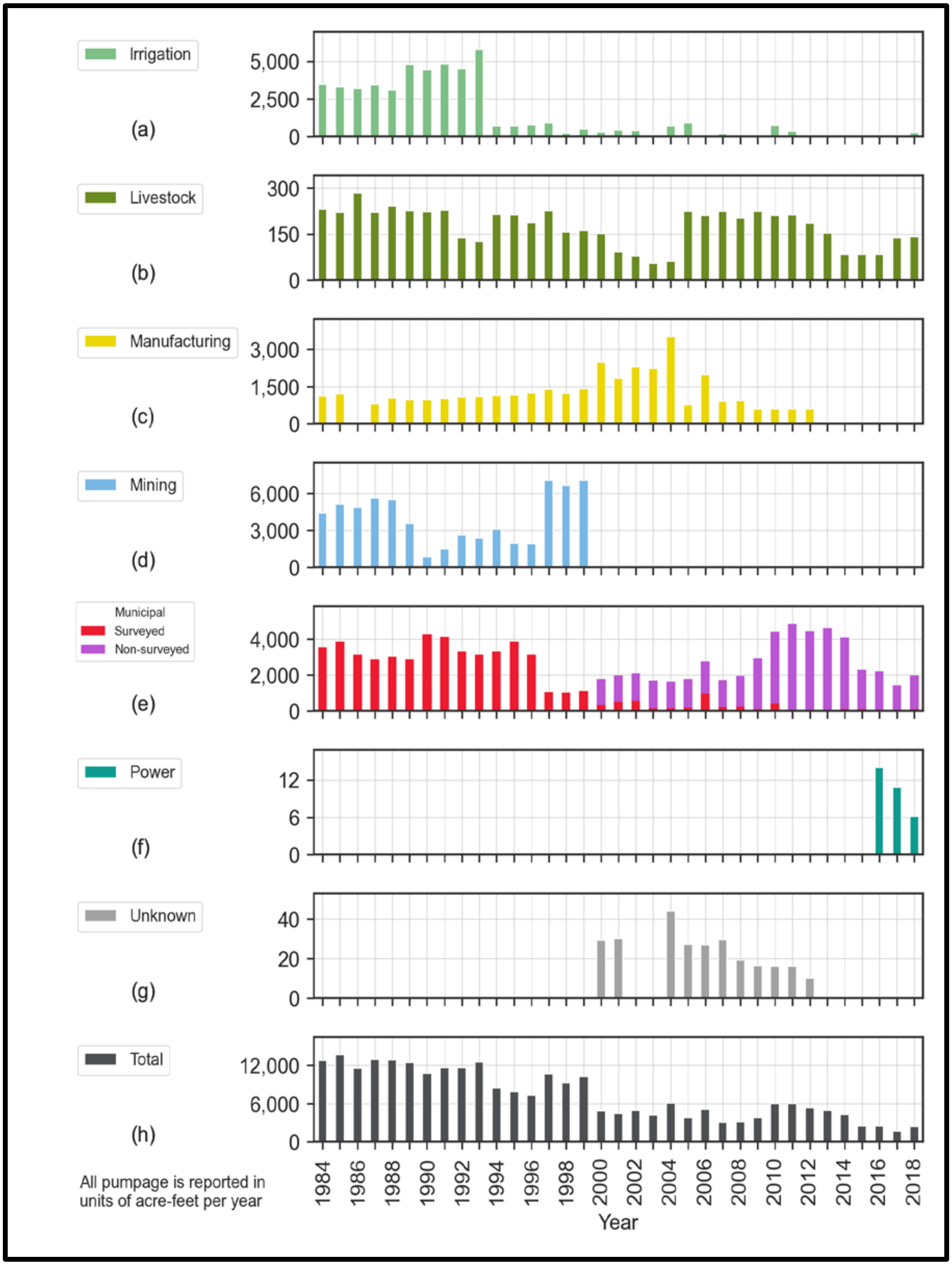


Figure 112. Ector County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Figure 113. Ector County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

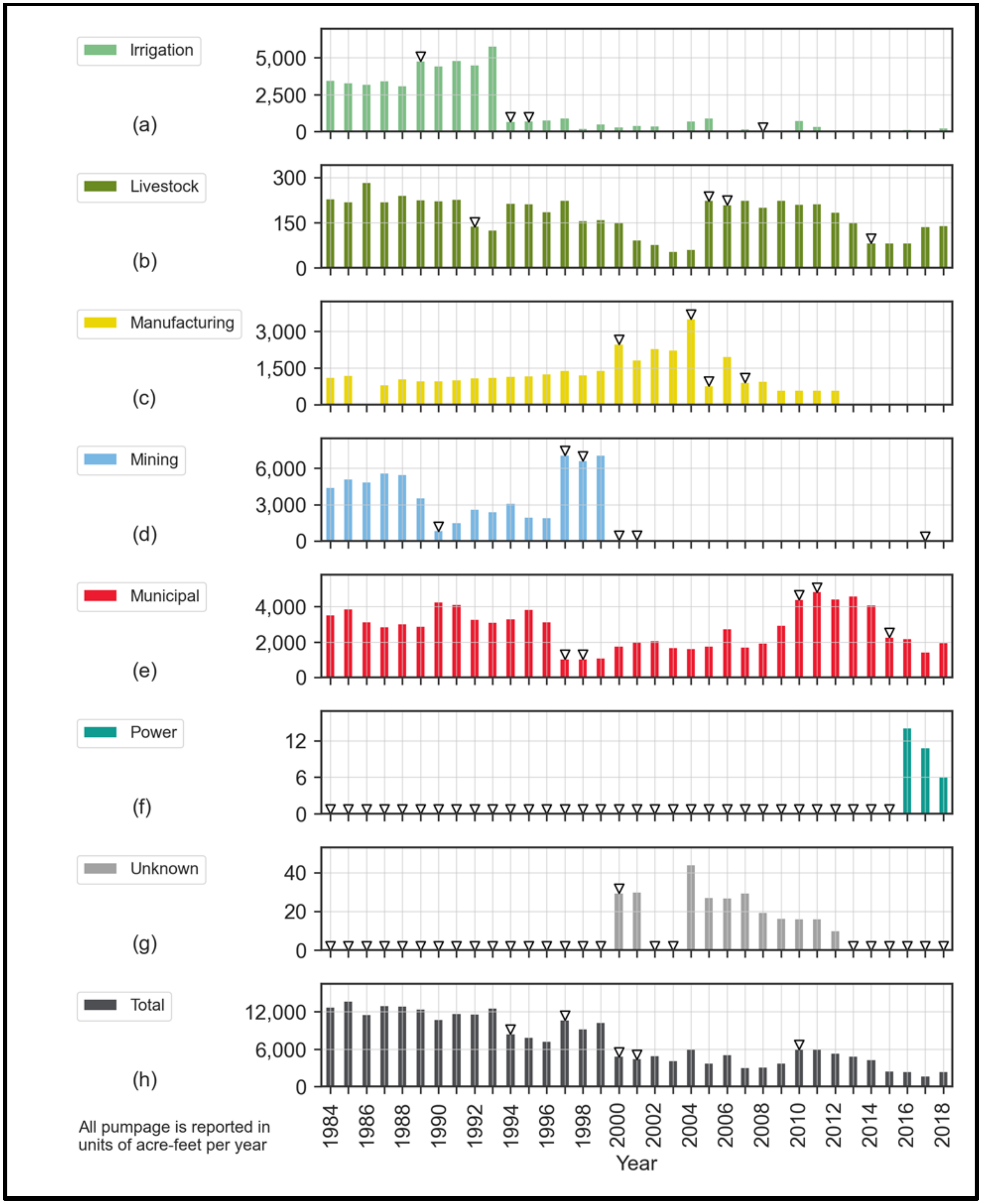


Figure 114. **Ector County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 23. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Ector County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Pecos Valley	Irrigation	1984-1993, 2000-2018	1984-1994, 1997-2017	1984-1994, 2000-2017
	Livestock	2004-2018	1986, 1987, 1992, 1994, 1997, 1998, 2001, 2004-2017	1992, 1994, 1995, 2001, 2004-2017
	Manufacturing	1984-1986, 1998, 2000-2018	1984-1990, 1992, 1993, 1995, 1998-2017	1984-1987, 1990, 1998, 2000-2017
	Mining	1985-1999	1984-1986, 1997-2000, 2002, 2016	1984, 1986, 1997-2000, 2016, 2017
	Municipal	2000, 2006-2018	2000, 2001, 2006-2009, 2011-2017	2000, 2001, 2006-2009, 2011-2017
Edwards-Trinity (Plateau)	Irrigation	1994	1989, 1993, 1994, 2006, 2008	1989, 1994, 1995, 2008, 2009
	Livestock	2005	1986, 1987, 1992, 1994, 1997, 1998, 2001, 2005, 2014, 2017	1992, 2005, 2006, 2014
	Manufacturing	1986, 2004-2006, 2013-2018	1986, 1987, 2000, 2001, 2004-2007, 2013	2000, 2004, 2005, 2007
	Mining	1997-2000	1989, 1990, 1992, 1995, 1997, 2000, 2017	1990, 1997, 1998, 2000, 2001, 2017, 2018
	Municipal	1997, 2006	1986, 1990, 1992, 1996, 1997, 2000, 2006, 2007, 2009, 2010, 2015, 2017	1997, 1998, 2010, 2011, 2015
	Power	1984-2016	1984-2018	1984-2015
	Unknown	2002-2003	1984-2000, 2002-2005, 2008, 2012-2018	1984-2000, 2002, 2003, 2013-2018
Trinity (Hill Country)	All	Not present in county		

3.3.16 Edwards County

The Edwards-Trinity (Plateau) Aquifer is present across the entirety of Edwards County (see Figure 115). Groundwater pumping estimates from the Water Use Survey indicates total pumping from the Edwards-Trinity (Plateau) Aquifer in Edwards County is up to approximately 1,000 acre-feet per year (Figure 116). Pumping from the Edwards-Trinity (Plateau) in Edwards County is primarily for irrigation, livestock, and municipal use.

As shown on Figure 116, there is not any reported data for irrigation pumping from 1984 through 1992. From 1993 through 2018, the irrigation pumping volume varies from less than 100 acre-feet per year up to nearly 400 acre-feet per year without any reported irrigation pumping in 2009. Pumping for livestock use averages about 300 acre-feet per year. From 2001 through 2004, pumping for livestock abruptly declined to less than 200 acre-feet per year.

Pumping for municipal use averages approximately 300 acre-feet per year during the study period. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounted for a relatively small amount of the total municipal water use. Manual review of the municipal pumping estimates does not suggest any anomalies in the data. However, review of the year-to-year change (Figure 117) and the standard deviation analysis (Figure 118) indicates sixteen and four anomalies, respectively.

Table 24 provides the years identified as having anomalous pumping amounts for Edwards County based on our manual review, year-to-year change (Figure 117), and standard deviation (Figure 118) analyses.

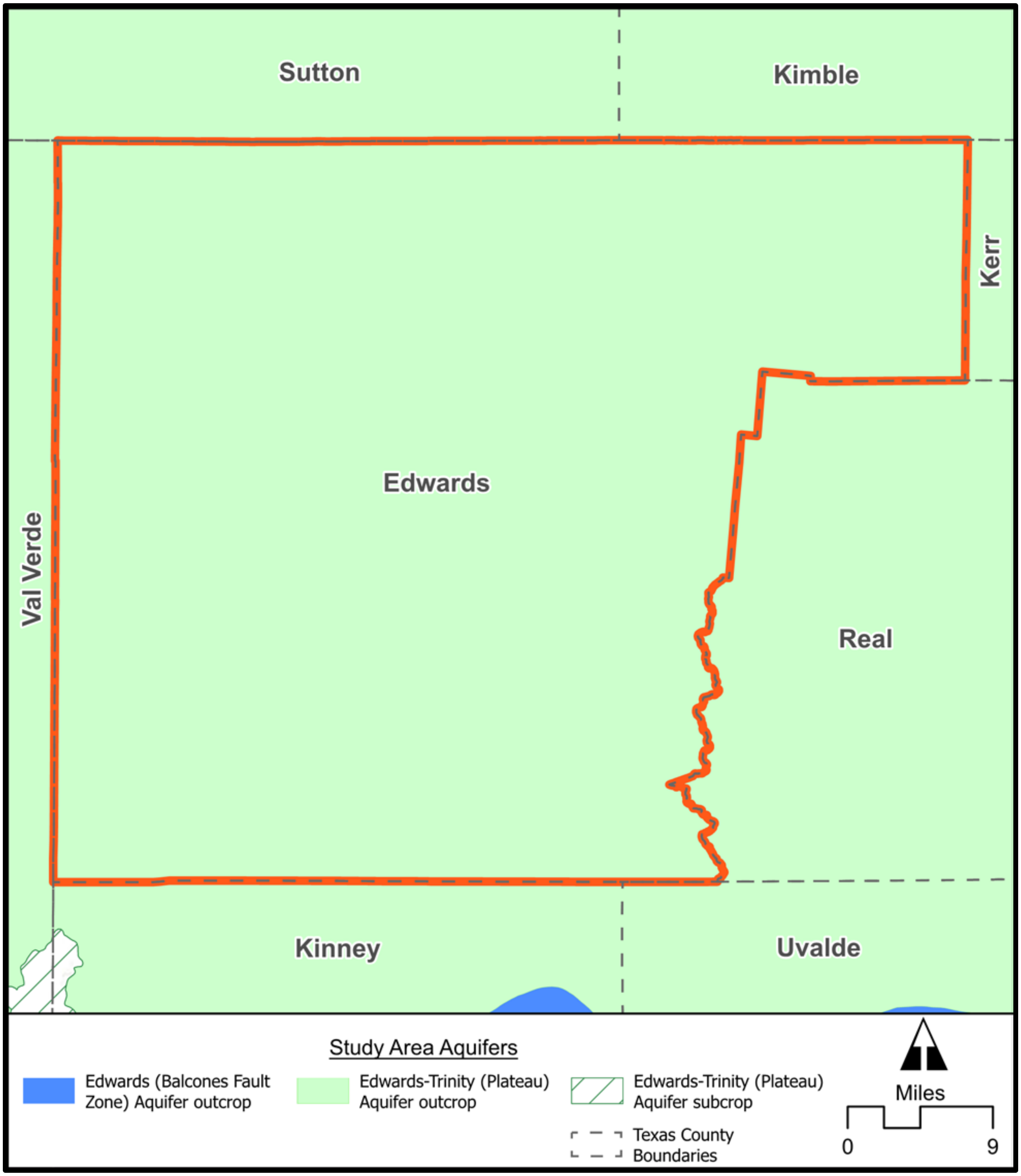


Figure 115. Edwards County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

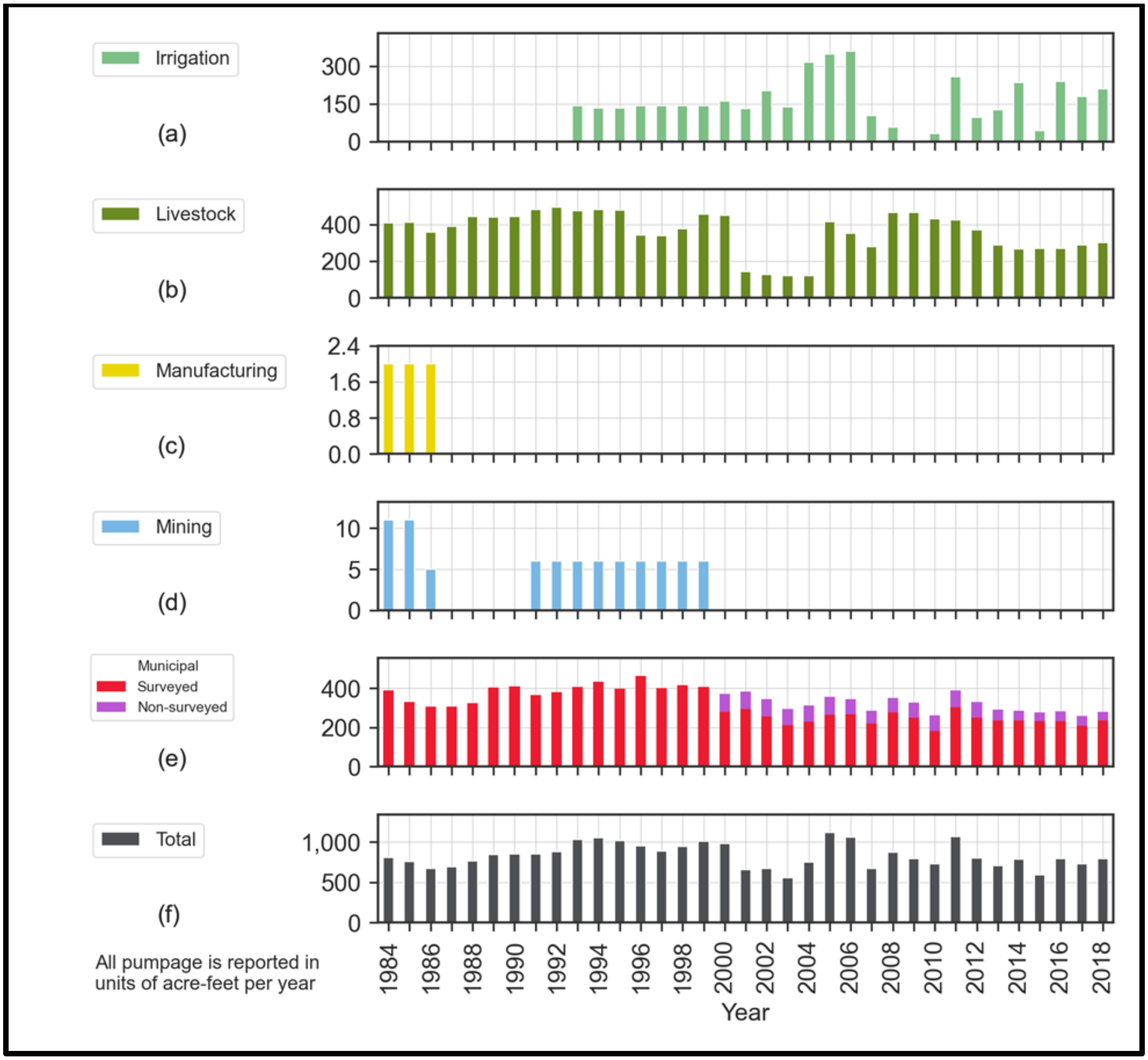


Figure 116. Edwards County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

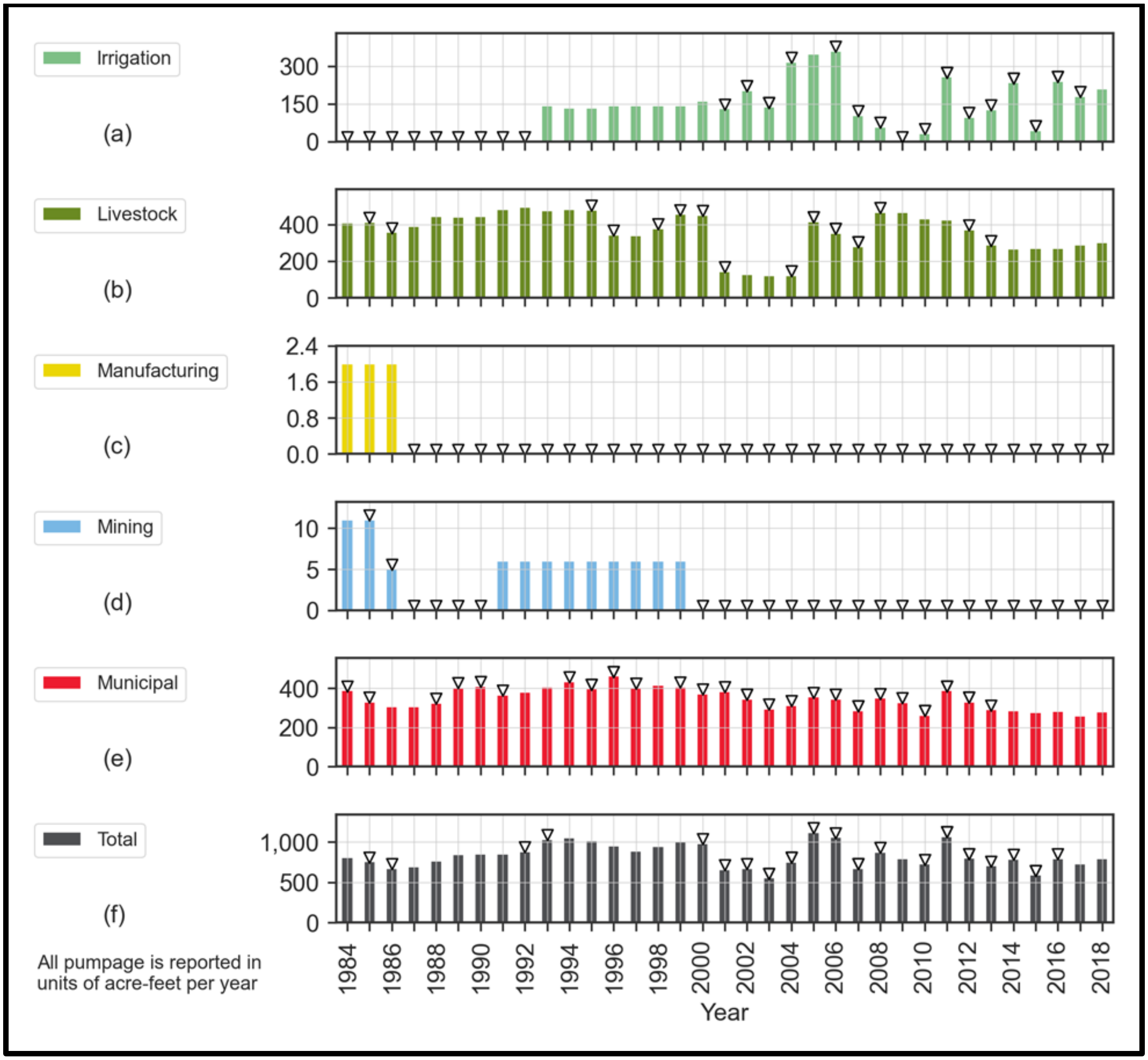


Figure 117. Edwards County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 118. Edwards County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 24. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Edwards County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	2007, 2011	1984-1993, 2002-2004, 2007, 2009, 2011, 2012, 2014-2017	1984-1992, 2007-2009, 2011
	Livestock	2001-2005	1986, 1996, 1999, 2001, 2005-2008, 2013	2001, 2002, 2005
	Manufacturing	None	1987-2018	1987-2018
	Mining	None	1986-1991, 2000-2018	1987-1991, 2000-2018
	Municipal	None	1984, 1985, 1989, 1991, 1995-1997, 2000, 2002, 2003, 2005, 2007, 2008, 2010-2013	1989, 1990, 2003, 2011

3.3.17 Gillespie County

The Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer cover nearly 90 percent of Gillespie County except for the northwest corner (see Figure 119). Groundwater pumping estimates from the TWDB Water Use Survey indicate that total pumping from the Edwards-Trinity (Plateau) Aquifer is up to approximately 1,200 acre-feet per year (Figure 120) and up to nearly 4,000 acre-feet per year from the Trinity (Hill Country) Aquifer (Figure 123).

There is a relatively small amount of reported pumping from the Edwards-Trinity (Plateau) Aquifer prior to the year 2000 (Figure 120). After 2000, usage increased for livestock and irrigation, with municipal usage commencing in 2006, mostly due to non-surveyed municipal usage. Estimated total production in 2010 and 2011 was much higher than previous years suggesting these data are anomalous. For municipal use, the abrupt increase in 2006 suggests an anomaly. Review of the year-to-year change analysis shown of Figure 121 and the standard deviation analysis illustrated on Figure 122 indicate other anomalous years in the pumping data for the Edwards-Trinity (Plateau) Aquifer in Gillespie County.

Groundwater pumping estimates from the TWDB Water Use Survey indicate that Gillespie County total pumping from the Trinity (Hill Country) Aquifer is up to nearly 4,000 acre-feet per year (Figure 123). In 1994, estimated pumping abruptly increased and in 2007 there was a low volume of reported pumping. We also noted an anomaly in pumpage for livestock in the year 1996 with an abnormally high volume of 800 acre-feet. From 1999 to 2000 pumping for municipal use declined from greater than 1,250 acre-feet to less than 500 acre-feet. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounts for most of the municipal water use from the Trinity (Hill Country) Aquifer in Gillespie County.

Table 25 provides the years identified as having anomalous pumping amounts for Gillespie County based on our manual review, year-to-year change (Figure 121 and Figure 124), and standard deviation (Figure 122 and Figure 125) analyses.

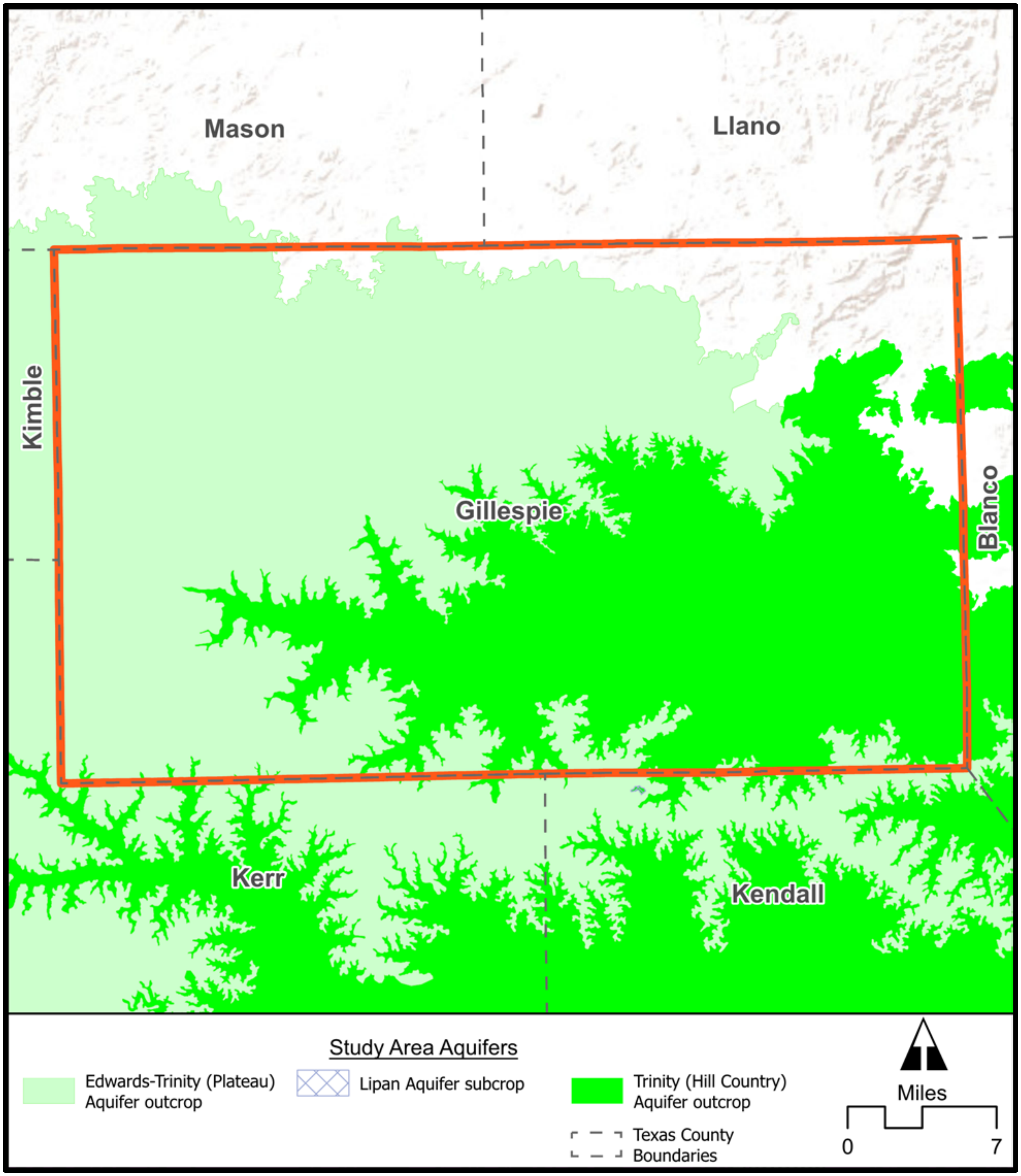


Figure 119. Gillespie County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer.

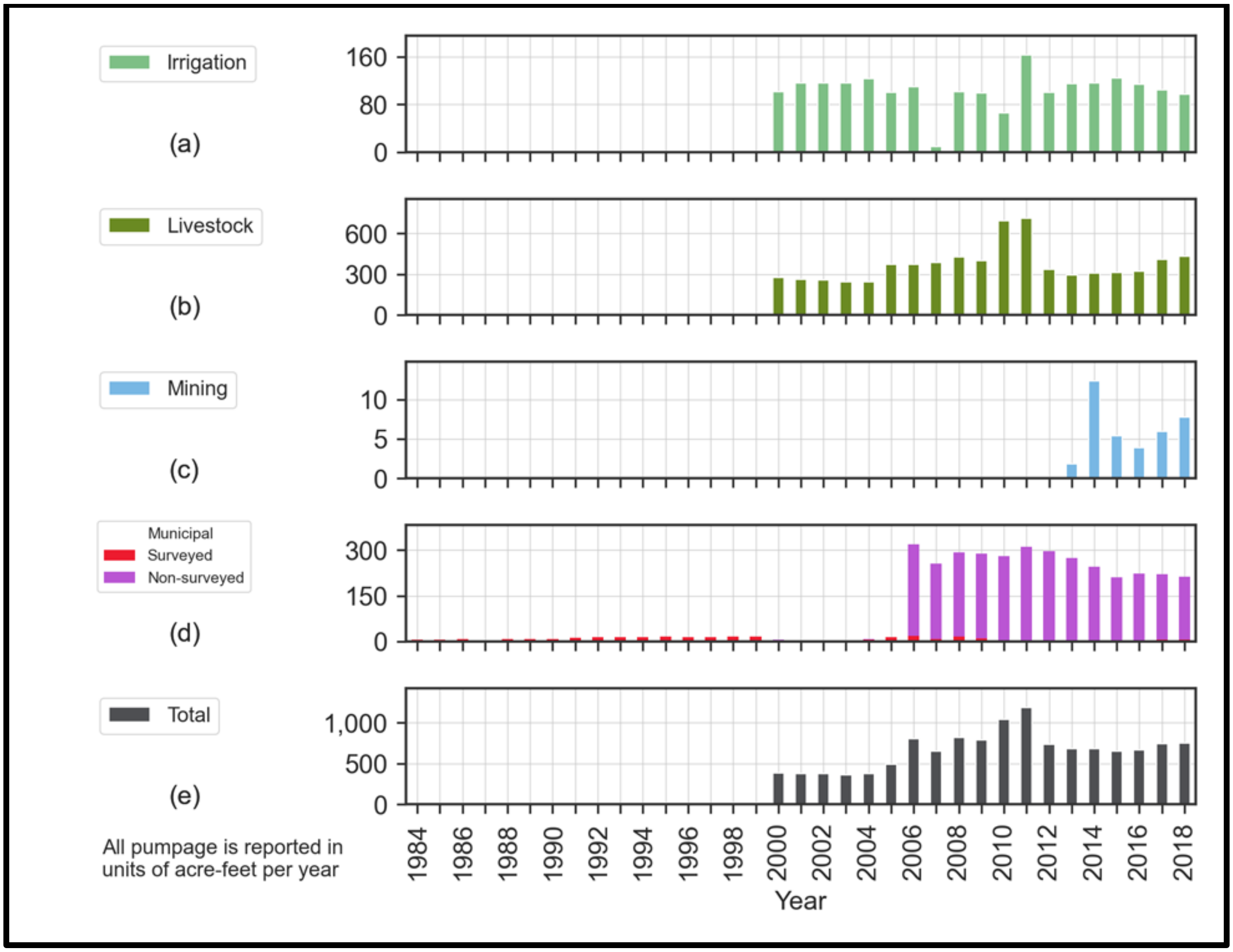


Figure 120. Gillespie County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

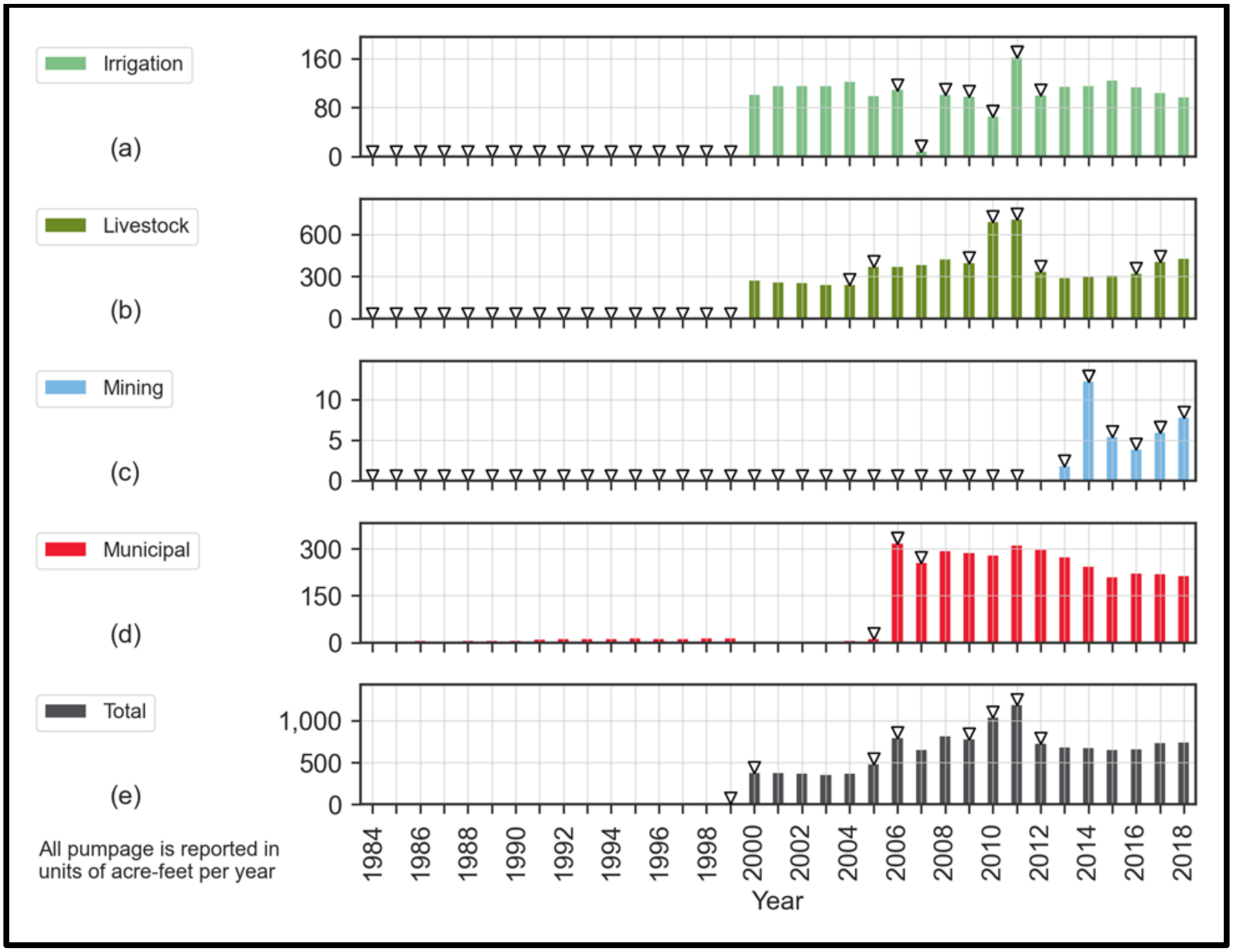


Figure 121. Gillespie County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

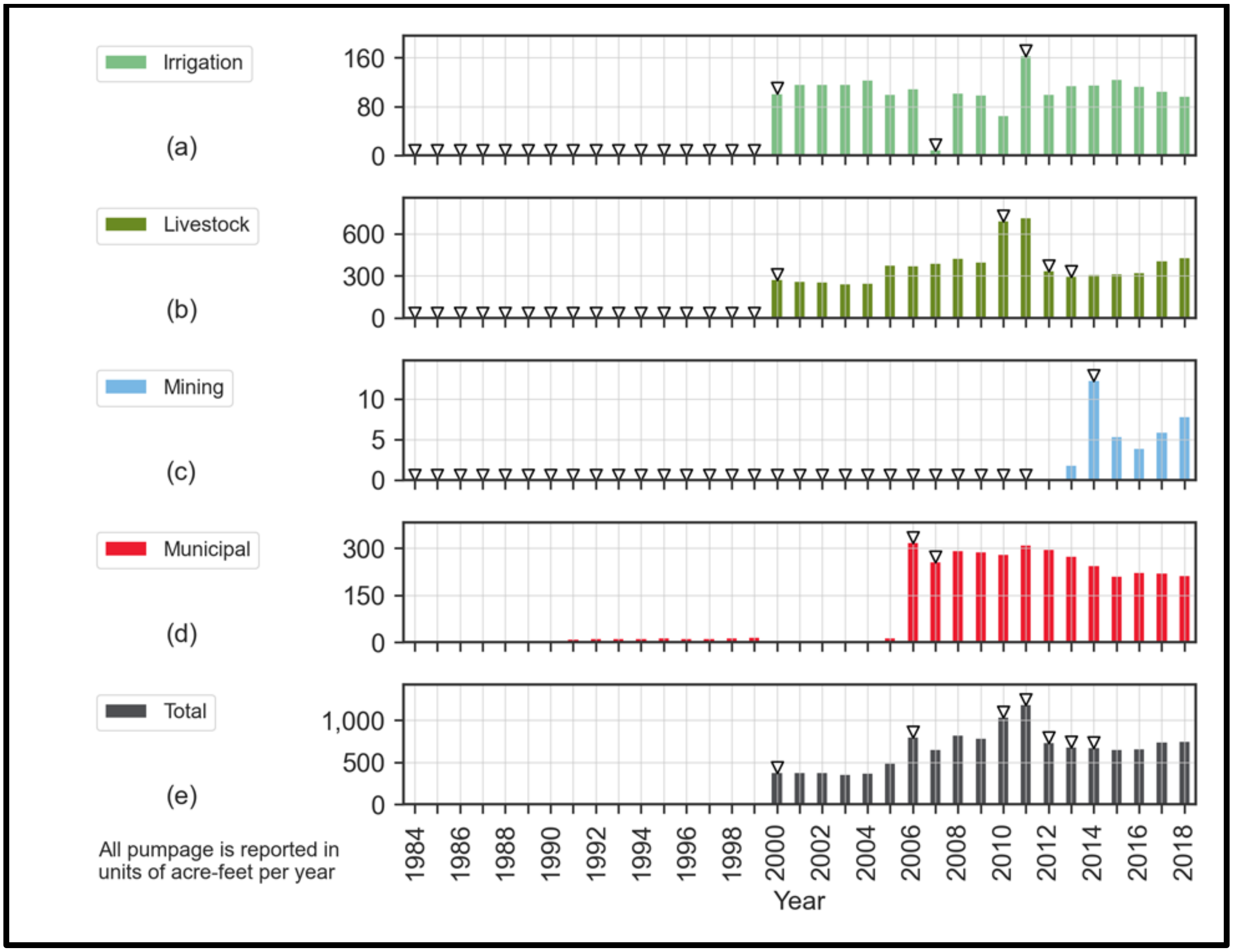


Figure 122. Gillespie County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

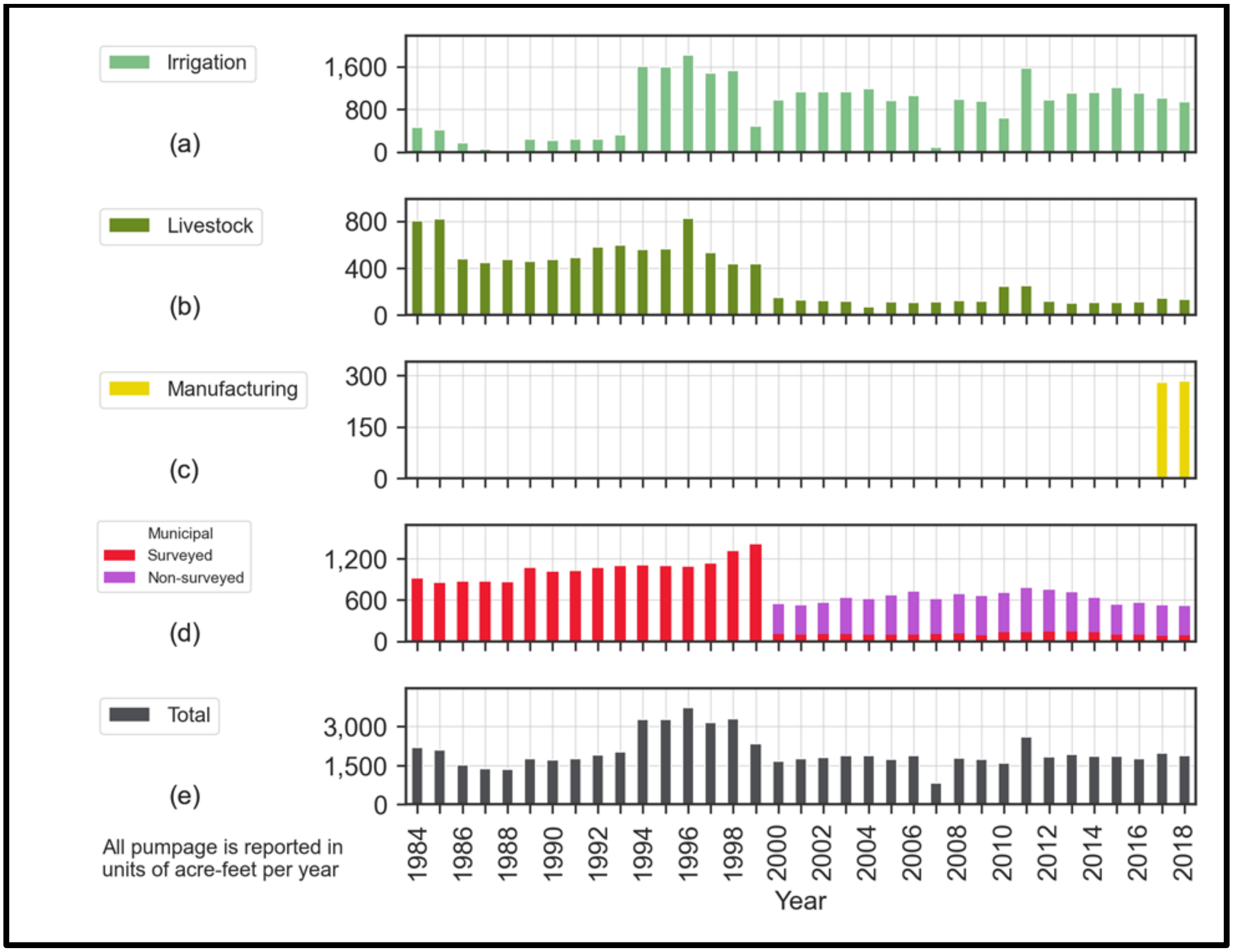


Figure 123. Gillespie County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

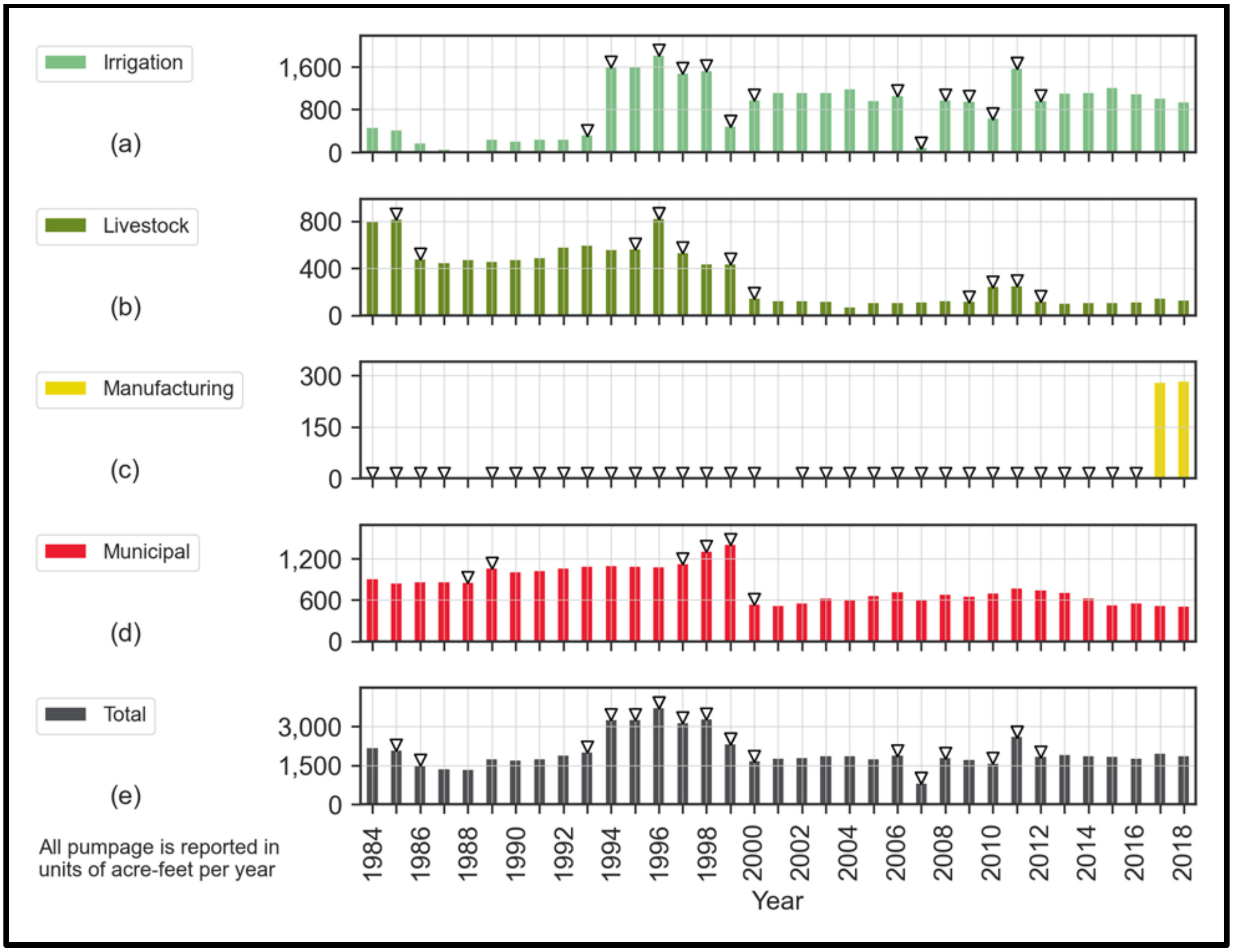


Figure 124. Gillespie County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

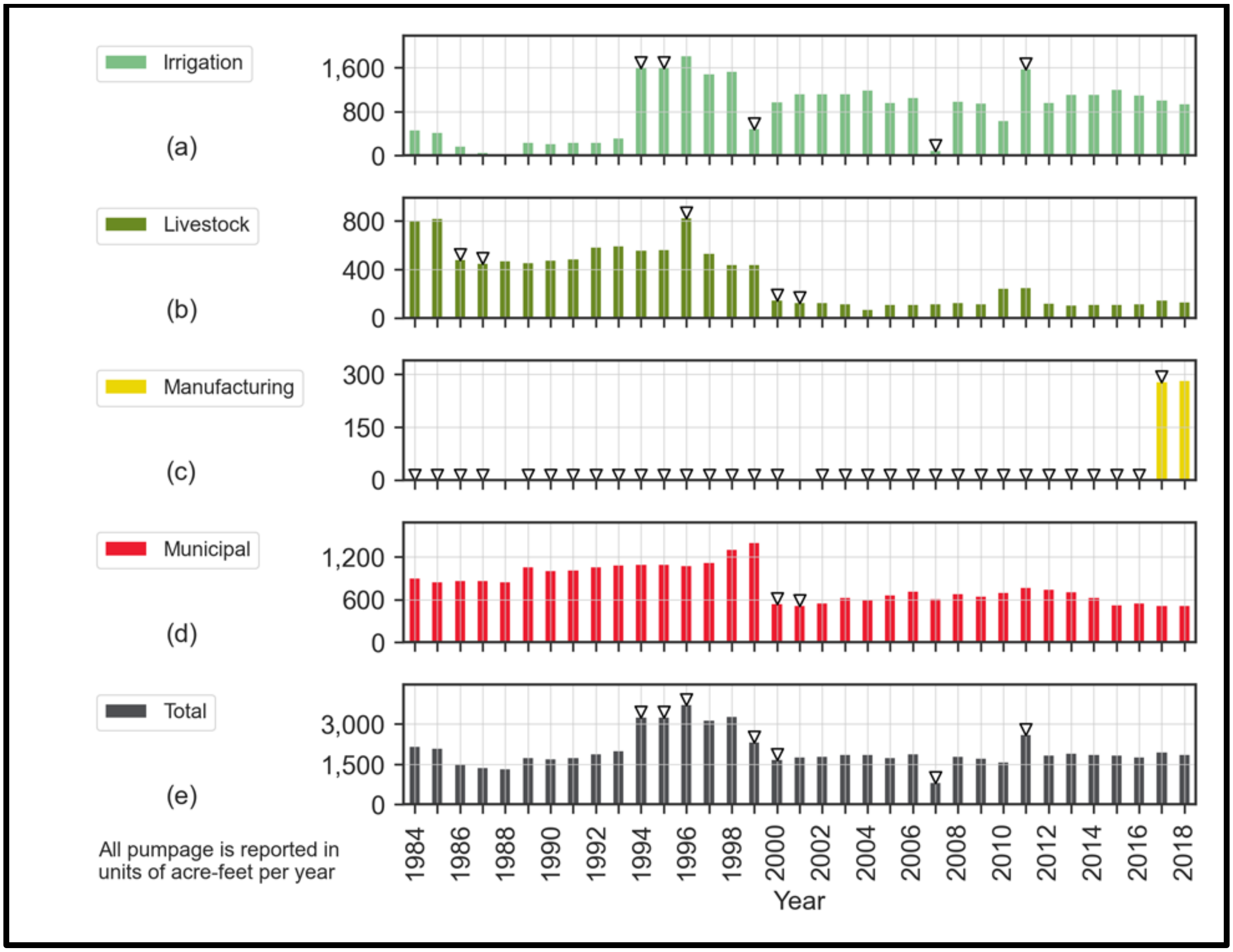


Figure 125. Gillespie County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 25. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Gillespie County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1984-1999, 2007, 2011	1984-2000, 2007, 2008, 2010-2012	1984-2000, 2007, 2011
	Livestock	1984-1999, 2010-2011	1984-2000, 2005, 2010, 2012, 2017	1984-2000, 2010, 2012, 2013
	Mining	1984-2012, 2014	1984-2011, 2014, 2015, 2017, 2018	1984-2011, 2014
	Municipal	2006	2006, 2007	2006, 2007
Trinity (Hill Country)	Irrigation	1994, 1999, 2007	1994, 1997, 1999, 2000, 2007, 2008, 2010-2012	1994, 1995, 1999, 2007, 2011
	Livestock	1996, 2000	1986, 1996, 1997, 2000, 2010, 2012	1986, 1987, 1996, 2000, 2001
	Manufacturing	1984-2016	1984-1987, 1989-2000, 2002-2017	1984-1987, 1989-2000, 2002-2017
	Municipal	2000	1989, 1998, 2000	2000, 2001

3.3.18 Glasscock County

The Edwards-Trinity (Plateau) Aquifer is present over approximately 93 percent of Glasscock County. The Lipan Aquifer also within a portion of the northeast corner of the county covering only about two percent of the county area. The TWDB Water Use Survey dataset did not contain records of any pumping from the Lipan Aquifer within Glasscock County. We will investigate this lack of pumping data during subsequent project tasks. Figure 126 illustrates the extent of the study area aquifers in the county.

Groundwater pumping estimates from the Water Use Survey dataset indicate that maximum total pumping from the Edwards-Trinity (Plateau) in Glasscock County was approximately 60,000 acre-feet, which occurred in 1995 (Figure 127). As shown on Figure 127, reported water uses include irrigation, livestock, manufacturing, mining, and municipal uses, with irrigation usage making up the vast majority of total pumping for the county. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounts for all the reported municipal water use though the total reported municipal use remains relatively constant. We will investigate the impact of the change in methodology for reporting municipal use during subsequent project phases. Manual review of the data in Figure 127 suggests numerous anomalies within the irrigation data due to numerous fluctuations in reported pumping.

The year-to-year change analysis (Figure 128) and standard deviation analysis (Figure 129) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer. Identified anomalies include 20 years of irrigation data with the anomalies identified largely through the year-to-year analysis rather than through the standard deviation analysis. Table 26 provides the years identified as having anomalous pumping amounts from the Edwards-Trinity (Plateau) Aquifer within Glasscock County.

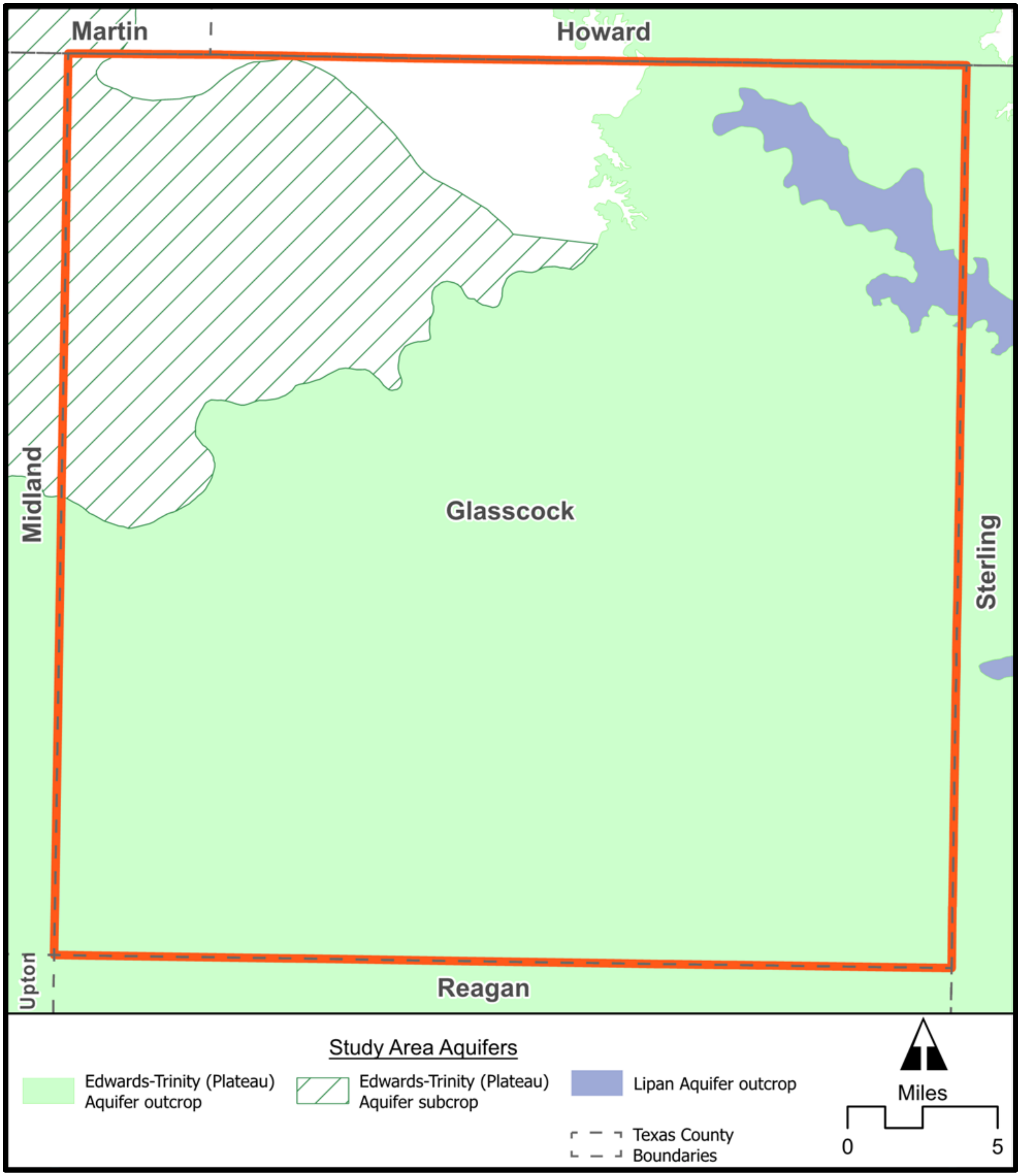


Figure 126. Glasscock County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer.

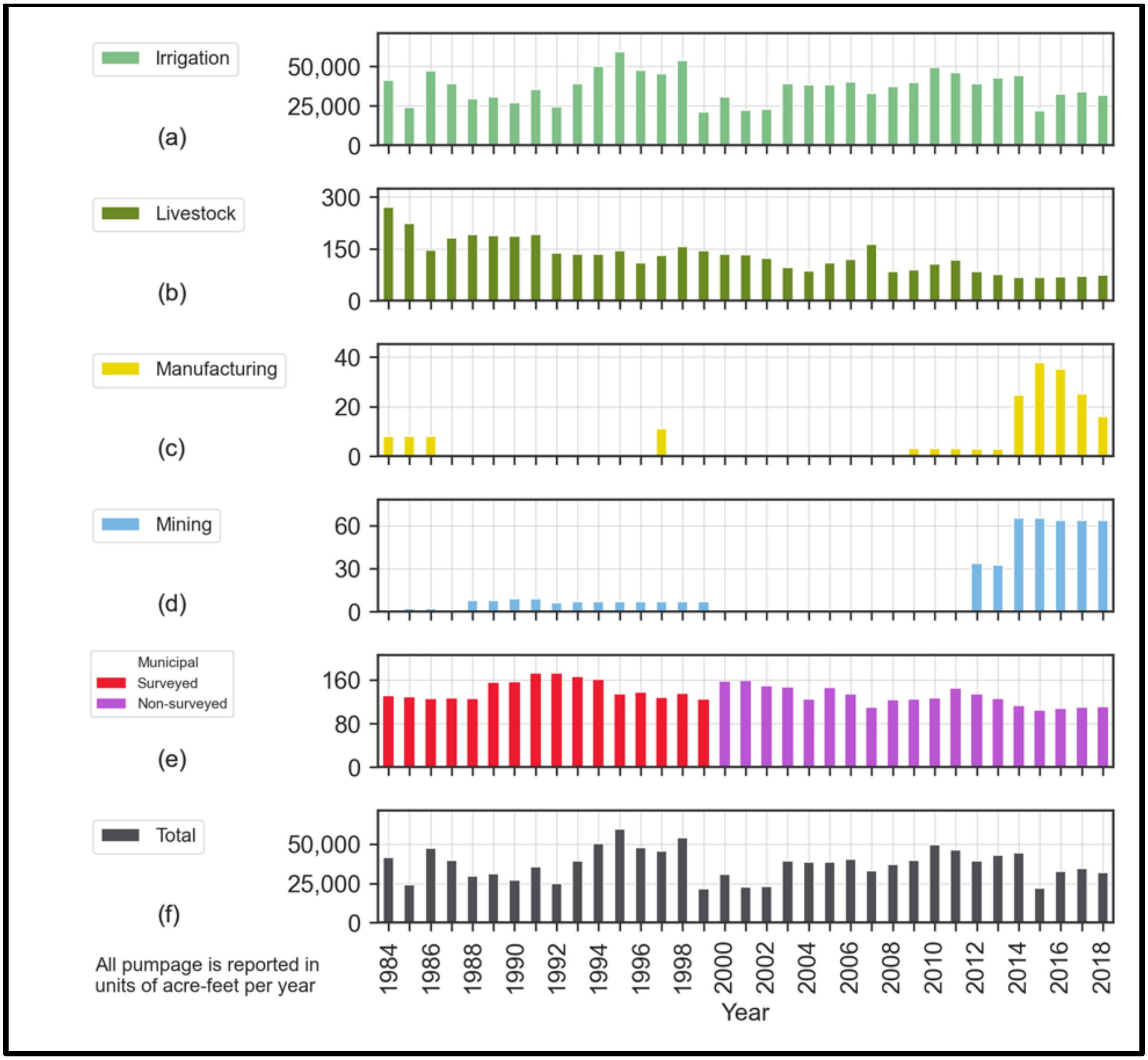


Figure 127. Glasscock County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

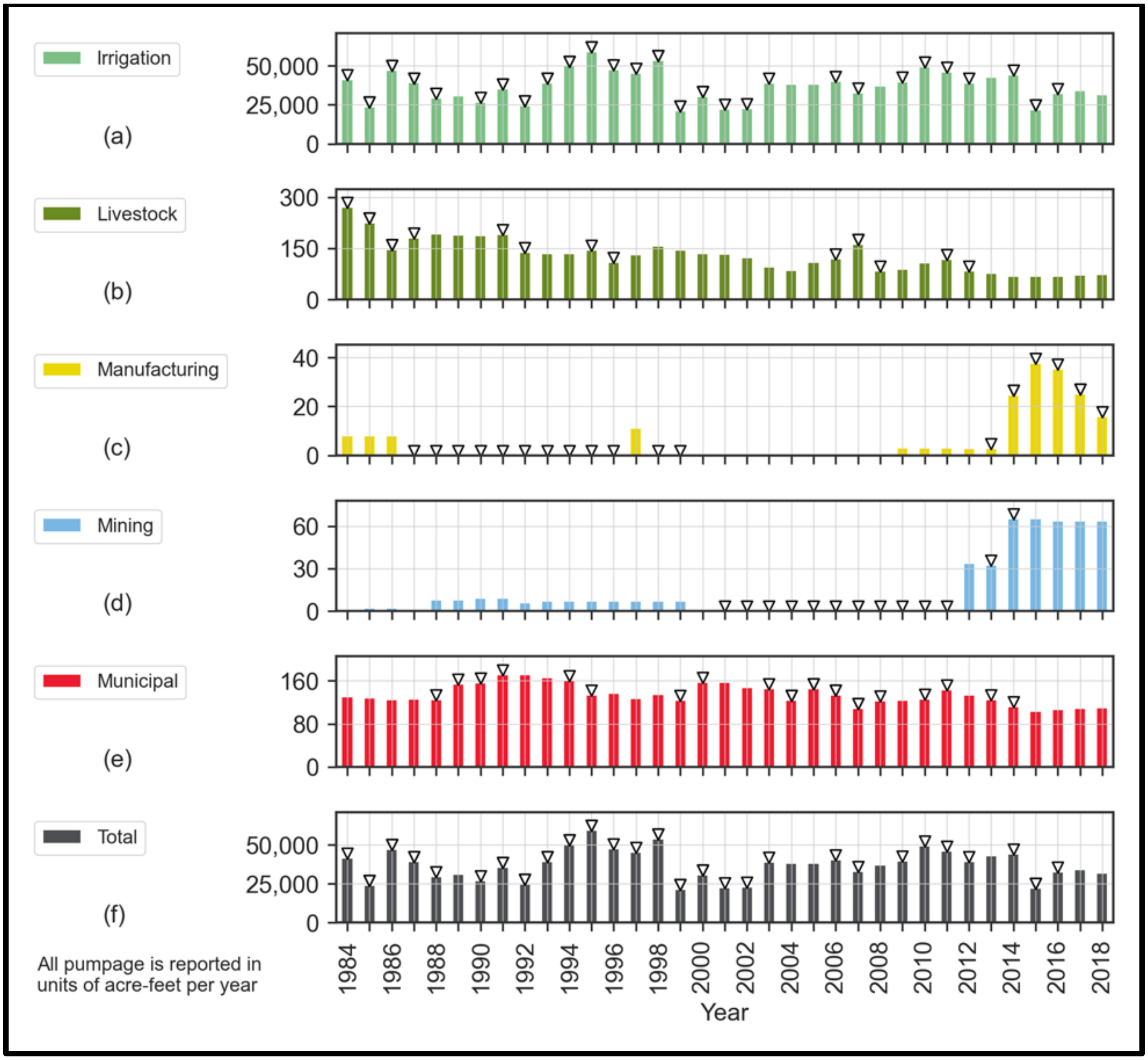


Figure 128. Glasscock County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

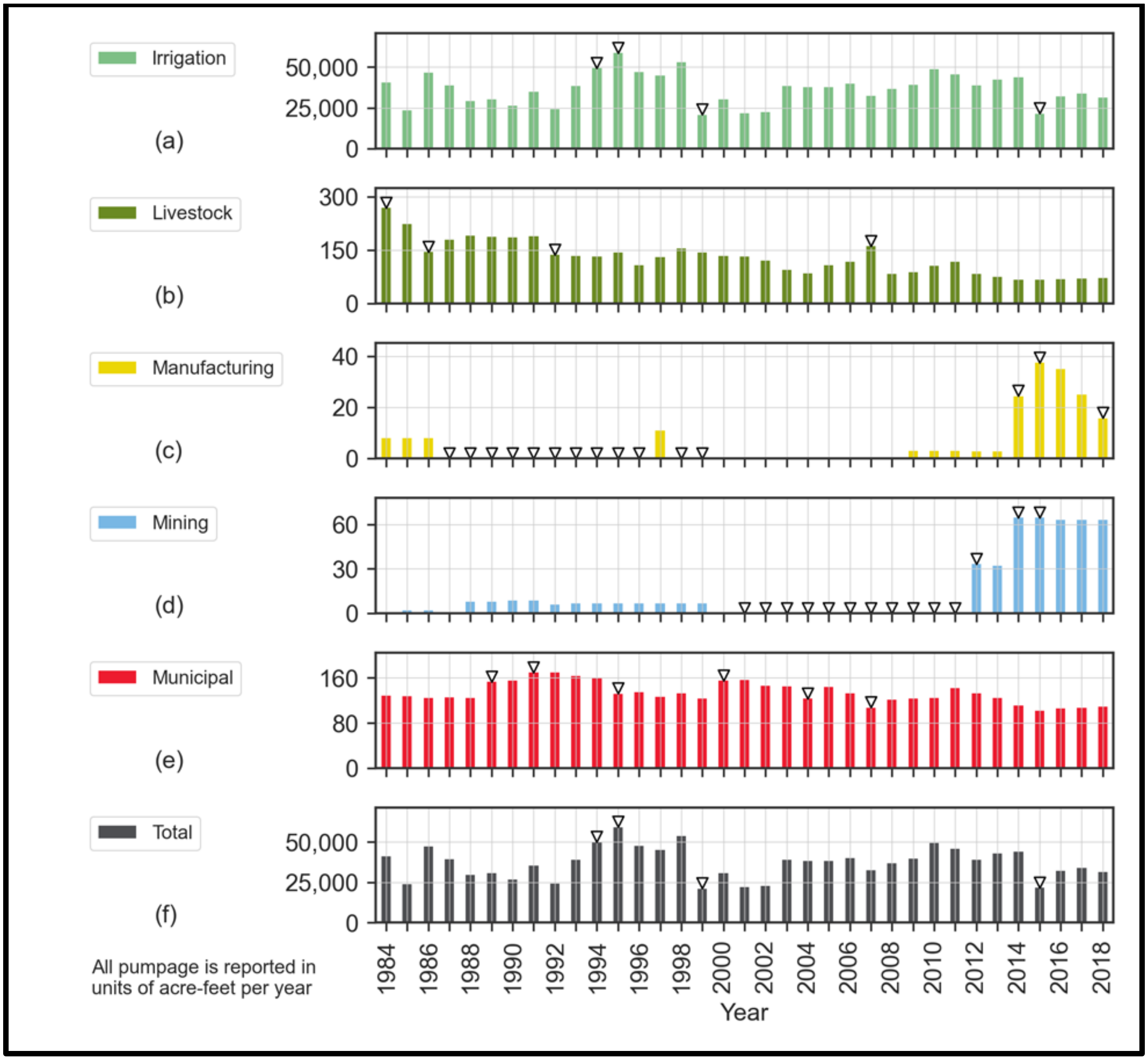


Figure 129. **Glasscock County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 26. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Glasscock County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1999	1984-1988, 1991-1996, 1998-2001, 2003, 2007, 2010, 2012, 2015, 2016	1994, 1995, 1999, 2015
	Livestock	None	1984-1987, 1992, 1996, 2007, 2008, 2012	1984, 1986, 1992, 2007
	Manufacturing	2014	1987-1999, 2014, 2015, 2017, 2018	1987-1996, 1998, 1999, 2014, 2015, 2018
	Mining	2012, 2014	2001-2012, 2014	2001-2012, 2014, 2015
	Municipal	None	1989, 1991, 1995, 2000, 2004-2008, 2011, 2014	1989, 1991, 1995, 2000, 2004, 2007

3.3.19 Guadalupe County

Only a small portion of the subcrop area of the Trinity (Hill Country) Aquifer and overlying Edwards (Balcones Fault Zone) Aquifer are present in the western corner of Guadalupe County (see Figure 130). Of all the water-bearing units underlying Guadalupe County, the Wilcox Group and the Carrizo Sand (that is, the Carrizo-Wilcox Aquifer) together constitute the most favorable aquifer for large-scale groundwater development (Shafer, 1966). Therefore, we do not expect large pumpage values from wells located in Guadalupe County that are completed in the study aquifers.

As shown in Figure 131, municipal is the main use of Edwards (Balcones Fault Zone) Aquifer groundwater identified in the Water Use Survey data. Reported pumping from the Edwards (Balcones Fault Zone) Aquifer for irrigation and livestock began in the year 2000 and indicates a steady moderate use of groundwater with an abrupt increase in 2011 for irrigation, reaching 100 acre-feet. Pumpage for livestock remained below 20 acre-feet.

Reported pumping from the Edwards (Balcones Fault Zone) Aquifer for municipal use occurs between 2002 and 2018. During this period, reported pumping from the aquifer for municipal use generally ranges between 1,000 and 1,500 acre-feet per year. However, for two years during this period (2007 and 2010), we observe abrupt decreases in usage. In addition, there was not any reported municipal usage in 2004.

Figure 132 presents the year-to-year change analysis for the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County that shows several anomalies in the data. The standard deviation analysis (Figure 133) also identified as anomalous the abrupt increase in pumpage from the Edwards (Balcones Fault Zone) Aquifer for irrigation in 2011, for livestock in 2005 and for manufacturing in 2005. Figure 133 also identifies the abrupt decreases in pumpage for livestock in 2012, and for municipal use in 2007.

Pumping from the Trinity (Hill Country) Aquifer is reported only for non-surveyed municipal use and appears steady between 2006 and 2018. The pumpage is also small compared to municipal pumpage from the Edwards (Balcones Fault Zone) Aquifer. Being near the subcrop boundary of the aquifer, the reported production from the Trinity (Hill Country) Aquifer is an anomaly and the pumping may be occurring from the overlying Edwards (Balcones Fault Zone) Aquifer subcrop or another overlying aquifer.

Table 27 provides the years identified as having anomalous pumping amounts for Guadalupe County based on our manual review, year-to-year change (Figure 132 and Figure 135), and standard deviation (Figure 133 and Figure 136) analyses.

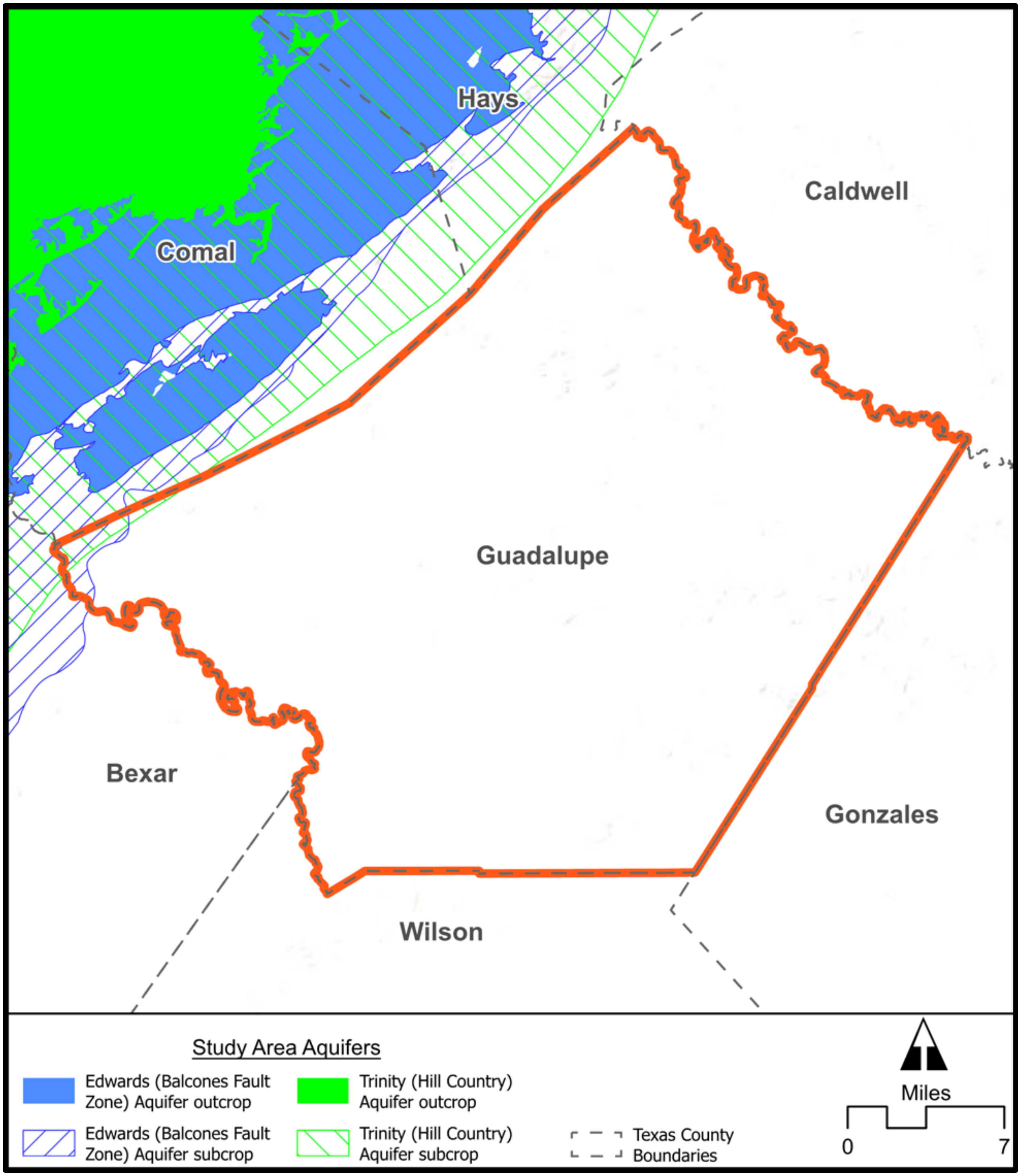


Figure 130. Guadalupe County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

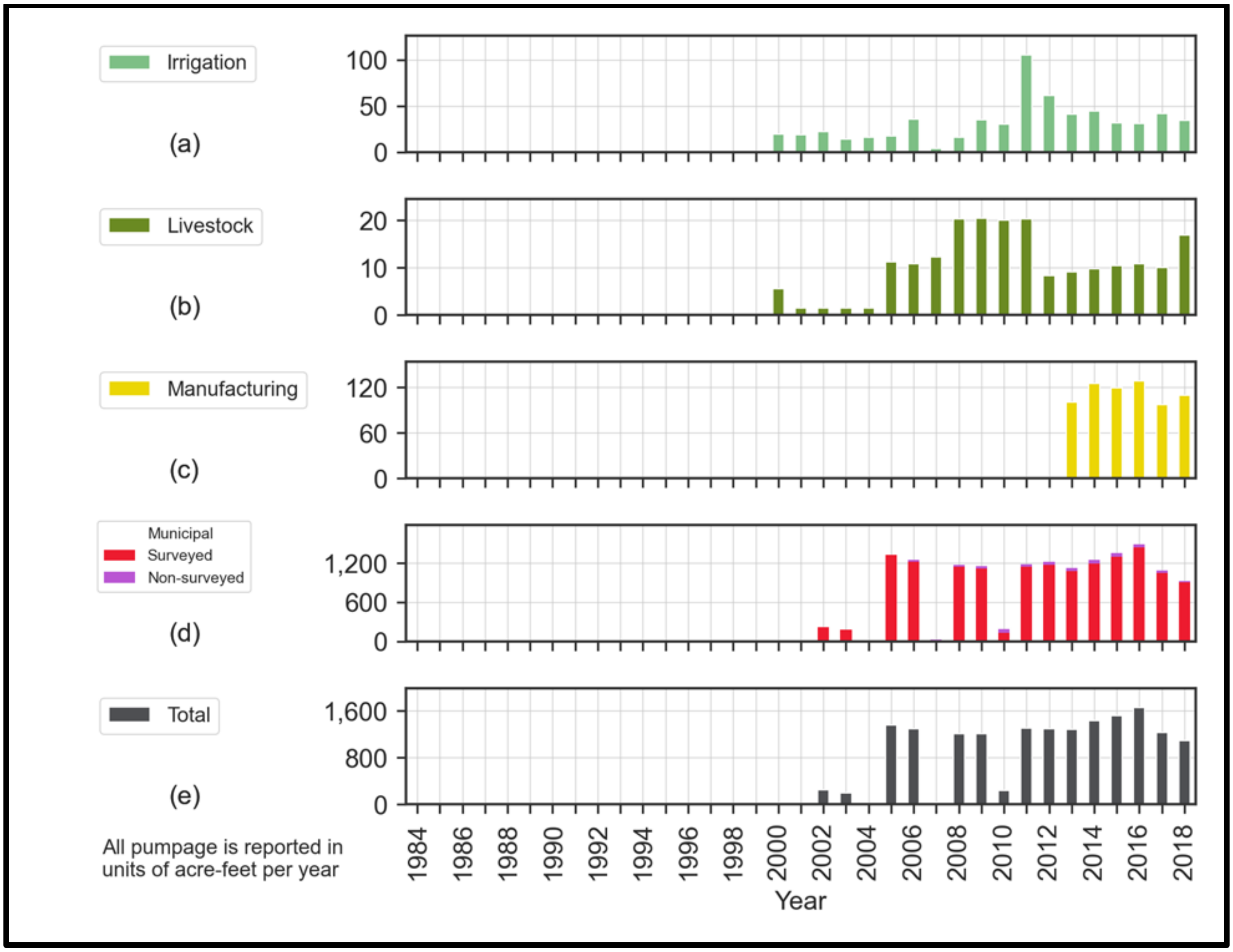


Figure 131. Guadalupe County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

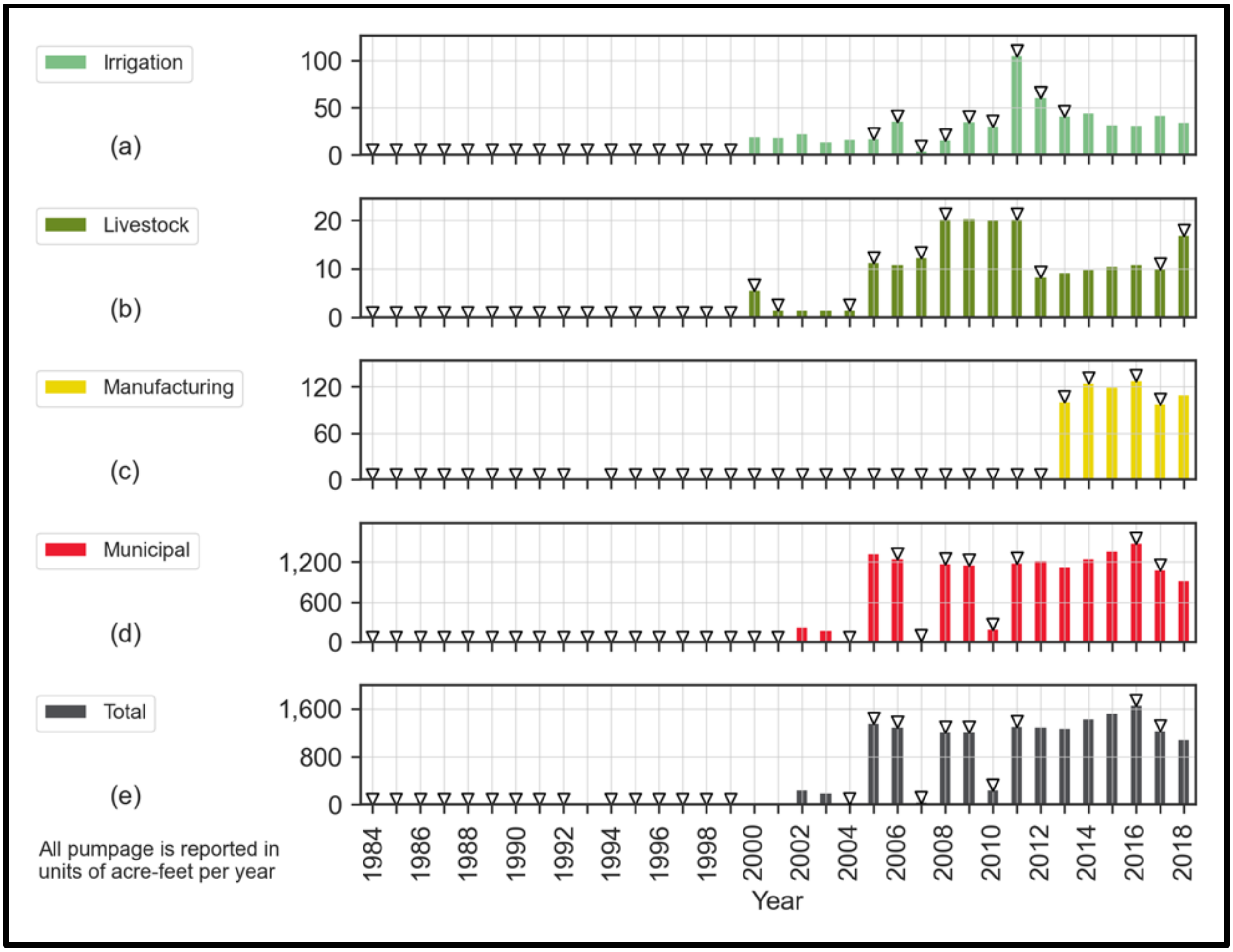


Figure 132. Guadalupe County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

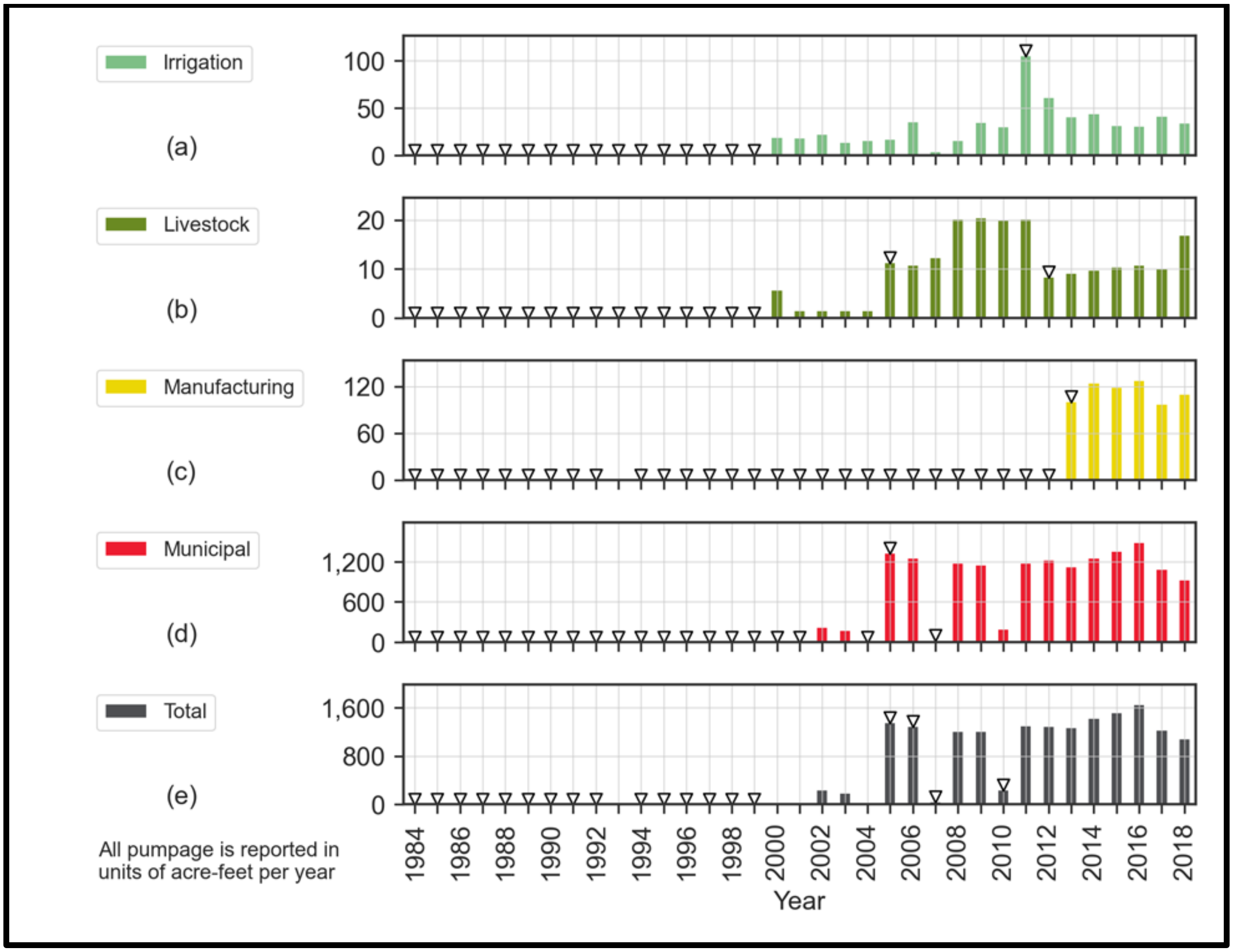


Figure 133. Guadalupe County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

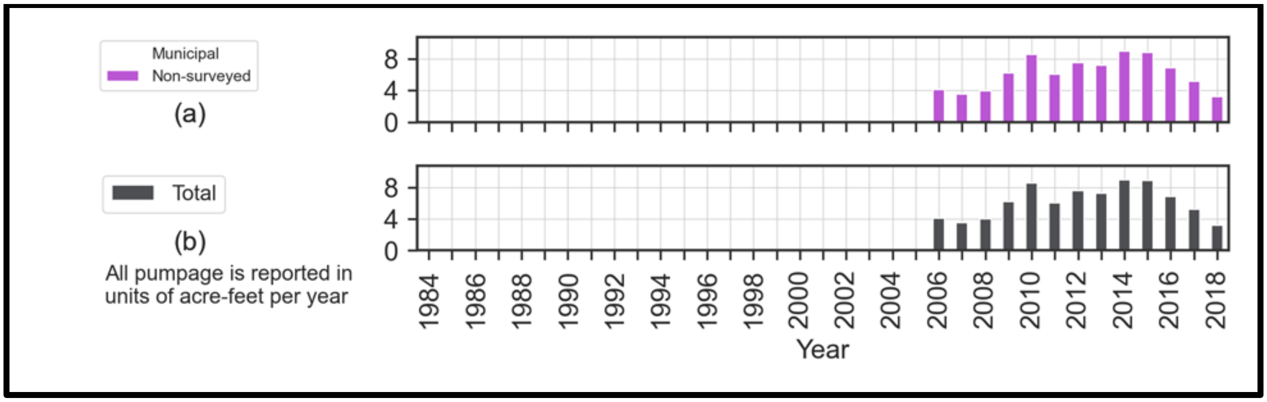


Figure 134. Guadalupe County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

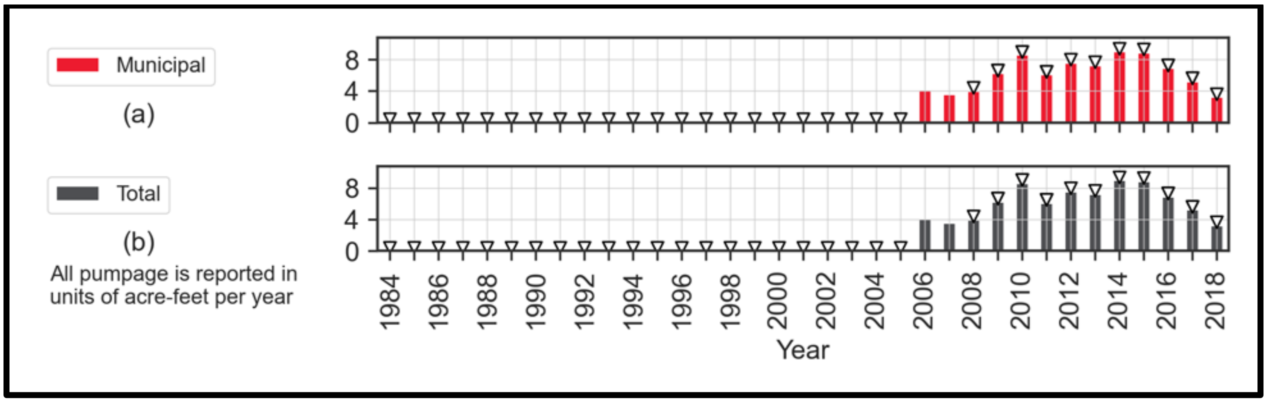


Figure 135. Guadalupe County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

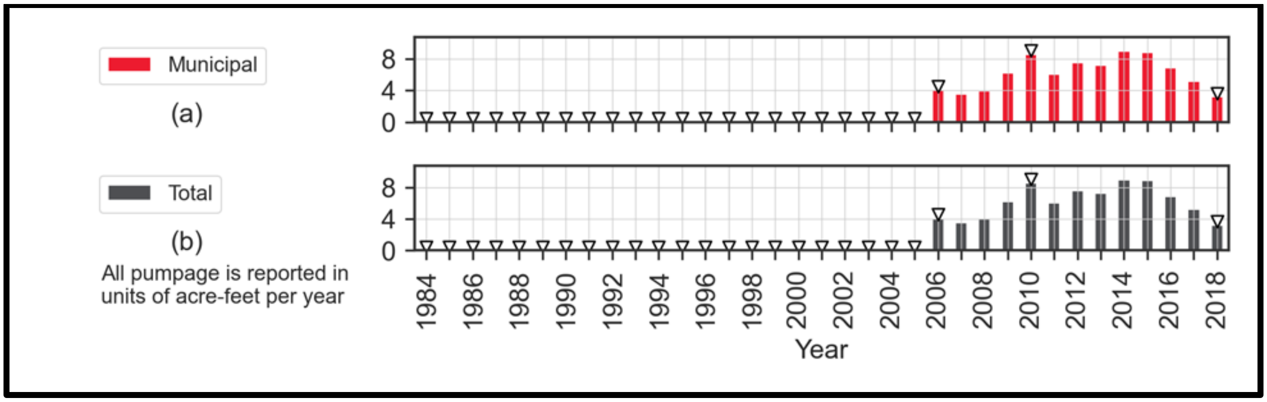


Figure 136. Guadalupe County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 27. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Guadalupe County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	2011	1993, 2000, 2006, 2007, 2009, 2011-2013	1993, 2011
	Livestock	2005, 2008, 2012	1993, 2000, 2001, 2005, 2008, 2012, 2018	1993, 2005, 2012
	Manufacturing	1984-2013	2000-2014, 2017	2000-2013
	Municipal	1984-2001, 2004, 2007, 2010	1993, 2000-2002, 2004, 2007, 2008, 2010, 2011, 2017, 2009-2012, 2014, 2016-2018	1993, 2000, 2001, 2004, 2005, 2007, 2010, 2018
Trinity (Hill Country)	Municipal	2006	2009-2012, 2014, 2016-2018	2010, 2018

3.3.20 Hays County

The Edwards (Balcones Fault Zone) Aquifer is present in the central portion of Hays County and covers about 32 percent of the county area. Approximately 94 percent of Hays County overlies the Trinity (Hill Country) Aquifer. Figure 137 illustrates the extent of the study area aquifers in Hays County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards (Balcones Fault Zone) Aquifer in Hays County was over 12,000 acre-feet per year, which occurred in 10 of the 16 years prior to 2000 (Figure 138). As shown on Figure 138, reported pumpage is for the irrigation, livestock, manufacturing, mining, municipal, power, and unknown water use categories, with the majority of pumping for municipal use. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounts for a relatively small portion of the total municipal water use from the Edwards (Balcones Fault Zone) Aquifer in Hays County. Manual review of Figure 138 suggests anomalies in irrigation (2007), livestock (1985 through 1998), and power (2013 and 2014).

The year-to-year change analysis (Figure 139) and standard deviation analysis (Figure 140) flagged many anomalies in the data for the Edwards (Balcones Fault Zone) Aquifer within Hays County. These included anomalies identified through the manual review, as well as numerous years for which the TWDB Water Use Survey database does not contain pumpage data for certain water use categories.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer in Hays County of approximately five acre-feet occurred in multiple years (Figure 141). We believe this pumping was improperly assigned to the Edwards-Trinity (Plateau) Aquifer in Hays County, as the TWDB defined aquifer footprint does not extend into Hays County. Through research conducted within subsequent tasks, we expect to re-assign this pumping to its proper aquifer and/or county.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Trinity (Hill Country) Aquifer within Hays County was approximately 6,000 acre-feet, which occurred in 2011 (Figure 142). As shown on Figure 142, reported pumpage is for irrigation, livestock, manufacturing, mining, and municipal use, with the majority of pumping supporting municipal use. Since its inclusion beginning in 2000, non-surveyed municipal use constituted a significant portion of the total municipal water use from the Trinity (Hill Country) Aquifer in Hays County. Manual review of Figure 142 suggests that irrigation anomalies occurred from 1989 through 2004 and in 2007, livestock use in 1984 was anomalous, and the reduction in municipal usage from 2013 through 2014 is anomalous.

The year-to-year change analysis (Figure 143) and standard deviation analysis (Figure 144) flagged several anomalies in the data for the Trinity (Hill Country) Aquifer. Identified anomalies included the unreported values for irrigation, mining, and manufacturing use, as well as five years of municipal usage. Table 28 provides the years identified as having anomalous pumping amounts for Hays County from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

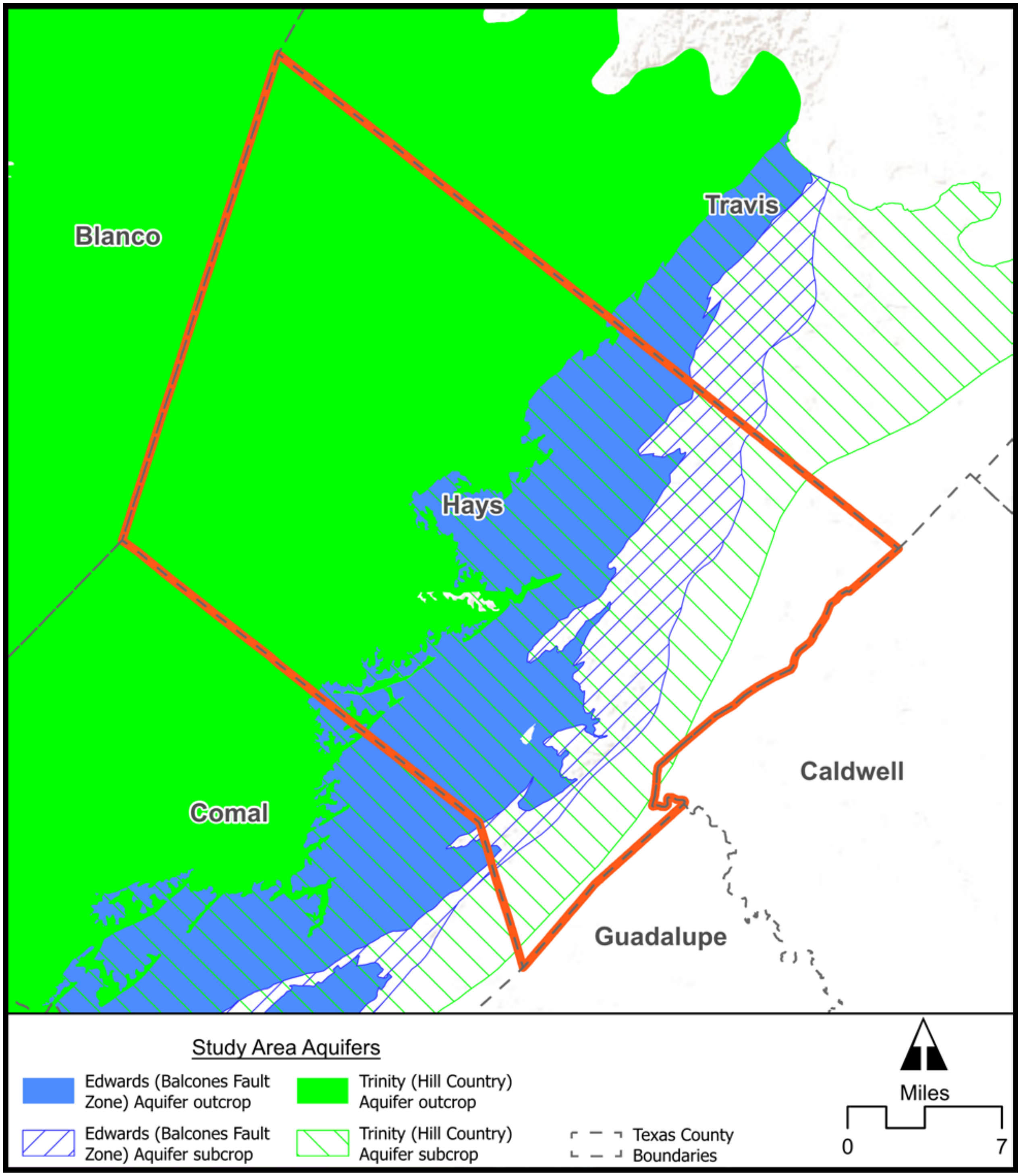


Figure 137. Hays County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

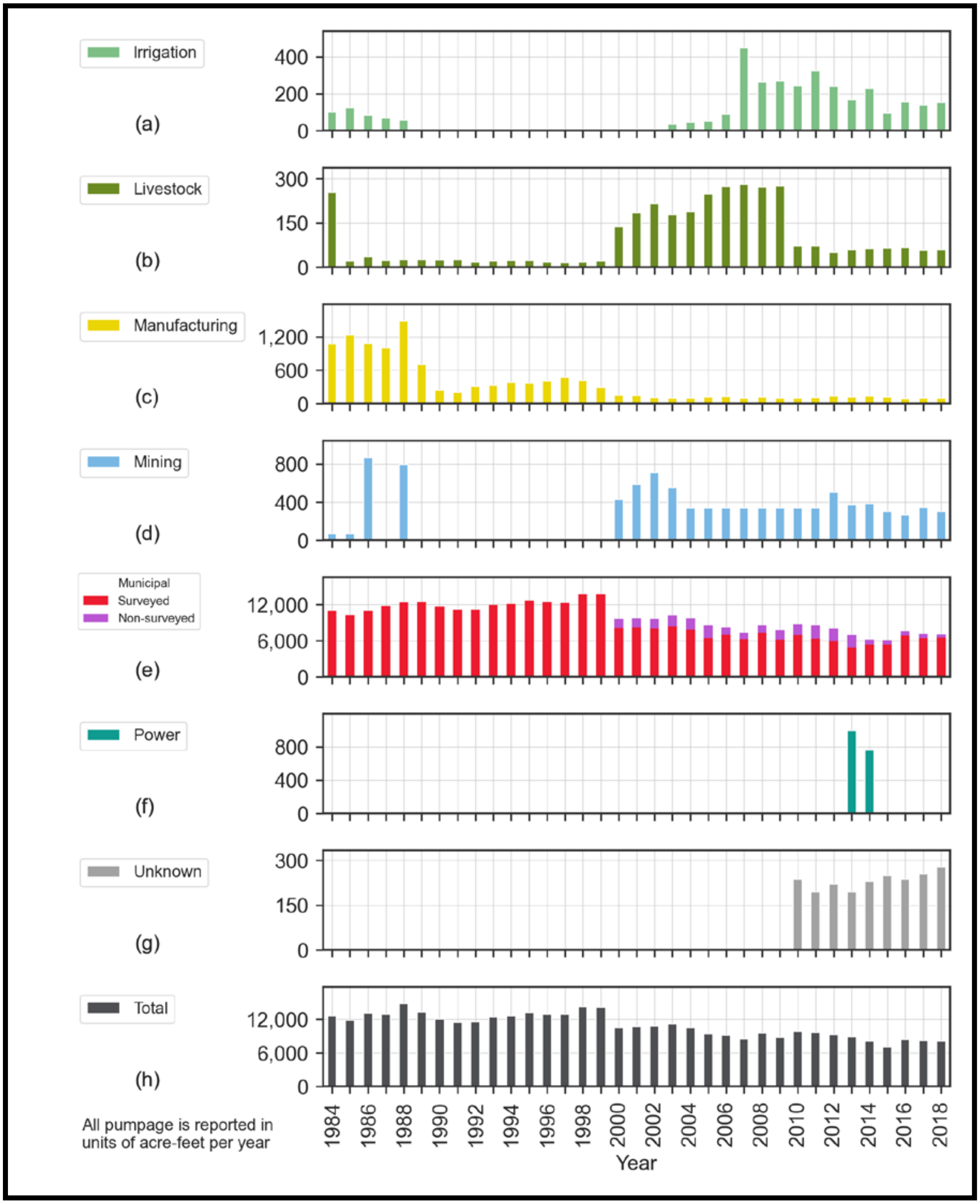


Figure 138. **Hays County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

Figure 139. Hays County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

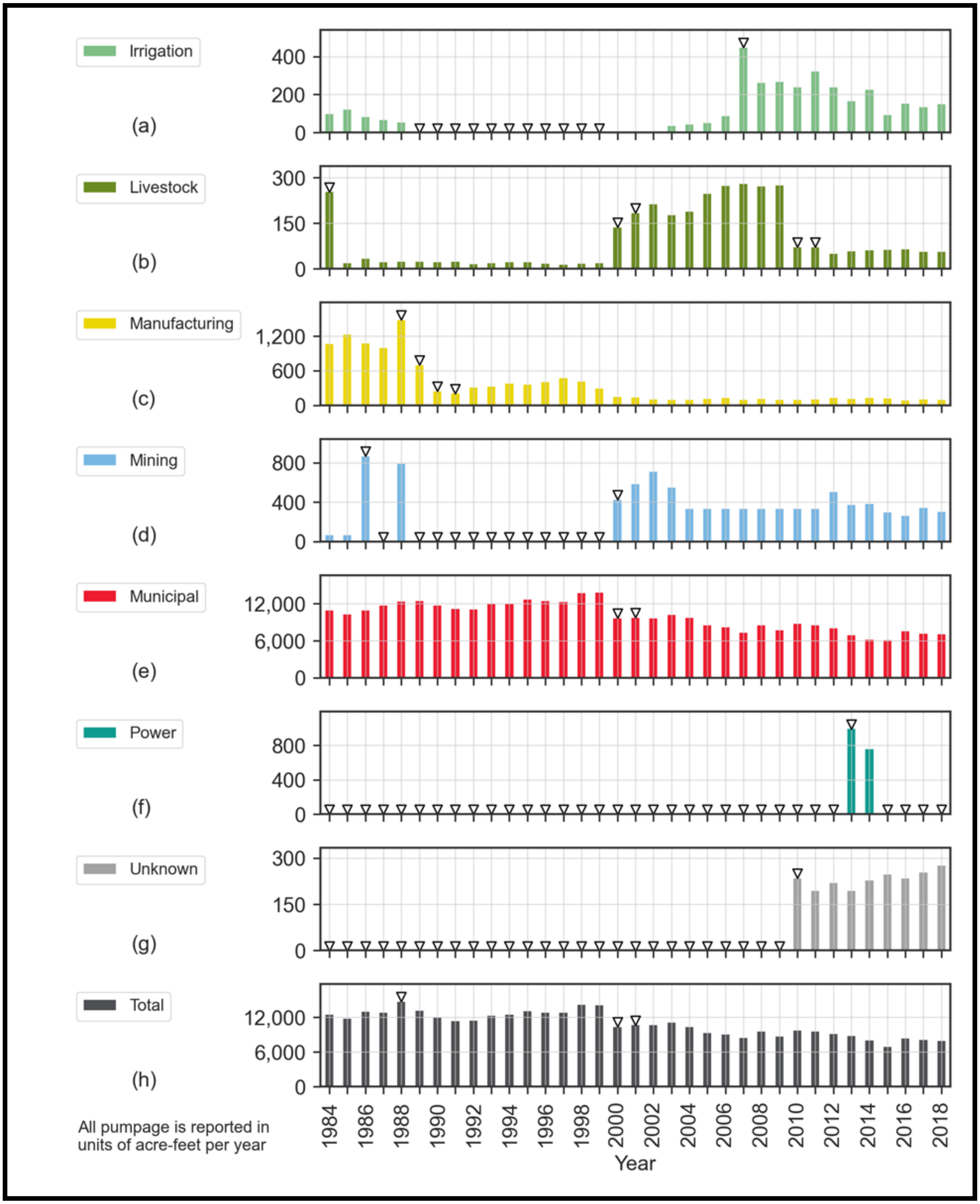


Figure 140. Hays County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

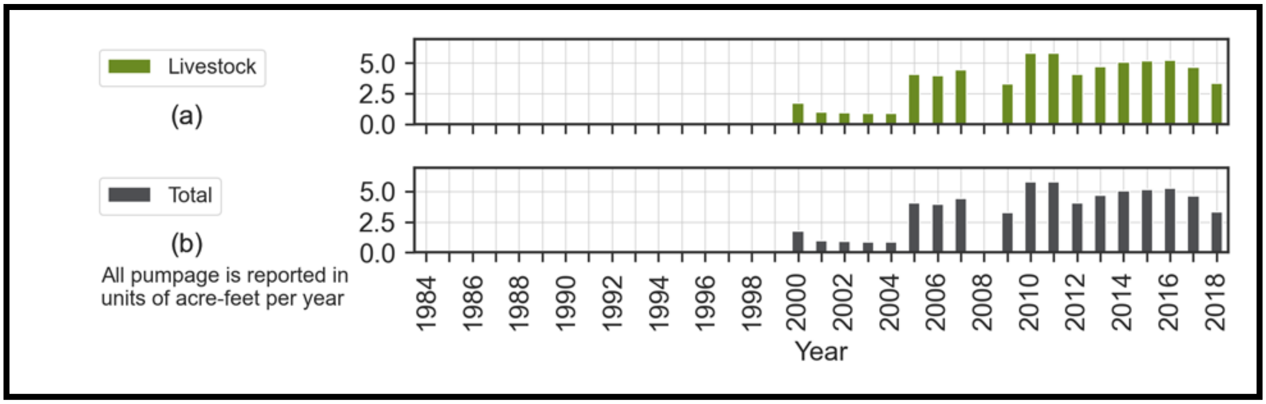


Figure 141. Hays County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

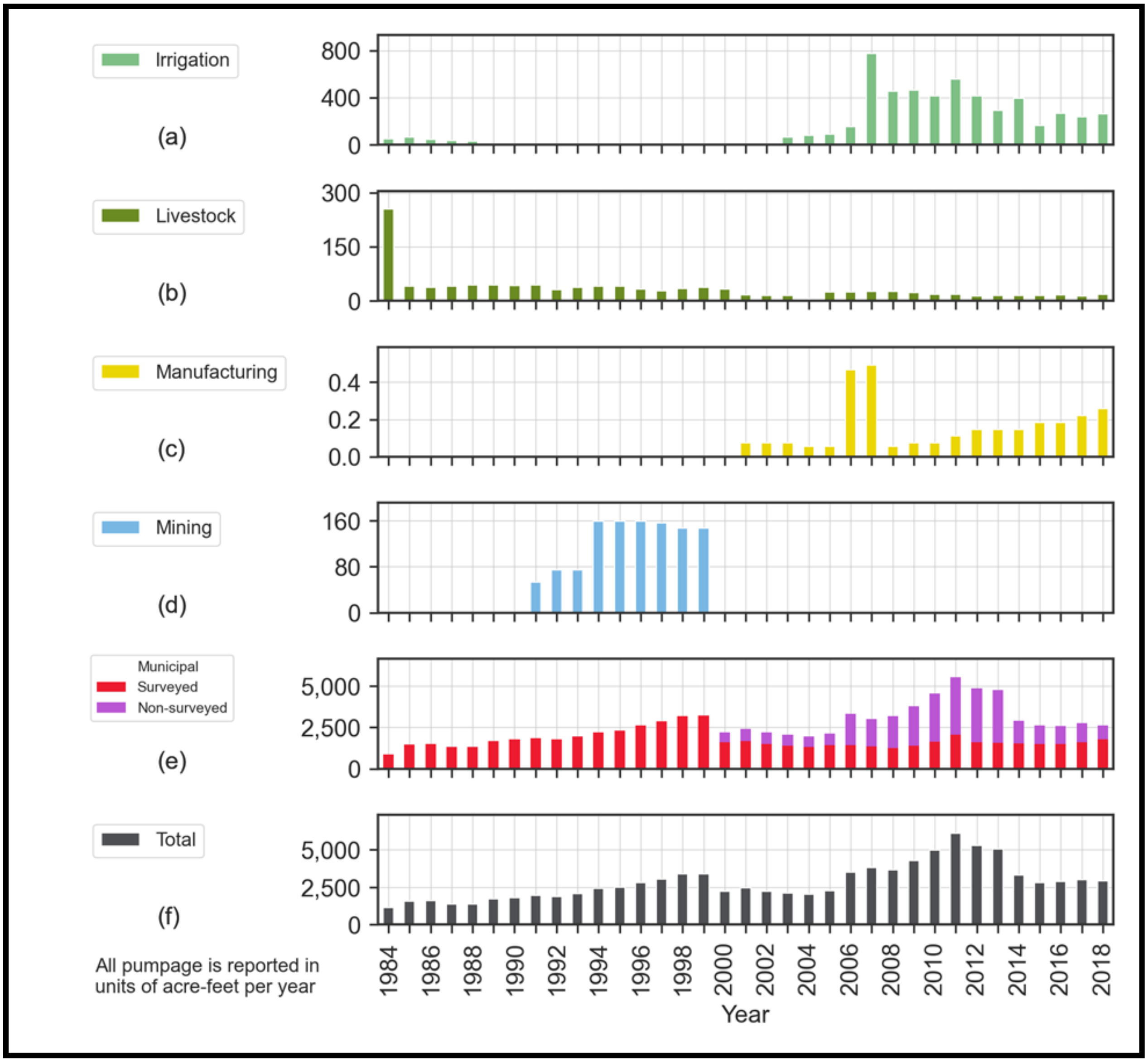


Figure 142. **Hays County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

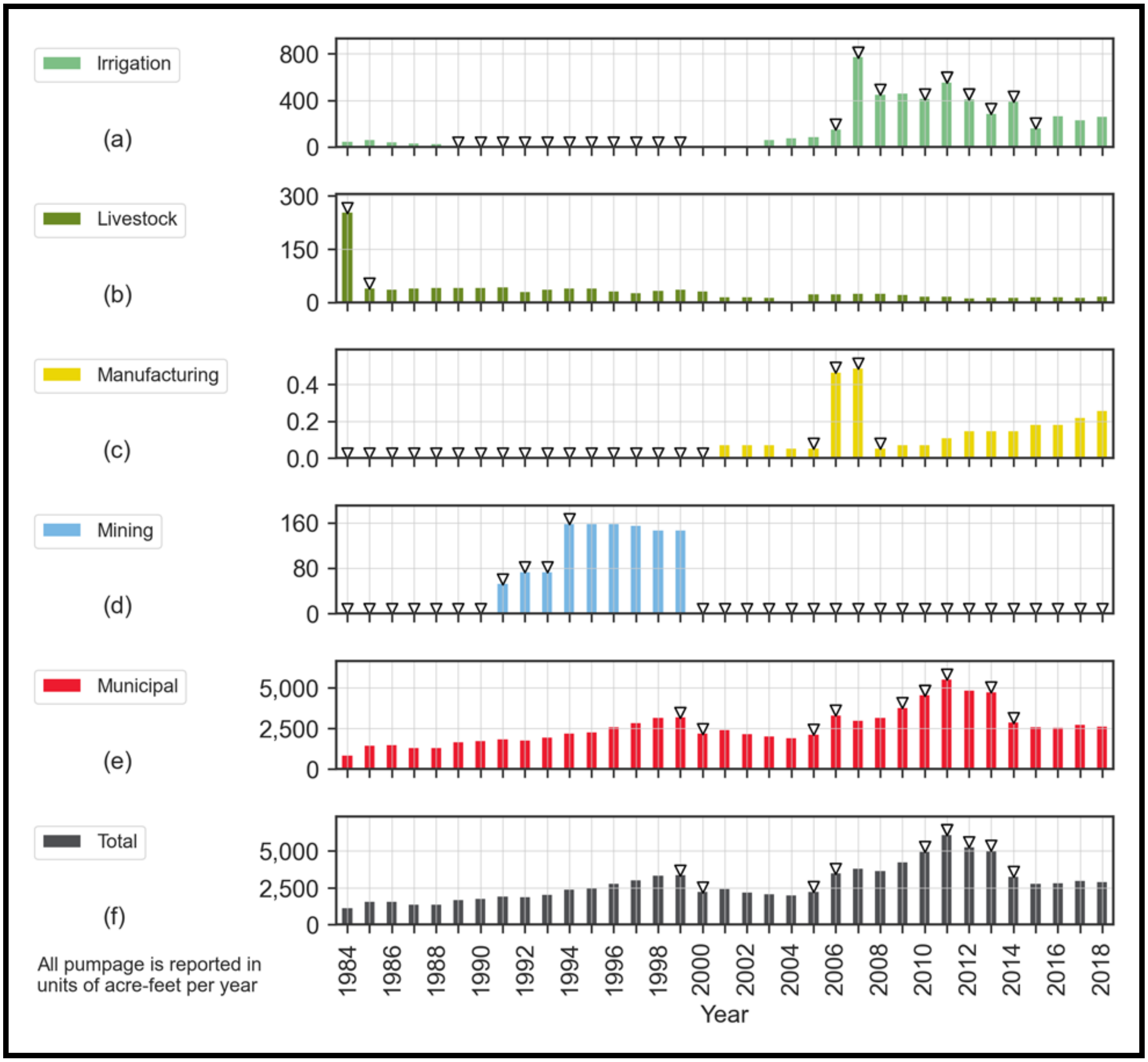


Figure 143. Hays County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

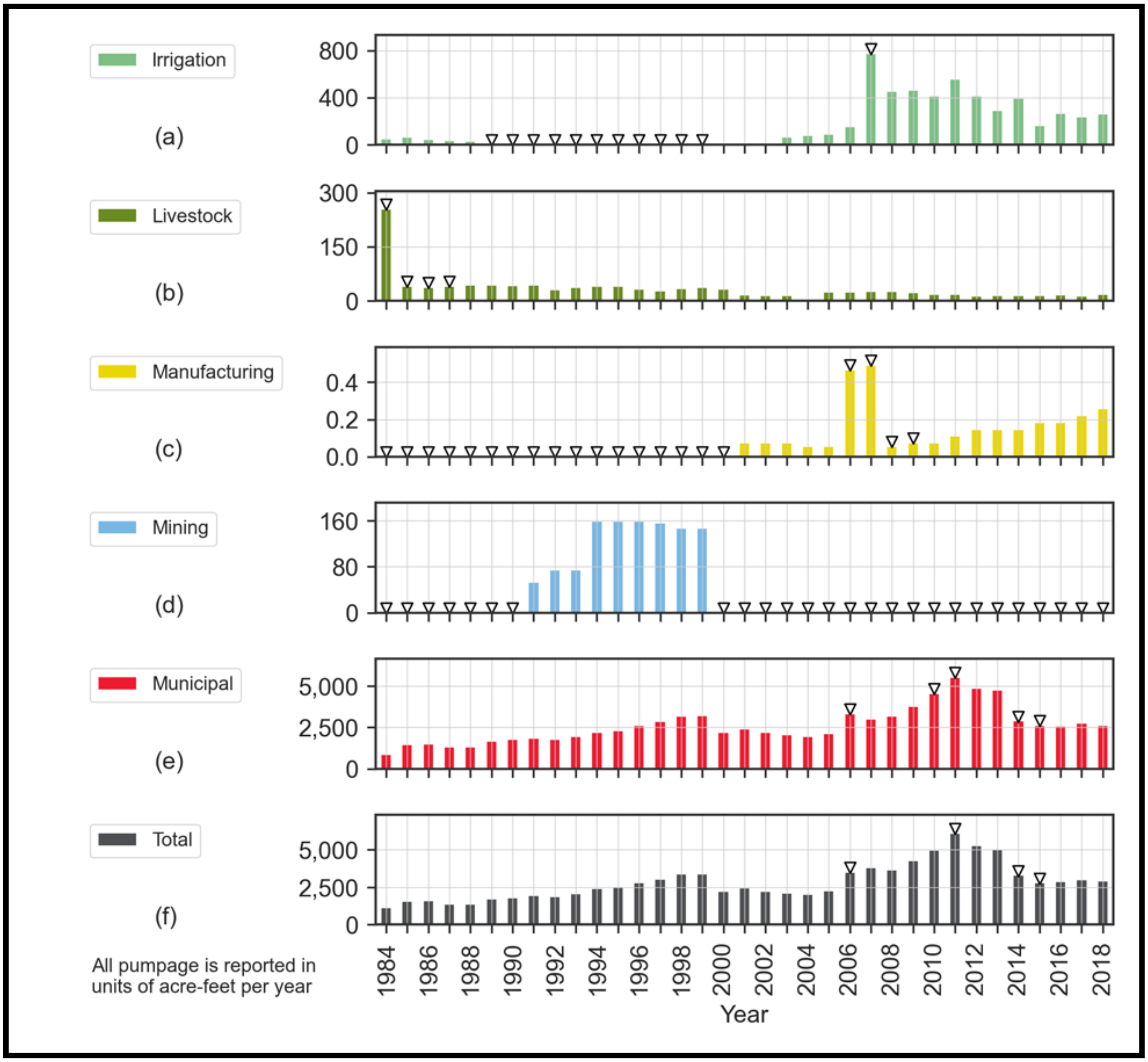


Figure 144. Hays County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 28. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Hays County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	2007	1989-1999, 2007, 2008, 2011-2013, 2015	1989-1999, 2007
	Livestock	1985-1999	1984, 1985, 2000, 2001, 2005, 2010	1984, 2000, 2001, 2010, 2011
	Manufacturing	1990	1988-1990	1988-1991
	Mining	1986, 1988-1999	1986-2004, 2012, 2013	1986, 1987, 1989-2000
	Municipal	None	1998, 2000, 2005, 2008, 2016	2000, 2001
	Power	2013-2014	1984-2018	1984-2013, 2015-2018
	Unknown	2010	1984-2011, 2014	1984-2010
Trinity (Hill Country)	Irrigation	1989-2002, 2007	1989-1999, 2007, 2008, 2011-2013, 2015	1989-1999, 2007
	Livestock	1984	1984, 1985	1984-1987
	Manufacturing	2006-2007	1984-2001, 2006, 2008	1984-2000, 2006-2009
	Mining	1984-1990, 2000-2018	1984-1992, 1994, 2000-2018	1984-1990, 2000-2018
	Municipal	2000, 2014	2000, 2006, 2010, 2011, 2014	2006, 2010, 2011, 2014, 2015

3.3.21 Howard County

The Edwards-Trinity (Plateau) Aquifer is present in the southern portion of Howard County, covering approximately nine percent of the county area. Figure 145 illustrates the extent of the aquifer in the Howard County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer in Howard County was approximately 8,000 acre-feet per year, which occurred in 2005 and 2006 (Figure 146). As shown on Figure 146, the Water Use Survey dataset includes pumpage data for each year of the study period for livestock and manufacturing use. However, the dataset does not include pumpage for irrigation, mining, and municipal usage for all years of the study period. Manual review of Figure 146 indicates anomalies in irrigation and municipal pumping datasets, including two years of municipal pumping (2005 and 2006) which greatly exceeded all other report years of municipal pumping from the county and aquifer.

The year-to-year change analysis (Figure 147) and standard deviation analysis (Figure 148) flagged numerous anomalies in the data for the Edwards-Trinity (Plateau) Aquifer within Howard County. Identified anomalies included many years of data for irrigation, livestock, and manufacturing uses, as well as many years of missing data for mining uses. Each analysis identified the 2005 and 2006 municipal pumping values as anomalous and worthy of further investigation. Table 29 provides the years identified as having anomalous pumping amounts from the Edwards-Trinity (Plateau) Aquifer within Howard County.

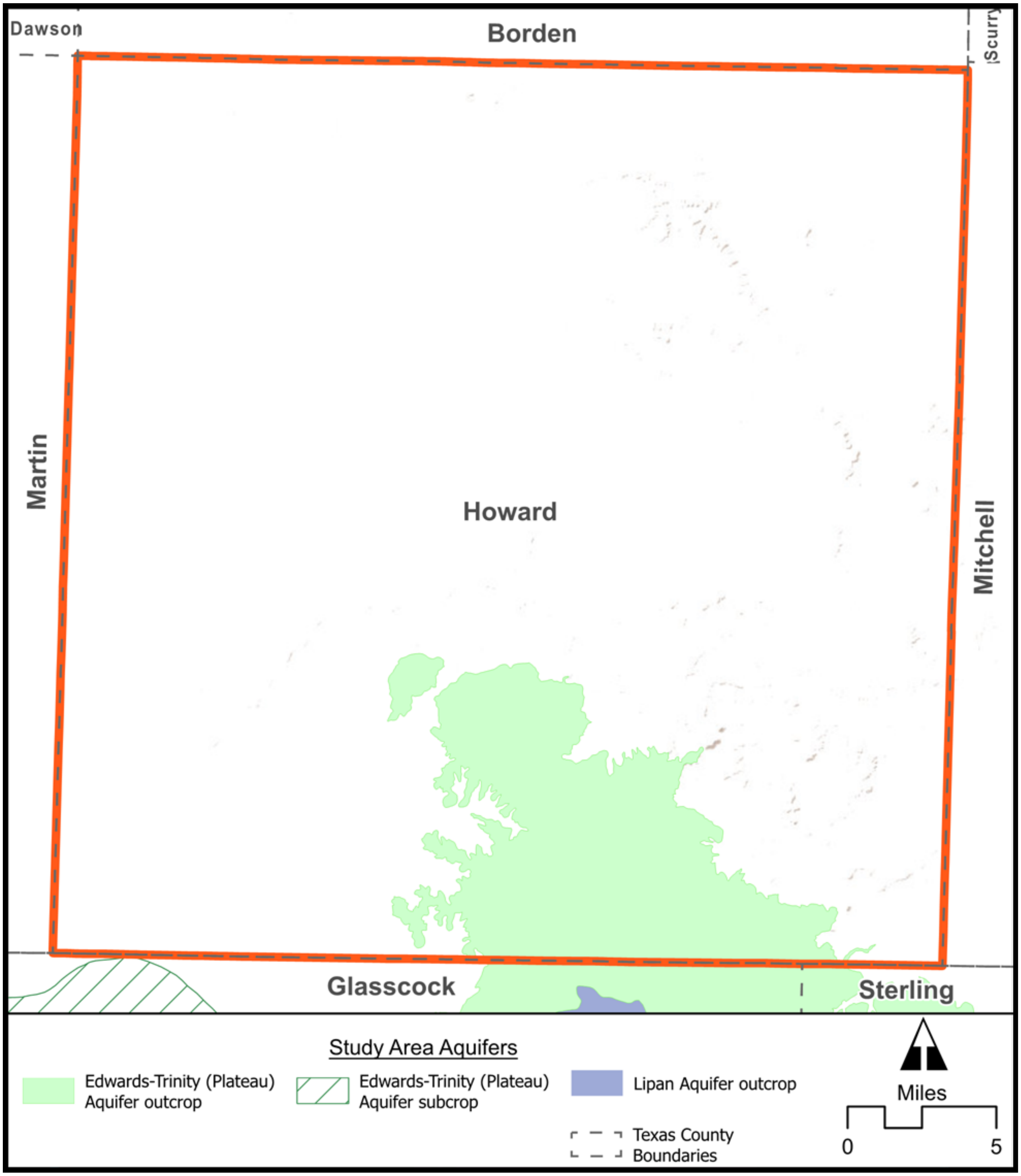


Figure 145. Howard County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

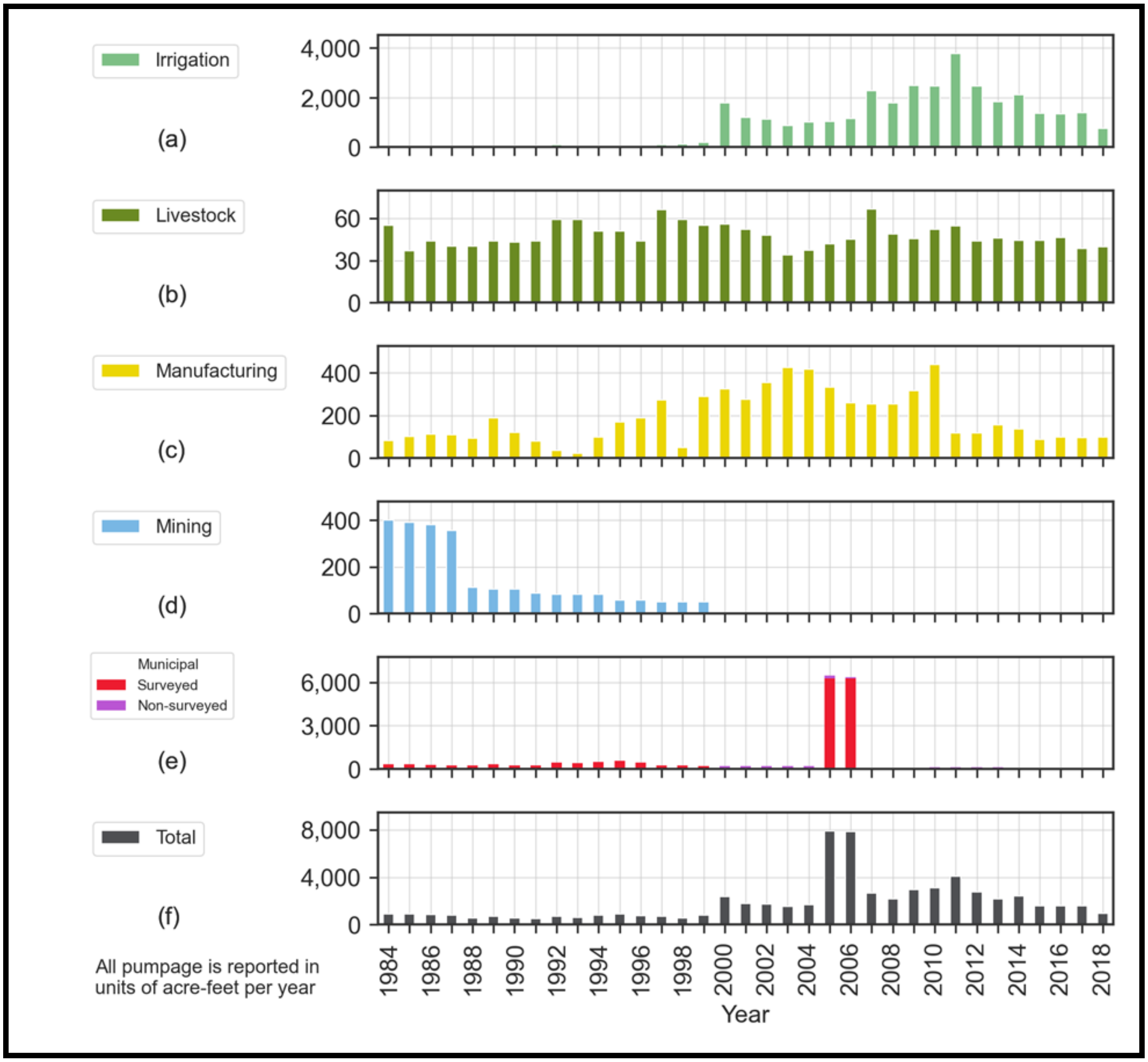


Figure 146. Howard County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

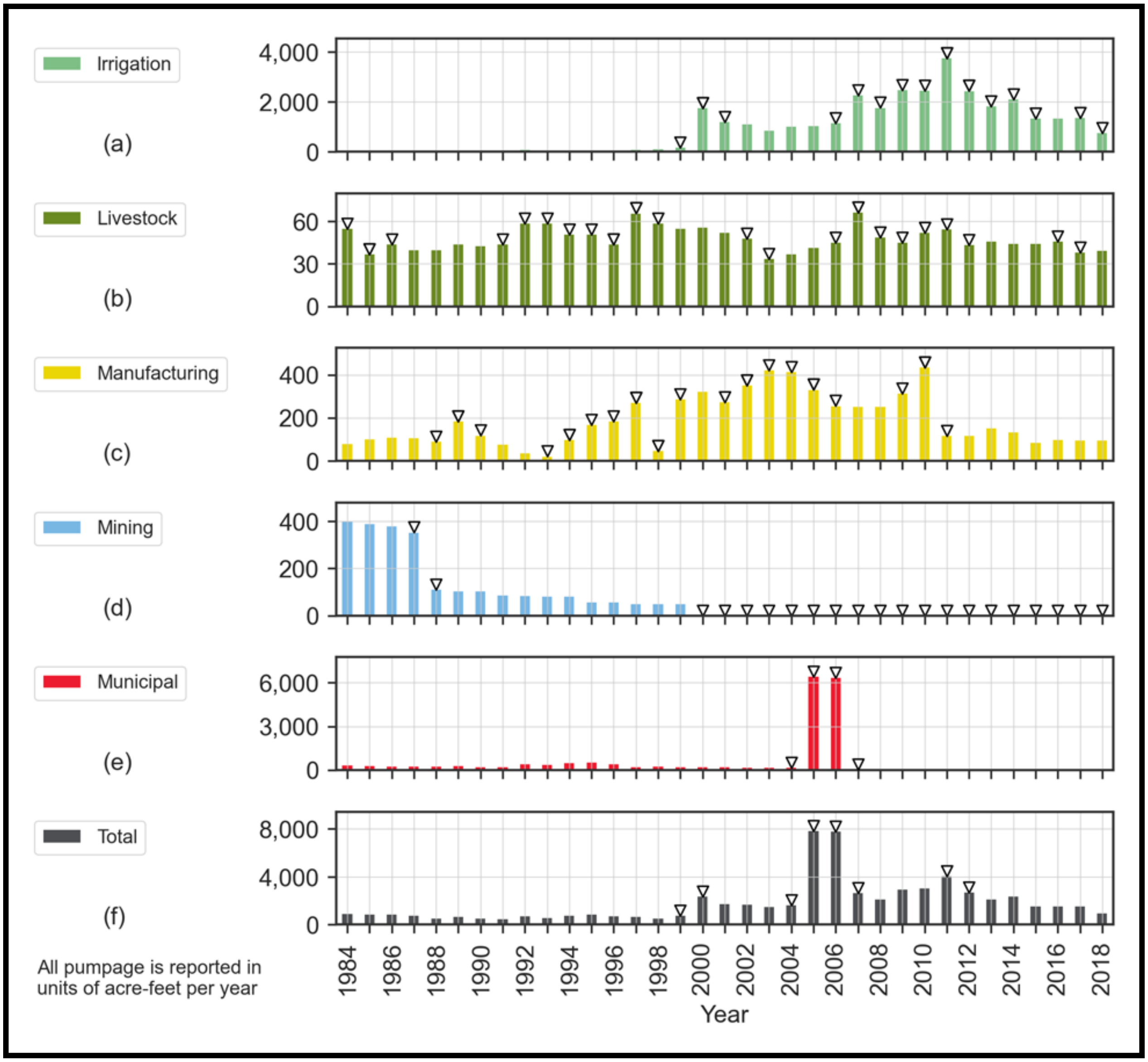


Figure 147. Howard County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

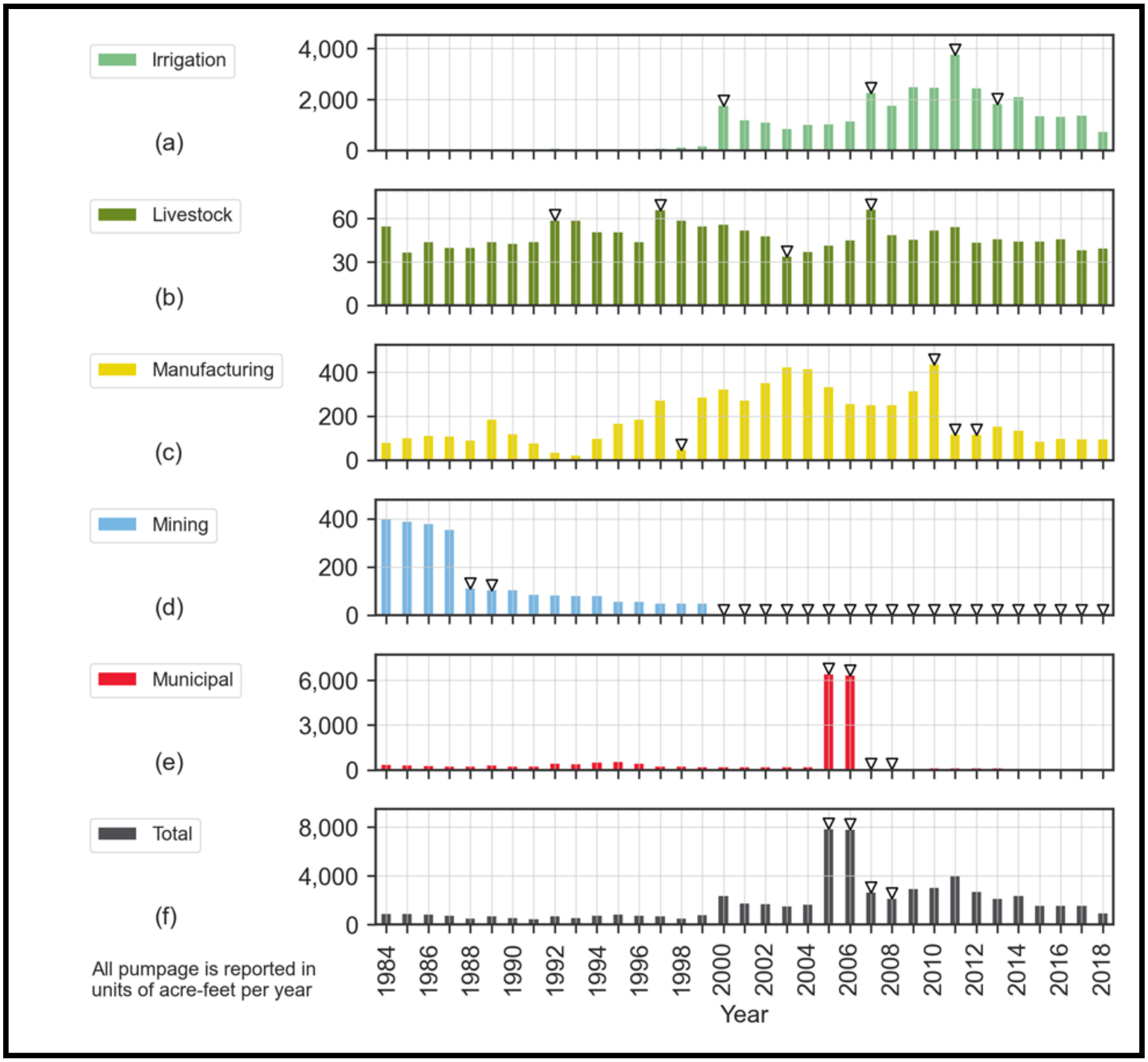


Figure 148. Howard County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 29. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Howard County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1984-1999	2000, 2001, 2007, 2009, 2011-2013, 2015, 2018	2000, 2007, 2011, 2013
	Livestock	None	1984-1986, 1992, 1994, 1996-1998, 2003, 2007, 2008, 2010, 2012, 2017	1992, 1997, 2003, 2007
	Manufacturing	1998, 2011	1989, 1990, 1994, 1995, 1997-1999, 2002, 2003, 2005, 2006, 2010, 2011	1998, 2010-2012
	Mining	1998, 2000-2018	1988, 2000-2018	1988, 1989, 2000-2018
	Municipal	2005-2006	2005, 2007	2005-2008

3.3.22 Irion County

The Edwards-Trinity (Plateau) Aquifer is present over most of Irion County, covering about 86 percent of the county area. The remaining 14 percent of the county overlies portions of the Lipan Aquifer. Figure 149 illustrates the extent of the study area aquifers in Irion County.

The TWDB Water Use Survey dataset did not contain records of any pumping from the Lipan Aquifer within Irion County. However, the TWDB Water Use Survey database does report pumping from an “Other” aquifer for municipal use. We suspect this “Other” aquifer is occurring from the Lipan Aquifer in the county, will investigate if pumping should be included for the aquifer in subsequent project phases.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the total pumping from the Edwards-Trinity (Plateau) Aquifer in Irion County exceeded 1,000 acre-feet per year from 1990 through 1993 and then again in 2000. (Figure 150). As shown on Figure 150, reported pumpage is for irrigation, livestock, manufacturing, mining, and municipal use, with irrigation pumpage often exceeding pumpage for all other uses. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounted for a significant portion of the total municipal water use from the Edwards-Trinity (Plateau) Aquifer in Irion County. Manual review of Figure 150 suggest various anomalies in irrigation use and manufacturing use, with generally steady temporal trends evident within the livestock and municipal use datasets.

The year-to-year change analysis (Figure 151) and standard deviation analysis (Figure 152) flagged several anomalies in the data for the Edwards-Trinity (Plateau) Aquifer for Irion County. One such identified anomaly was from the irrigation dataset, where data is missing for the period from 1994 through 1999. Available irrigation data from before and after this period suggest that up to 800 acre-feet per year of pumpage for irrigation may have occurred during that period. Table 30 provides the years identified as having anomalous pumping amounts for Irion County from the Edwards-Trinity (Plateau) Aquifer.

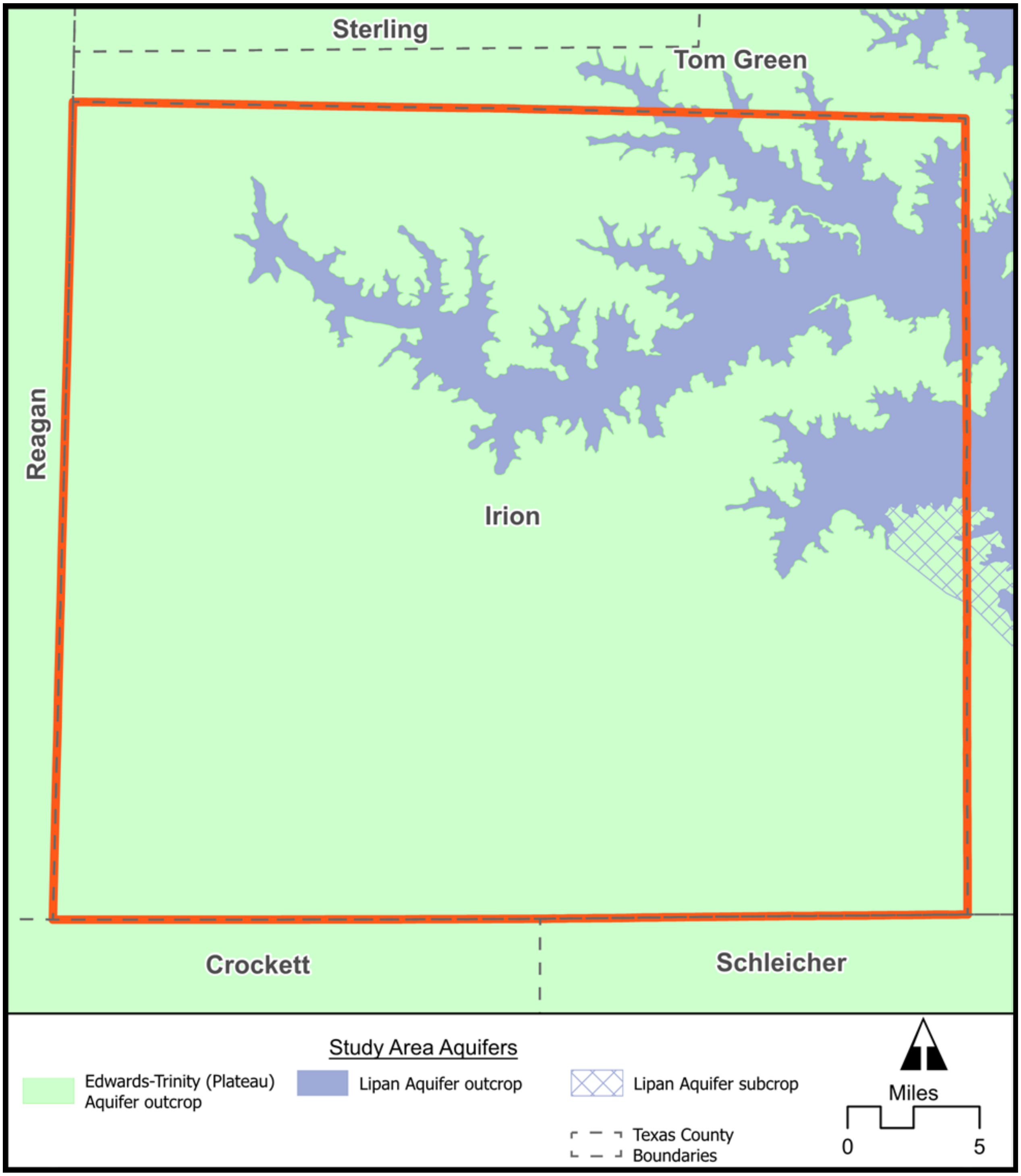


Figure 149. Irion County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

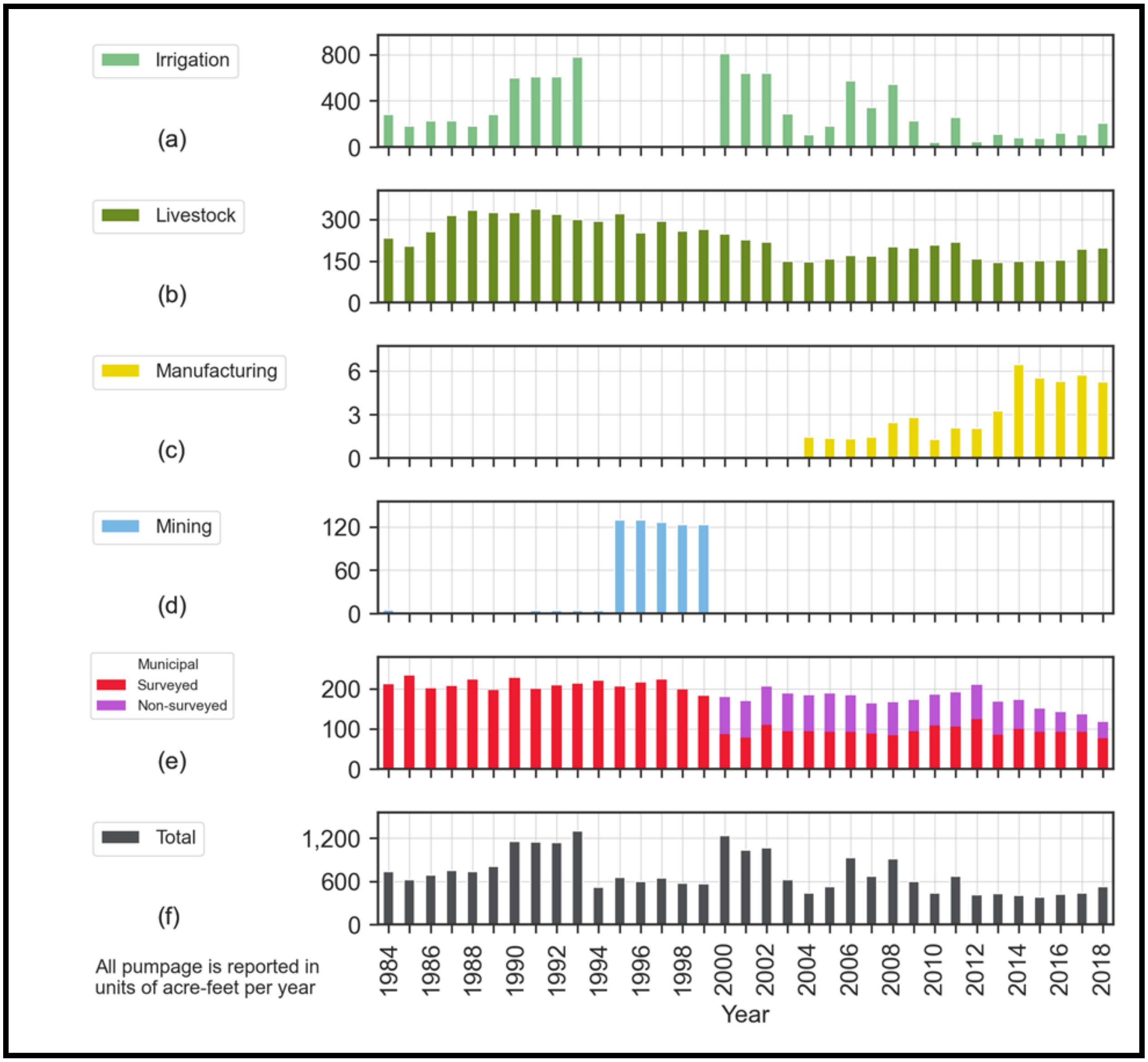


Figure 150. Irion County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

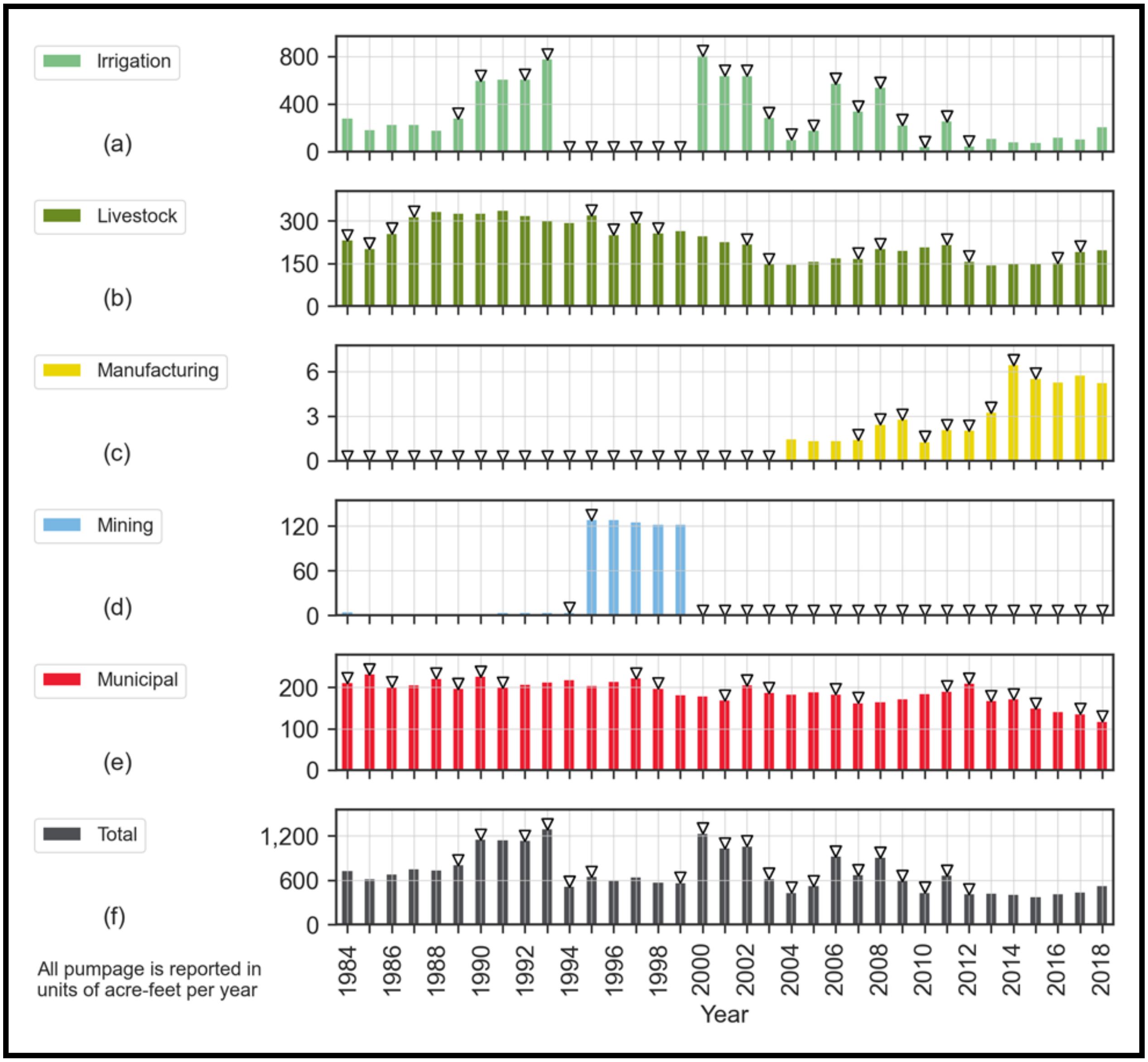


Figure 151. Irion County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

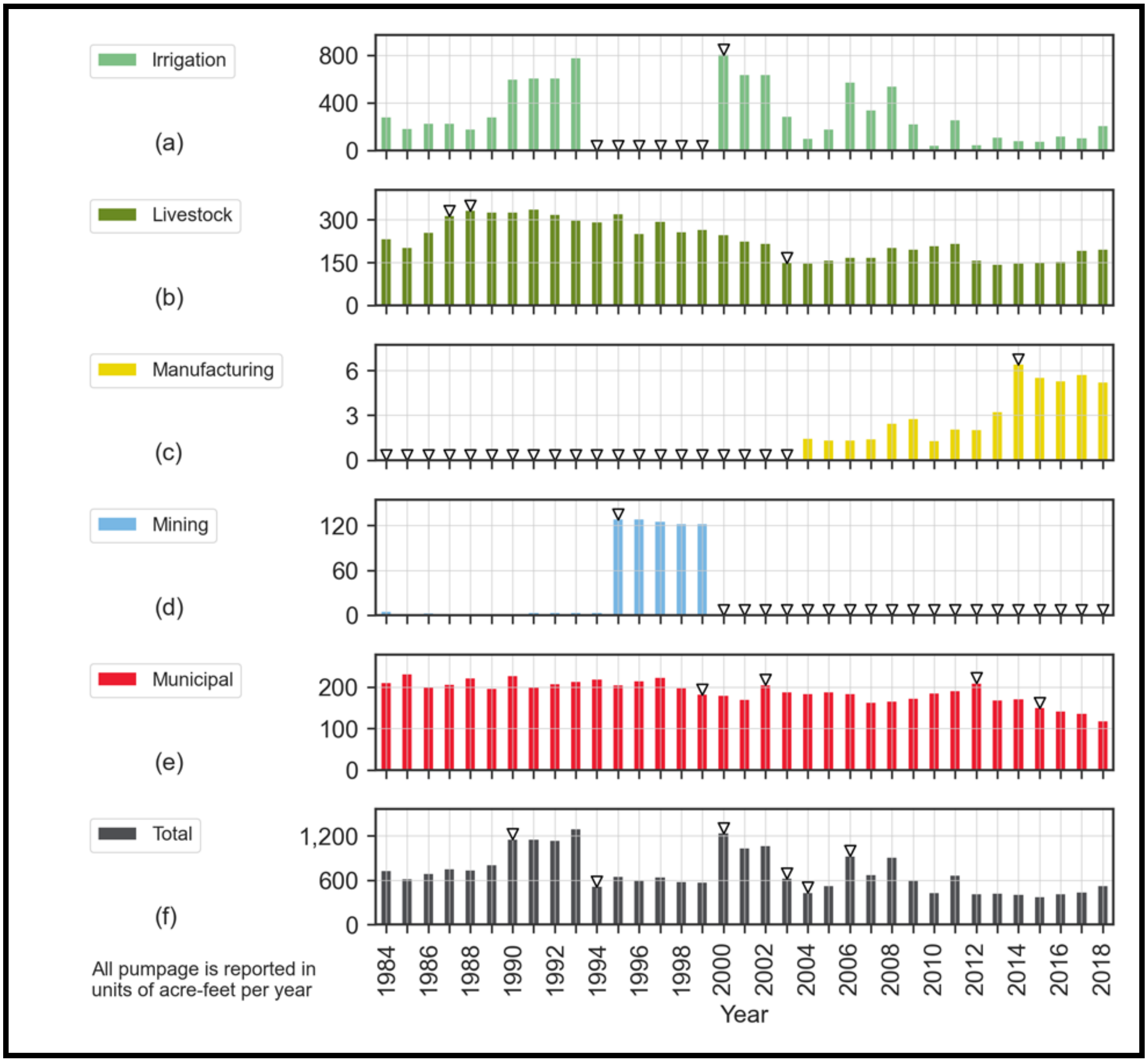


Figure 152. Irion County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 30. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Irion County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1994-1999	1990, 1993-2001, 2003, 2004, 2006-2012	1994-2000
	Livestock	None	1984-1987, 1996-1998, 2003, 2008, 2012, 2017	1987, 1988, 2003
	Manufacturing	1984-2003	1984-2004, 2008, 2010, 2011, 2013-2015	1984-2003, 2014
	Mining	1995-1999	1995, 2000-2018	1995, 2000-2018
	Municipal	None	1984-1986, 1989-1991, 1998, 2002, 2003, 2007, 2012, 2013, 2015, 2018	1999, 2002, 2012, 2015

3.3.23 Jeff Davis County

The Edwards-Trinity (Plateau) Aquifer underlies about 25 percent of Jeff Davis County (see Figure 153). Only a small portion of the Pecos Valley aquifer is present in the northeastern portion of the county with little pumping from the aquifer (

Figure 154). Municipal use is the only reported pumpage of groundwater from the Pecos Valley Aquifer in Jeff Davis County and there are few anomalies (Figure 155 and Figure 156).

Pumping from the Edwards-Trinity (Plateau) in Jeff Davis County is primarily for municipal use at approximately 200-300 acre-feet per year (Figure 157). The remaining reported groundwater use is for irrigation and livestock (both up to 125 acre-feet per year). We observed a few anomalies in the Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Jeff Davis County (Figure 158 and Figure 159). For example, on Figure 159 where livestock pumping abruptly decreased from about 75 acre-feet in 2003 to less than 25 acre-feet in 2004. Similarly, we noted an anomaly with the municipal use in 2010 when the reported pumping abruptly increased to nearly 600 acre-feet from a previously reported 100 acre-feet in 2009.

Table 31 provides the years identified as having anomalous pumping amounts for Jeff Davis County based on our manual review, year-to-year change (Figure 155 and Figure 158), and standard deviation (Figure 156 and Figure 159) analyses.

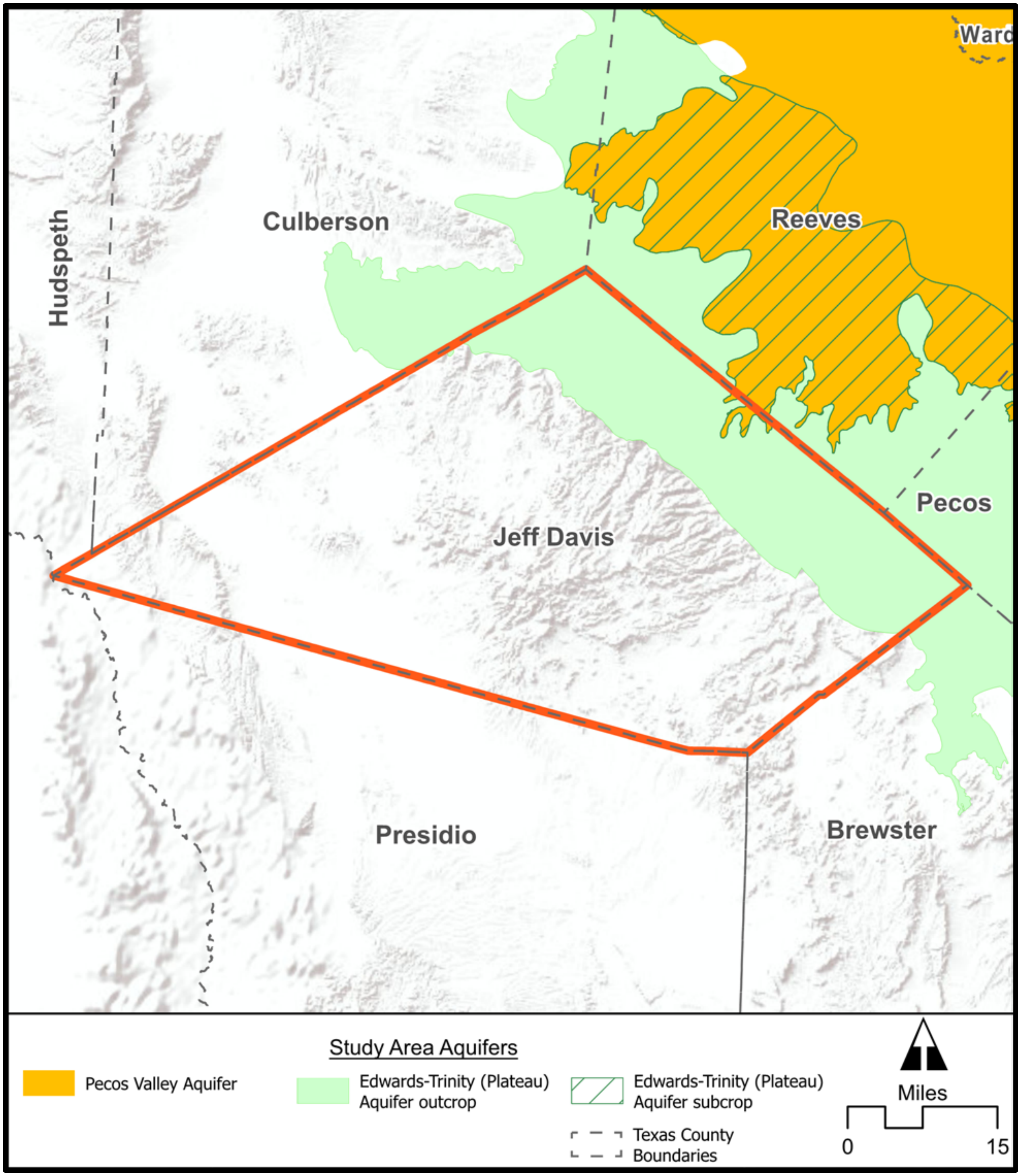


Figure 153. Jeff Davis County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer.

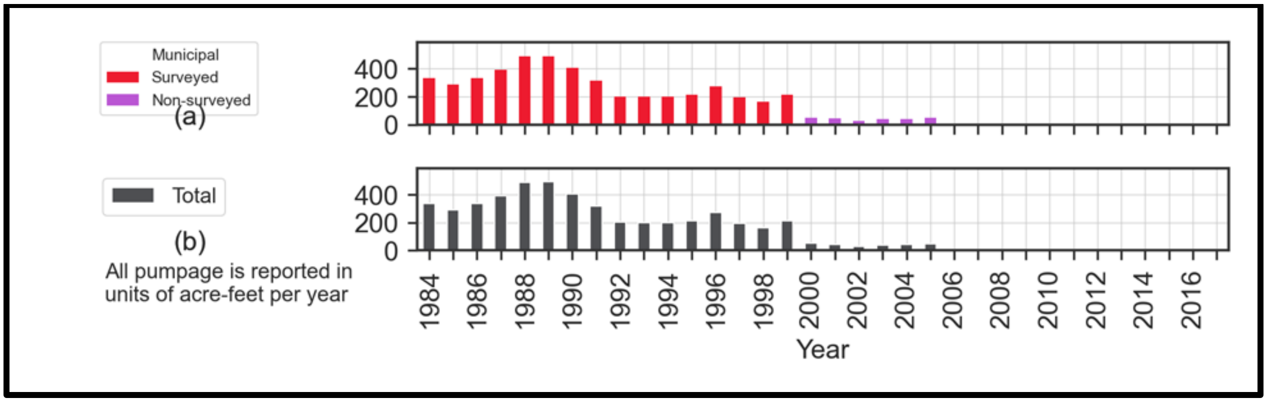


Figure 154. **Jeff Davis County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

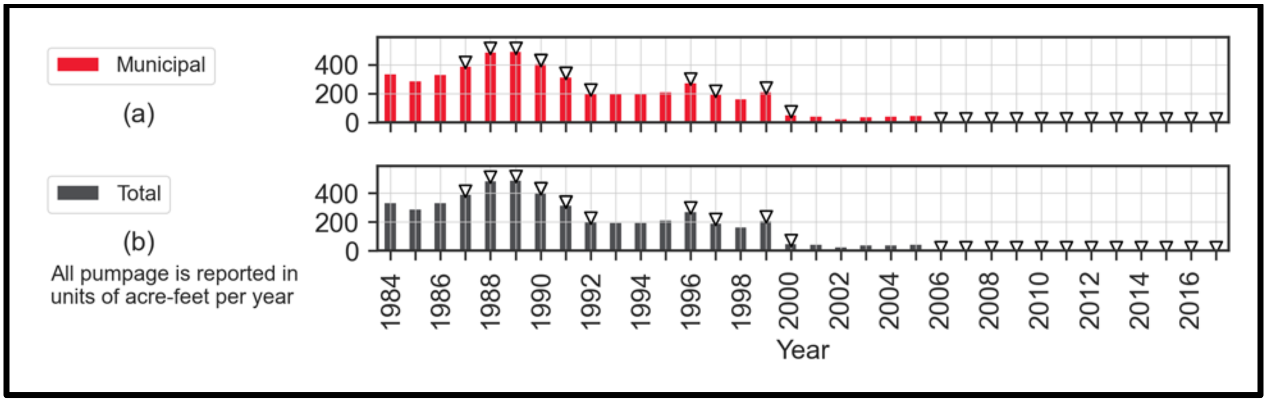


Figure 155. **Jeff Davis County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

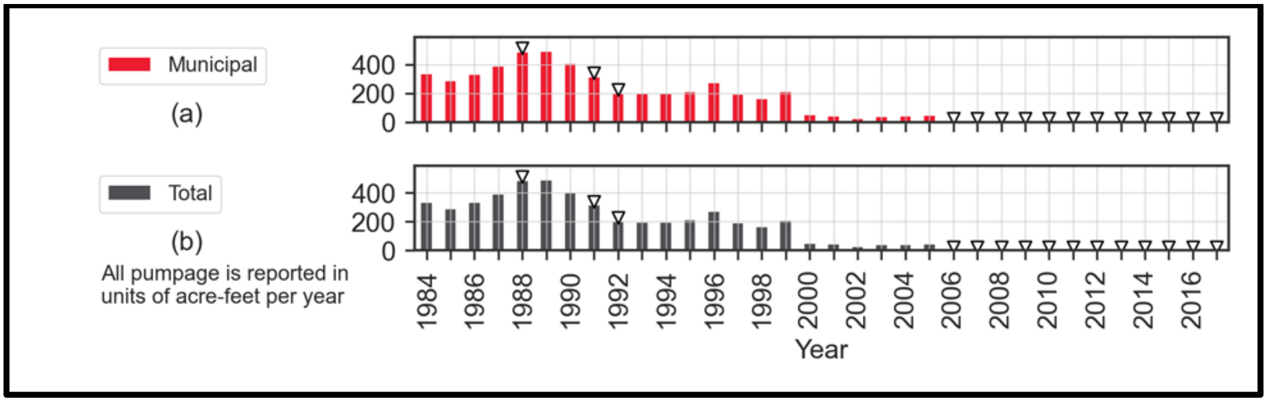


Figure 156. **Jeff Davis County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

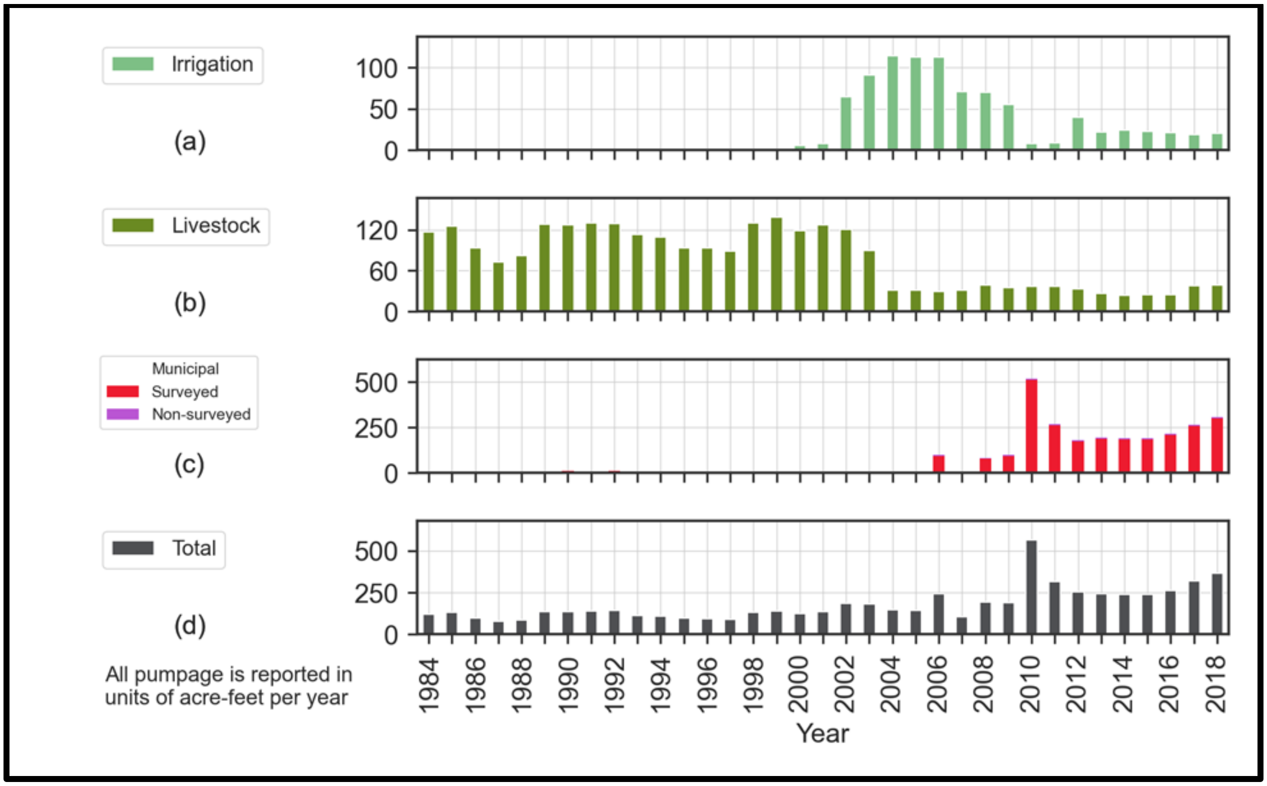


Figure 157. Jeff Davis County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

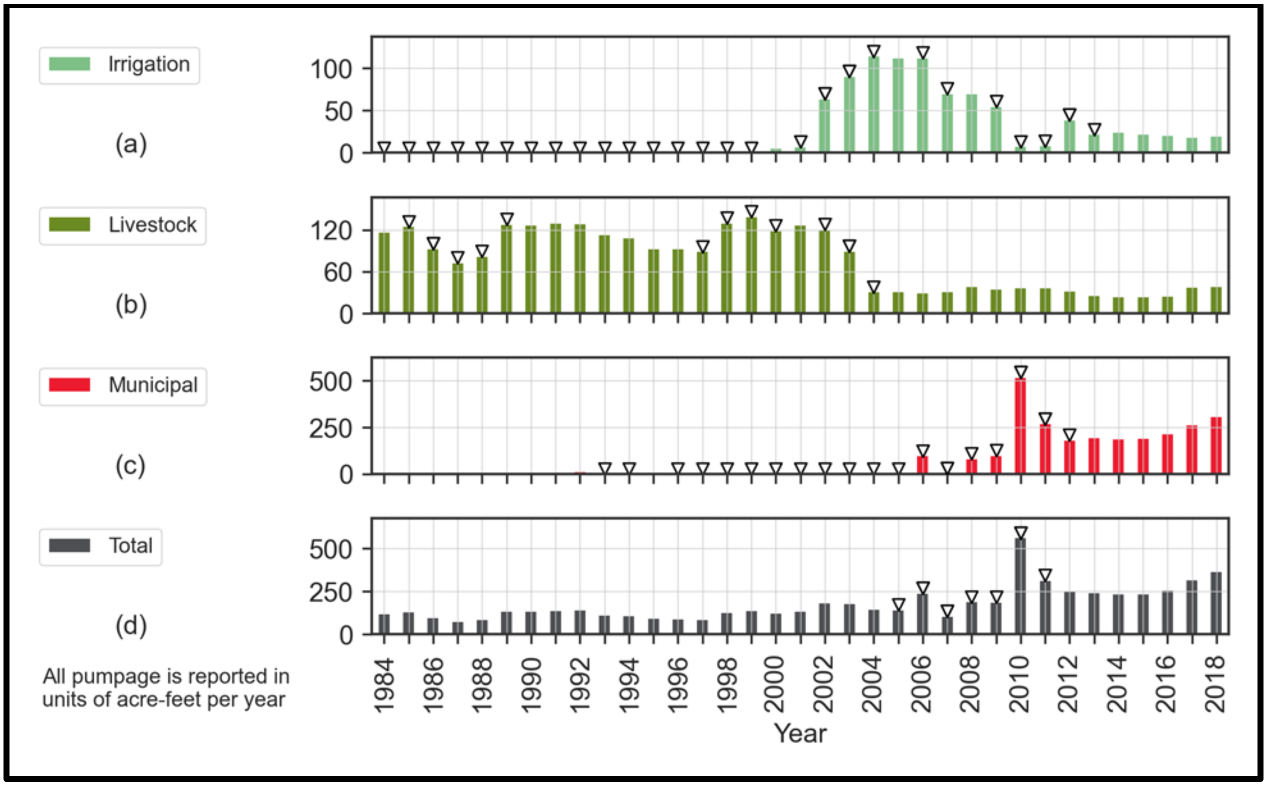


Figure 158. Jeff Davis County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

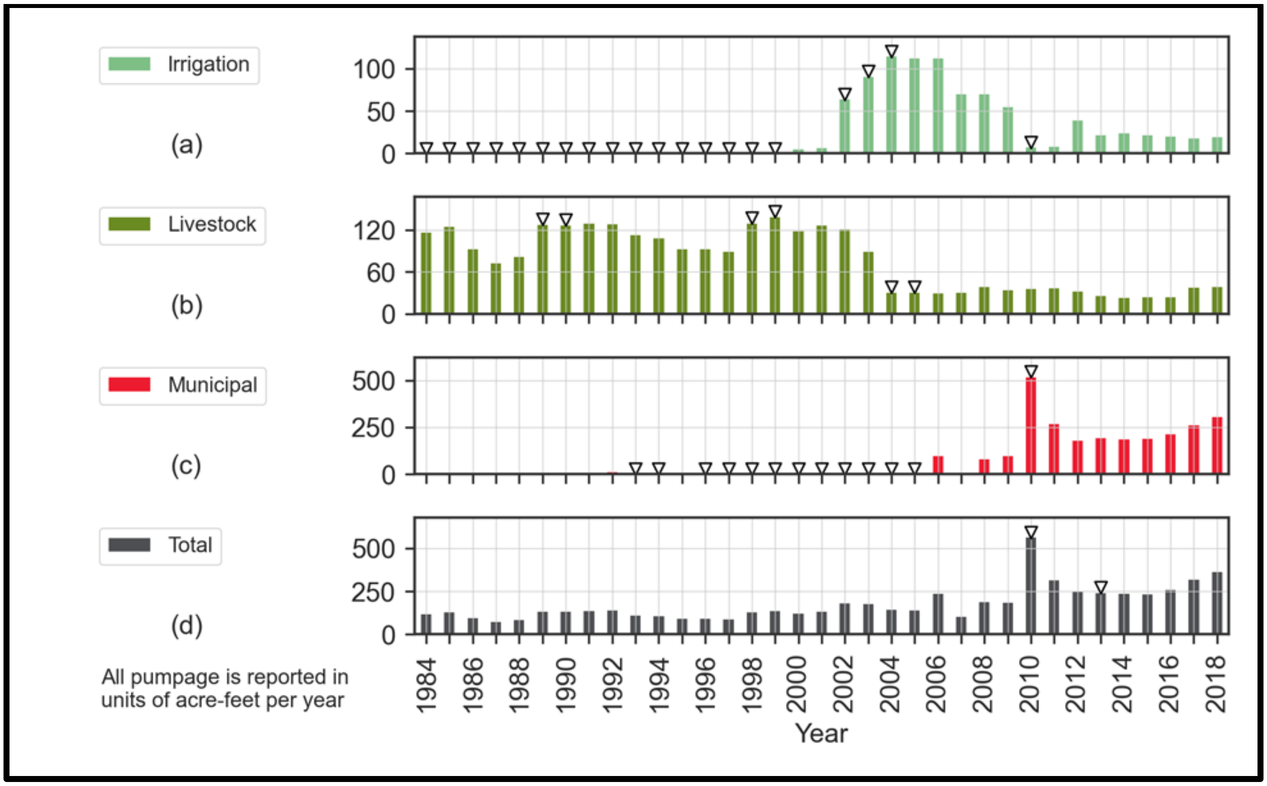


Figure 159. Jeff Davis County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 31. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Jeff Davis County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1984-1999	1984-1999, 2002-2004, 2007, 2010, 2012, 2013	1984-1999, 2002-2004, 2010
	Livestock	2004	1986, 1987, 1989, 1998, 2000, 2003, 2004	1989, 1990, 1998, 1999, 2004, 2005
	Municipal	1984-2005, 2007, 2010	1993, 1994, 1996-2008, 2010-2012, 1988, 1990-1992, 1997, 2000	1993, 1994, 1996-2005, 2010, 1988, 1992
Pecos Valley	Municipal	2000	1988, 1990-1992, 1997, 2000	1988, 1992

3.3.24 Kendall County

The Edwards-Trinity (Plateau) Aquifer is present in the northern portion of Kendall County covering about 14 percent of the county area. The Trinity (Hill Country) Aquifer is present the remaining 86 percent of Kendall County. Figure 160 illustrates the extent of the study area aquifers in the county, showing that all of Kendall County is included within the study area.

Groundwater pumping estimates from the TWDB Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer in Kendall County was approximately 80 acre-feet per year (Figure 161). As shown on Figure 161, livestock and municipal uses are the only reported uses of groundwater from the Edwards-Trinity (Plateau) Aquifer within Kendall County. Manual review of Figure 161 suggests that reported livestock usage in 2008 and 2009 may be anomalous, as is the change in municipal usage that occurred between 2005 and 2006. Since 2006, non-surveyed municipal use accounts for almost all municipal water use from the Edwards-Trinity (Plateau) Aquifer in Kendall County. It is also notable that the TWDB Water Use Survey database does not contain reported pumpage values for Kendall County for years prior to 2000. We consider this to be anomalous and worthy of further scrutiny under subsequent project tasks.

The year-to-year change analysis (Figure 162) and standard deviation analysis (Figure 163) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer in Kendall County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Trinity (Hill Country) Aquifer was approximately 5,000 acre-feet per year (Figure 164) in Kendall County. As shown on Figure 164, irrigation, livestock, manufacturing, mining, and municipal uses are the reported uses of groundwater from the Trinity (Hill Country) Aquifer, with the majority of pumpage being for municipal uses. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, it accounts for a significant portion of the municipal water use from the Trinity (Hill Country) in Kendall County.

The year-to-year change analysis (Figure 165) and standard deviation analysis (Figure 166) flagged many anomalies in the data for the Trinity (Hill Country) Aquifer in Kendall County. Within the irrigation dataset, our analyses indicate several anomalies including multiple periods of abrupt year-to-year changes in reported pumping. Similar changes are evident within the livestock and municipal datasets. Anomalies identified for manufacturing and mining use are primarily due to these datasets missing or having zero pumpage reporting in many years. Table 32 provides the years identified as having anomalous pumping amounts for Kendall County from the Edwards-Trinity (Plateau) Aquifer and from the Trinity (Hill Country) Aquifer.

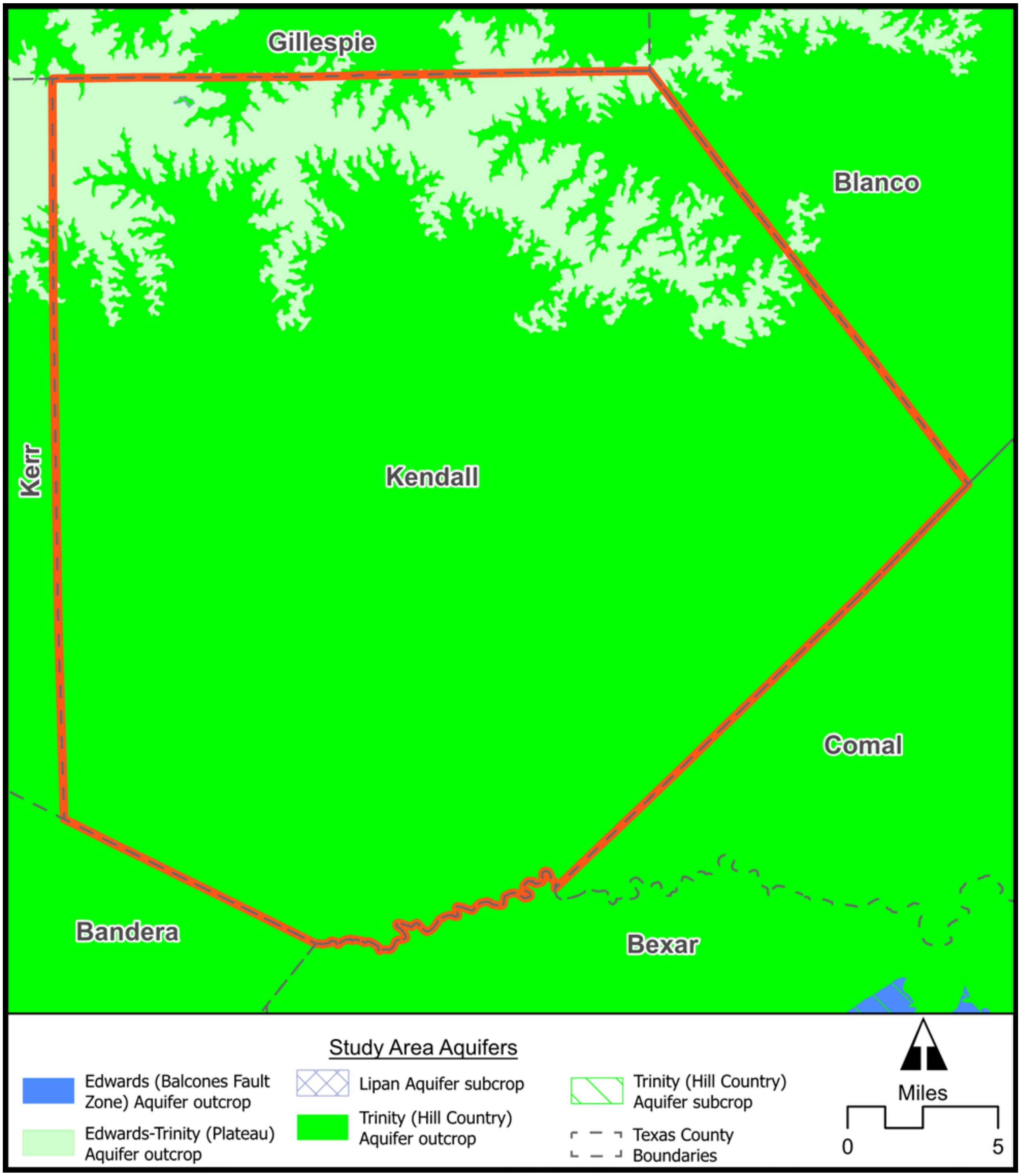


Figure 160. **Kendall County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer.**

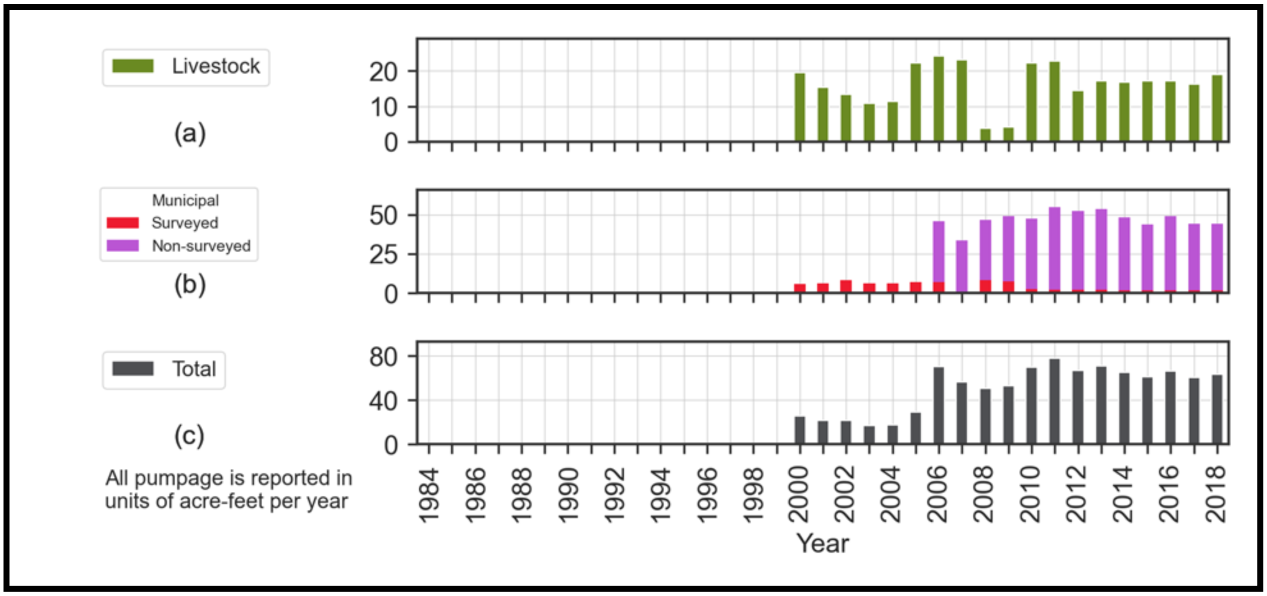


Figure 161. Kendall County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

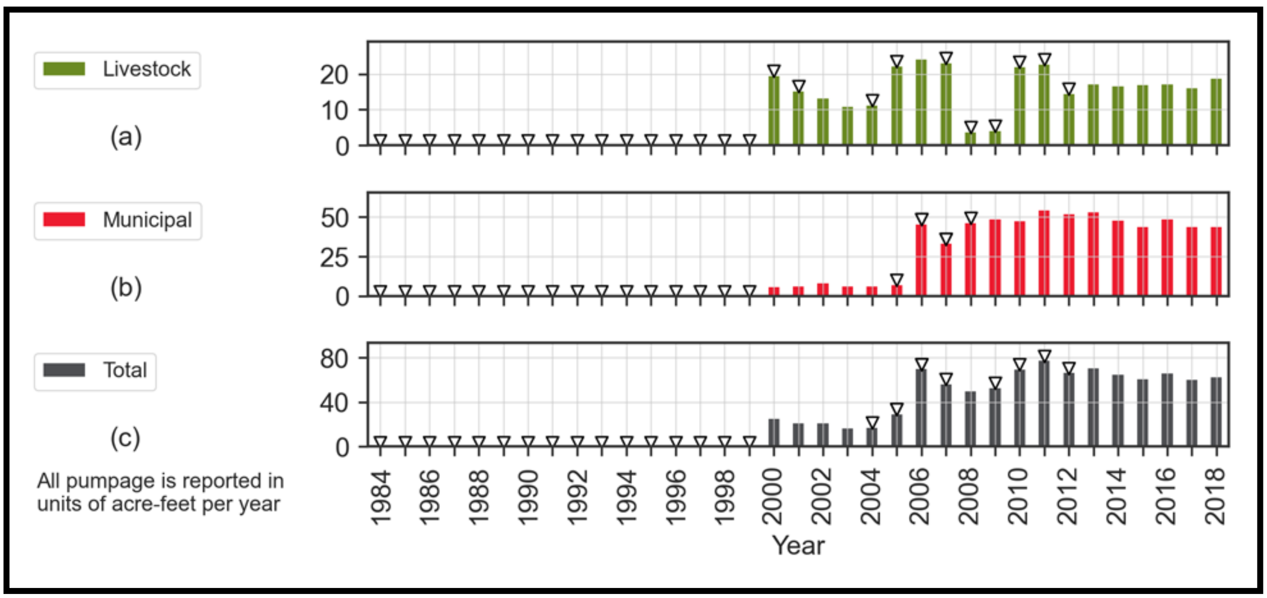


Figure 162. Kendall County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

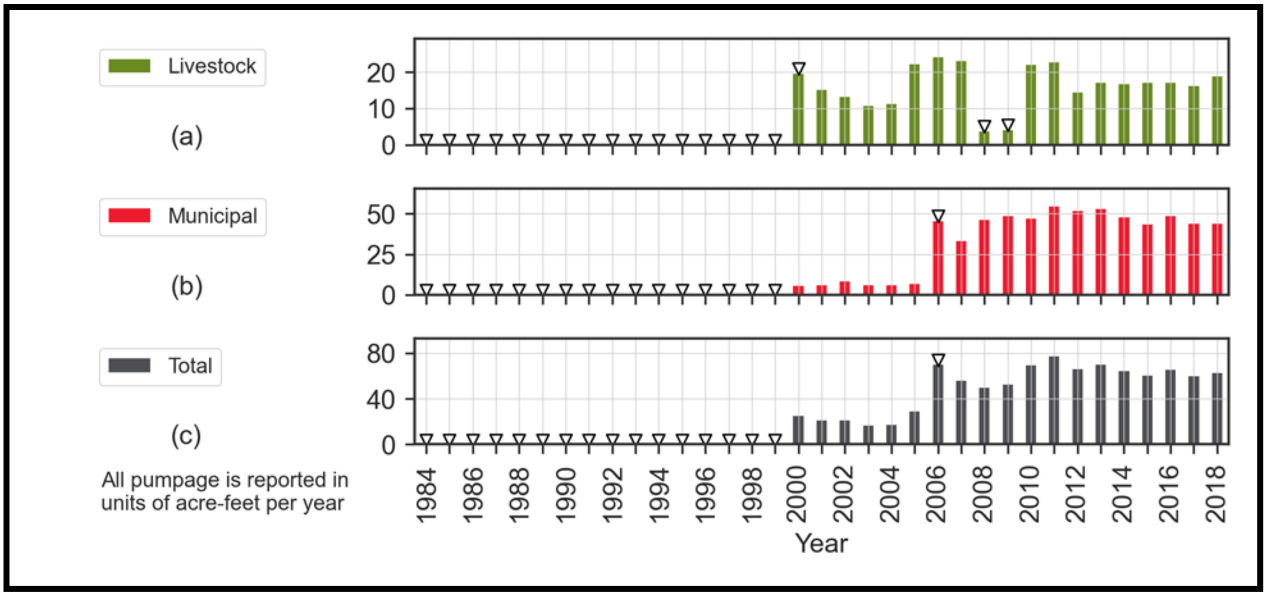


Figure 163. Kendall County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

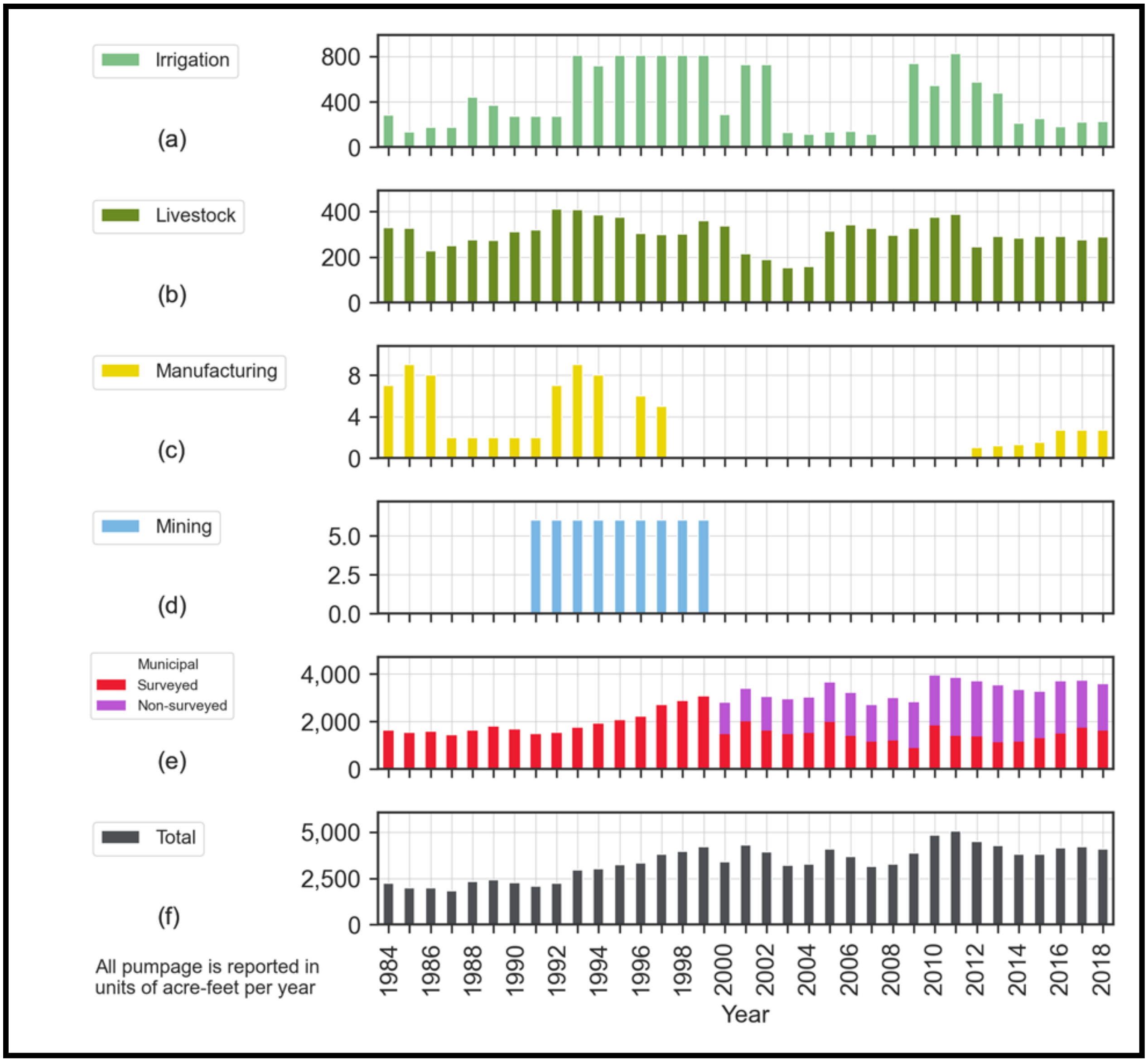


Figure 164. **Kendall County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

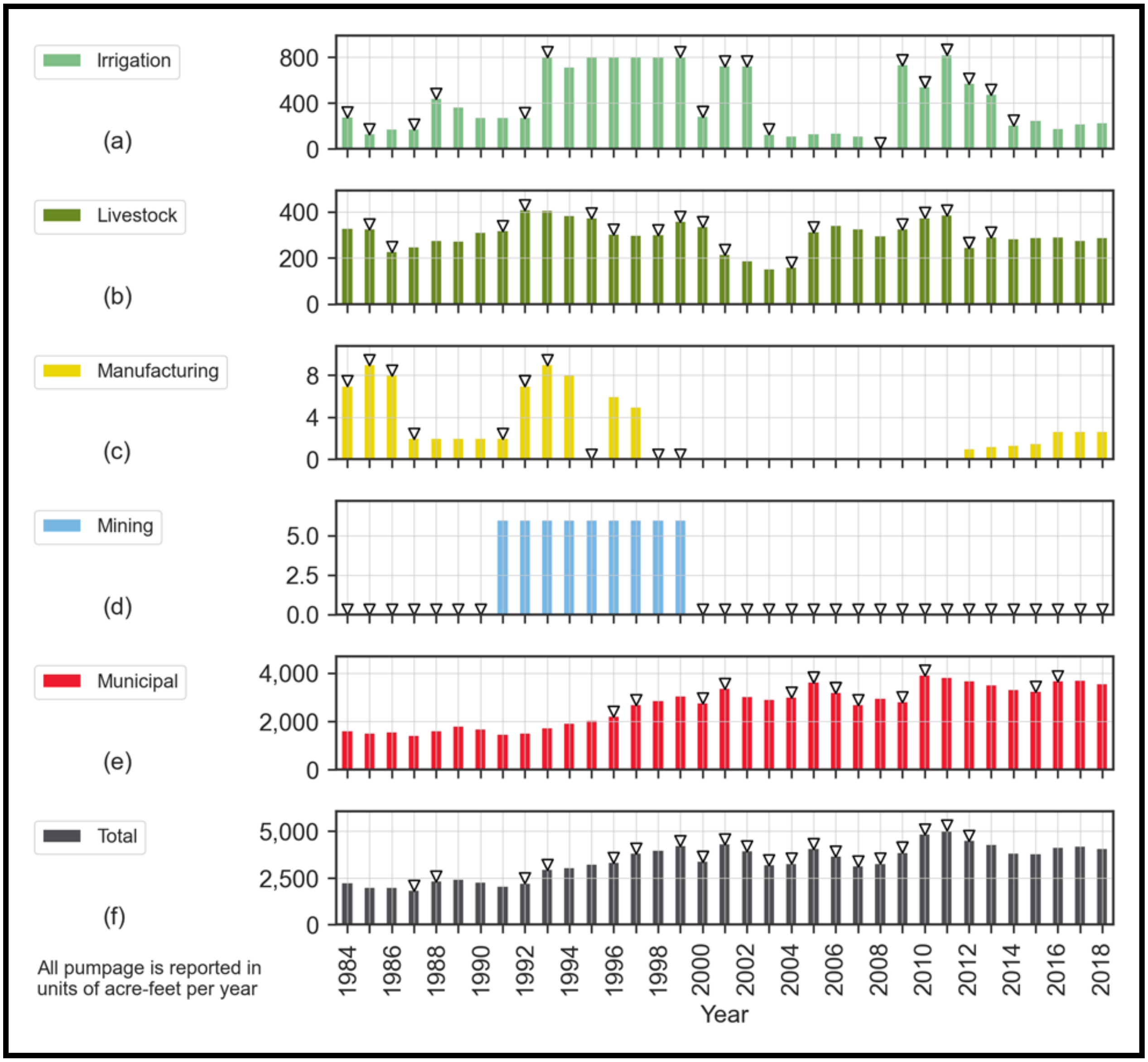


Figure 165. Kendall County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

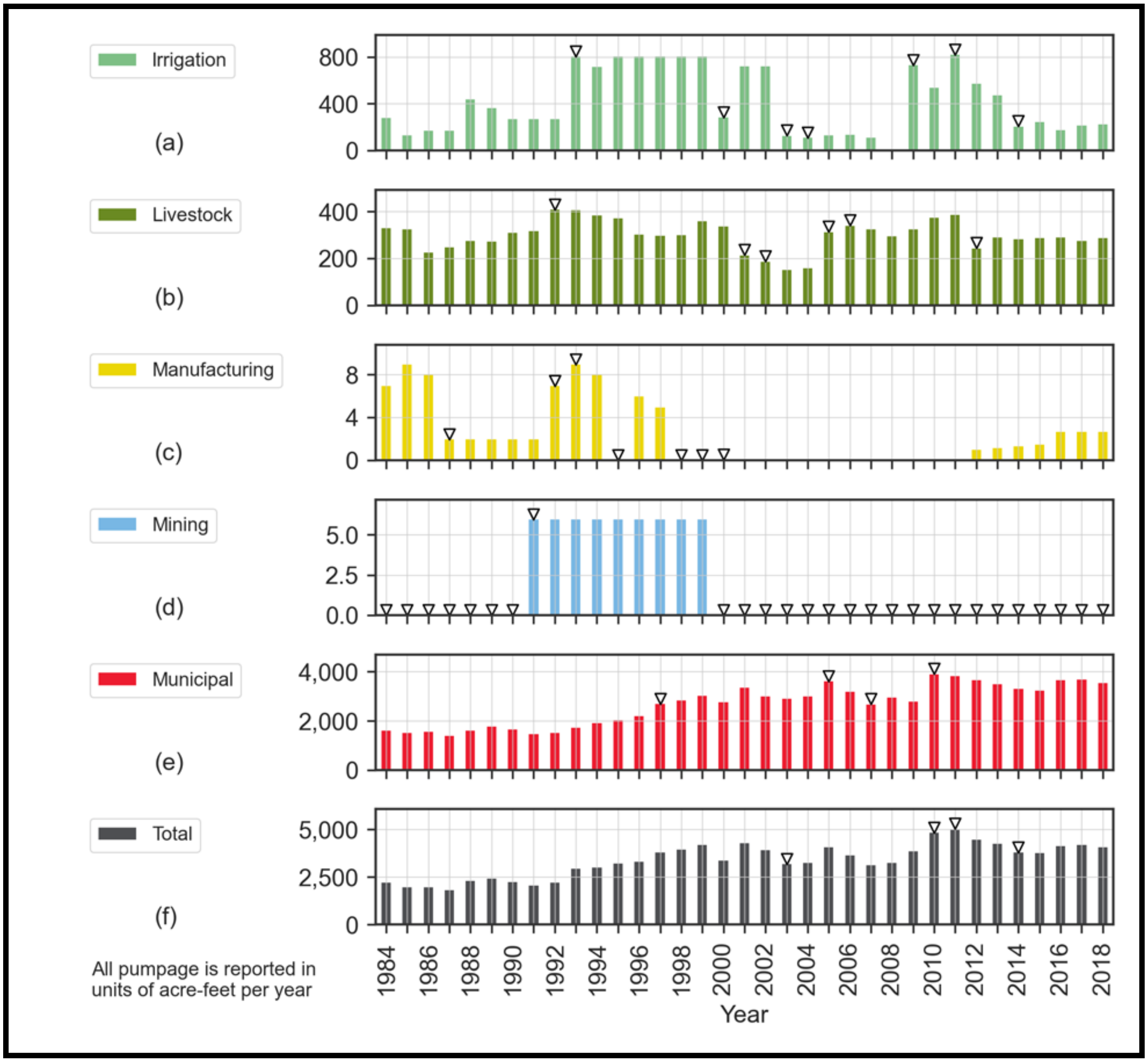


Figure 166. Kendall County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 32. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Kendall County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	1984-1999, 2008, 2009	2000, 2001, 2005, 2008, 2010, 2012	2008, 2009, 2011
	Municipal	2000, 2006	2006-2008	2006
Trinity (Hill Country)	Irrigation	1993, 2000, 2003-2008	1984, 1985, 1988, 1993, 2000, 2001, 2003, 2009-2012, 2014	1993, 2000, 2003, 2004, 2009, 2011, 2014
	Livestock	None	1986, 1992, 1996, 1999, 2001, 2005, 2010, 2012, 2013	1992, 2001, 2002, 2005, 2006, 2012
	Manufacturing	1995, 1998-2011	1984, 1985, 1987, 1992, 1993, 1995, 1996, 1998, 1999	1987, 1992, 1993, 1995, 1998-2000
	Mining	1984-1990, 200-2018	1984-1990, 2000-2018	1984-1991, 2000-2018
	Municipal	2010	1997, 2001, 2005-2007, 2010, 2016	1997, 2005, 2007, 2010

3.3.25 Kerr County

The Edwards-Trinity (Plateau) Aquifer is present in the western portion of Kerr County and covers about 75 percent of the county area. The eastern portion of Kerr County, consisting of about 25 percent of the county area, is underlain by the Trinity (Hill Country) Aquifer. Figure 167 illustrates the extent of the study area aquifers in Kerr County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that maximum total pumping from the Edwards-Trinity (Plateau) Aquifer occurred in 2007 and was approximately 1,800 acre-feet (Figure 168). As shown on Figure 168, reported pumpage is for irrigation, livestock, manufacturing, mining, and municipal use categories, with most pumpage after 1999 being for municipal use. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounts for most of the total municipal water use from the Edwards-Trinity (Plateau) Aquifer in Kerr County. Prior to 1999, pumpage for municipal and livestock uses was about equal. Manual review of

Figure 168 suggests anomalies in municipal pumping for 2007 and prior to 2000, as well as for the period from 2001 to 2005 for livestock usage. Irrigation usage for 2015 and 2016 are also anomalous, and the Water Use Survey dataset does not include irrigation data for the period from 1984 through 2009.

The year-to-year change analysis (Figure 169) and standard deviation analysis (Figure 170) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer, including the 2007 high pumpage for municipal use. Results from both analyses largely corroborated annual values flagged during the manual review process.

Potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in Kerr County correlates linearly to groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation use. Figure 171 indicates that as the area of potentially irrigated land over the aquifer increases in the county, so has the reported pumpage for irrigation. Figure 172 indicates a linear correlation value ("*r*") of 0.72 between potentially irrigated land area overlying the aquifer and groundwater pumpage for irrigation. This strong positive correlation suggests that pumpage for irrigation in Kerr County matches the trend in potentially irrigated land. We note, however, that the water usage database does not contain irrigation pumpage for Kerr County from the Edwards-Trinity (Plateau) Aquifer for years prior to 2010. We will re-evaluate this correlation after researching Kerr County irrigation pumpage during subsequent project tasks.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Trinity (Hill Country) Aquifer within Kerr County was approximately 5,000 acre-feet, which occurred in 2014 (Figure 173). As shown on Figure 173, reported pumpage is for irrigation, livestock, manufacturing, mining, and municipal use categories, with the majority of pumping for municipal use. Since 2000, non-surveyed municipal use accounted for a relatively small amount of the total municipal water use from the Trinity (Hill Country) Aquifer in Kerr County. Manual review of Figure 173 suggests numerous anomalies within the irrigation data, anomalies for livestock (1984 and 2005), and anomalies in mining usage (including many years of missing data). While there are year-to-year variations in municipal usage, manual review of that data does not indicate anomalous years.

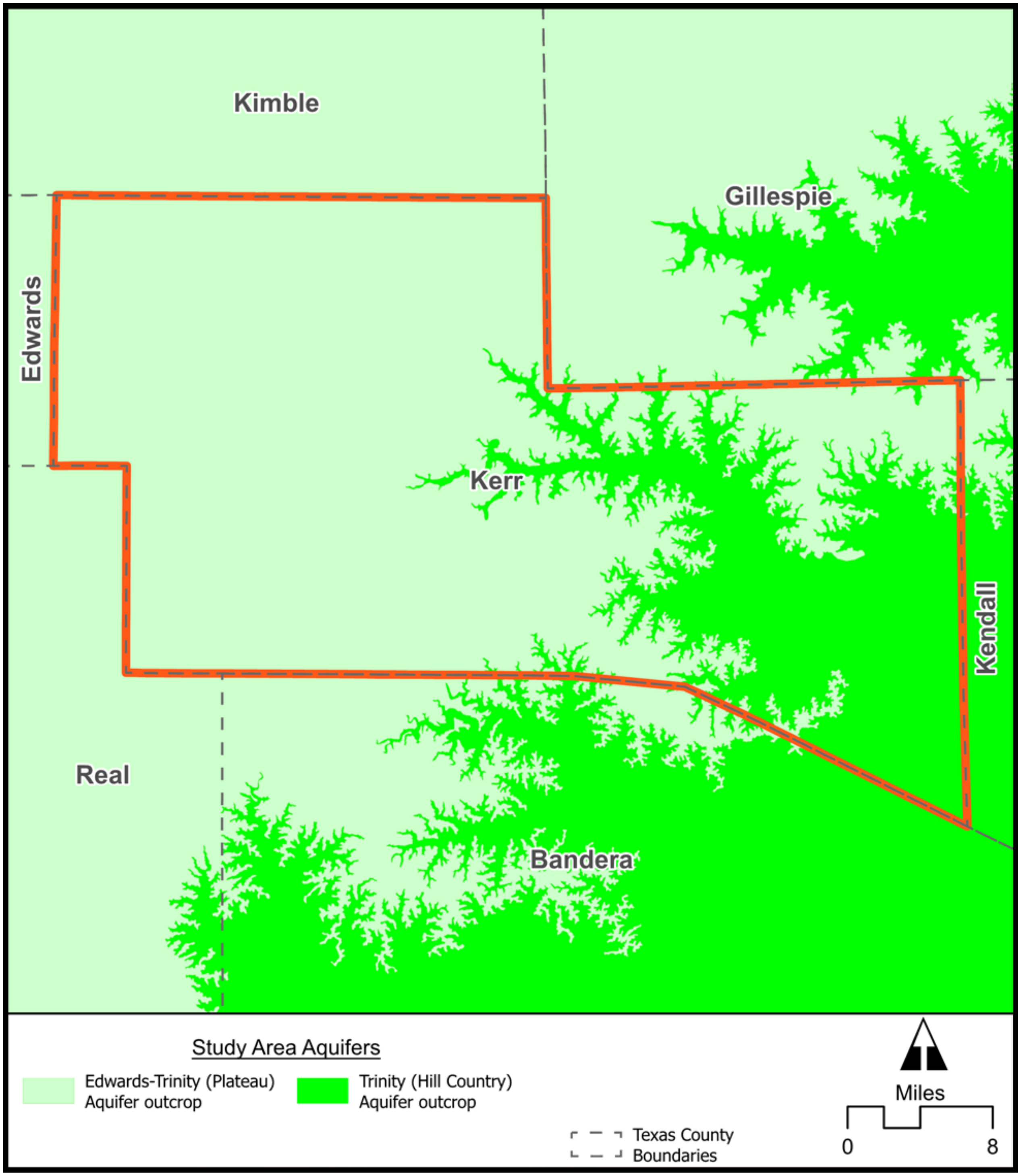


Figure 167. Kerr County showing the extent of the Edwards-Trinity (Plateau) and Trinity (Hill Country) aquifers.

The year-to-year change analysis (Figure 174) and standard deviation analysis (Figure 175) flagged many anomalies in the data for the Trinity (Hill Country) Aquifer, including those identified through manual review. Each method also resulted in numerous flagged years of municipal pumpage, which were not identified through manual review.

Table 33 provides the years identified as having anomalous pumping amounts for Kerr County from the Edwards-Trinity (Plateau) Aquifer and from the Trinity (Hill Country) Aquifer.

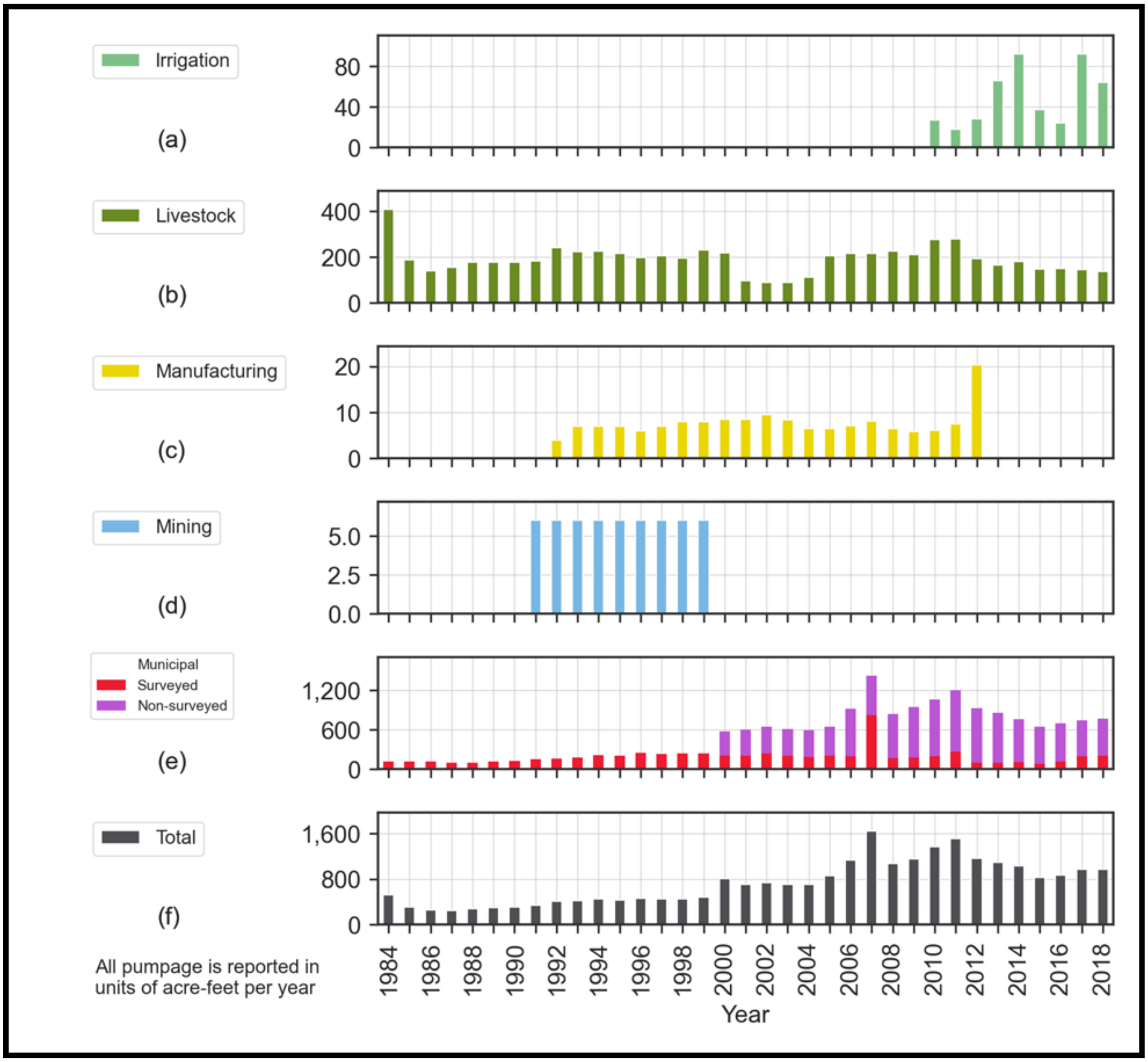


Figure 168. Kerr County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

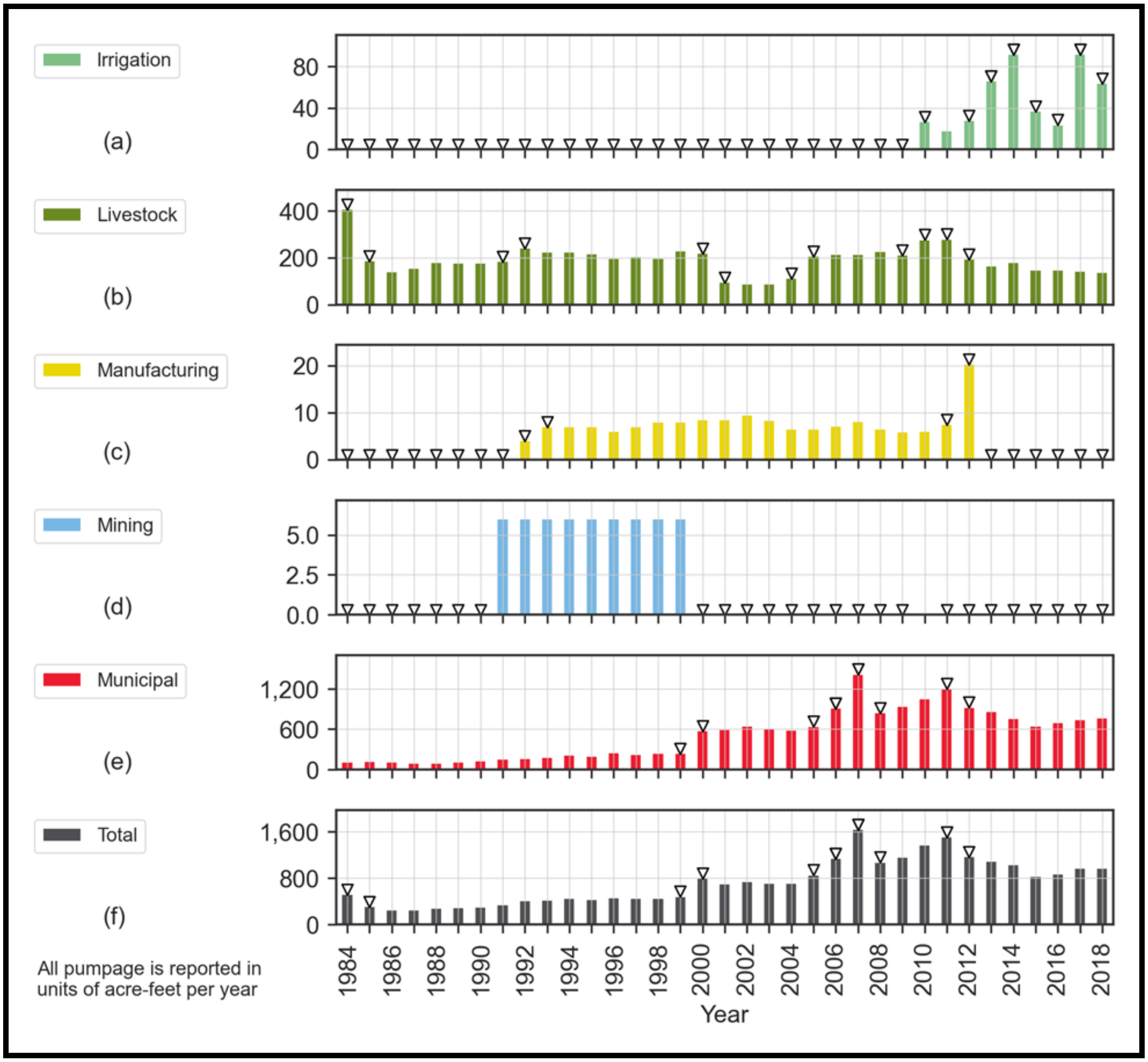


Figure 169. Kerr County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

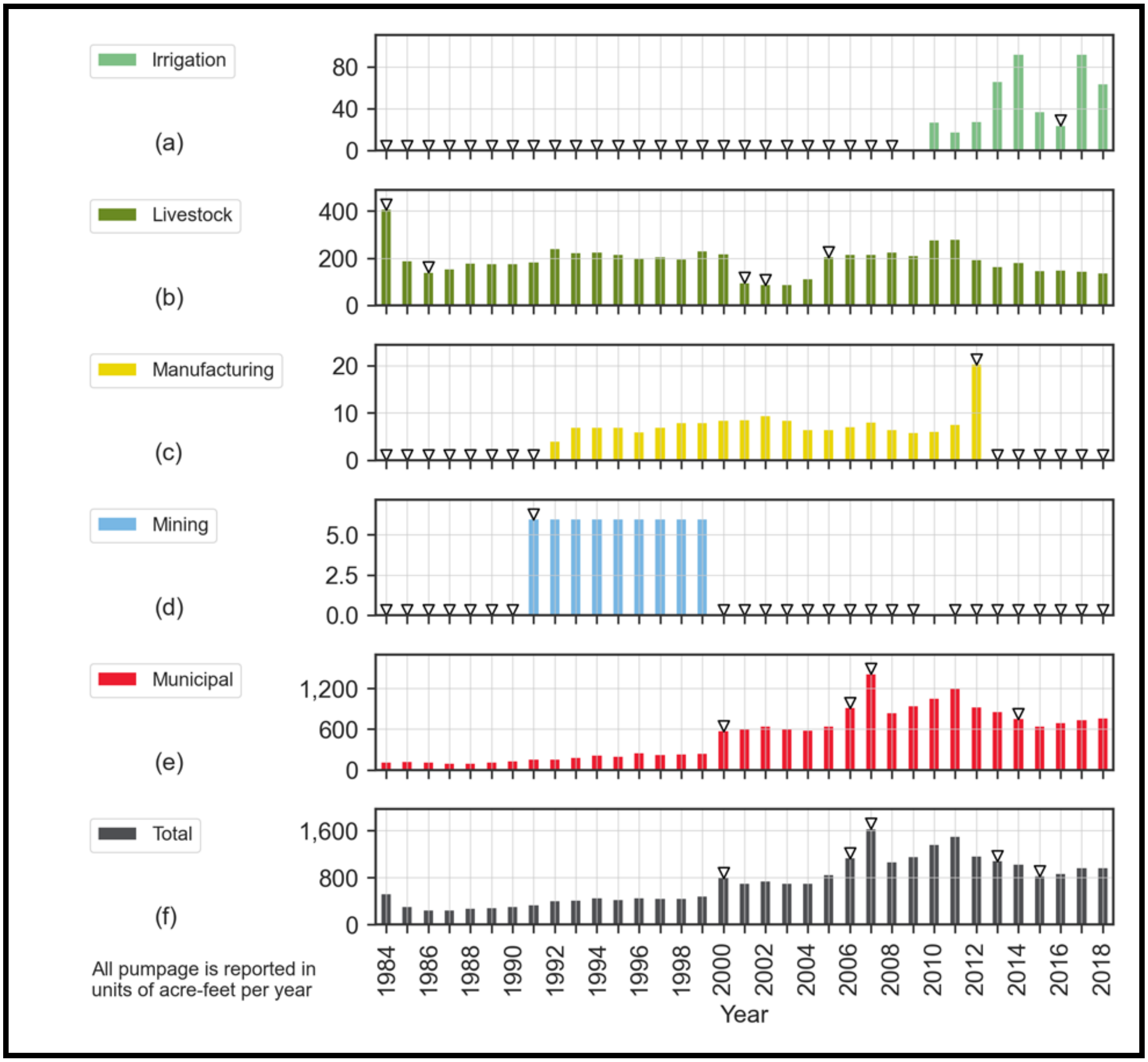


Figure 170. Kerr County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

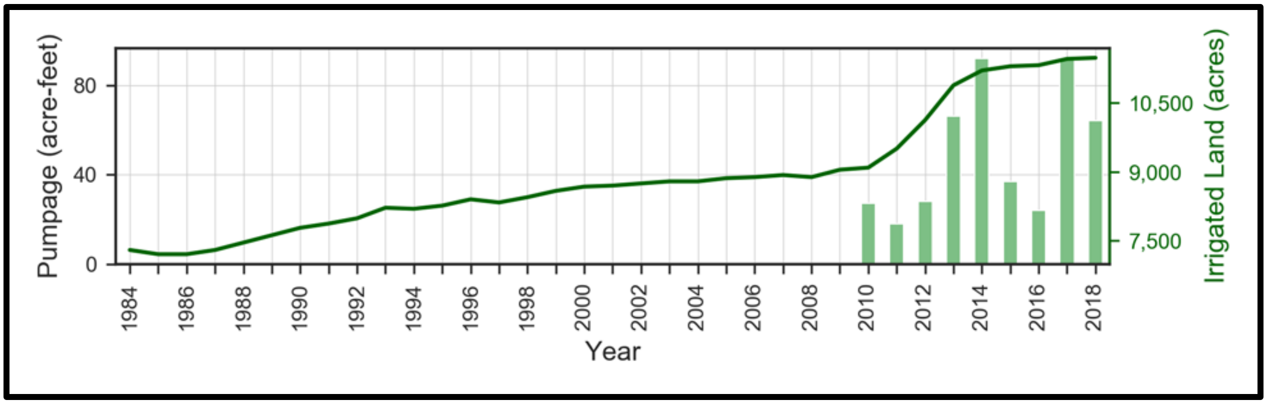


Figure 171. Kerr County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area in acres per year (according to land use data) overlying the aquifer.

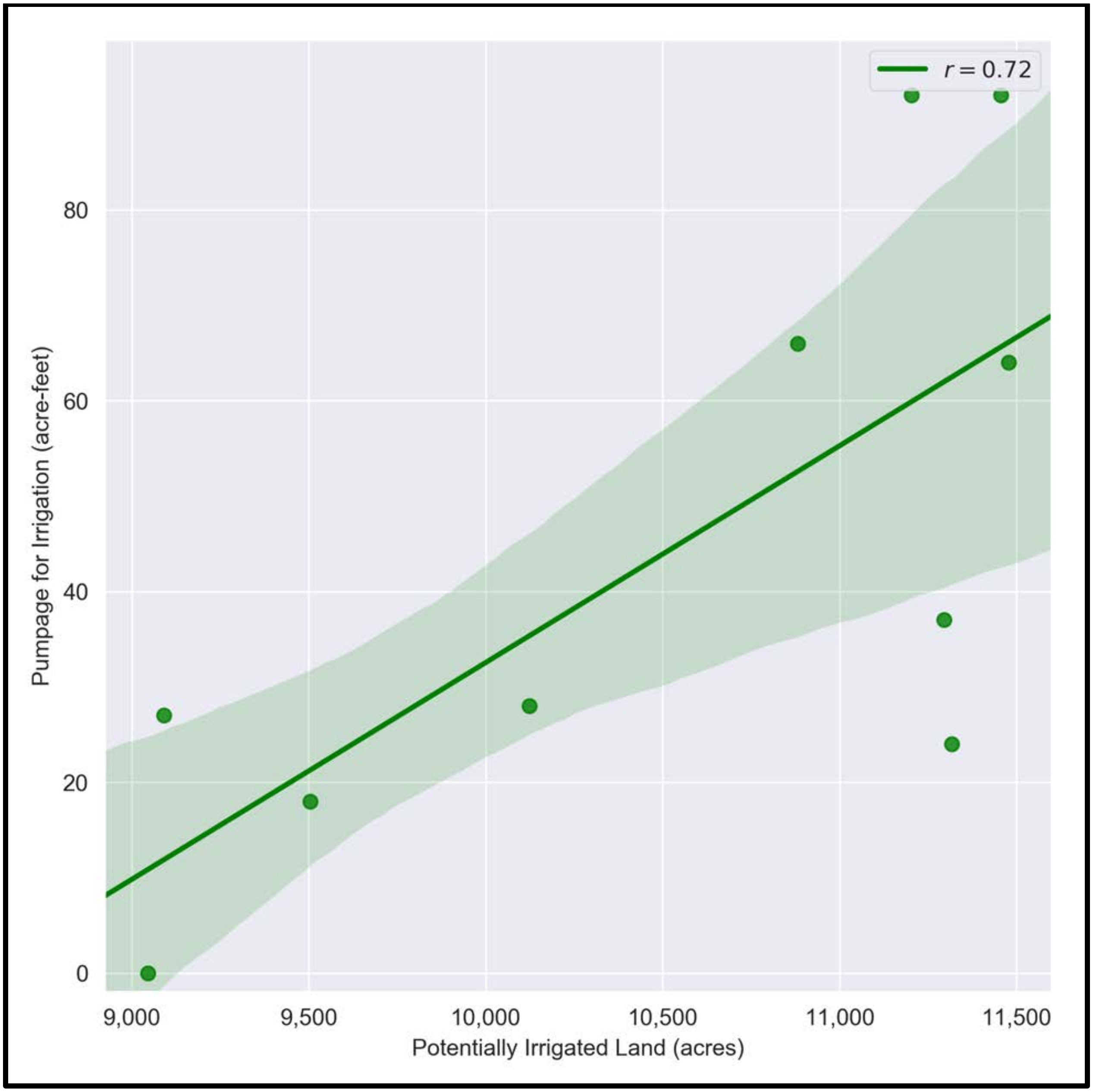


Figure 172. Kerr County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

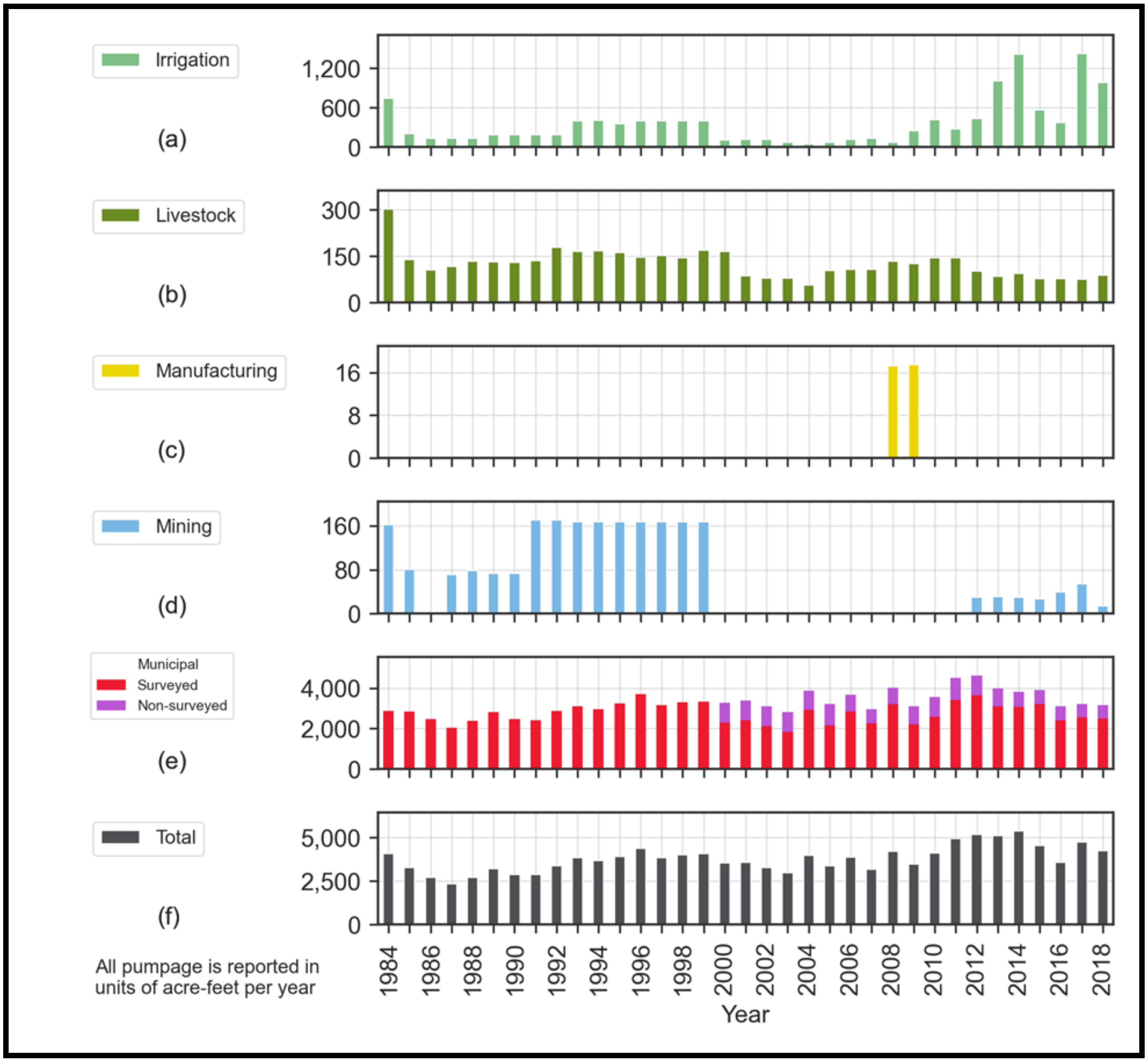


Figure 173. Kerr County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

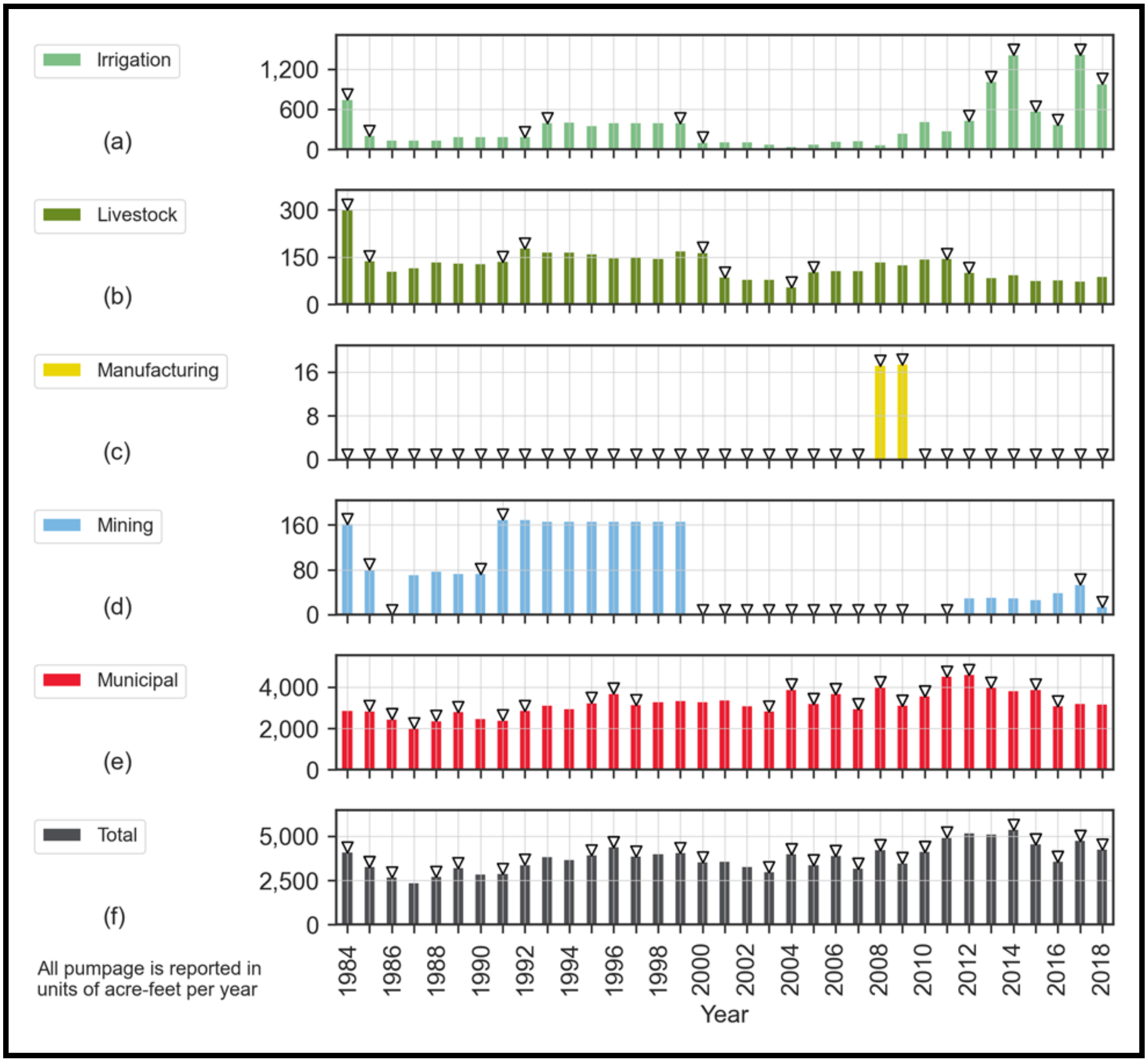


Figure 174. Kerr County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

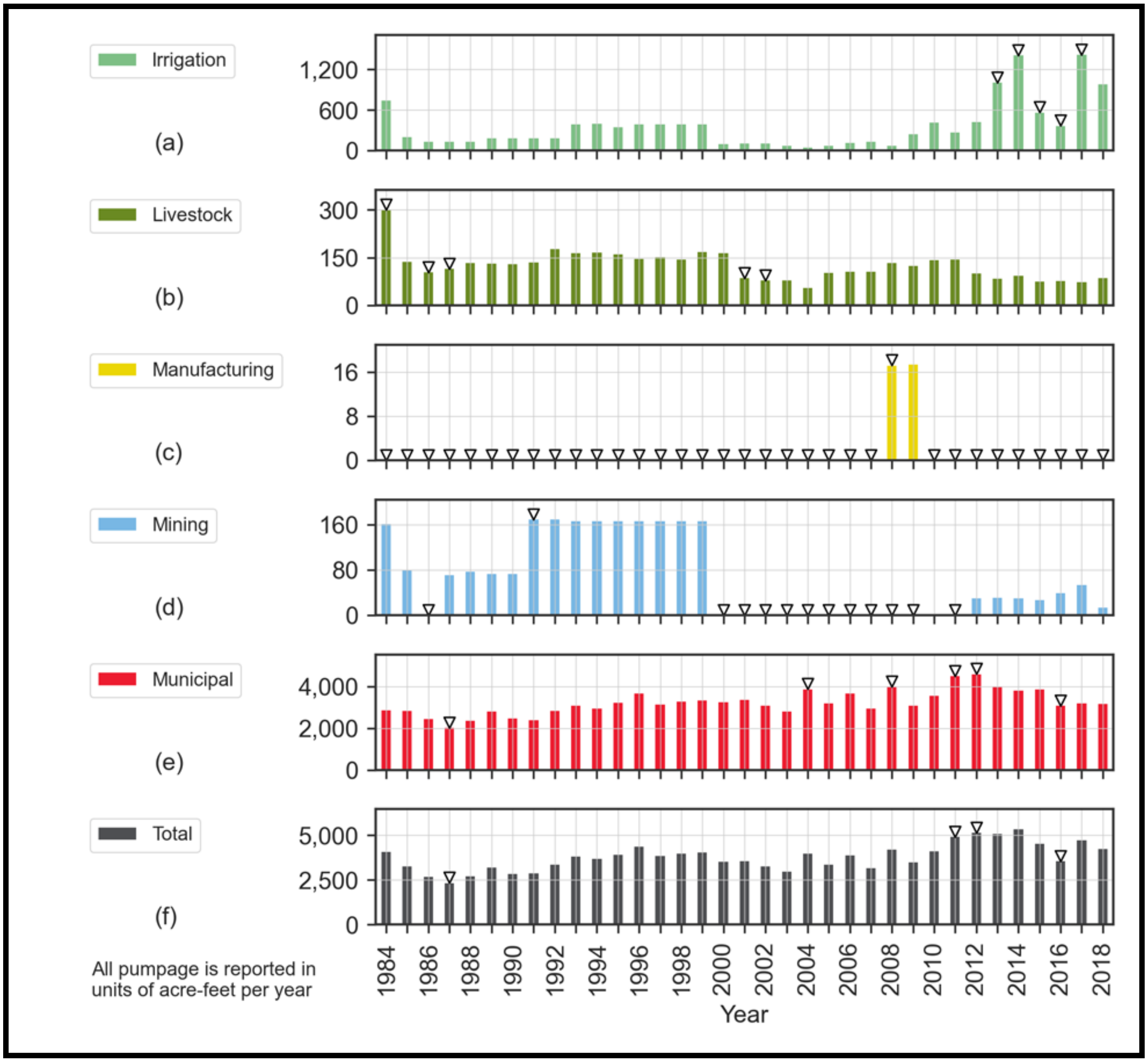


Figure 175. Kerr County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 33. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Kerr County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1984-2009, 2015, 2016	1984-2008, 2010, 2013-2015, 2017, 2018	1984-2009, 2016
	Livestock	1984, 2001-2005	1984, 1985, 1992, 2001, 2005, 2010, 2012	1984, 1986, 2001, 2002, 2005
	Manufacturing	1985-1991, 2012,2013-2018	1984-1993, 2012-2018	1984-1991, 2012-2018
	Mining	1984-1990, 2000-2018	1984-1991, 2000-2009, 2011-2018	1984-1991, 2000-2018
	Municipal	1984-1999, 2007	2000, 2006-2008, 2012	2000, 2006, 2007, 2014
Trinity (Hill Country)	Irrigation	1999-2009, 2015, 2016	1984, 1985, 1993, 2000, 2013-2015, 2017, 2018	2013-2017
	Livestock	1984, 2001	1984, 1985, 1992, 2001, 2005, 2012	1984, 1986, 1987, 2001, 2002
	Manufacturing	2009-2009	1984-2018	1984-2008, 2010-2018
	Mining	1986, 1991, 2000-2011	1984-1987, 1991, 2000-2009, 2011, 2012, 2018	1986, 1991, 2000-2011
	Municipal	None	1986, 1987, 1989, 1992, 1996, 1997, 2004-2011, 2013, 2016	1987, 2004, 2008, 2011, 2012, 2016

3.3.26 Kimble County

The Edwards-Trinity (Plateau) Aquifer underlies nearly the entire area of Kimble County (see Figure 176). The aquifer is the most extensive source of fresh groundwater in the county (Alexander Jr. and Pattman, 1969). As shown on Figure 177, reported total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Kimble County between 1984 and 2018 reached a maximum of approximately 1,000 acre-feet in 1986. In addition, the TWDB Water Use Survey indicates pumping of up to about 5 acre-feet from the Trinity (Hill Country) Aquifer (see Figure 178); however, the TWDB footprint for the Trinity (Hill Country) Aquifer does not extend to Kimble County and we expect the pumping is likely from the Edwards-Trinity (Plateau) Aquifer.

With respect to groundwater pumpage within Kimble County from the Edwards-Trinity (Plateau) Aquifer, irrigation, livestock, and municipal are the main uses, with less pumpage for manufacturing and mining uses. From 1984 to approximately 1989, irrigation use exceeded all other uses. After 1989, the greatest annual pumpage occurred for livestock use. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounted all the municipal water use from the Edwards-Trinity (Plateau) Aquifer in Kimble County.

As illustrated on Figure 177, pumping from the Edwards-Trinity (Plateau) Aquifer for irrigation and mining indicates steady pumping rates up until 1999 where the volumes drop to negligible amounts. Pumpage for mining is not reported after 1999 while pumping for irrigation abruptly decreases in 2000 and then remains at less than 200 acre-feet per year. Pumping for livestock and municipal use appears steady ranging from about 200 to 400 acre-feet per year for livestock and about 200 acre-feet per year for municipal. Pumpage for livestock shows a gradual decrease after 1999 whereas municipal pumpage shows a gradual decrease after 2012. Groundwater pumpage for manufacturing shows an abrupt decrease in 1989 and 1993, after which pumpage for manufacturing is not reported within the database.

Review of the year-to-year change (Figure 179) and standard deviation (Figure 180) analyses identifies an abrupt decrease in pumpage from the Edwards-Trinity (Plateau) for irrigation in 1989 and in 2000, for manufacturing in 1989, for mining in 2000 and an anomalous decreasing trend in municipal pumpage after 2014. We also observe an abrupt increase in pumpage for the years 2010 and 2011 for livestock use. Table 34 provides the years identified as having anomalous pumping amounts for Kimble County based on our manual review, year-to-year change (Figure 179), and standard deviation (Figure 180) analyses.

Intuitively, we would expect a linear correlation between the land overlying the Edwards-Trinity (Plateau) Aquifer in Kimble County that is potentially used for irrigation and groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer used for irrigation. However, although the acres of potentially irrigated land overlying the aquifer appear to be increasing in the county, the reported pumping for irrigation has reportedly decreased (see Figure 181). Figure 182 indicates a linear correlation value (“*r*”) of -0.85 between the potentially irrigated land area and reported groundwater pumpage for irrigation. This very strong negative correlation suggests that pumpage for irrigation in Kimble County is anomalous. We note, however, that the water usage database contains relatively low values irrigation pumpage for Kimble County from the Edwards-Trinity (Plateau) Aquifer for years after 1999 and that some of these years are flagged as anomalous. We will reevaluate this correlation after researching Kimble County irrigation pumpage during subsequent project tasks.

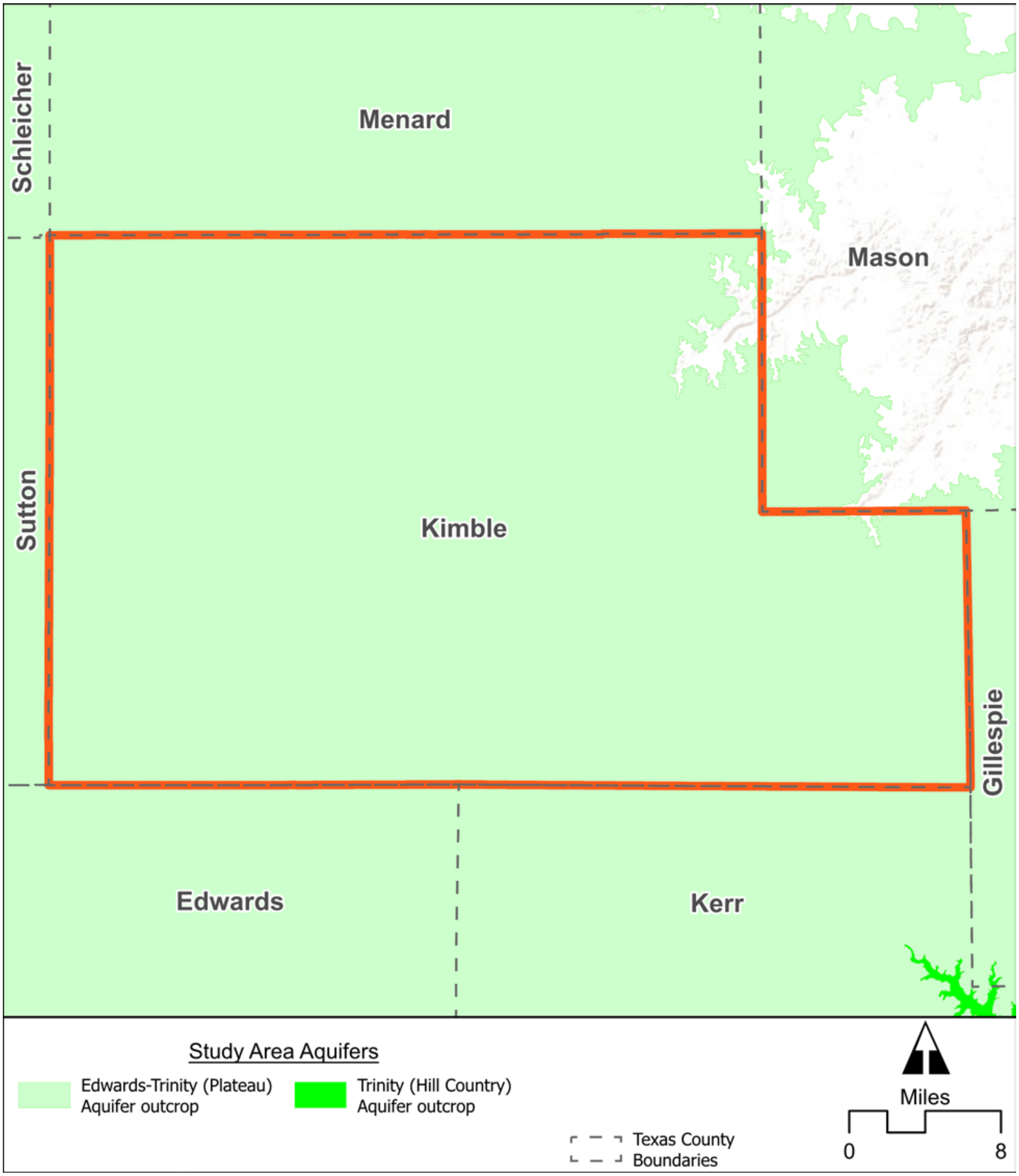


Figure 176. Kimble County showing the extent of the Edwards-Trinity (Plateau) aquifer.

Similarly, we would expect groundwater pumping for irrigation in Kimble County to correlate negatively to precipitation on potentially irrigated land such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 183 suggests that as precipitation increased on the potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in the county, the reported pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer decreased. Figure 184 indicates a negative correlation value ("r") of -0.48 between precipitation and groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer in Kimble County. This moderate negative correlation suggests that the reported pumpage for irrigation in Kimble County inversely follows the trend in precipitation. We note, however, that the water usage database contains relatively low values irrigation pumpage for Kimble County from the Edwards-Trinity (Plateau) Aquifer for years after 1999, and that some of these years are flagged as anomalous. We will reevaluate this correlation after researching Kimble County irrigation pumpage during subsequent project tasks.

Figure 185 shows approximately 75 new wells completed in the county since 2015 with a proposed livestock use. However, livestock pumpage since 2015 is lower than the previous years. Similarly, irrigation wells increased from 11 to 14 between 2016 and 2018, yet pumpage for irrigation did not change. An additional municipal well was added in 2018, without any increase in municipal pumping. These observations combine to suggest that well drilling and development do not necessarily correlate with increased pumping. During subsequent project phases we will investigate the validity of correlations between the number of wells and total pumpage.

Figure 177. Kimble County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

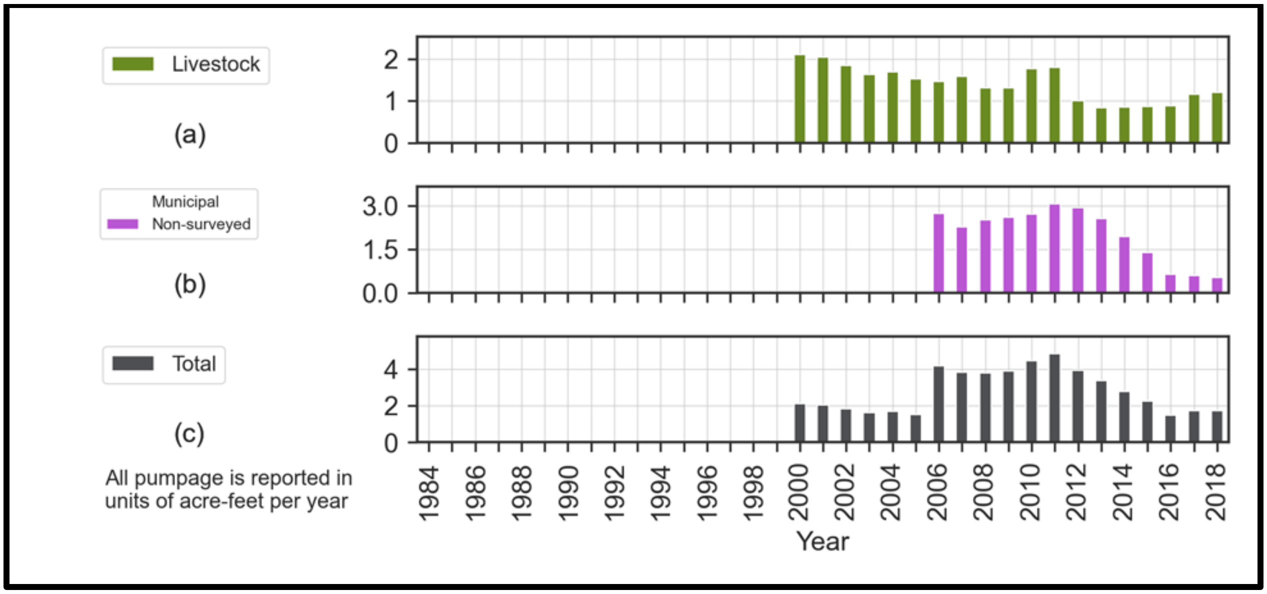


Figure 178. Kimble County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. We believe this pumping data should be attributed to the Edwards-Trinity (Plateau) Aquifer in Kimble County.

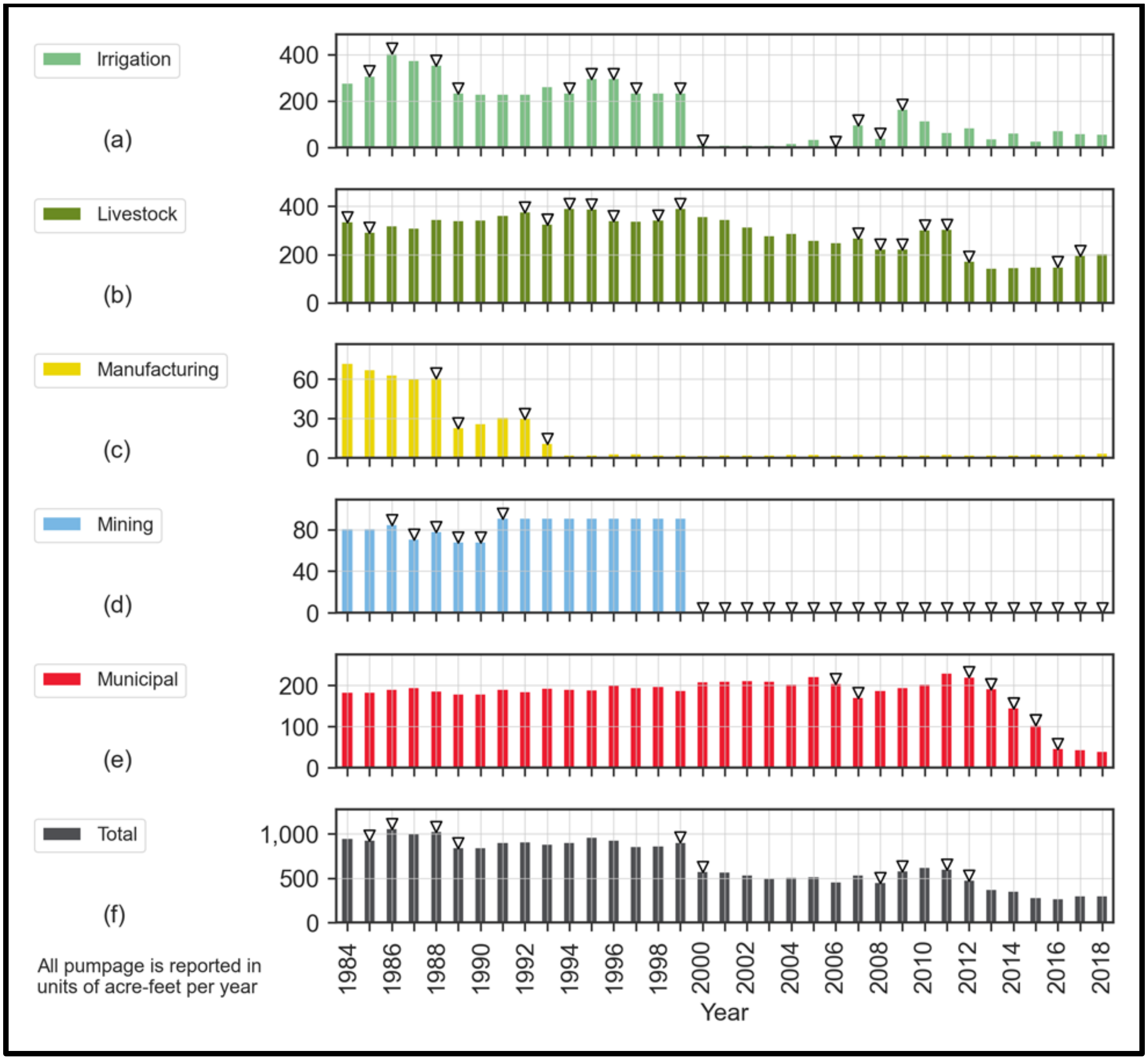


Figure 179. Kimble County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

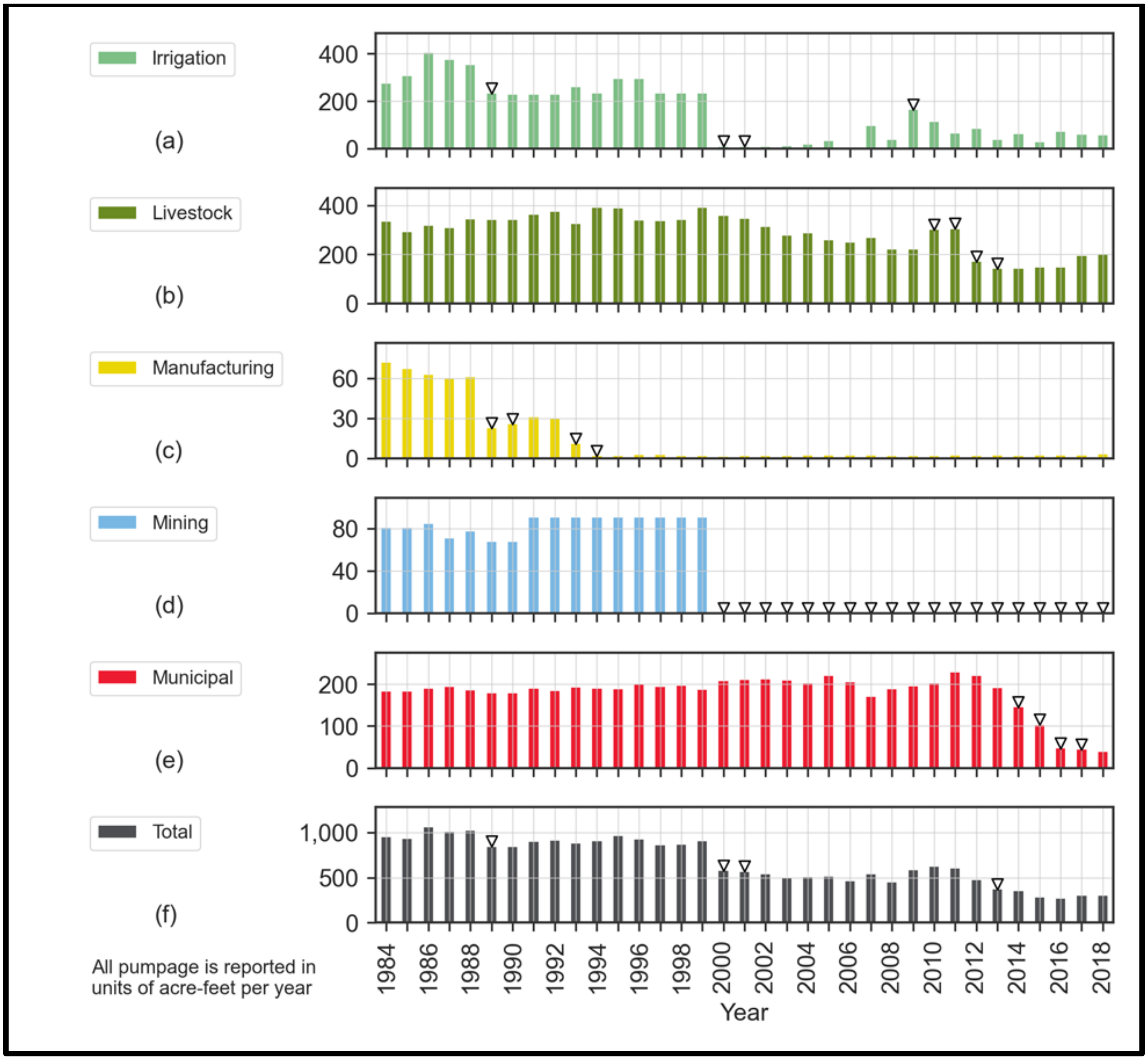


Figure 180. Kimble County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 34. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Kimble County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1989, 2000	1986, 1989, 1995, 1997, 2000, 2007, 2009	1989, 2000, 2001, 2009-2011-2013
	Livestock	2010, 2011	1984, 1985, 1993, 1994, 1996, 1999, 2008, 2010, 2012, 2017	2010-2013
	Manufacturing	1989, 1993	1989, 1993	1989, 1990, 1993, 1994
	Mining	2000-2018	1987, 1989, 1991, 2000-2018	2000-2018
	Municipal	2014-2018	2007, 2013-2016	2014-2017

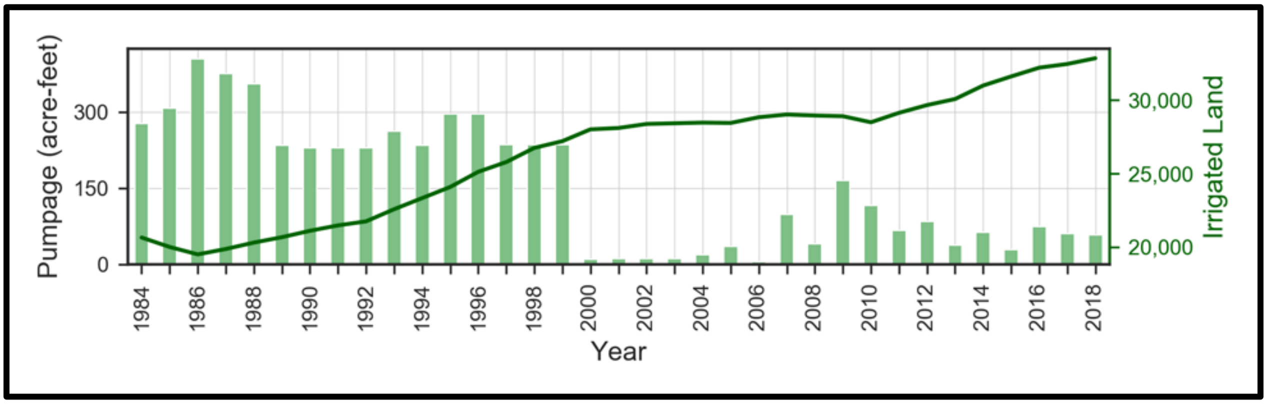


Figure 181. Kimble County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation in acre-feet per year as reported in the TWDB Water Use Survey data and acres of potentially irrigated land area in acres per year (according to land use data) overlying the aquifer.

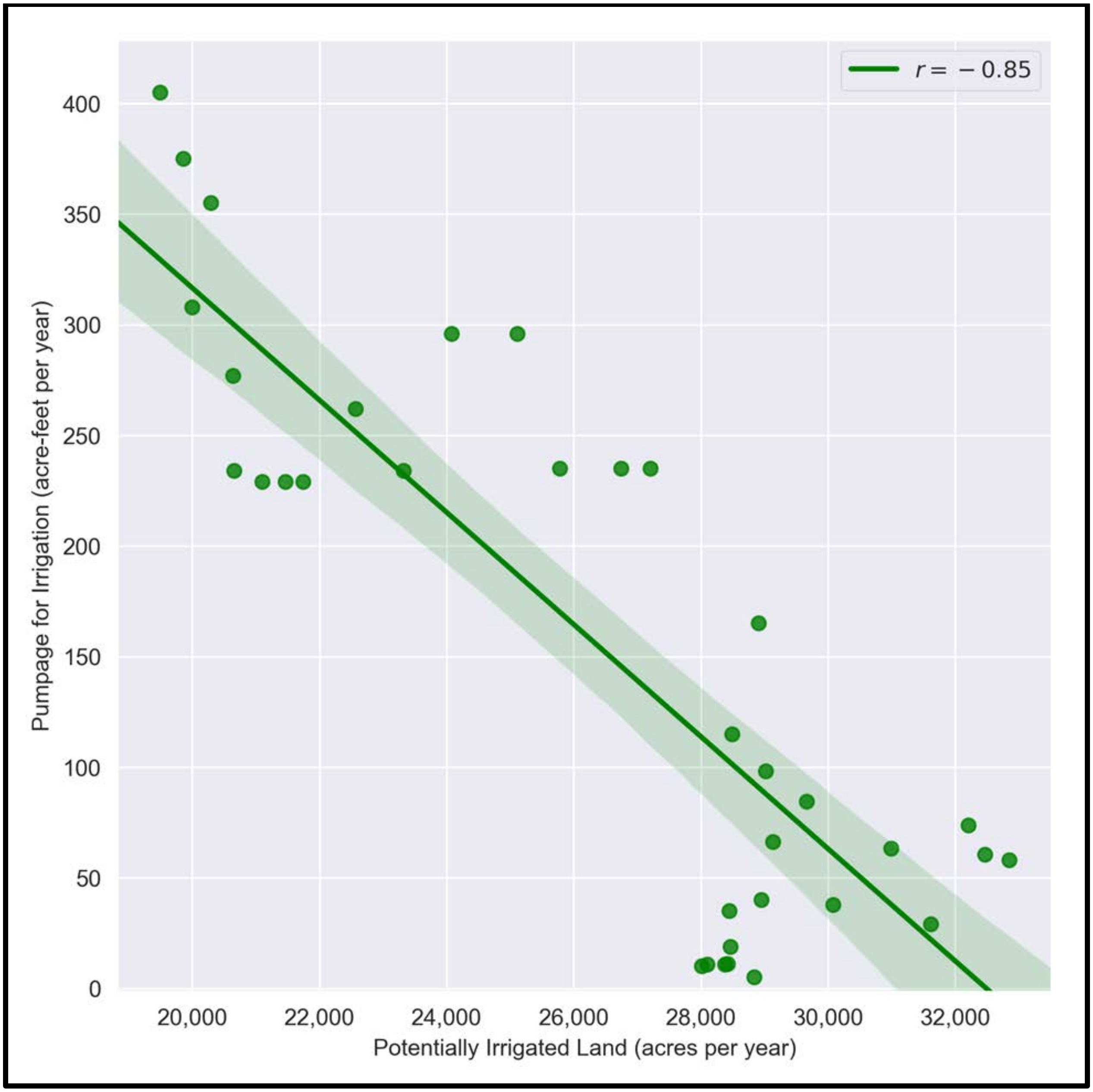


Figure 182. Kimble County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

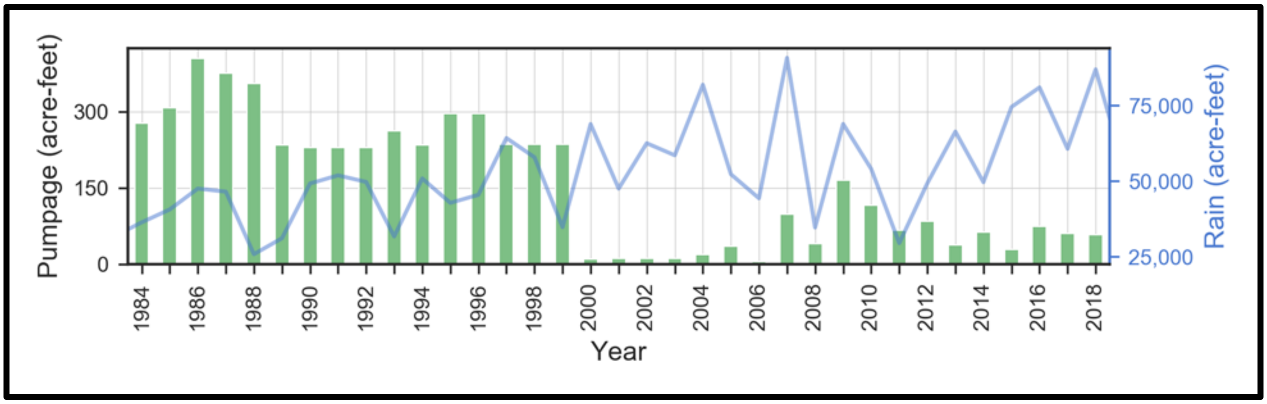


Figure 183. Kimble County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

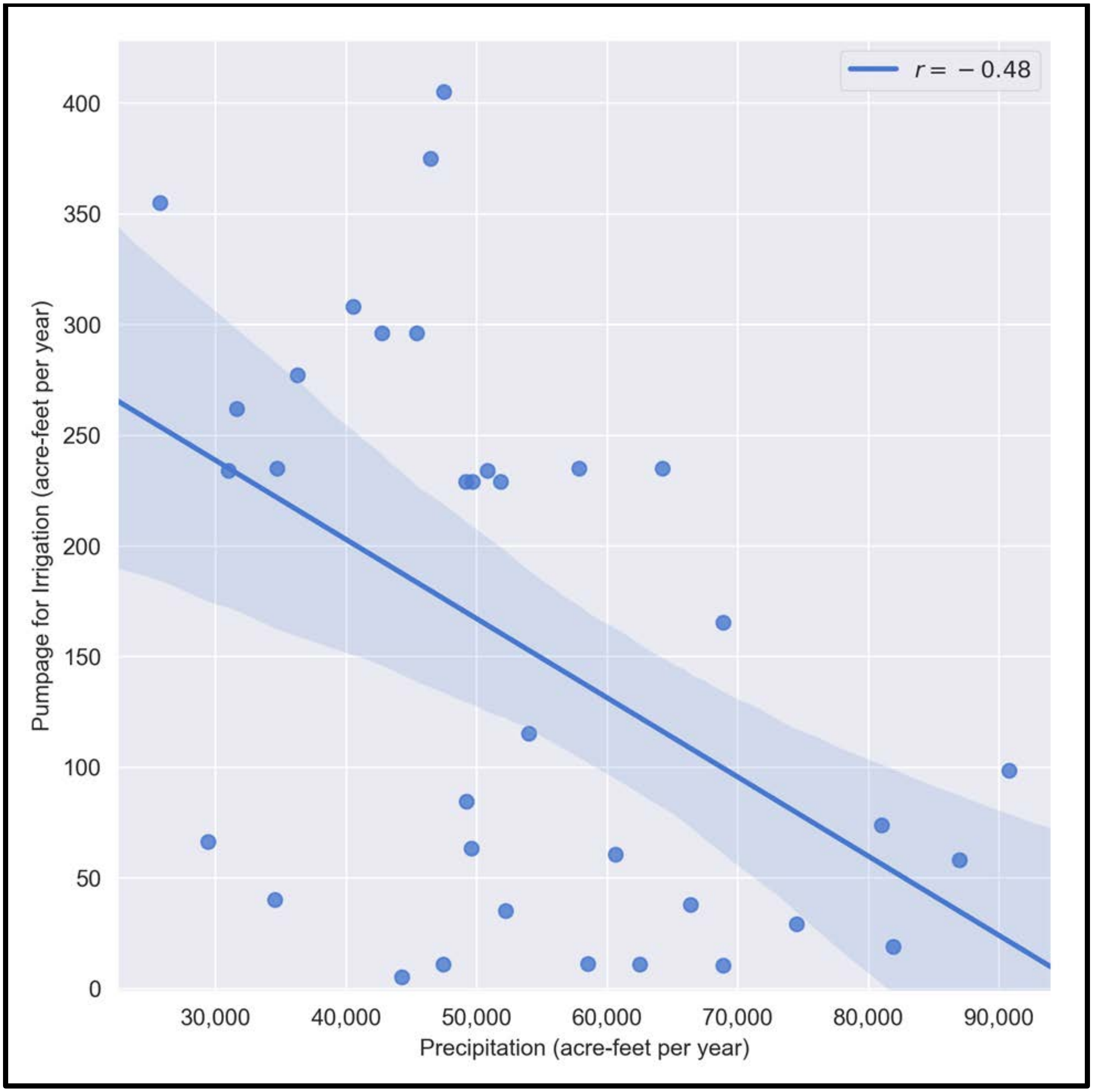


Figure 184. Kimble County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

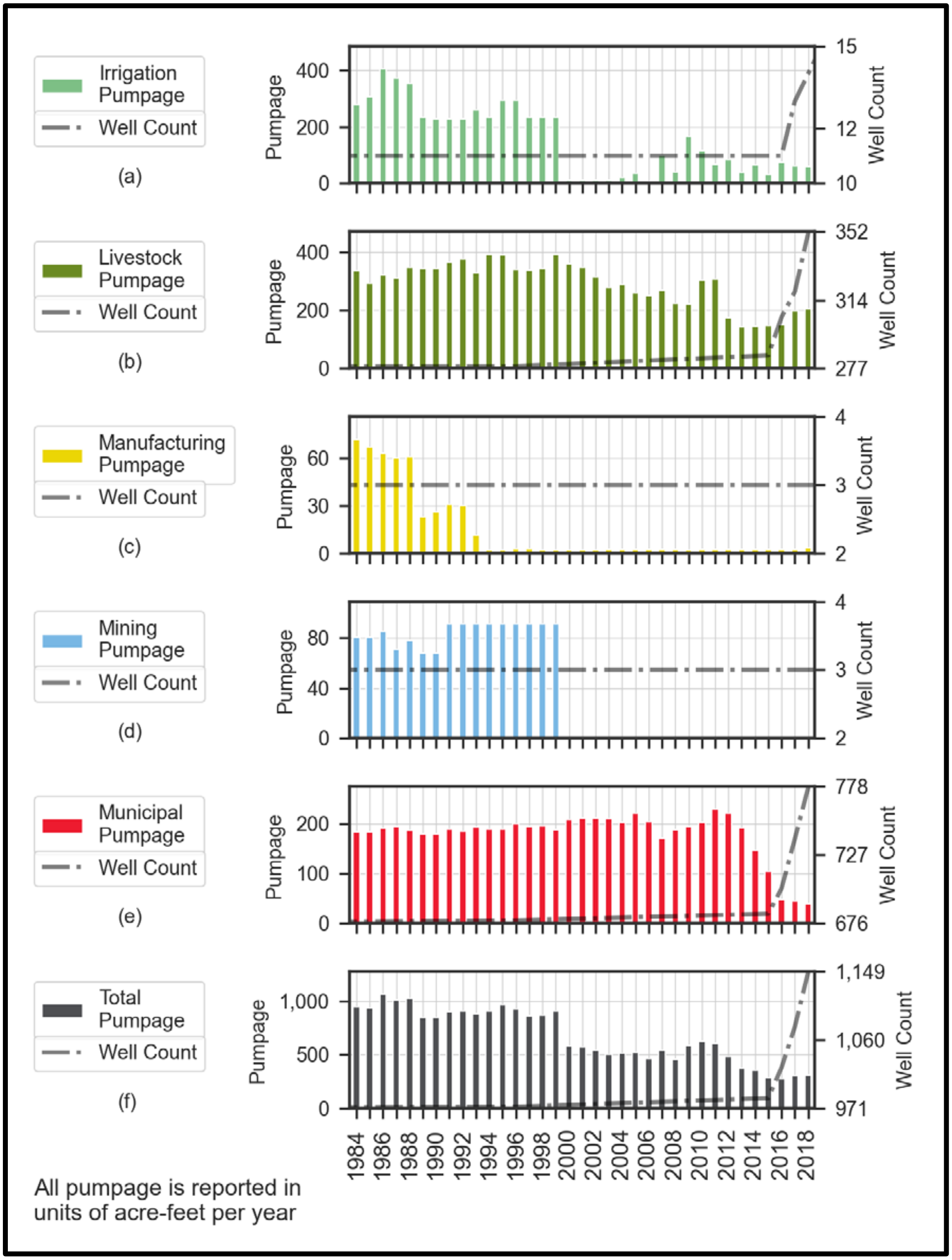


Figure 185. Kimble County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer as recorded in publicly available databases.

3.3.27 Kinney County

The Edwards (Balcones Fault Zone) and Edwards-Trinity (Plateau) aquifers underlie the northern portion of Kinney County (see Figure 186). Pumping from the Edwards (Balcones Fault Zone) in Kinney County is primarily for irrigation and municipal use, with the maximum reported total volume approaching 3,000 acre-feet in 2011 (Figure 187). Livestock is relatively minor use of groundwater from Edwards (Balcones Fault Zone) in Kinney County with an average reported volume of approximately 60 acre-feet per year.

In 2011, there was an abrupt increase in the reported pumpage volume for irrigation from the Edwards (Balcones Fault Zone) Aquifer which is a possible anomaly in the reported data (see Figure 188 and Figure 189). Reported pumping for livestock use from the Edwards (Balcones Fault Zone) had two abnormally low years from 2008 and 2009. Pumping for municipal use decreased abruptly from about 1,000 acre-feet in 2009 to less than 500 acre-feet in 2010.

For most years, reported pumping data from the Edwards-Trinity (Plateau) Aquifer is much greater than pumping from the Edwards (Balcones Fault Zone) Aquifer (Figure 190). Reported pumping data from the Edwards-Trinity (Plateau) Aquifer for irrigation had abrupt increases in 1989, 2000, and 2011 (see Figure 191 and Figure 192). Pumping for municipal use from the Edwards-Trinity (Plateau) Aquifer abruptly increased in 2010 after reported low values from 1984 through 2009. Surveyed municipal use accounts for almost all municipal water use from both the Edwards (Balcones Fault Zone) and the Edwards-Trinity (Plateau) Aquifers in Kinney County.

Upon review of the land potentially used for irrigation within the Kinney County footprint of the Edwards (Balcones Fault Zone) Aquifer and the groundwater pumpage from the aquifer used for irrigation, we noticed a positive correlation. Irrigation pumpage generally increased as the area of land potentially available for irrigation has increased (Figure 193). Figure 194 indicates a linear correlation value (“r”) of 0.67 between the area of potentially irrigated land overlying the aquifer and groundwater pumpage for irrigation. Such strong positive correlation suggests we can place more confidence in the pumpage data from the Edwards (Balcones Fault Zone) Aquifer for irrigation in Kinney County. However, we will revisit this correlation after researching (and possibly correcting) identified anomalous years of irrigation pumping data for Kinney County.

In contrast to the correlation observed for irrigation pumping in the Edwards (Balcones Fault Zone) Aquifer, data comparisons for the Edwards-Trinity (Plateau) Aquifer indicate a negative correlation, with irrigation pumpage decreasing as the acres of potentially irrigated land overlying the aquifer have increased (Figure 195). Figure 196 indicates a linear correlation value of -0.52 between the area of potentially irrigated land and groundwater pumpage for irrigation. Such strong negative correlation suggests potentially anomalous pumpage data from the Edwards-Trinity (Plateau) for irrigation in Kinney County. It is noted, however, that we may discover explanations for the lack of the expected correlation through the anomaly research we will conduct during subsequent project tasks. We will revisit this correlation after researching (and possibly correcting) identified anomalous years of irrigation pumping data for Kinney County.

Table 35 provides the years identified as having anomalous pumping amounts for Kinney County based on our manual review, year-to-year change (Figure 188 and Figure 191), and standard deviation (Figure 189 and Figure 192) analyses for both the Edwards (Balcones Fault Zone) Aquifer and the Edwards-Trinity (Plateau) Aquifer.

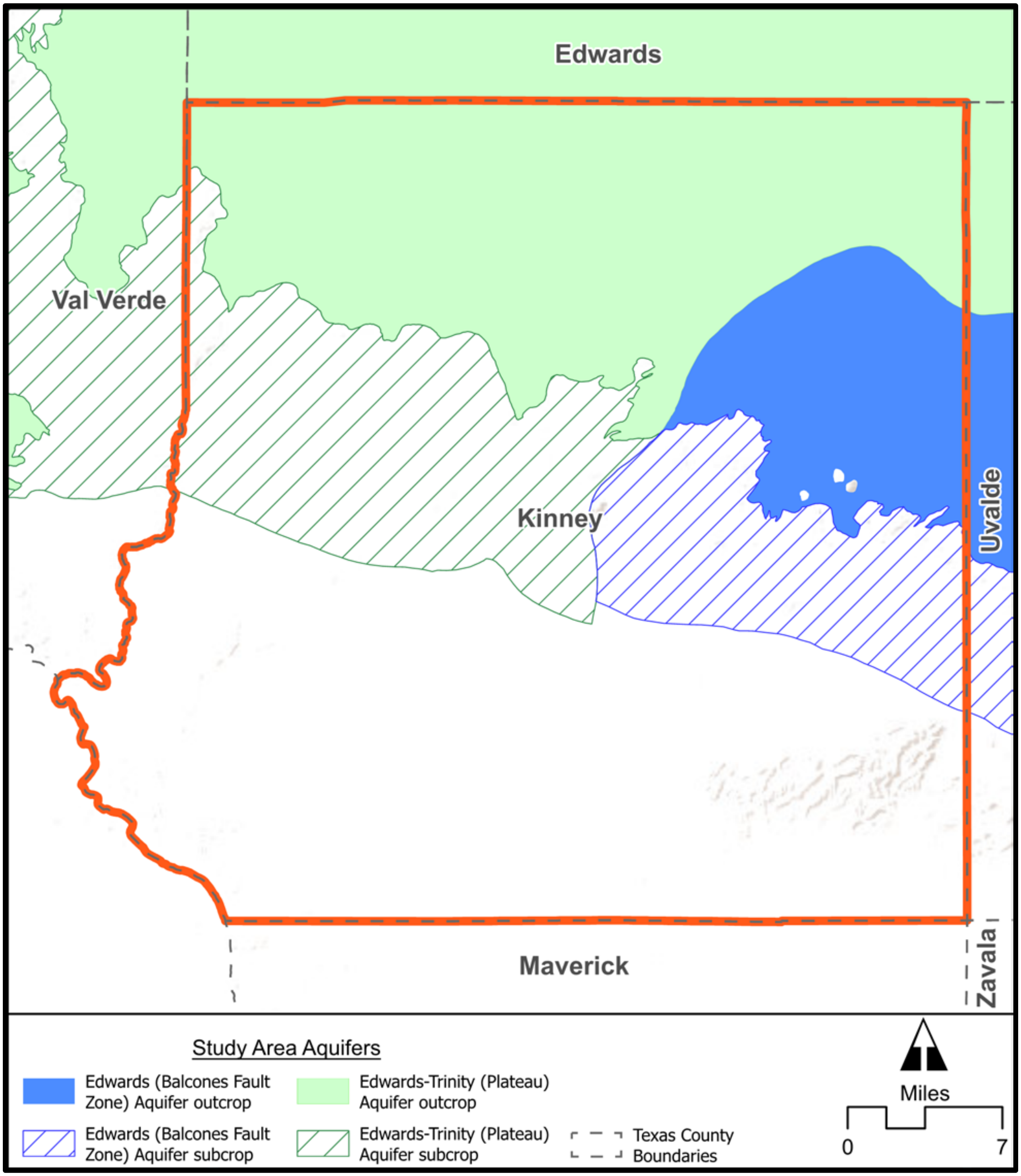


Figure 186. Kinney County showing the extent of the Edwards-Trinity (Plateau) and Edwards (BFZ) aquifers.

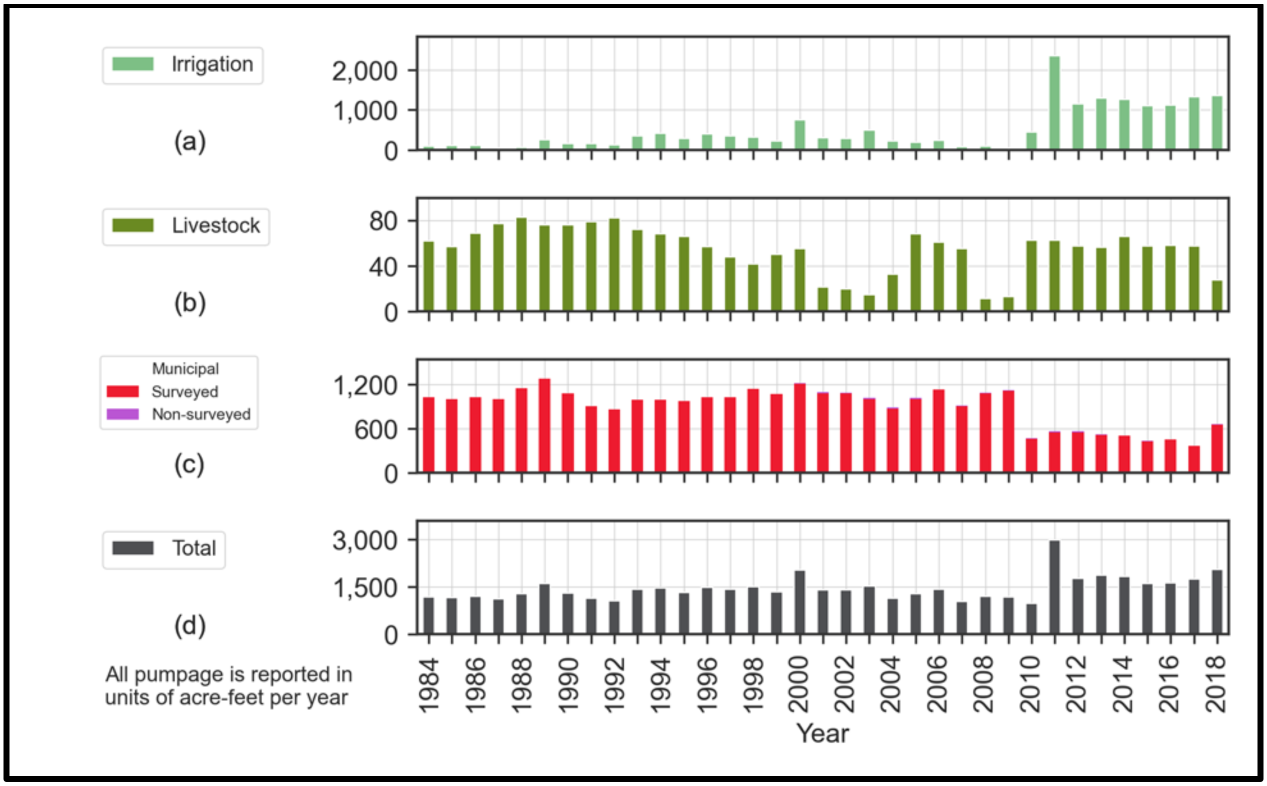


Figure 187. Kinney County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

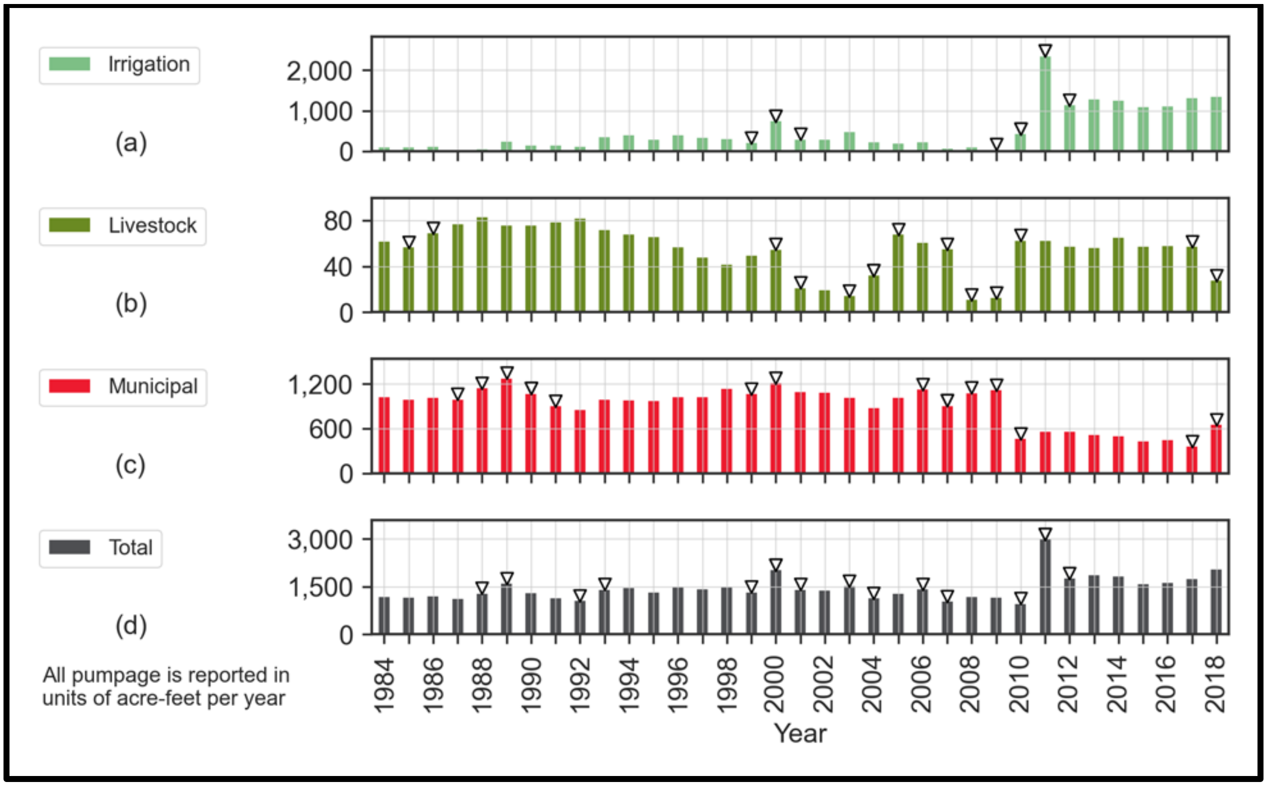


Figure 188. **Kinney County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

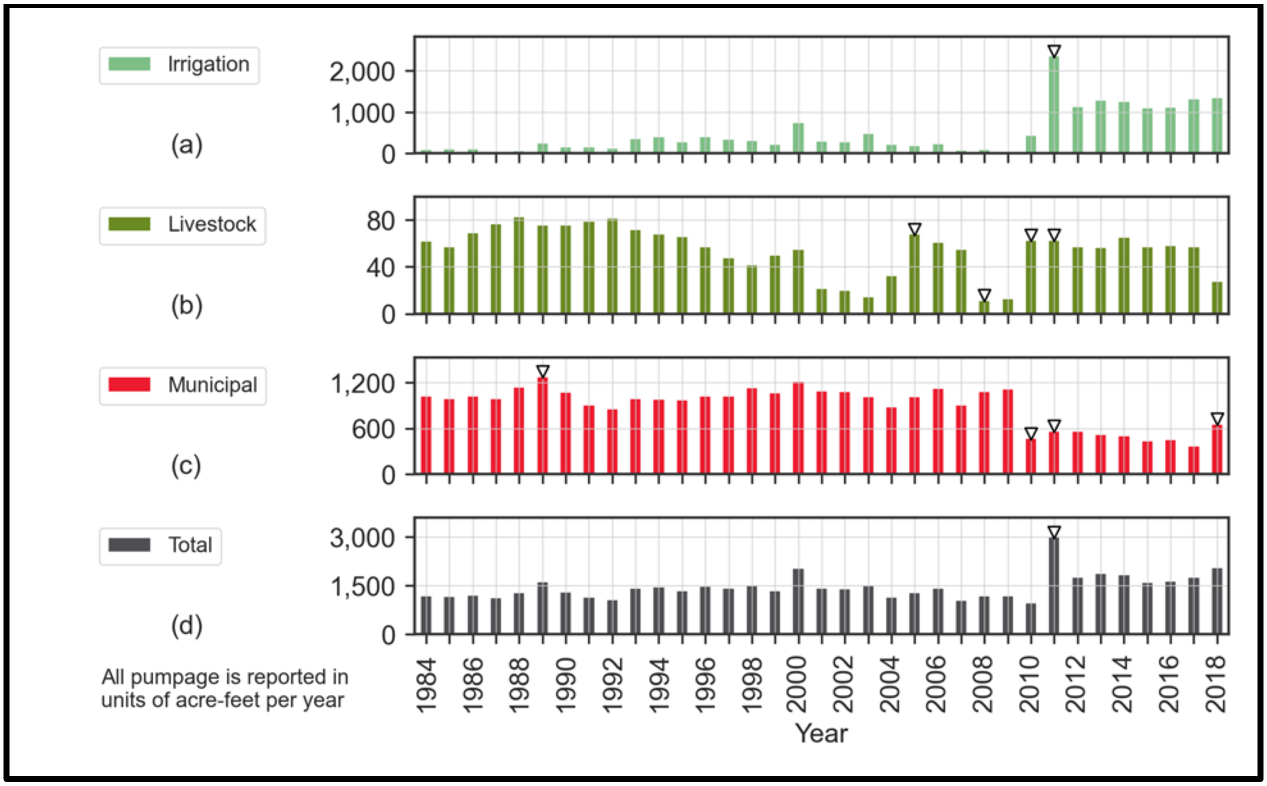


Figure 189. Kinney County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

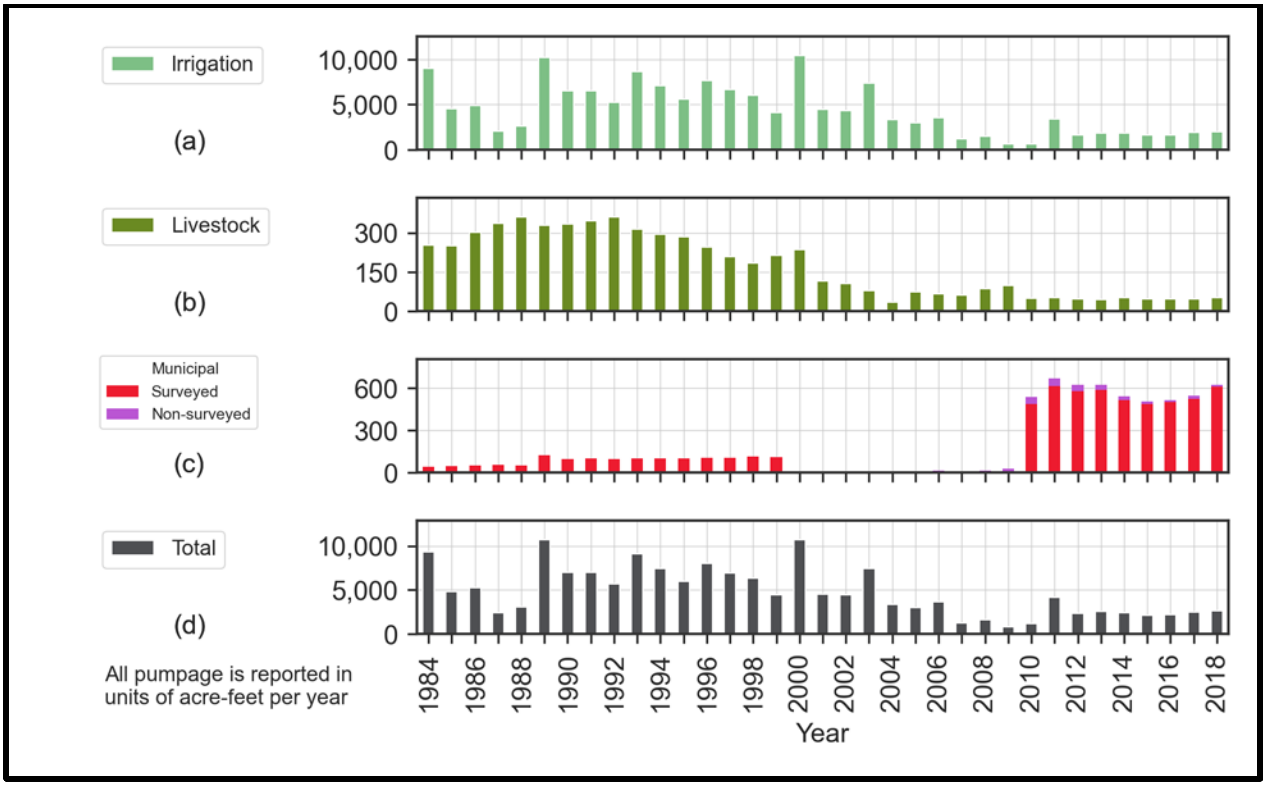


Figure 190. Kinney County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

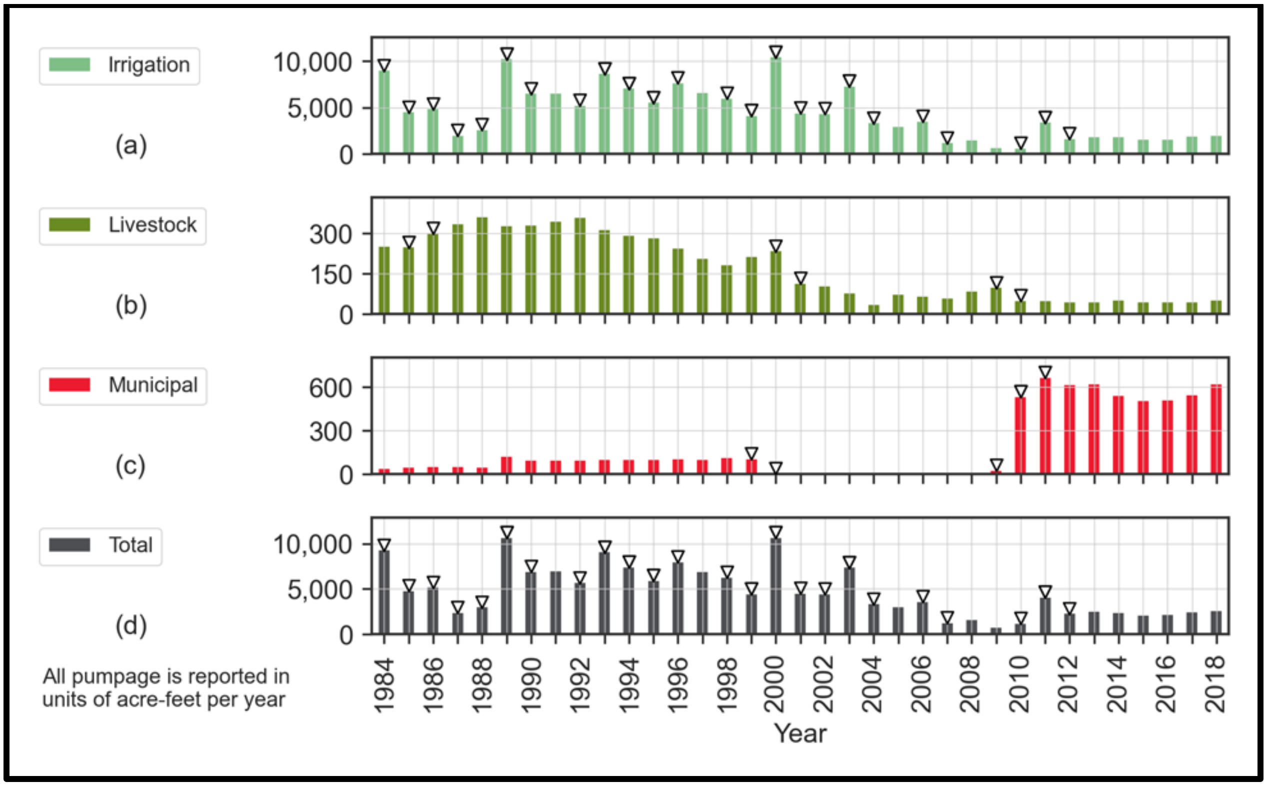


Figure 191. Kinney County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

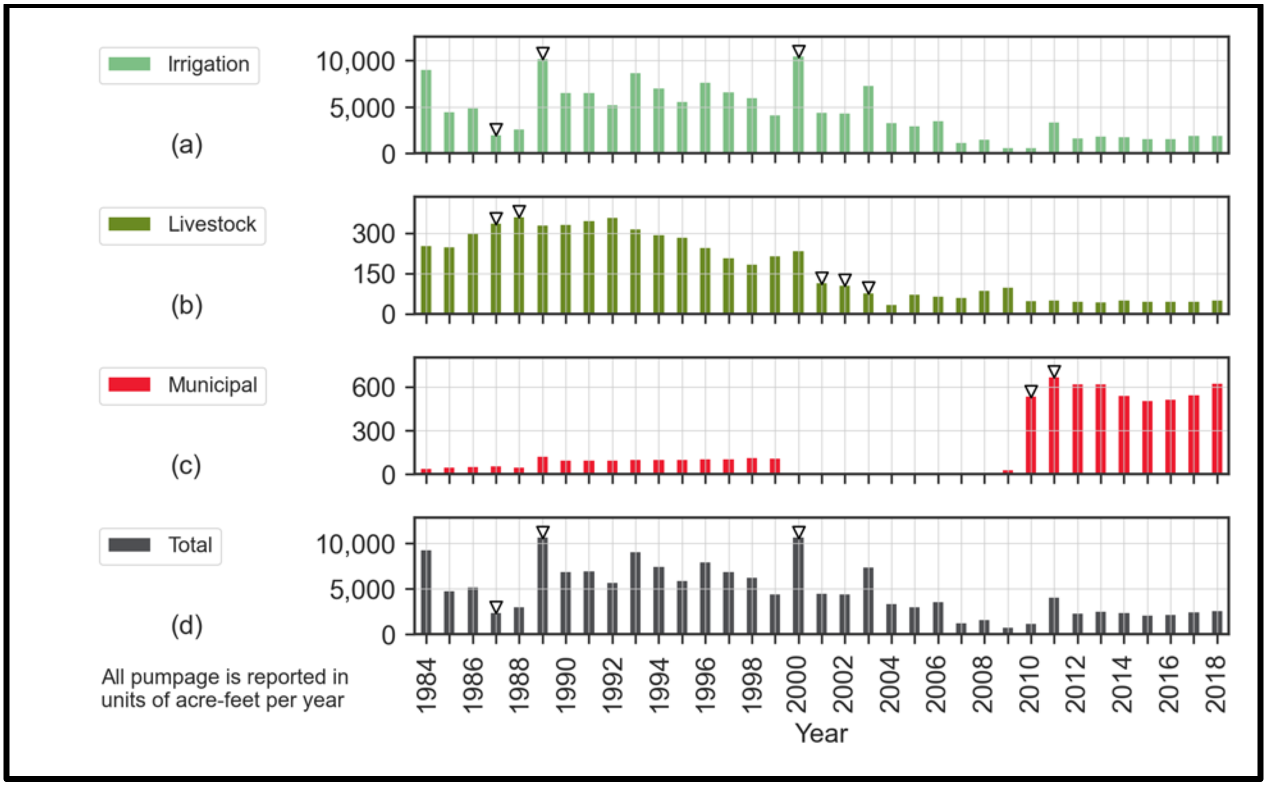


Figure 192. Kinney County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

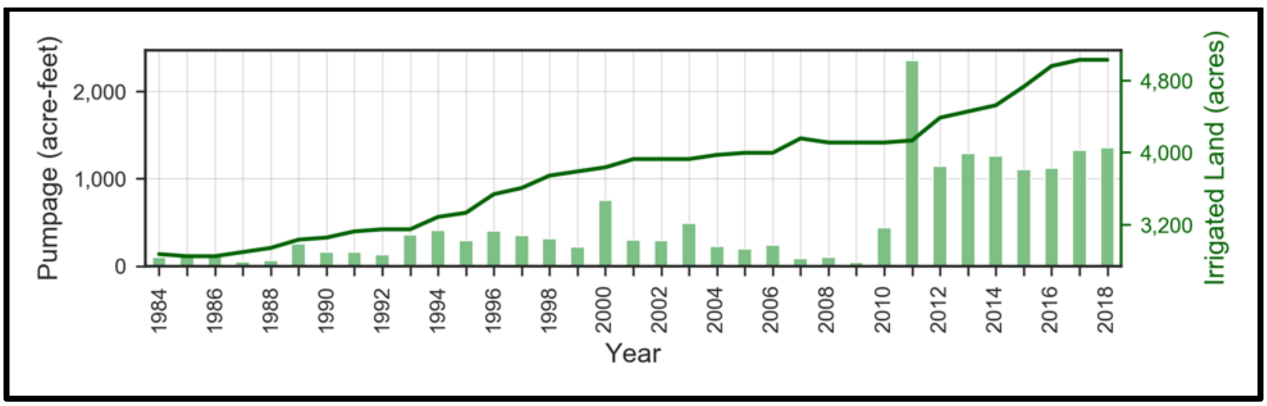


Figure 193. Kinney County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area in acres per year (according to land use data) overlying the aquifer.

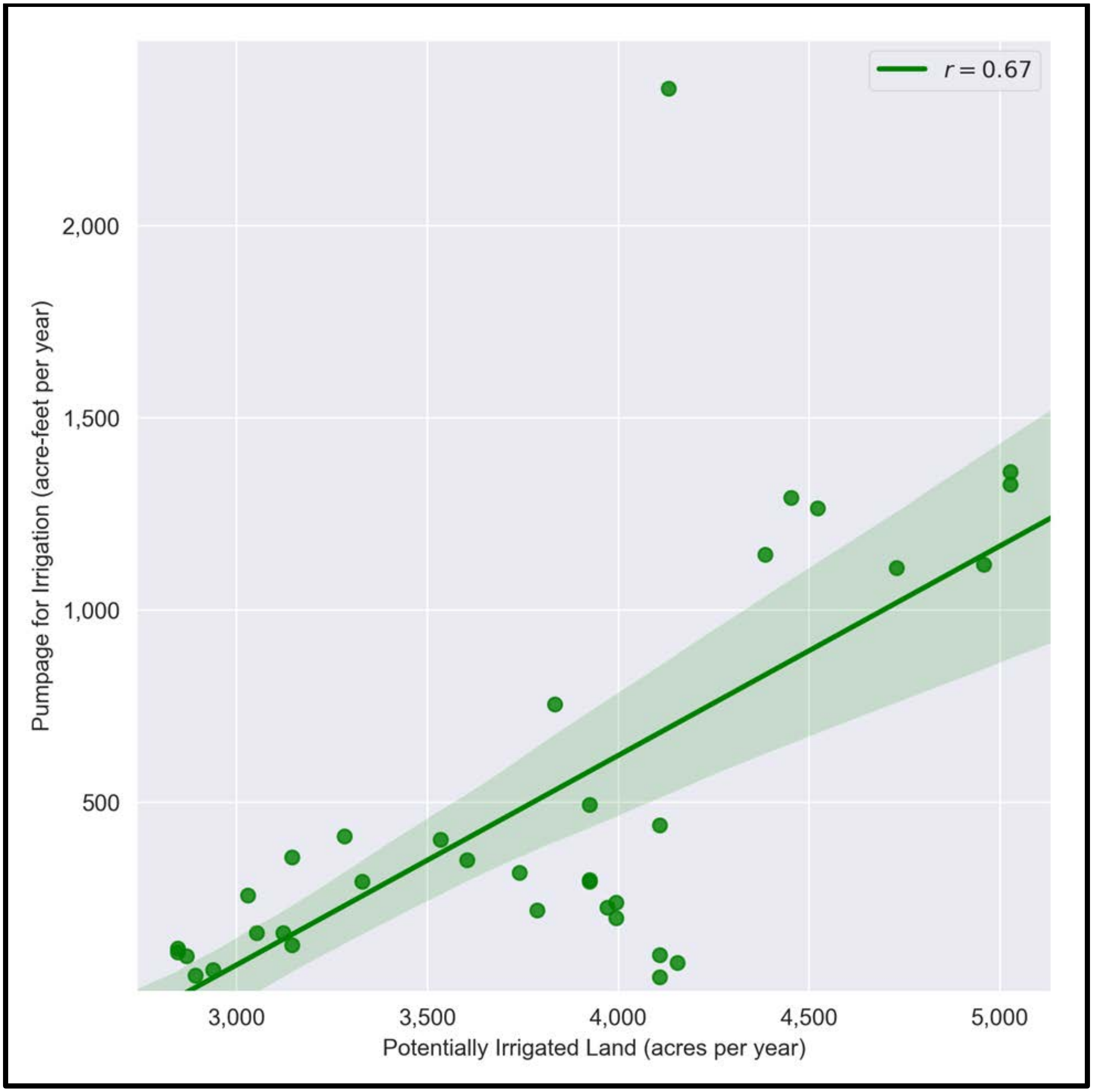


Figure 194. Kinney County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

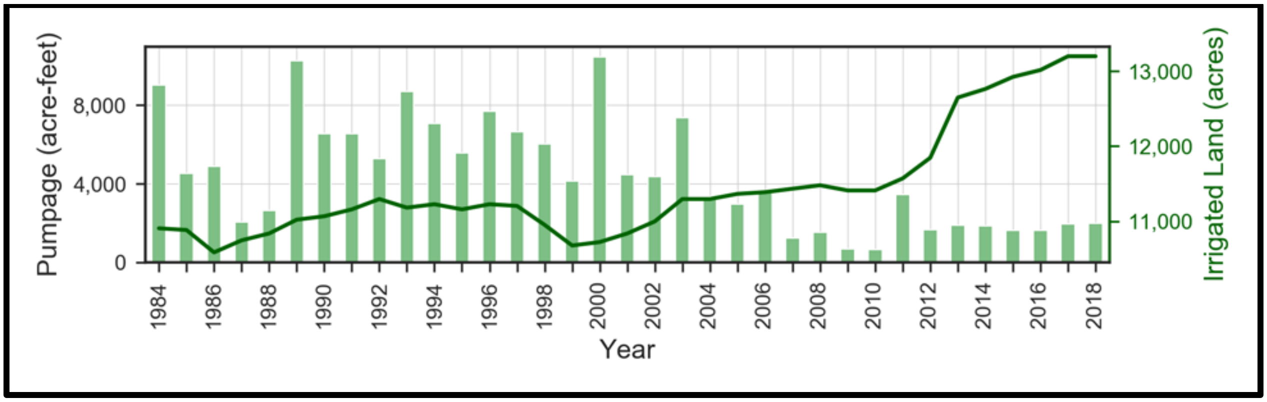


Figure 195. Kinney County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area, in acres per year, (according to land use data) overlying the aquifer.

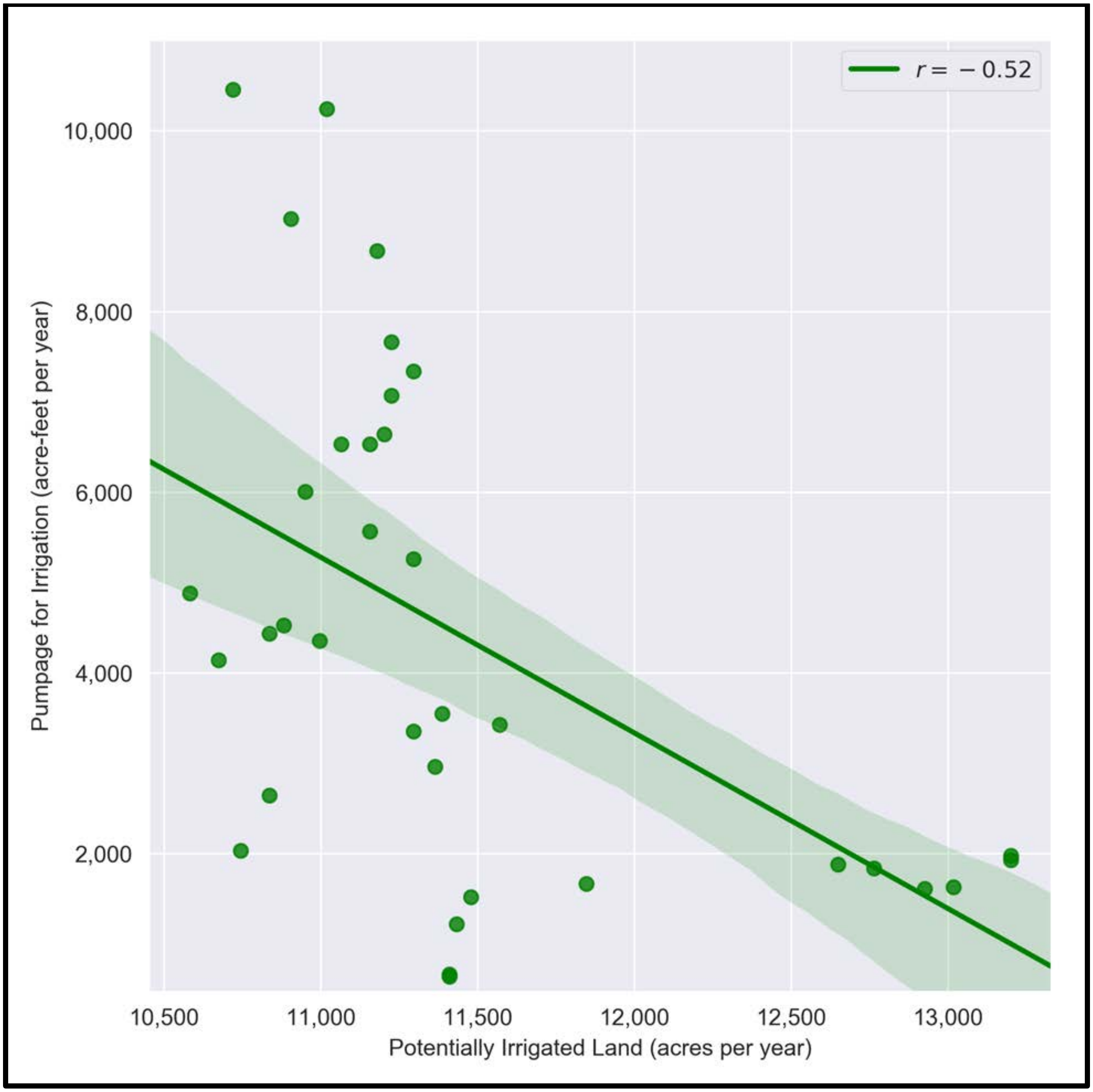


Figure 196. Kinney County Edwards-Trinity (Plateau) Aquifer pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area overlying the aquifer (according to land use data), in acres per year. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 35. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Kinney County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (BFZ)	Irrigation	2011	2000, 2001, 2010-2012	2011
	Livestock	2008-2009	1986, 2001, 2004, 2005, 2008, 2010, 2018	2005, 2008, 2010, 2011
	Municipal	2010	1988, 1990, 1991, 2000, 2007, 2008, 2010, 2018	1989, 2010, 2011, 2018
Edwards-Trinity (Plateau)	Irrigation	1989, 2000, 2011	1984, 1985, 1987, 1989, 1990, 1993-1996, 1999-2001, 2003, 2004, 2007, 2011, 2012	1987, 1989, 2000
	Livestock	1999-2000	1986, 2001, 2010	1987, 1988, 2001-2003
	Municipal	2000, 2010	2000, 2010, 2011	2010, 2011

3.3.28 Loving County

Loving County is in west Texas just south of the New Mexico border (see Figure 197). The primary aquifer underlying nearly all Loving County is the Pecos Valley Aquifer. Groundwater pumping from the Pecos Valley Aquifer in Loving County is for livestock and municipal use, with a maximum annual reported total pumpage of just under 60 acre-feet in 1994, 1995, and 1997. The average reported pumping volume for municipal use is approximately 15 to 20 acre-feet per year. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounted for all the municipal water use until 2010, after which surveyed municipal use constituted most of the municipal water pumped from the Pecos Valley Aquifer in Loving County.

The TWDB Water Use Survey database contains pumping for irrigation use for three years, with the reported value being zero acre-feet each year. Manual review of the pumping data for Loving County suggests multiple anomalies in pumpage for livestock, and an anomaly in municipal use over the 2010 through 2011 period.

Figure 199 presents the anomalies identified through the year-to-year change analysis and Figure 200 presents the anomalies identified through the standard deviation analysis. The identified anomalies largely match those identified through the manual review process. One anomaly that is not present on the figures is pumping for mining use. Given the extensive presence of the oil and gas industry within Loving County, we expected pumpage for mining use within the Water User Survey database. We will investigate this lack of reported data during subsequent project phases.

Table 36 provides the years identified as having anomalous pumping amounts for Loving County from the Pecos Valley Aquifer based on our manual review, year-to-year change (Figure 199), and standard deviation (Figure 200) analyses.

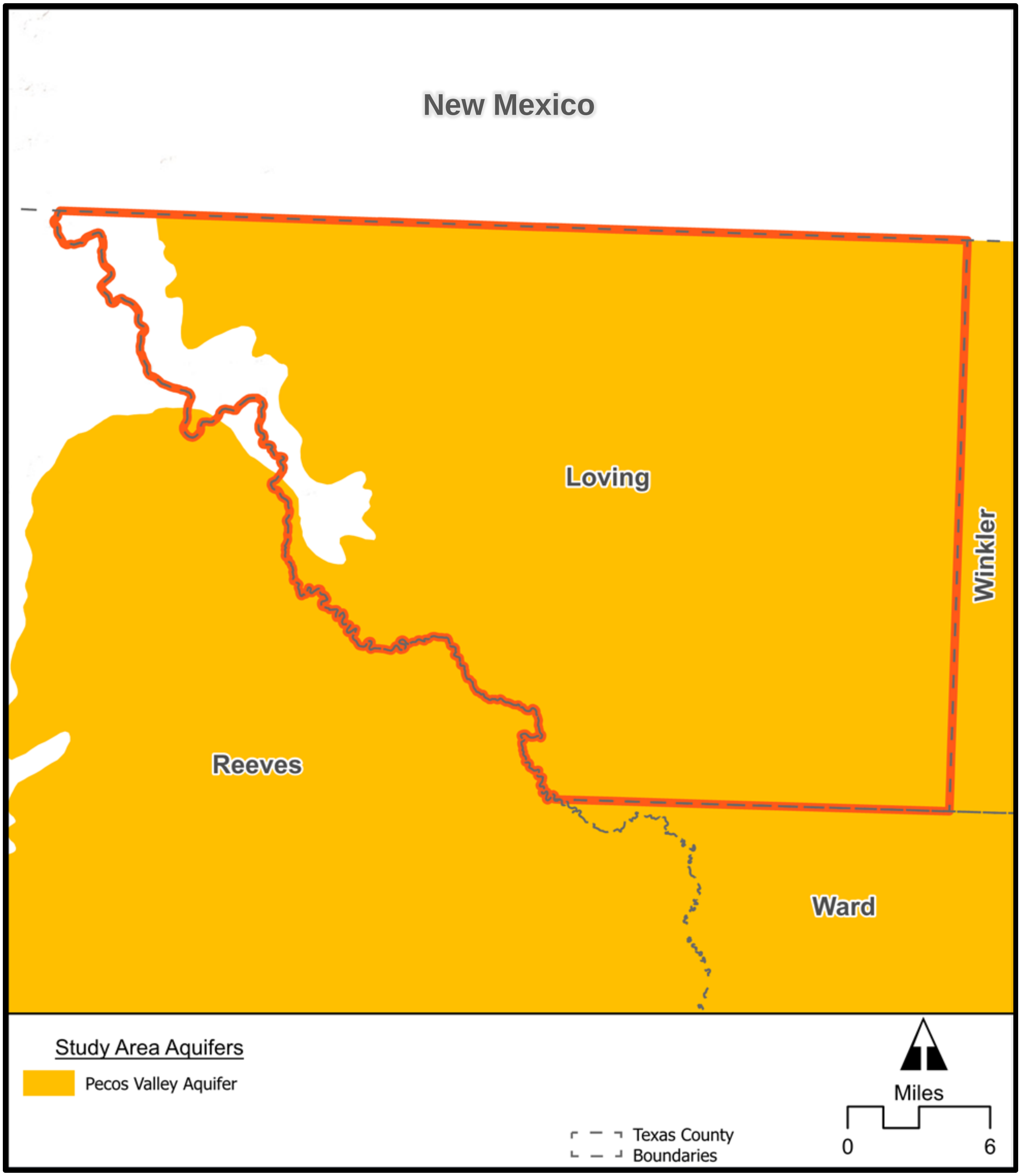


Figure 197. Loving County showing the extent of the Pecos Valley Aquifer.

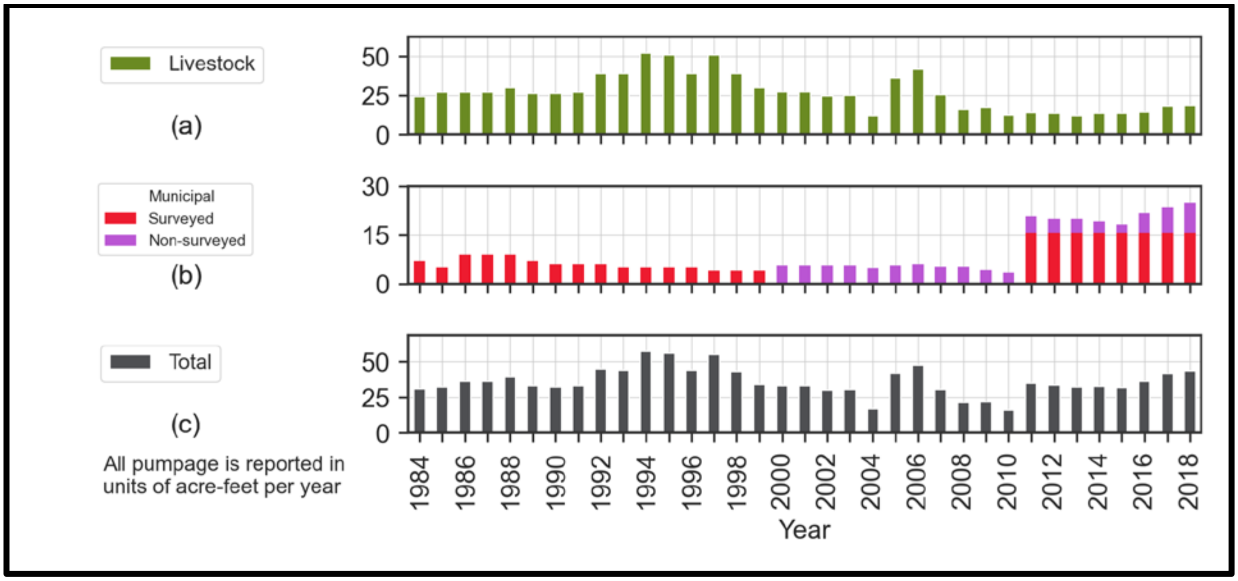


Figure 198. Loving County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

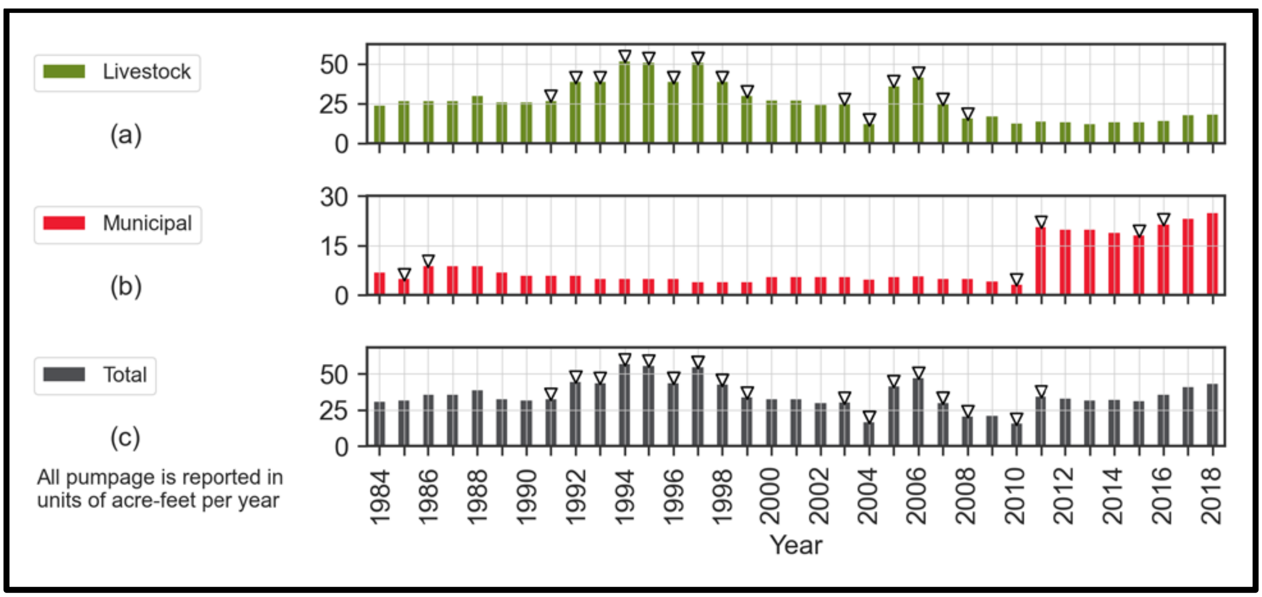


Figure 199. Loving County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

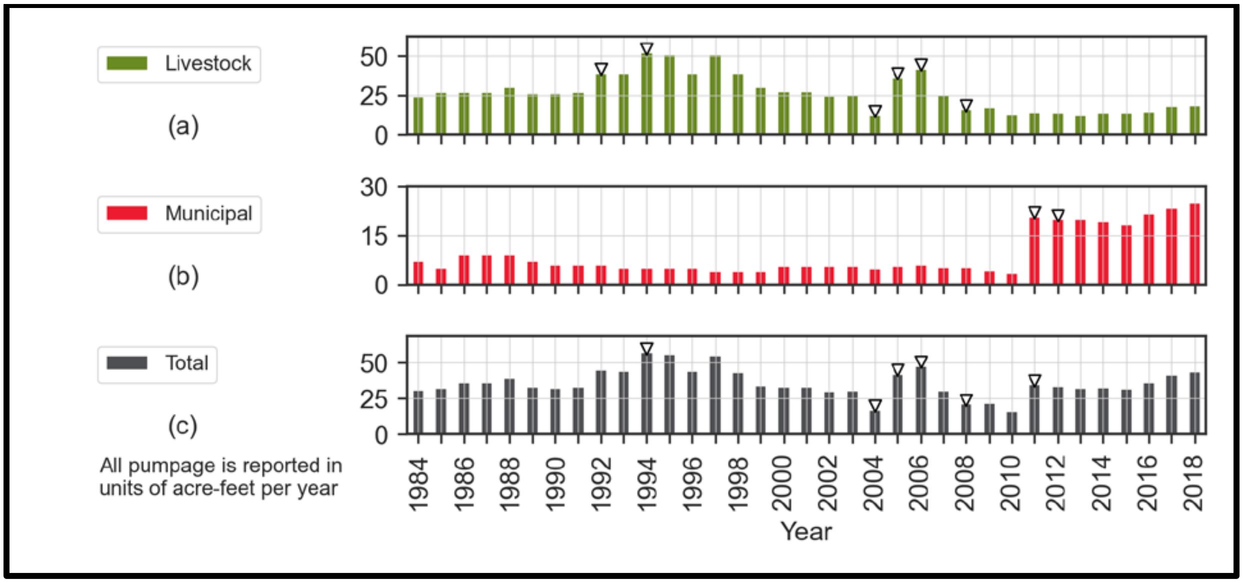


Figure 200. Loving County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 36. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Loving County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Pecos Valley	Irrigation	None	1986, 1990, 1991, 1993, 1997-1999, 2003, 2006-2008, 2011, 2015	1984-2018
	Livestock	2004	1992, 1994, 1996-1999, 2004, 2005, 2007, 2008	1992, 1994, 2004-2006, 2008
	Municipal	2011	1986, 2011, 2016, 2012-2015	2011, 2012
	Mining	1984-2018	None	None

3.3.29 Martin County

Only a small portion of the Edwards-Trinity (Plateau) Aquifer outcrop is present within Martin County, and the aquifer subcrop is present mostly along the county border with Midland County (Figure 201). Withdrawals in Martin County are primarily from other aquifers (Lurry and Pavlicek, 1991) that are not subjects of this study. As shown on Figure 202, groundwater pumping for municipal use from the Edwards-Trinity (Plateau) Aquifer within Martin County was reported only from 2012 through 2015 and ranges from 4 acre-feet/year to 16 acre-feet/year. We did not identify any anomalies in the available and applicable Water Use Survey data for Martin County.

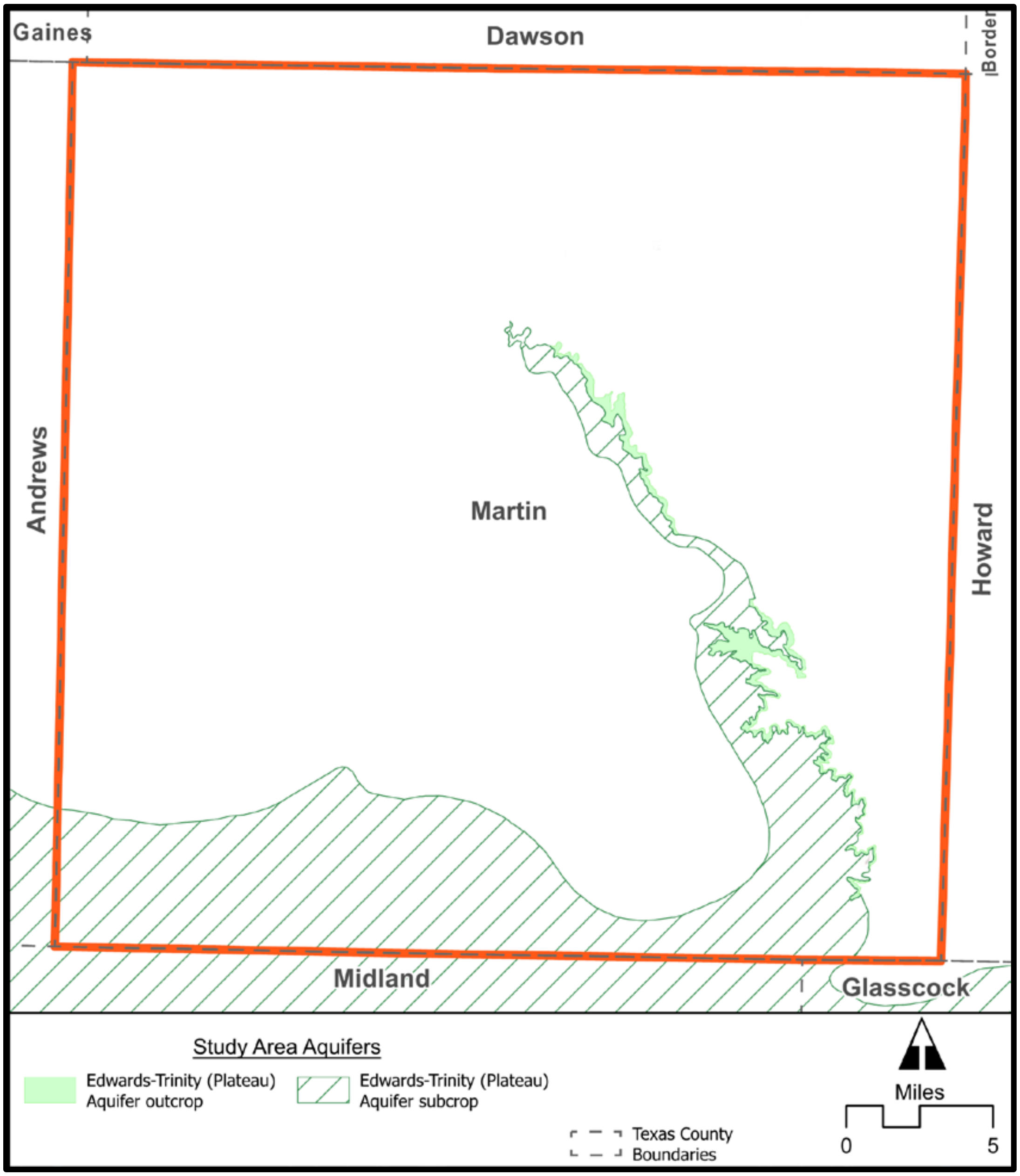


Figure 201. Martin County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

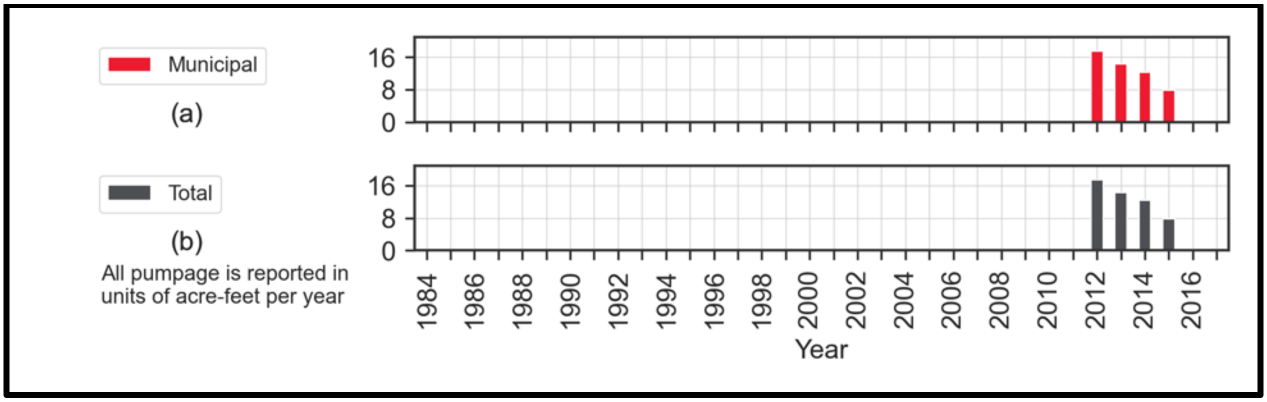


Figure 202. Martin County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

3.3.30 Mason County

The only aquifer subject to this study present in Mason County is the Edwards-Trinity (Plateau) Aquifer (see Figure 203). Other aquifers within Mason County serve as the primary groundwater sources for pumpage in the county (Black, 1988), with pumpage records included within the Water Use Survey data yet not presented in this report. Well yields are known to be low in the eastern portion of the Edwards-Trinity (Plateau) Aquifer, so there is little pumpage from the aquifer within Mason County (HUWCD, 2019).

As shown on Figure 204, groundwater pumping from the Edwards-Trinity (Plateau) Aquifer reportedly occurred since 2000 for only livestock and non-surveyed municipal uses. Pumping for livestock ranged between 5 and 15 acre-feet per year while pumping for municipal use ranged from zero to 1.6 acre-feet per year. Manual review of the data did not yield any anomalies, except for the fact that the Water Use Survey database does not contain pumpage values prior to 2000.

Figure 205 presents the year-to-year change analysis and Figure 206 presents the standard deviation analysis. These analyses detected anomalies, yet as the magnitude of the reported use is small (relative to usage from within other study area counties), we do not recommend researching the validity of the reported data. We do recommend, however, researching the possibility of estimation and quantification of pumpage values not currently contained within the Water User Survey database, especially for the period from 1984 to 1999.

The TWDB Water Use Survey data also includes reported pumping of less than two acre-feet per year for municipal use within Mason County from the Trinity (Hill Country) Aquifer. However, the TWDB defined footprint for the Trinity (Hill Country) Aquifer does not extend into Mason County. The pumping assigned to the Trinity (Hill Country) Aquifer is likely coming from the Edwards-Trinity (Plateau) Aquifer. We will research this anomalous pumping source in subsequent project tasks.

Table 37 provides the years identified as having anomalous pumping amounts for Mason County for the Edwards-Trinity (Plateau) Aquifer, based on our manual review, year-to-year change (Figure 205), and standard deviation (Figure 206) analyses.

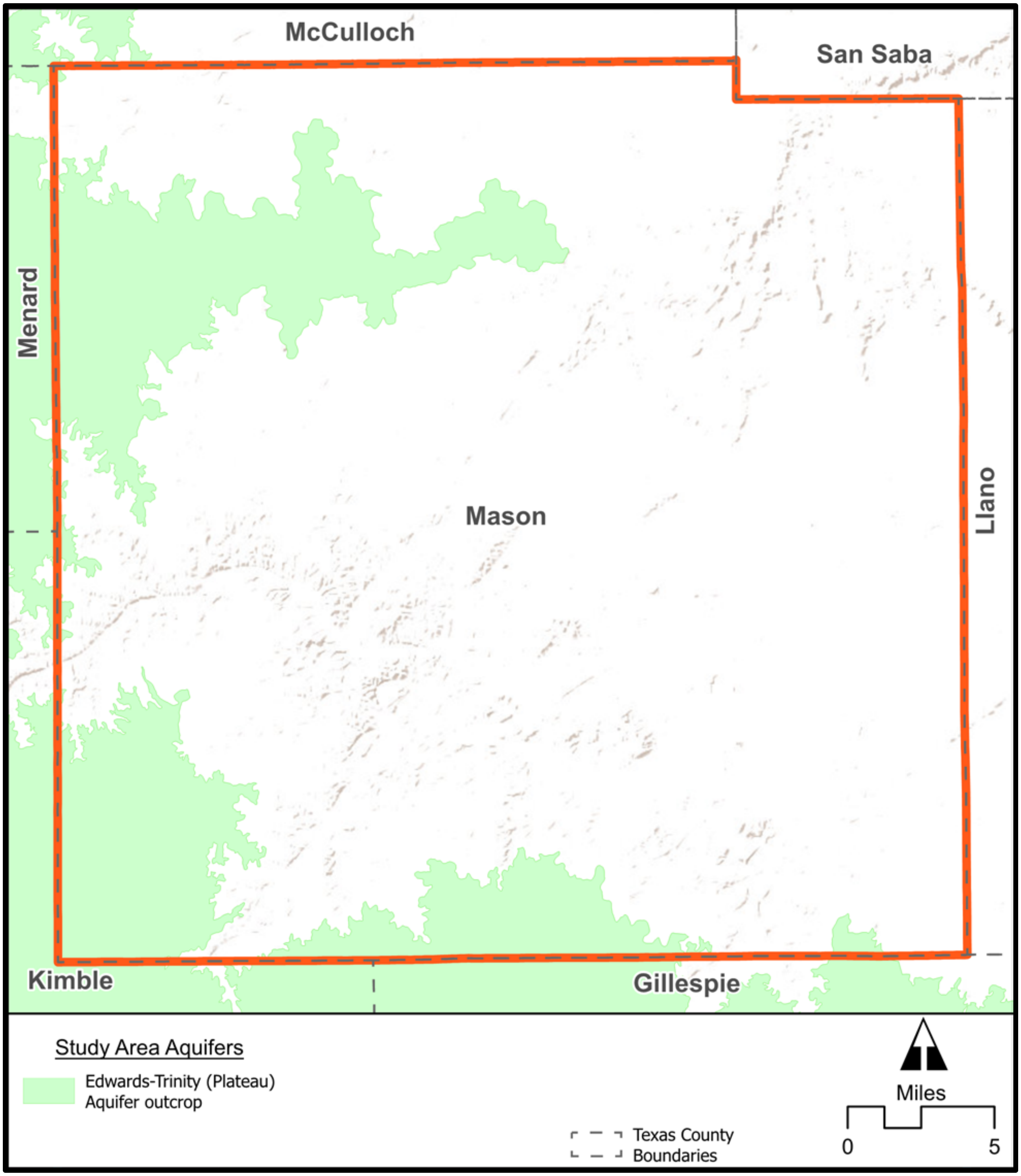


Figure 203. Mason County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

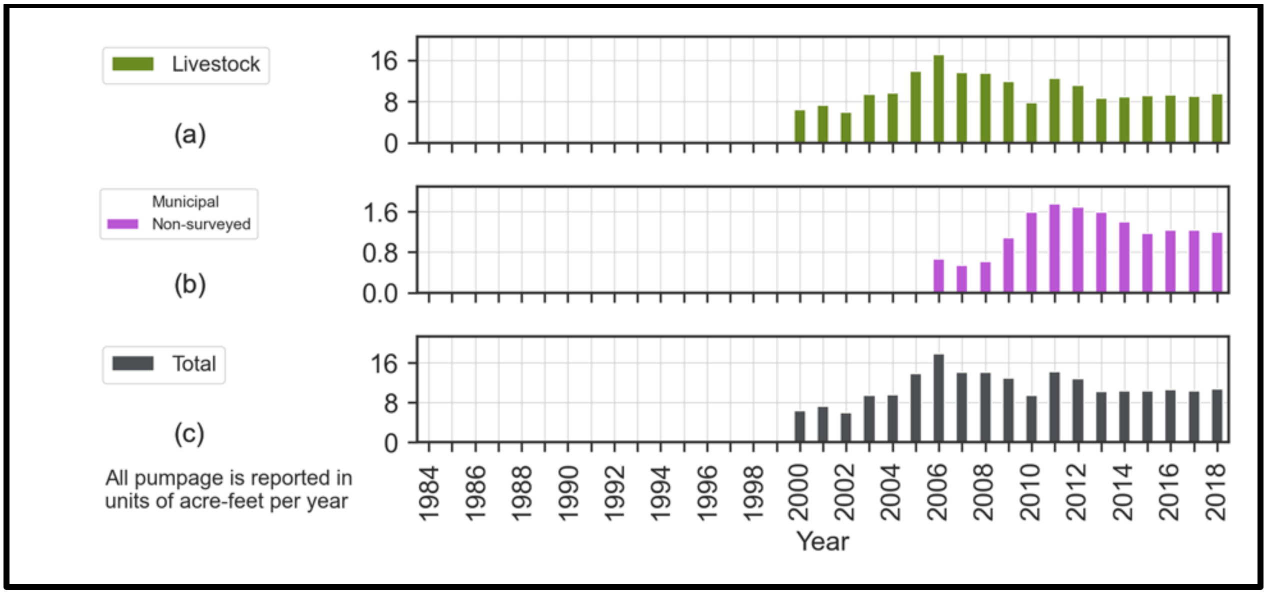


Figure 204. Mason County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

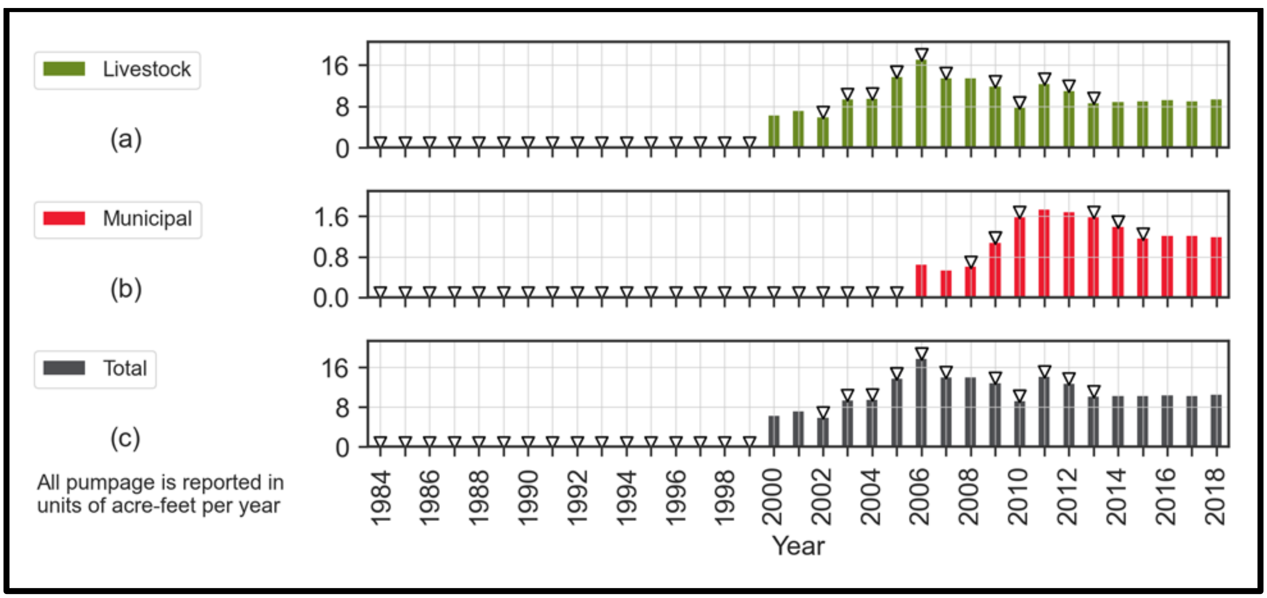


Figure 205. Mason County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

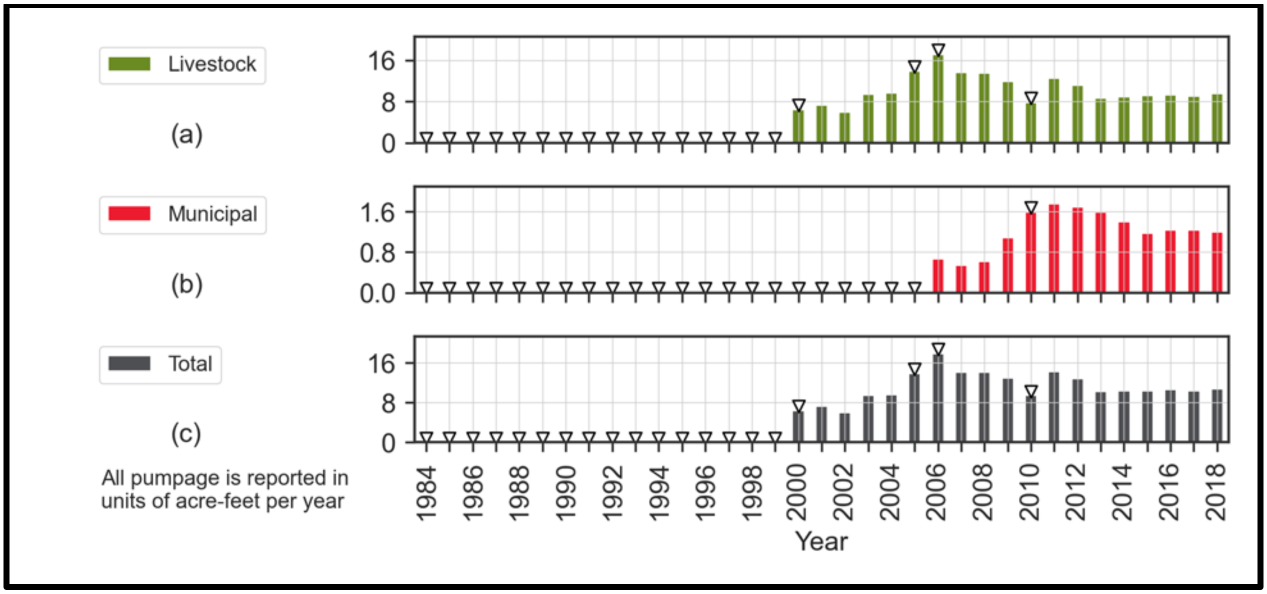


Figure 206. Mason County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 37. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Mason County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	1984-1999, 2010	2003, 2005-2007, 2010, 2011, 2013	2005, 2006, 2010
	Municipal	1984-2005	2000-2006, 2009, 2010, 2014, 2015, 2009, 2010, 2014, 2015	2000-2005, 2010, 2010, 2011

3.3.31 McCulloch County

The Edwards-Trinity (Plateau) Aquifer is present in the central and southwestern portions of McCulloch County, covering about 26 percent of the total county area. Figure 207 illustrates the extent of the Edwards-Trinity (Plateau) Aquifer in McCulloch County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer within McCulloch County was approximately 500 acre-feet, which occurred both in 2017 and 2018 (Figure 208). As shown on Figure 208, reported pumpage is for livestock, manufacturing, and municipal uses. Since 2006, non-surveyed municipal use accounts for all the municipal water use from the Edwards-Trinity (Plateau) Aquifer in McCulloch County. Manual review of Figure 208 suggests anomalies in livestock use for 1984, 1993, and 2003, as well as a large anomaly in manufacturing use in 2017. The Water Use Survey dataset contain neither manufacturing data for 1984 through 2011 nor municipal data for 1993 through 2005.

The year-to-year change analysis (Figure 209) and standard deviation analysis (Figure 210) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer. These anomalies included those identified within the manual review. Table 38 provides the years identified as having anomalous pumping amounts for McCulloch County for the Edwards-Trinity (Plateau) Aquifer.

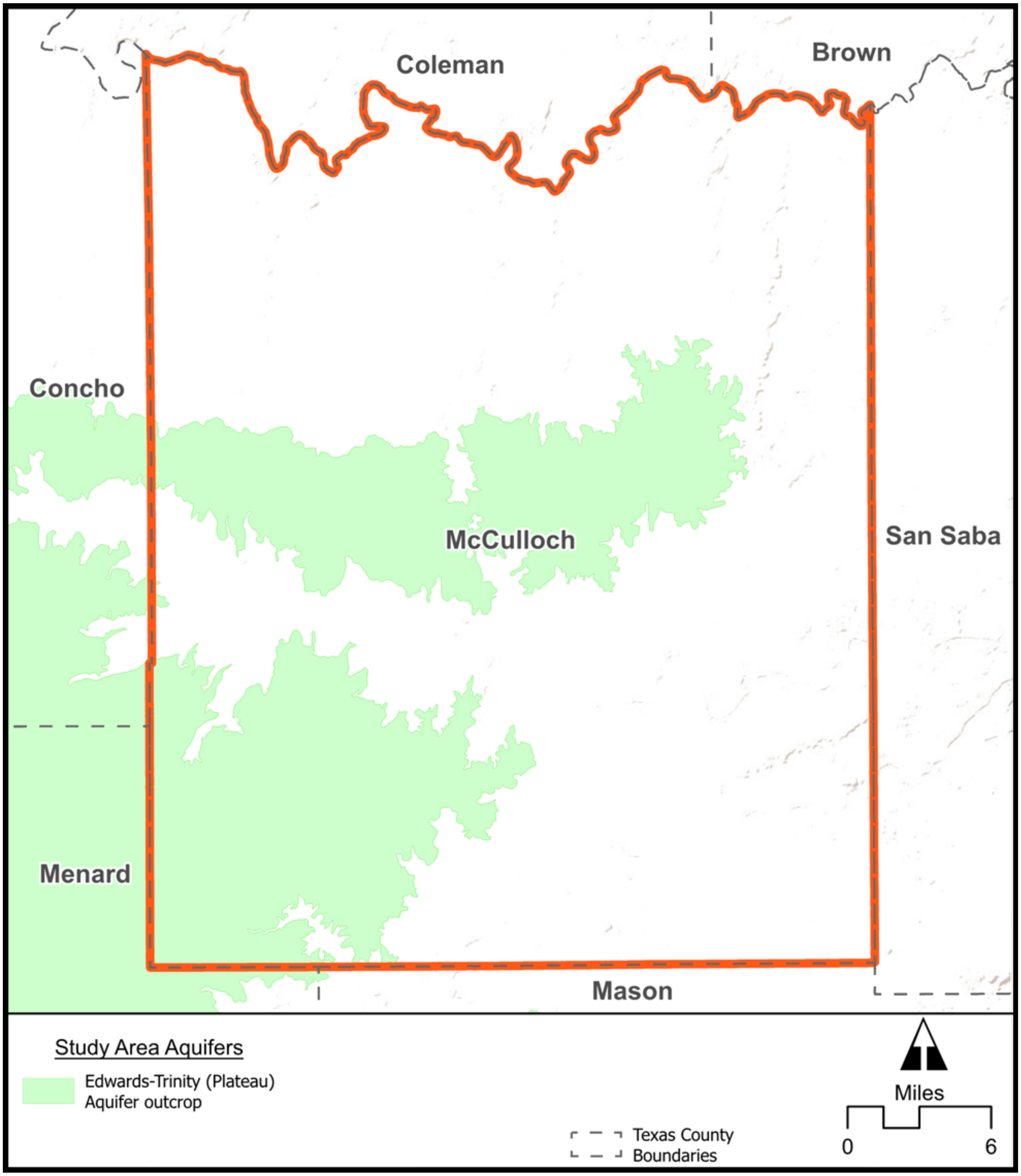


Figure 207. McCulloch County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

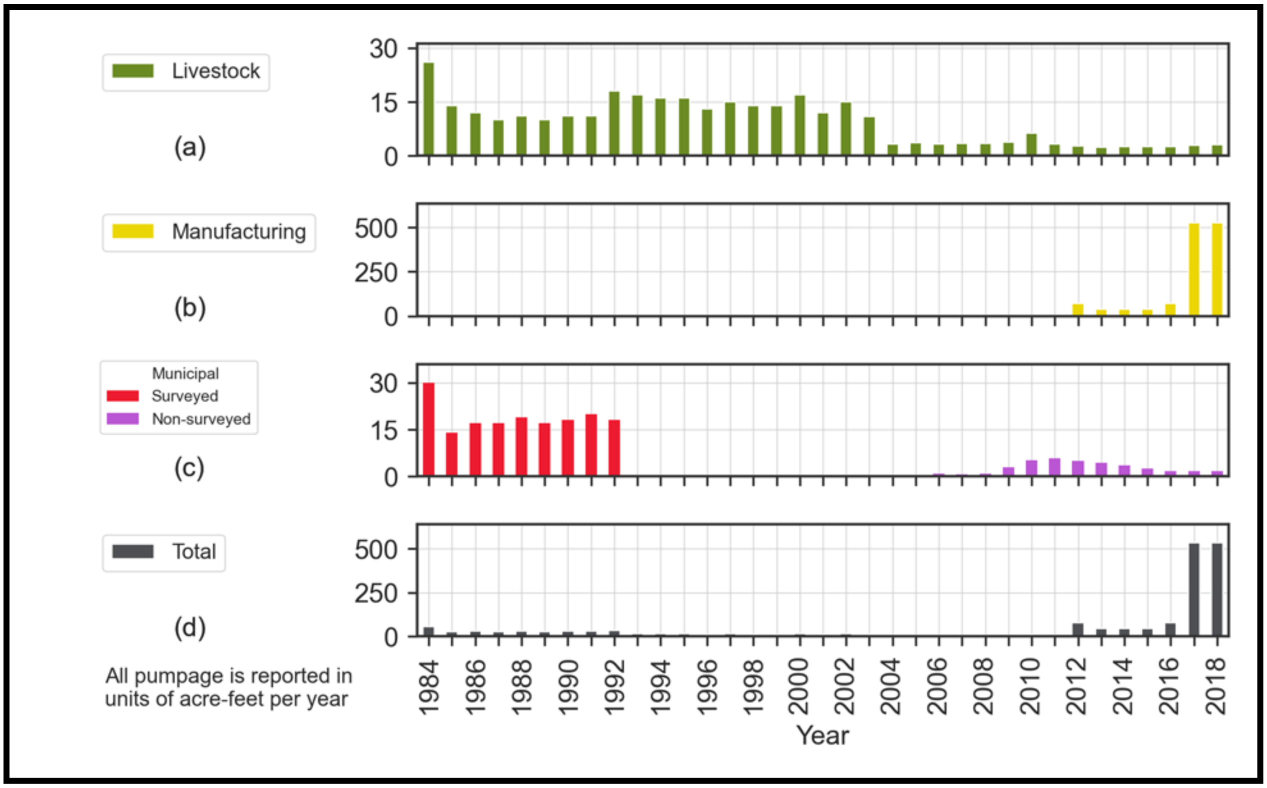


Figure 208. **McCulloch County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

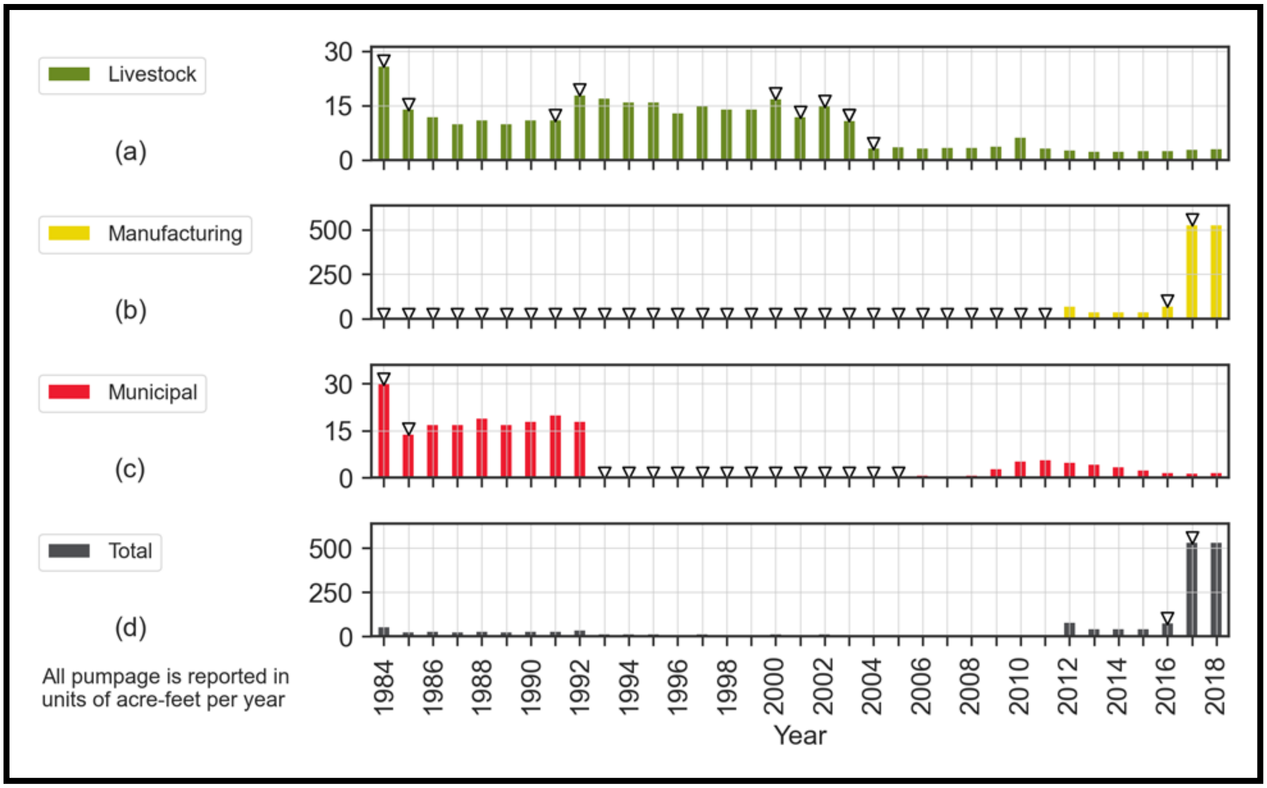


Figure 209. McCulloch County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

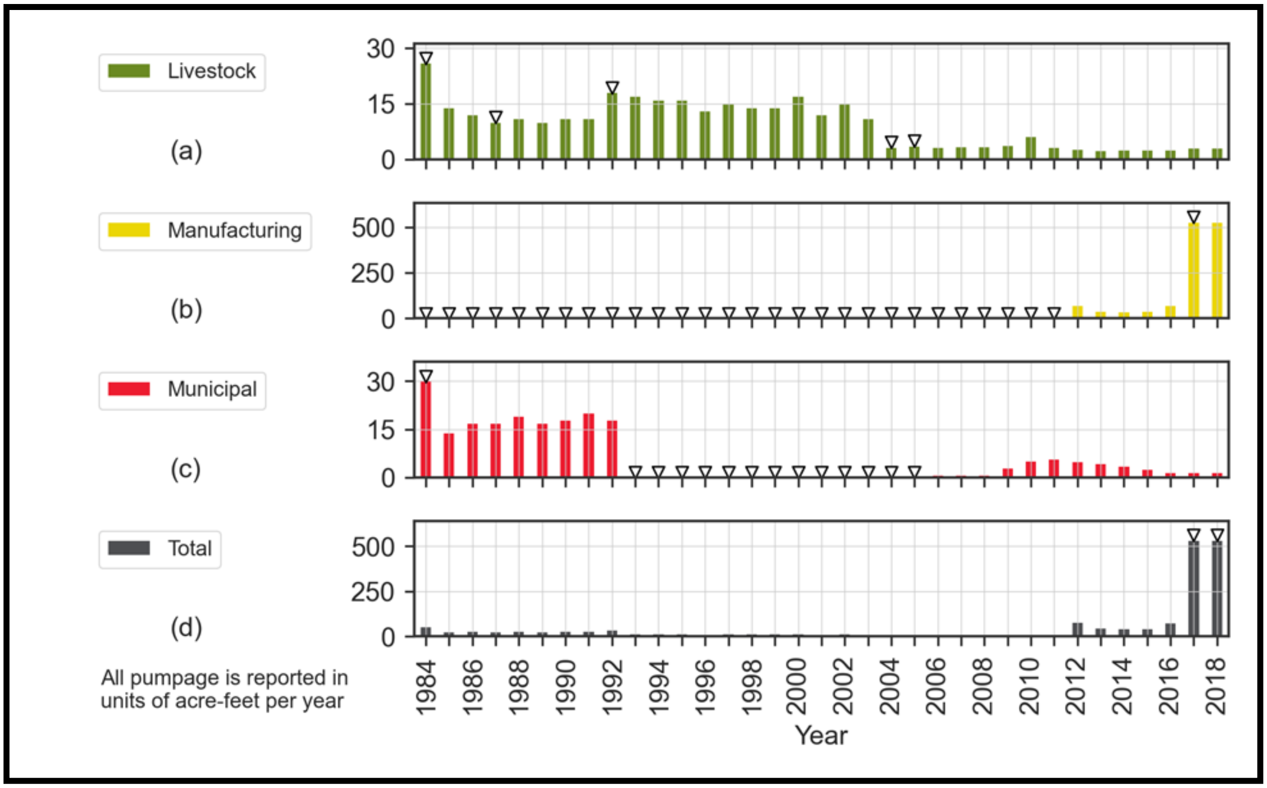


Figure 210. **McCulloch County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

Table 38. **Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for McCulloch County.**

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Livestock	1984, 1993, 2003, 2004	1984, 1985, 1992, 2001, 2003, 2004	1984, 1987, 1992, 2004, 2005
	Manufacturing	1984-2011, 2017	1984-2011, 2017	1984-2011, 2017
	Municipal	1993-2005	1984, 1985, 1993-2005	1984, 1993-2005

3.3.32 Medina County

The Trinity (Hill Country) Aquifer and overlying Edwards (Balcones Fault Zone) Aquifer underlie nearly all of Medina County (see Figure 211). As shown on Figure 212, total annual groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer was more than 100,000 acre-feet in some years at the beginning of the study period. Irrigation is the primary use of Edwards (Balcones Fault Zone) Aquifer groundwater followed by municipal use.

Pumping from the Edwards (Balcones Fault Zone) Aquifer for irrigation shows a generally increasing trend from 1984 to 1991 that almost doubled pumpage from about 50,000 acre-feet in 1985 to about 100,000 acre-feet in 1991. After 1991, we observe a gradual decrease in groundwater pumpage to approximately 25,000 acre-feet in 2003. Pumping for municipal use appears to have a relatively small constant increase over the study period with annual use ranging between 4,000 and 7,000 acre-feet. Surveyed municipal water usage from the Edwards (Balcones Fault Zones) Aquifer in Medina County accounts for practically all the total municipal use.

Reported pumping from the Edwards (Balcones Fault Zone) Aquifer for livestock remained very low between 1984 and 2004 and then abruptly increased in 2005. Similarly, pumping for mining remained low throughout the entire study period until 2018 when the pumpage volume peaked at about 1,600 acre-feet. The year-to-year change analysis (Figure 213) and standard deviation analysis (Figure 214) flagged many of the same anomalies identified in the manual review process.

As shown on Figure 215, total groundwater pumping from the Trinity (Hill Country) Aquifer is significantly less than that from the Edwards (Balcones Fault Zone) Aquifer, with a maximum annual pumpage of 1,000 acre-feet occurring in 2018. Pumpage values for livestock, mining, and municipal usage are within the Water Use Survey database, yet mining data is only included for 2018. Pumping for municipal use from the Trinity (Hill Country) Aquifer is consistently low from 1984 through 2004 followed by a gradual increase until 2011 when it peaked at approximately 250 acre-feet before subsequently decreasing through 2018. Since 2006, non-surveyed municipal use accounts for a significant portion of the total municipal water use from the Trinity (Hill Country) Aquifer in Medina County. Like pumping from the Edwards (Balcones Fault Zone) Aquifer, the Trinity (Hill Country) Aquifer pumping for livestock remained low between 1984 and 2004 and then abruptly increased in 2005. Figure 216 (year-to-year change analysis) and Figure 217 (standard deviation analysis) each identify as anomalies the abrupt increase in pumpage from the Trinity (Hill Country) Aquifer for livestock use in 2005, for mining use in 2018, and in 2011 for municipal use.

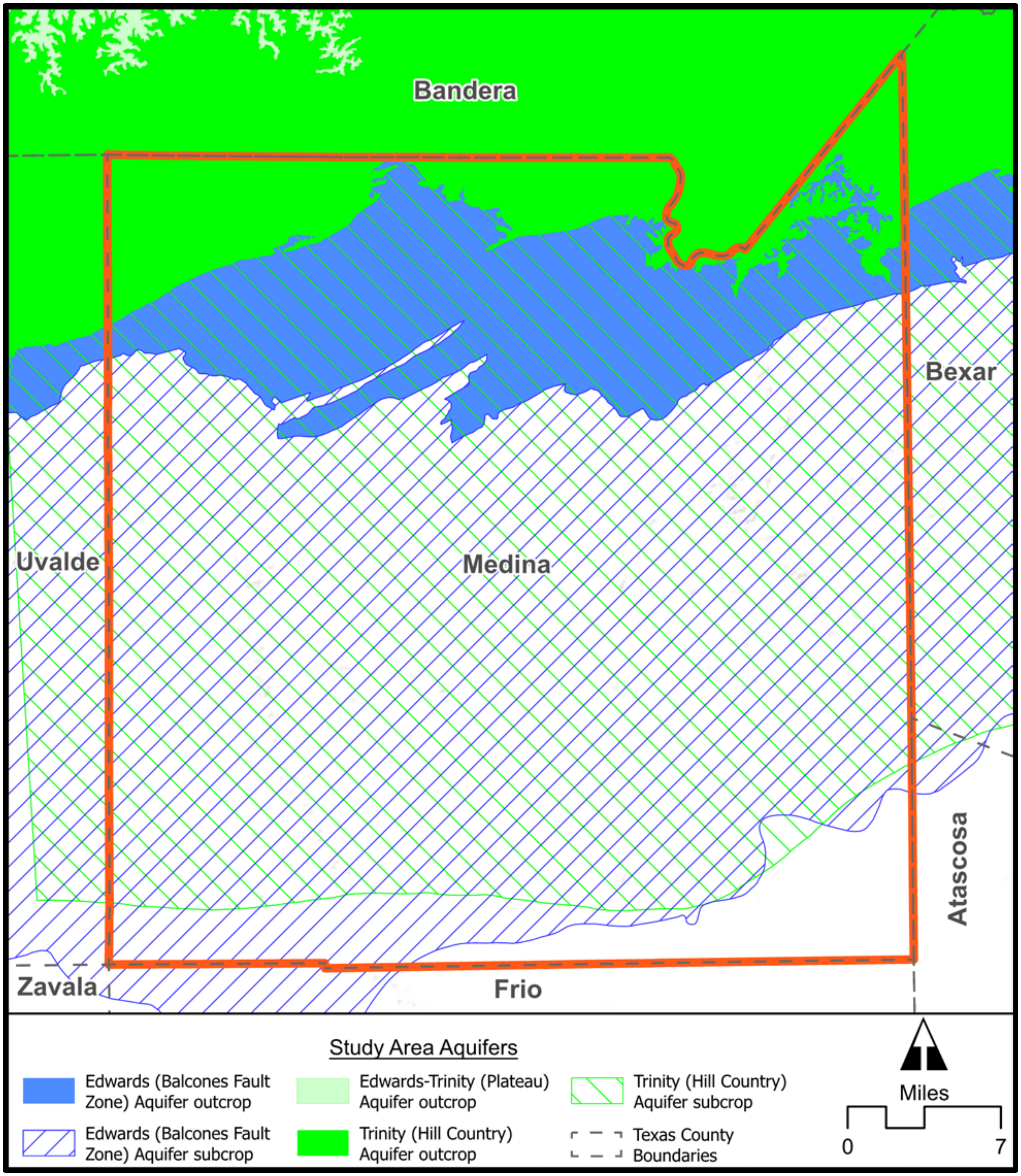


Figure 211. Medina County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer.

Land overlying the Edwards (Balcones Fault Zone) Aquifer in Medina County potentially used for irrigation negatively correlates to groundwater pumpage from the Edwards (Balcones Fault Zone) Aquifer for irrigation use. Figure 218 indicates that although the acres of potentially irrigated land overlying the aquifer have increased within Median County, the reported pumpage for irrigation use has decreased. Figure 219 indicates a linear correlation value (“*r*”) of -0.74 between potentially irrigated land area and groundwater pumpage for irrigation. The observed strong negative correlation suggests that pumpage for irrigation in Medina County is potentially anomalous. Another interpretation of the negative correlation is that farming practices have evolved over the study period such that irrigators use less water to grow identical crops or have switched to different crops (with different water needs). We will revisit this correlation relationship after researching Medina County farming and irrigation practices under subsequent project phases.

Table 39 provides the years identified as having anomalous pumping amounts for Medina County for the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer based on our manual review, year-to-year change (Figure 213 and Figure 216), and standard deviation (Figure 214 and Figure 217) analyses.

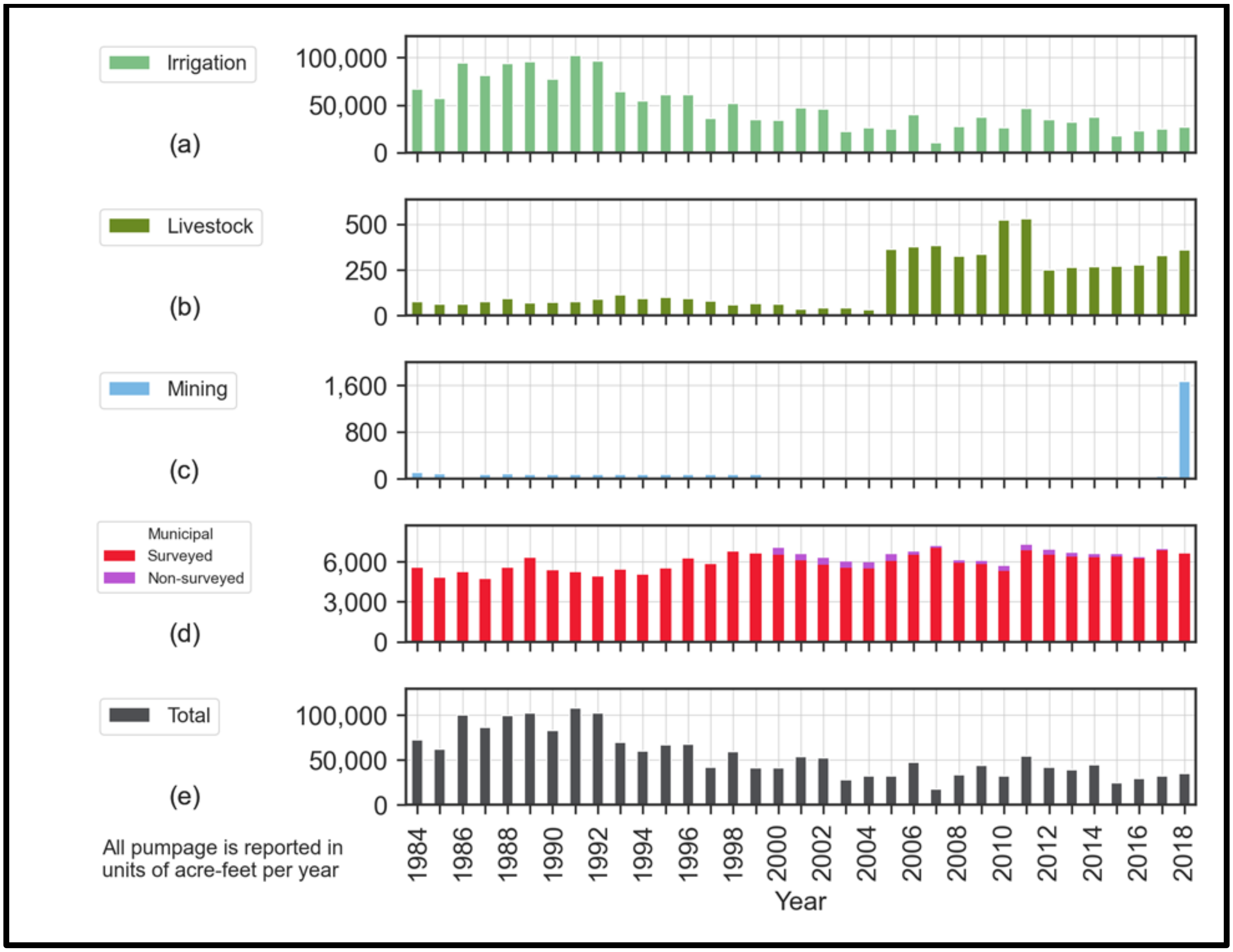


Figure 212. Medina County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

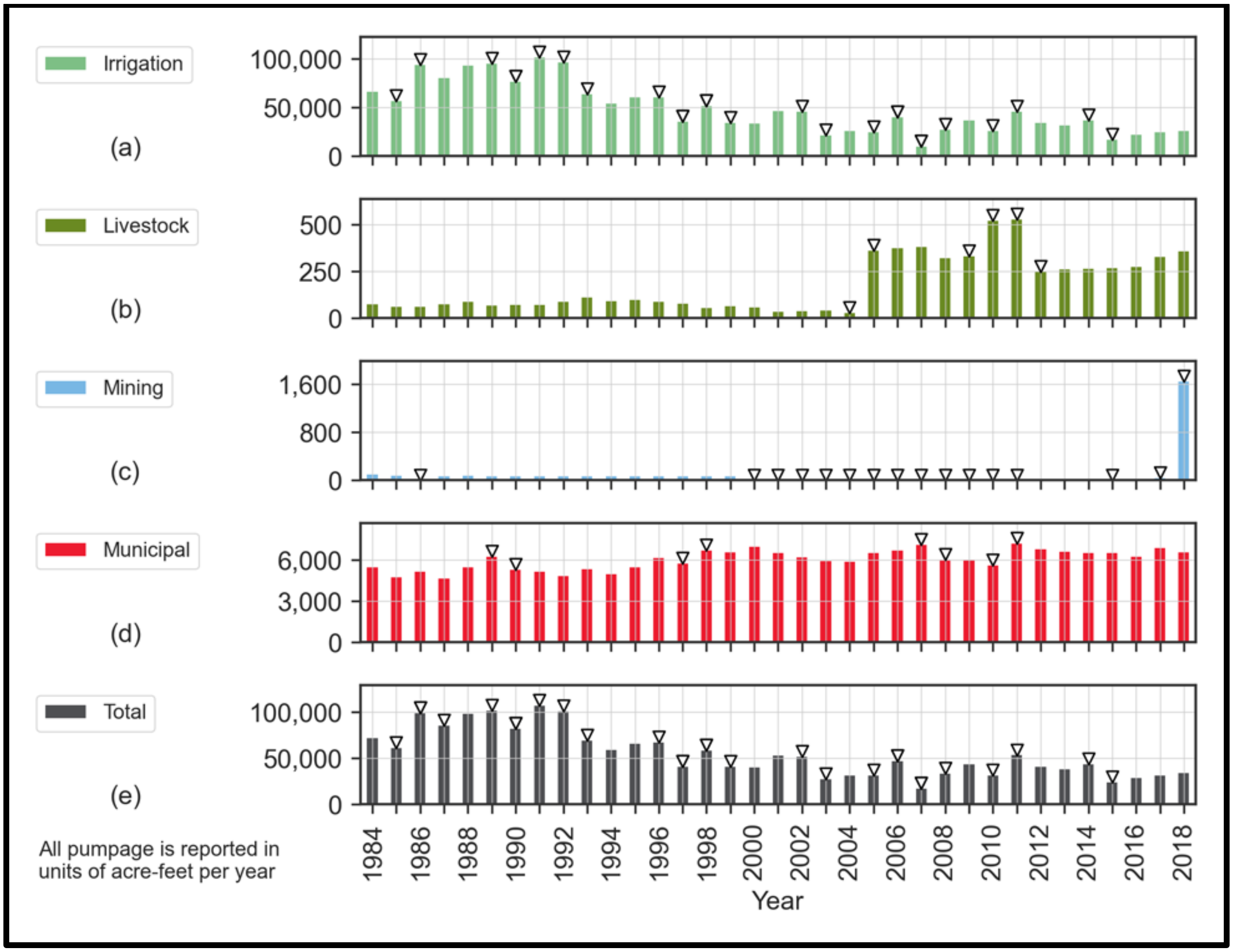


Figure 213. Medina County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

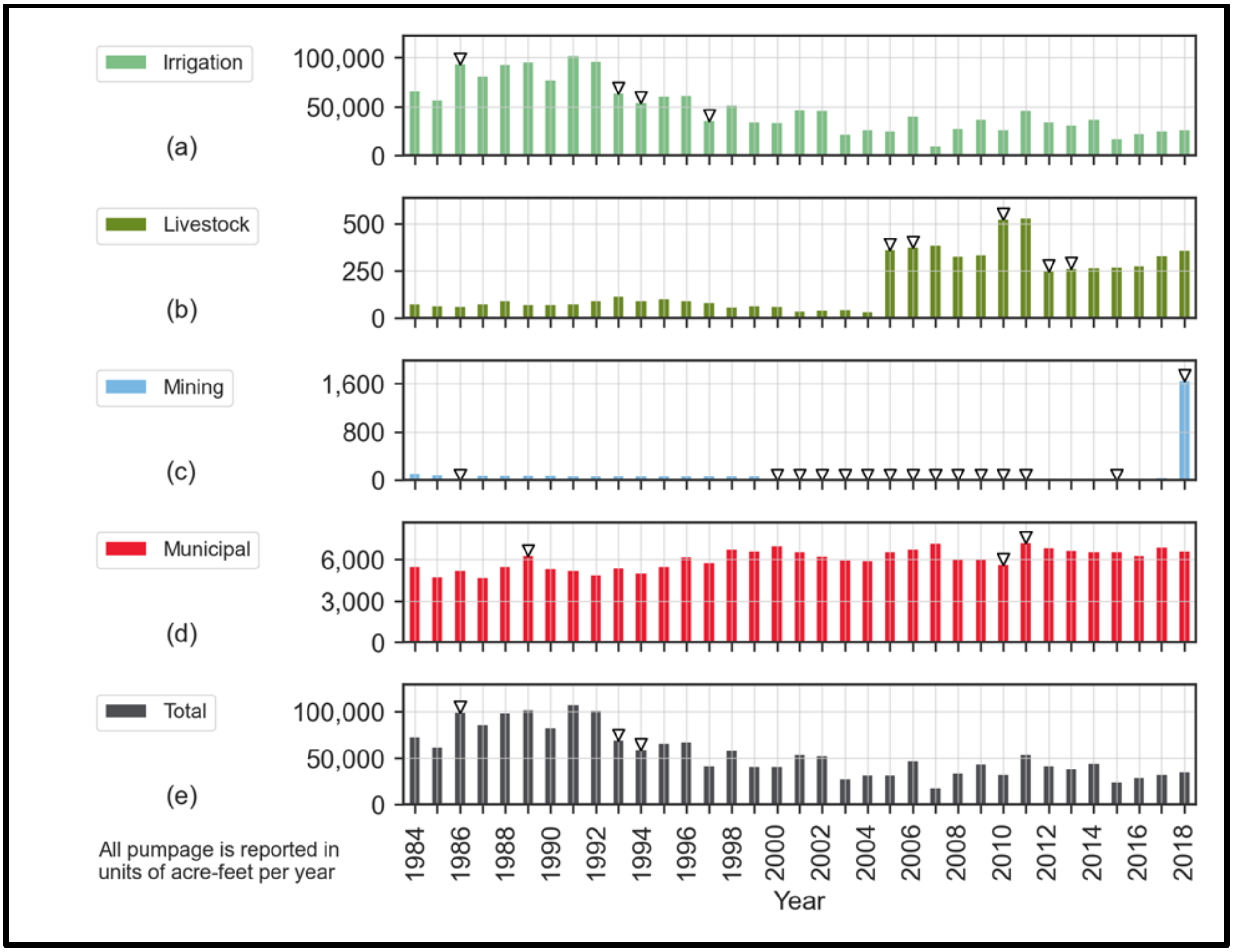


Figure 214. Medina County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

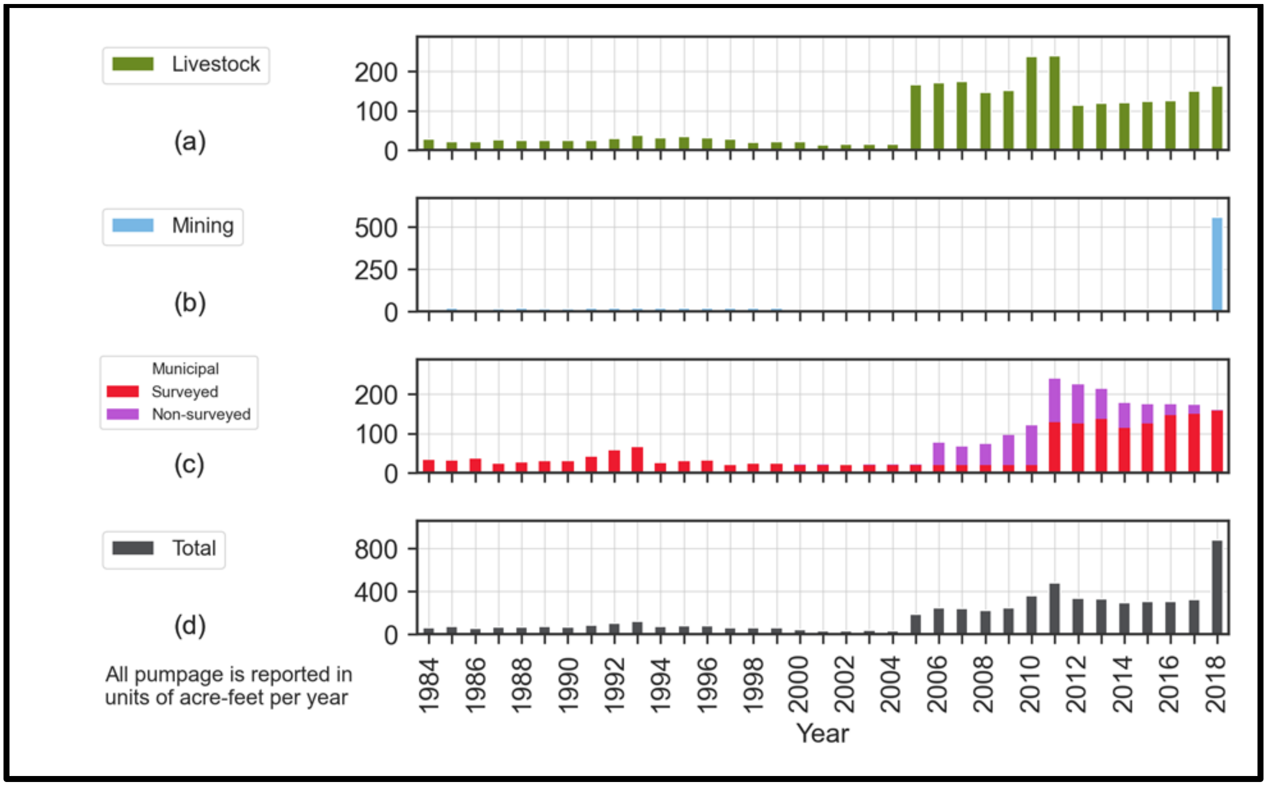


Figure 215. Medina County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

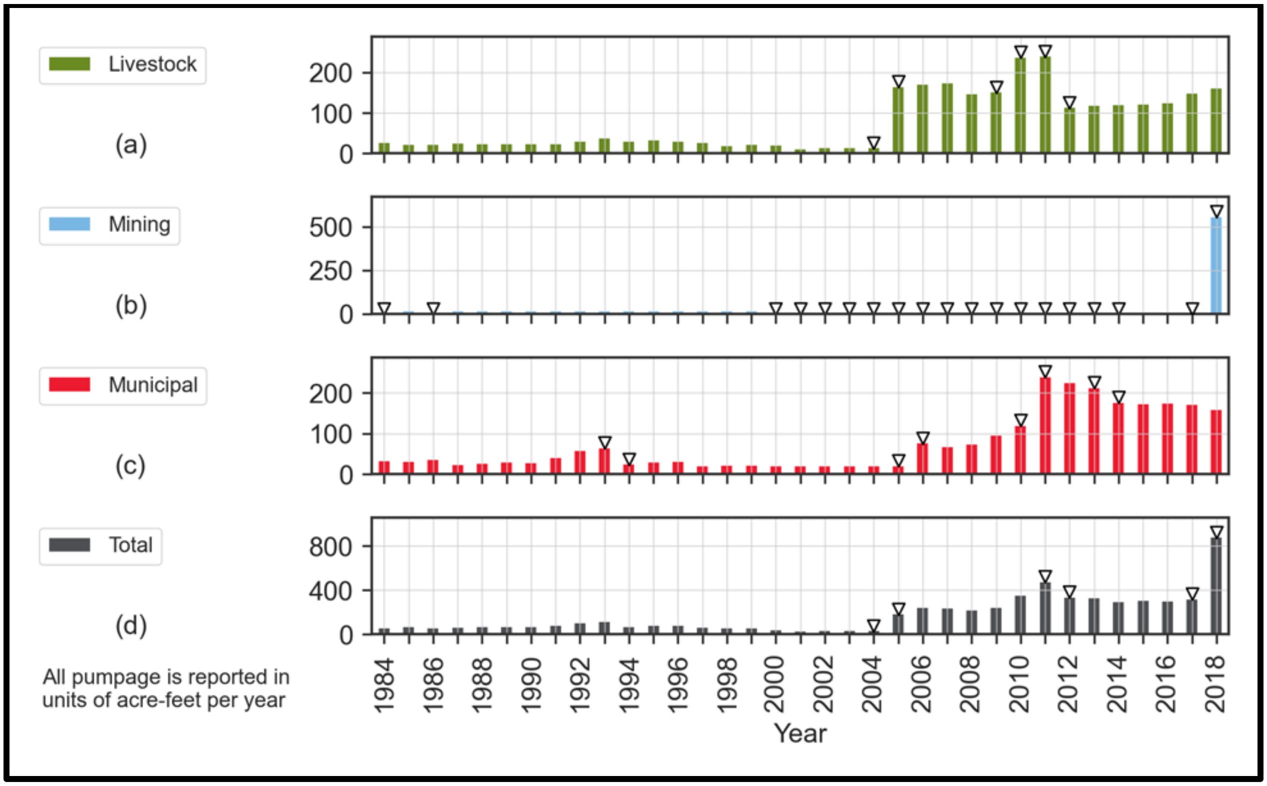


Figure 216. Medina County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

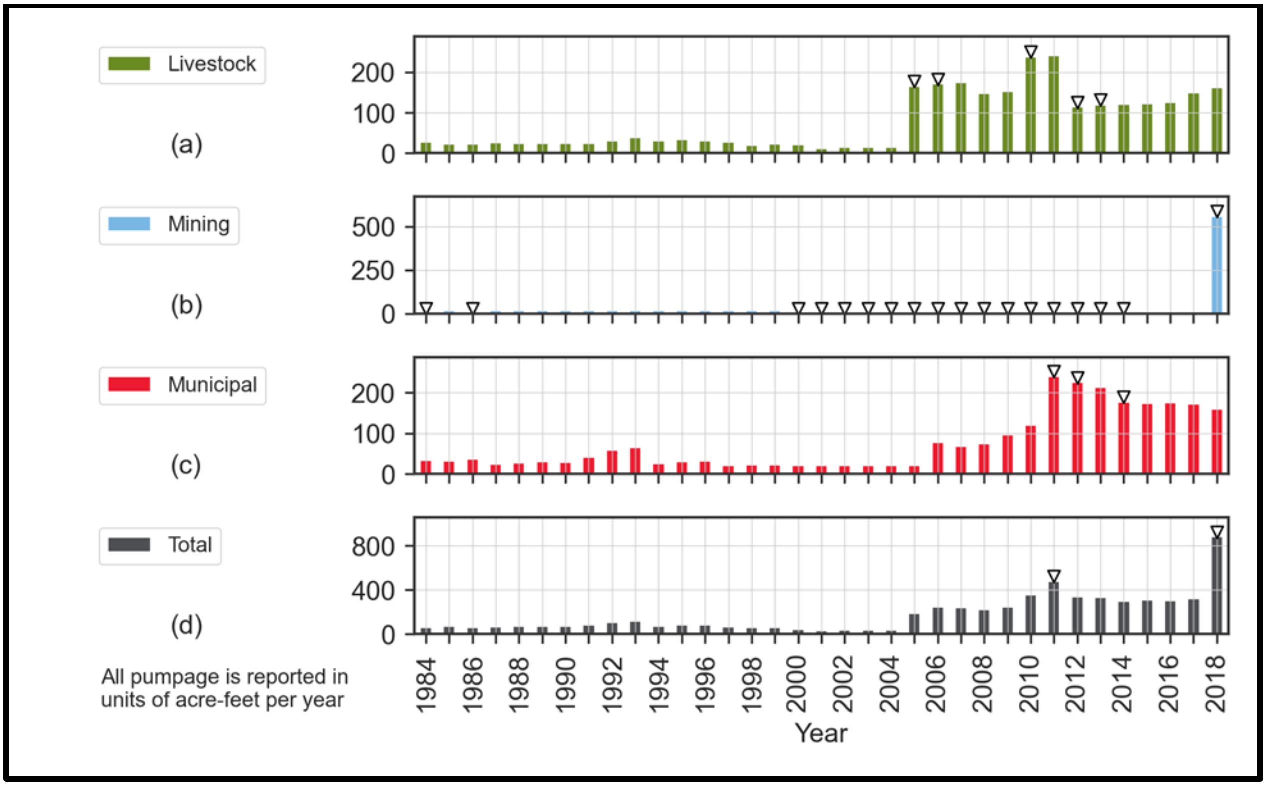


Figure 217. Medina County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

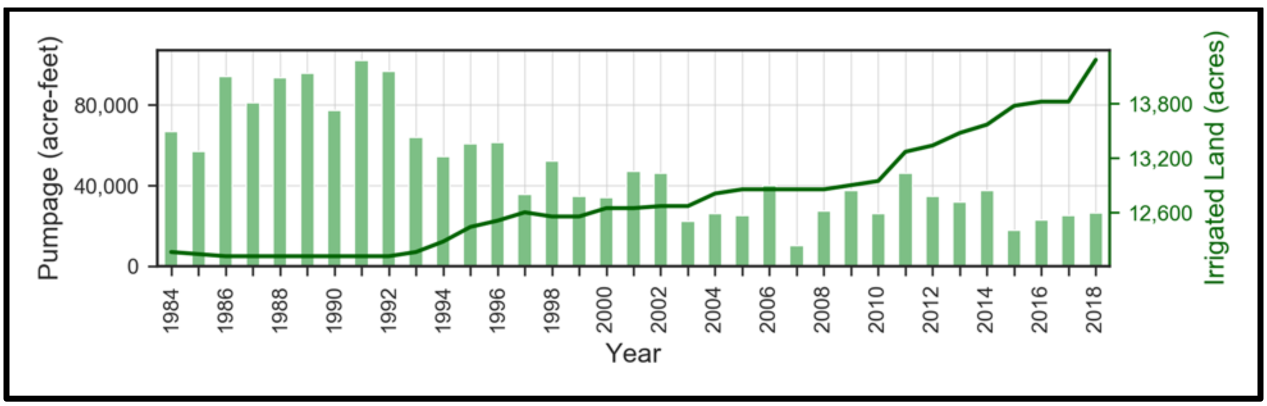


Figure 218. Medina County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation in acre-feet per year as reported in the TWDB Water Use Survey data and acres of potentially irrigated land area (according to land use data) overlying the aquifer.

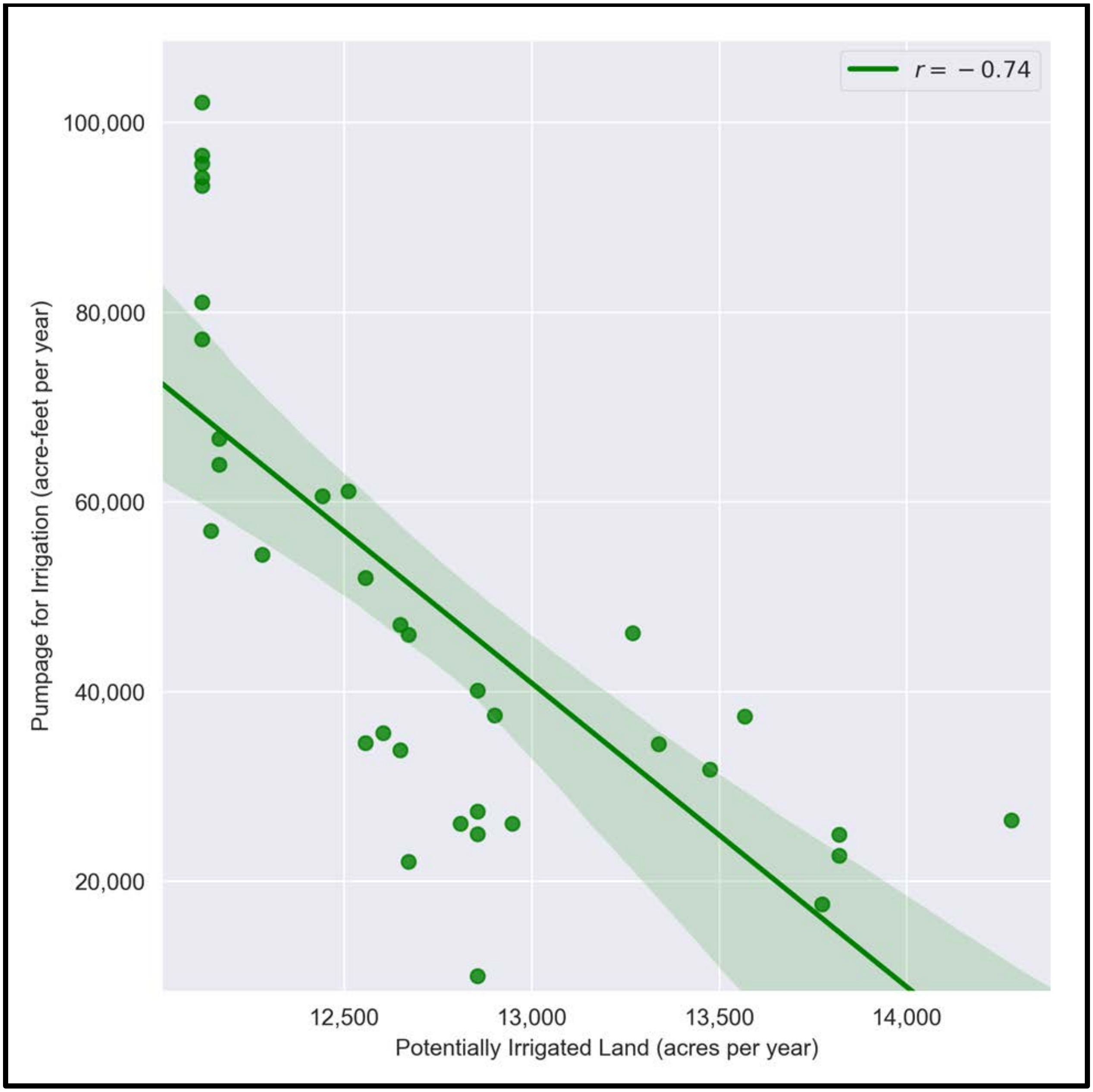


Figure 219. Medina County Edwards (Balcones Fault Zone) Aquifer groundwater pumping or irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 39. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Medina County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	1986, 1993, 1997	1986, 1990, 1991, 1993, 1997-1999, 2003, 2006-2008, 2011, 2015	1986, 1993, 1994, 1997
	Livestock	2005, 2010-2011	2005, 2010, 2012	2005, 2006, 2010, 2012, 2013
	Mining	2018	1986, 2000-2011, 2015, 2018	1986, 2000-2011, 2015, 2018
	Municipal	1989, 2011	1990, 1998, 2008, 2011	1989, 2010, 2011
Trinity (Hill Country)	Livestock	2005, 2010-2011	2005, 2010, 2012	2005, 2006, 2010, 2012, 2013
	Mining	2018	1984, 1986, 2000-2014, 2018	1984, 1986, 2000-2014, 2018
	Municipal	2011, 2014	1994, 2006, 2011, 2014	2011, 2012, 2014

3.3.33 Menard County

The Edwards-Trinity (Plateau) Aquifer is present over almost all of Menard County. Figure 220 illustrates the extent of the Edwards-Trinity (Plateau) Aquifer in the county.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer was approximately 1,000 acre-feet in 1994, 1999 and 2006 (Figure 221). As shown on Figure 221, reported pumpage is for irrigation, livestock, and municipal use. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, it has accounted for only a small portion of the total municipal water use until 2010 after which it accounts for all the municipal water use from the Edwards-Trinity (Plateau) Aquifer in Menard County. Manual review of Figure 221 suggests numerous anomalies, including the low irrigation pumping reported between 2000 and 2005. The 1994 reported pumpage for livestock is also likely anomalous along with the amounts for 2000 and 2010 municipal use.

The year-to-year change analysis (Figure 222) and standard deviation analysis (Figure 223) flagged numerous anomalies in the data for the Edwards-Trinity (Plateau) Aquifer in Menard County. Identified anomalies included those identified from the manual data review, as well as numerous additional years of irrigation pumping.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Trinity (Hill Country) Aquifer was negligible. The TWDB Water Use Survey indicates pumping of less than one acre-foot per year from the Trinity (Hill Country) Aquifer for the period from 2006 through 2018 (see Figure 224). However, the TWDB footprint for the Trinity (Hill Country) Aquifer does not extend to Menard County and we expect the pumping is likely from the Edwards-Trinity (Plateau) Aquifer.

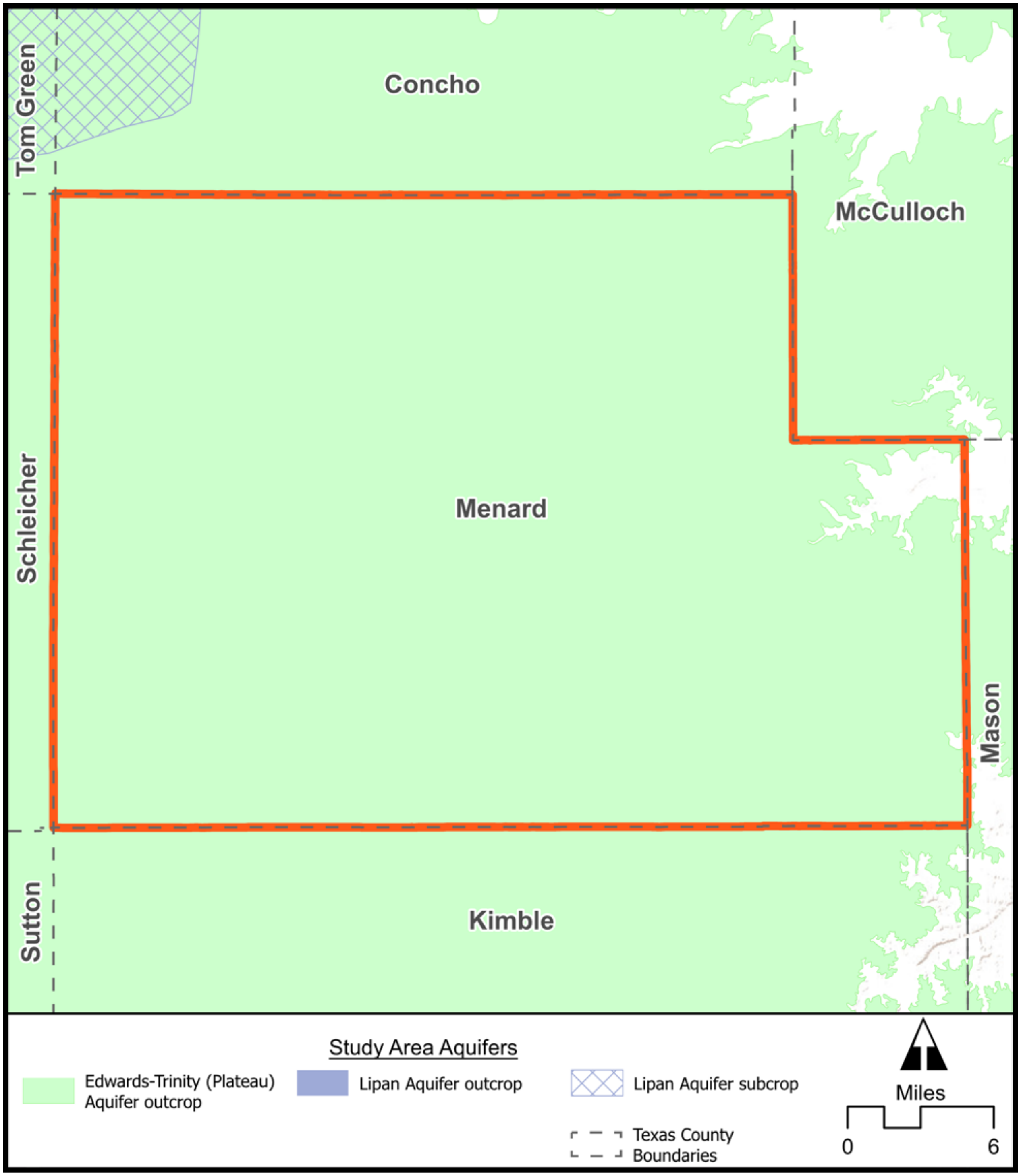


Figure 220. **Menard County showing the extent of the Edwards-Trinity (Plateau) Aquifer.**

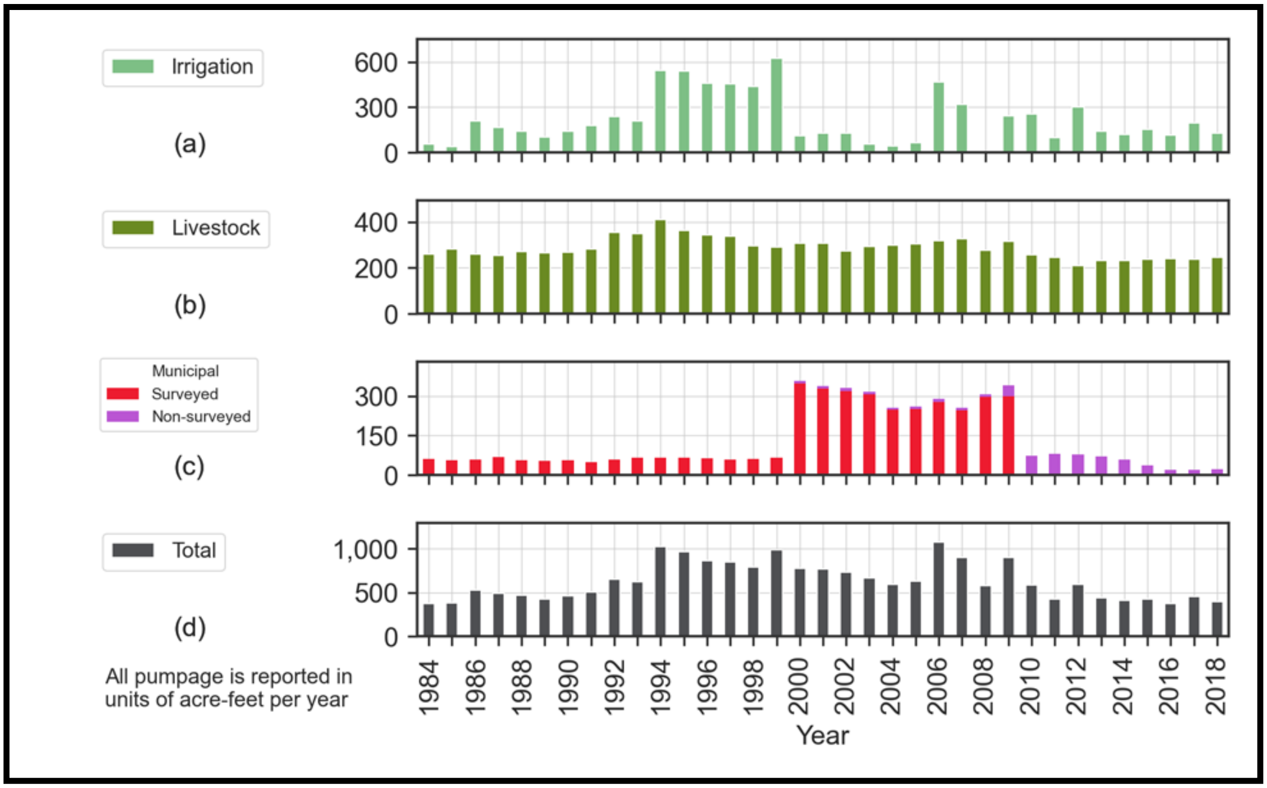


Figure 221. Menard County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

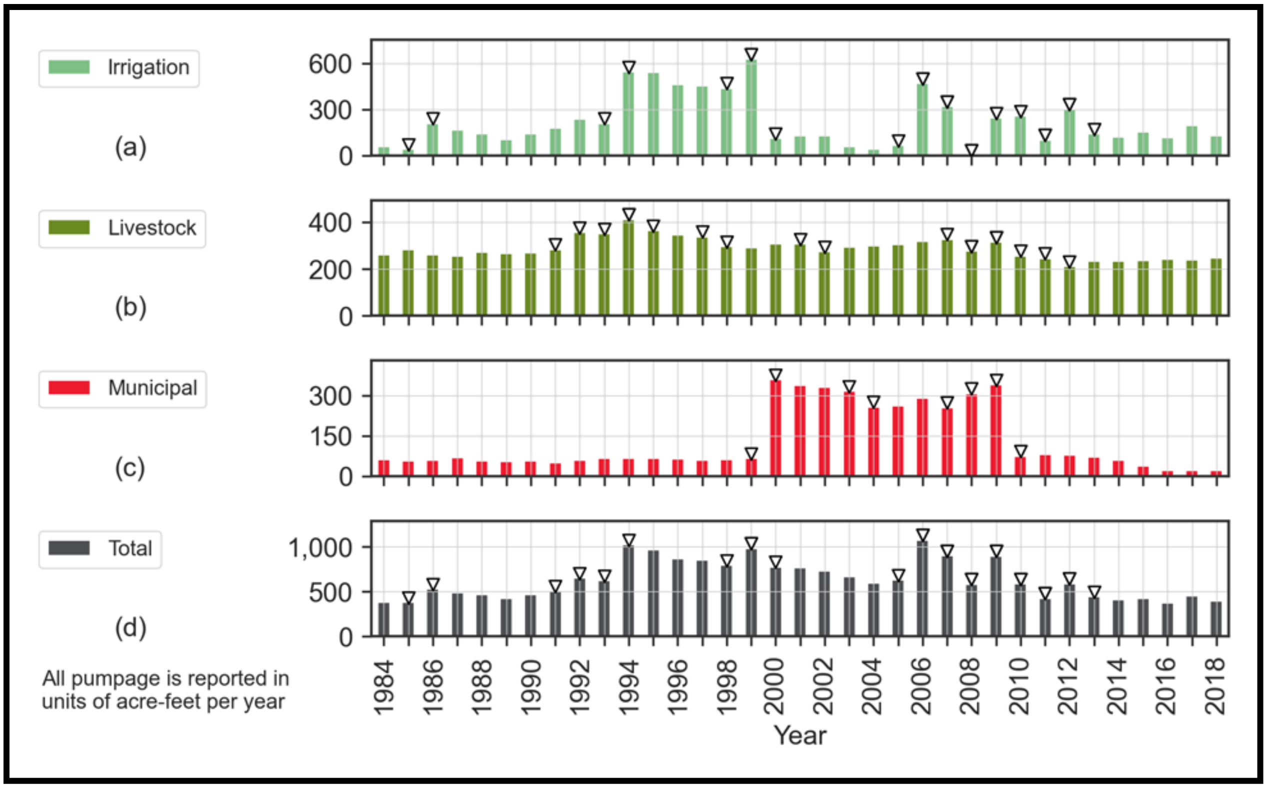


Figure 222. Menard County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

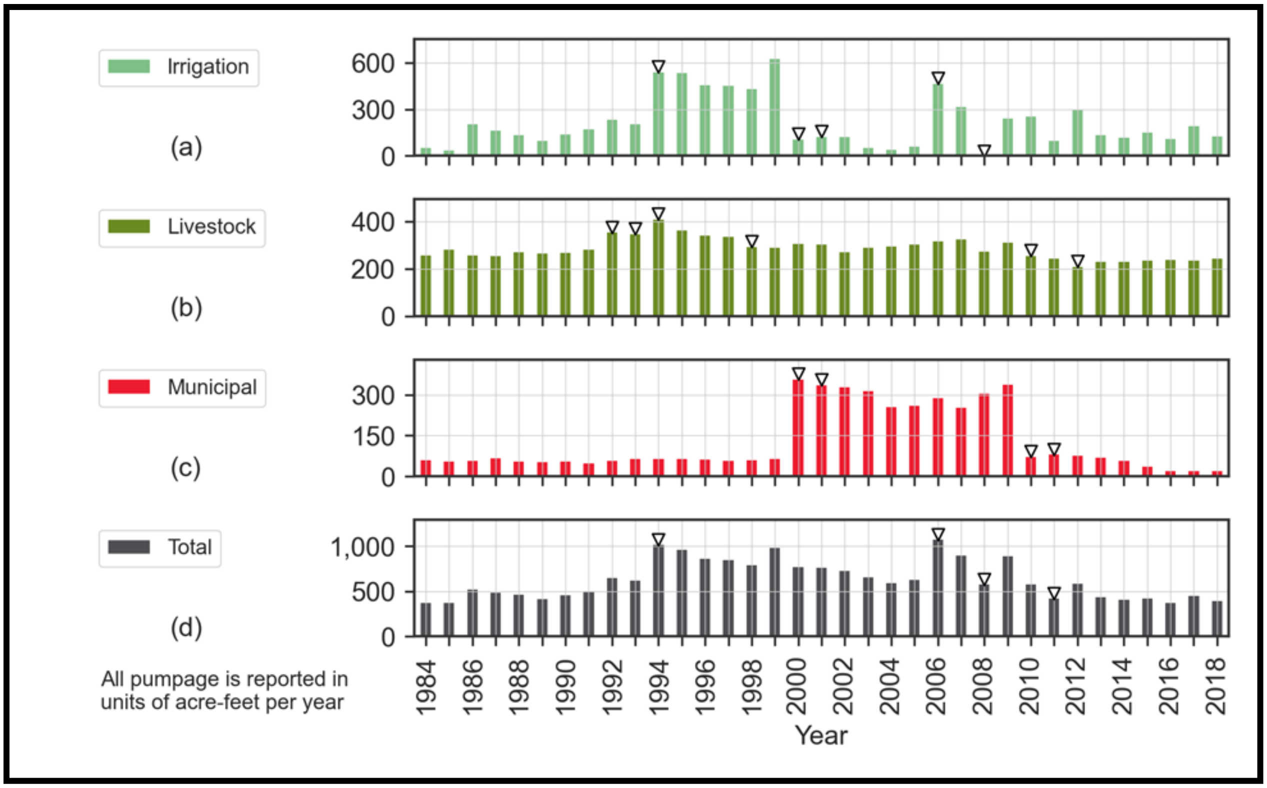


Figure 223. Menard County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

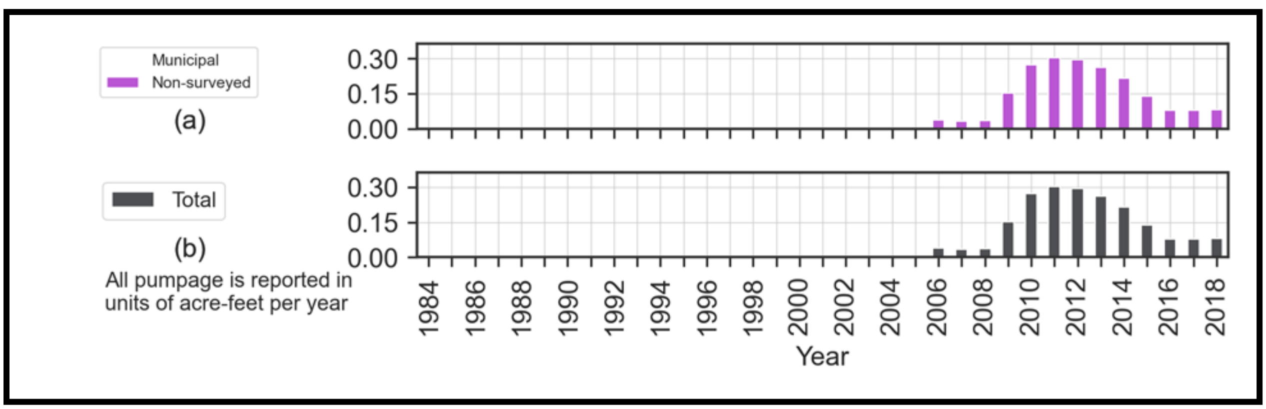


Figure 224. Menard County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. We expect this data should be attributed to pumping from the Edwards-Trinity (Plateau) Aquifer.

Table 40. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Menard County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	2000-2006, 2008	1986, 1994, 1999, 2000, 2006-2009, 2011-2013	1994, 2000, 2001, 2006, 2008
	Livestock	1994	1992, 1994, 1995, 1998, 2002, 2008-2010, 2012	1992-1994, 1998, 2010, 2012
	Municipal	1984-2000, 2010	2000, 2004, 2008, 2010, 2009, 2010, 2015, 2016	2000, 2001, 2010, 2011, 2010
Trinity (Hill Country)	Municipal	Not present in county	None	None

3.3.34 Midland County

The Edwards-Trinity (Plateau) Aquifer underlies all of Midland County (see Figure 225). However, most withdrawals in northern Midland County are attributed to an aquifer not under investigation in this project (Lurry and Pavlicek, 1991). As shown on Figure 226, reported total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer from 1984 through 2018 generally ranges between 2,000 and 20,000 acre-feet per year. According to the Water Use Survey data, pumpage occurred for irrigation, livestock, manufacturing, mining, and municipal uses, with most of the pumpage supporting irrigation operations.

Pumping from the Edwards-Trinity (Plateau) Aquifer for irrigation shows a fairly steady increase from 1984 to 1994 and an abrupt increase in pumpage in 1995 which peaked at approximately 16,000 acre-feet. After 1995, estimated pumping was relatively consistent until an abrupt decline in 2013 as noted in the year-to-year change (Figure 227) and standard deviation (Figure 228) analyses. Pumping for livestock generally mimics the trend in pumping for irrigation with annual volumes ranging between 200 acre-feet and 400 acre-feet. In 1998, pumpage for livestock seems to decrease abruptly by 200 acre-feet following a comparatively high estimate in 1997. Pumping for municipal needs generally ranges between 1,000 and 3,000 acre-feet per year. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use accounts for a significant portion of the total municipal water use from the Edwards-Trinity (Plateau) Aquifer in Midland County.

Pumping for mining indicates a gradual decrease from 1,000 acre-feet in 1984 to 500 acre-feet in 1999. Beginning in 2000, pumping estimates for mining are significantly lower than the 1984 to 1999 trend or are unreported. In a similar manner, reported pumping for manufacturing began in 2000 and then appears relatively consistent between 100 acre-feet and 200 acre-feet. Prior to 2000, there was not any reported pumpage for manufacturing for Midland County from the Edwards-Trinity (Plateau) Aquifer.

Figure 228 captures the abrupt decrease in pumpage from the Edwards-Trinity (Plateau) for irrigation in 2013, for livestock in 1998, mining in 2000 and for municipal in 2000 and 2015. Figure 228 also identifies abrupt increases in pumpage for irrigation in 1995, for livestock in 1997, for manufacturing in 2000 and 2002, and for municipal needs in 1990, 1998 and 2011.

Figure 229 shows approximately 280 new irrigation wells and 23 new livestock wells completed in Midland County since 2015. However, irrigation and livestock pumpage since 2015 is significantly lower than the previous years. The increase in the number of wells with the decrease in estimated pumping amounts suggests an anomaly in the data or that actual groundwater pumpage is not well correlated to the total number of wells included in available public databases. We review this potential correlation further during subsequent project phases.

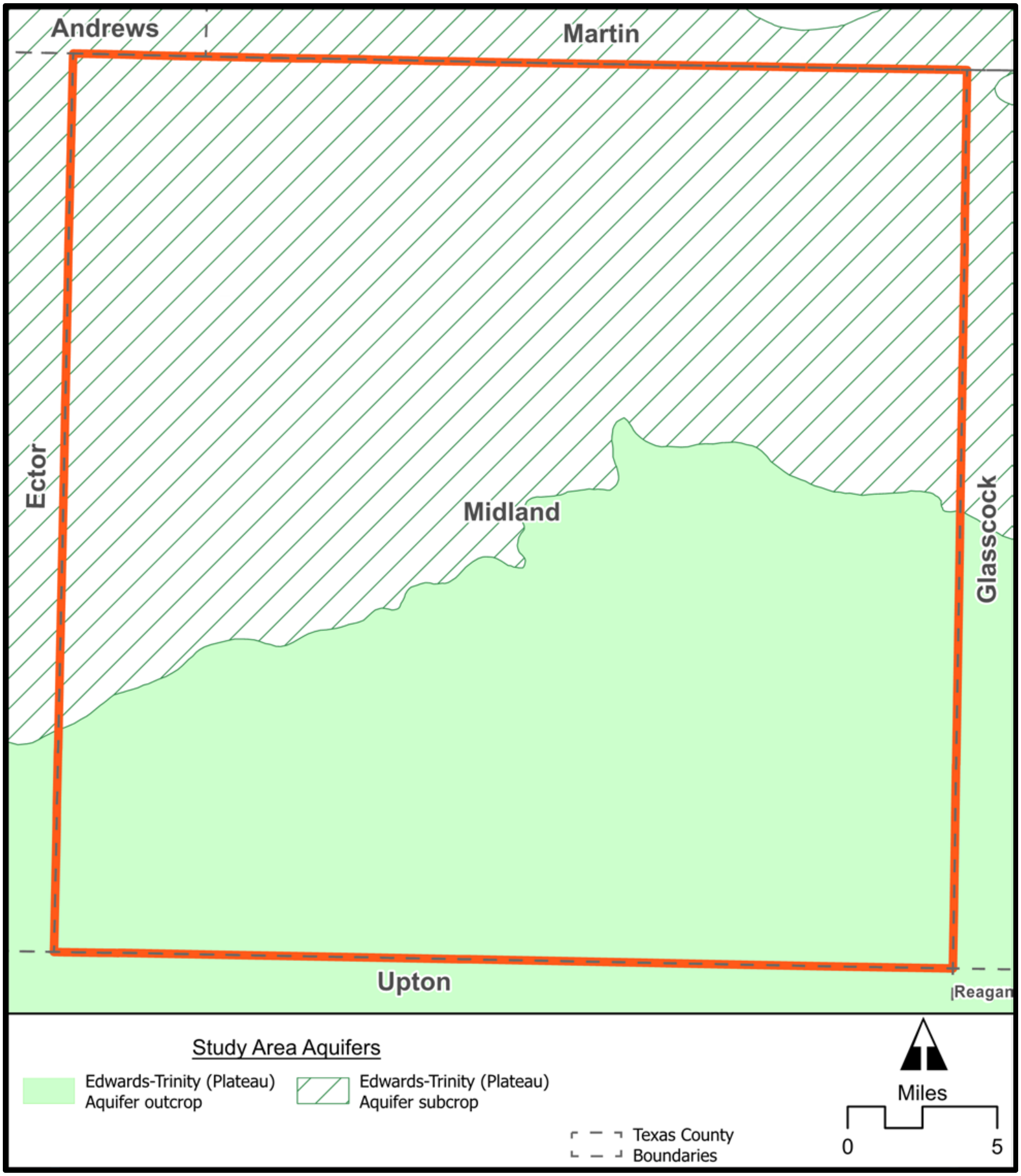


Figure 225. Midland County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

We would expect groundwater pumping for irrigation in Midland County to correlate negatively to precipitation such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 230 indicates that as precipitation increased over potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in the county, the reported pumpage for irrigation from the aquifer also increased. Figure 231 indicates a negative correlation value of -0.50 between precipitation and groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer. This moderate negative correlation suggests that the reported pumpage for irrigation in Midland County inversely follows the trend in precipitation. We note, however, that the Water Use Survey database contains relatively low values for irrigation pumpage for Midland County from the Edwards-Trinity (Plateau) Aquifer for years after 2012, and that some of these years are flagged as anomalous. We will reevaluate this correlation after researching Midland County irrigation pumpage during subsequent project phases.

Table 41 provides the years identified as having anomalous pumping amounts for Midland County for the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 227), and standard deviation (Figure 228) analyses.

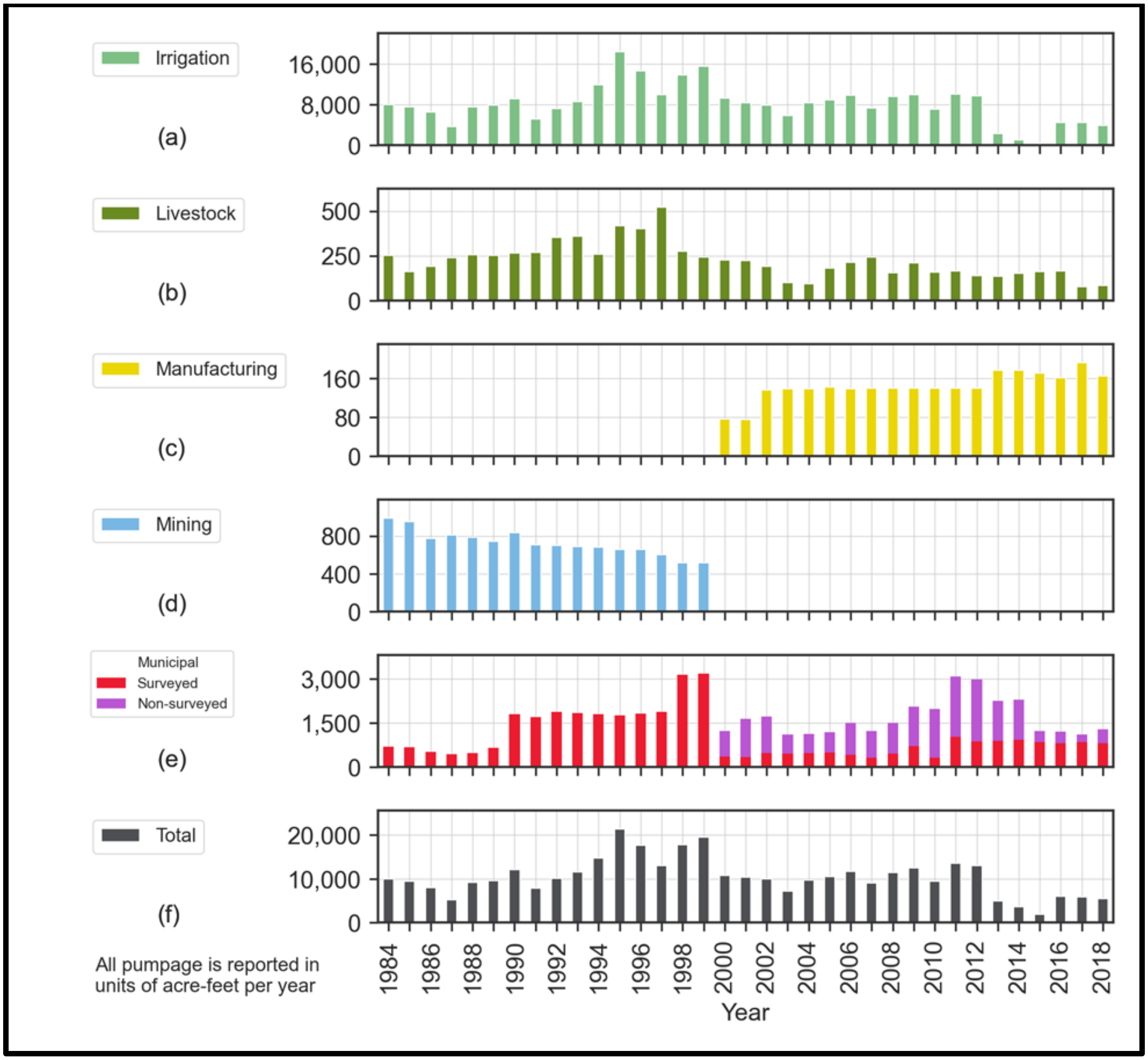


Figure 226. Midland County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

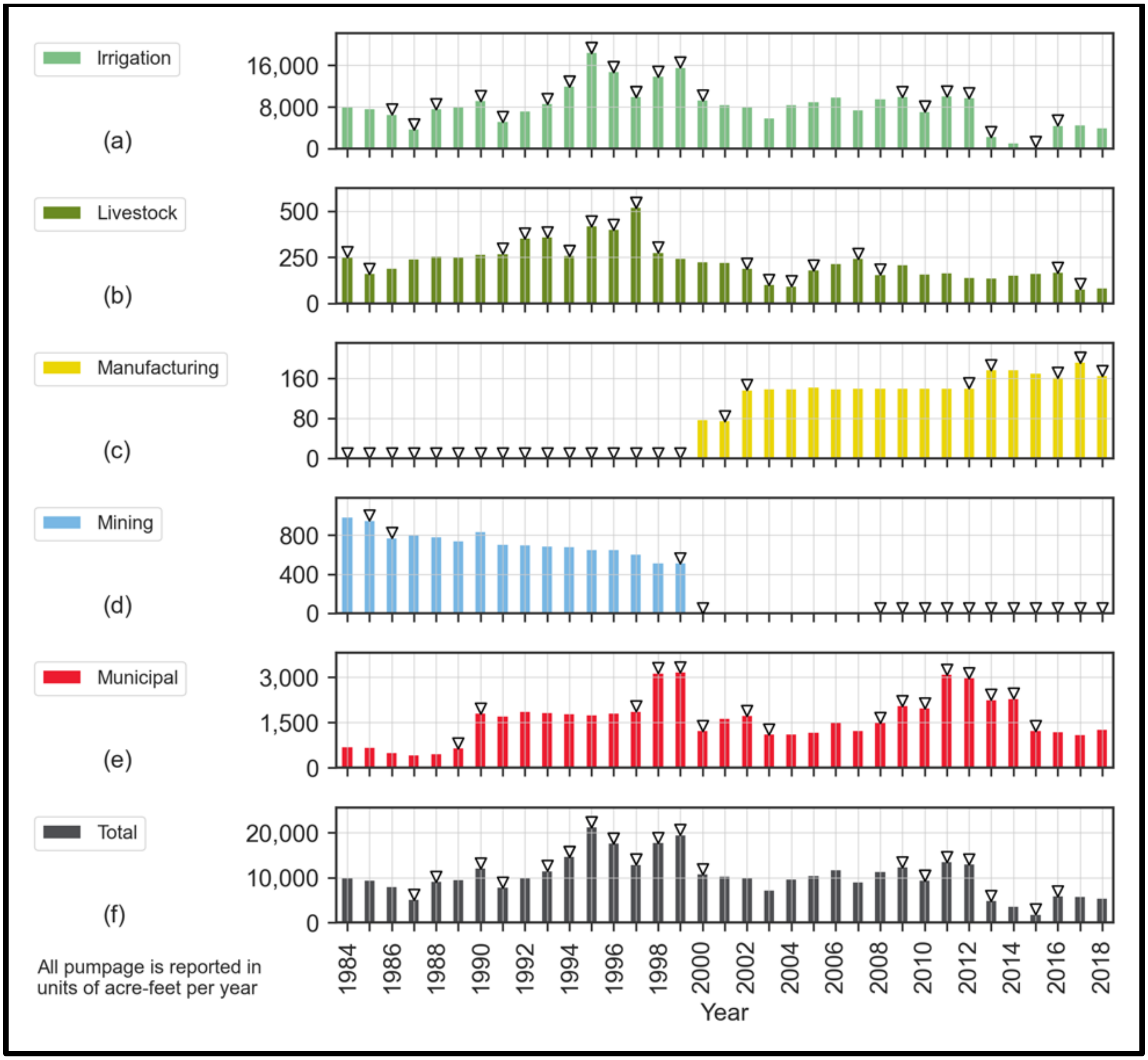


Figure 227. Midland County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 228. **Midland County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

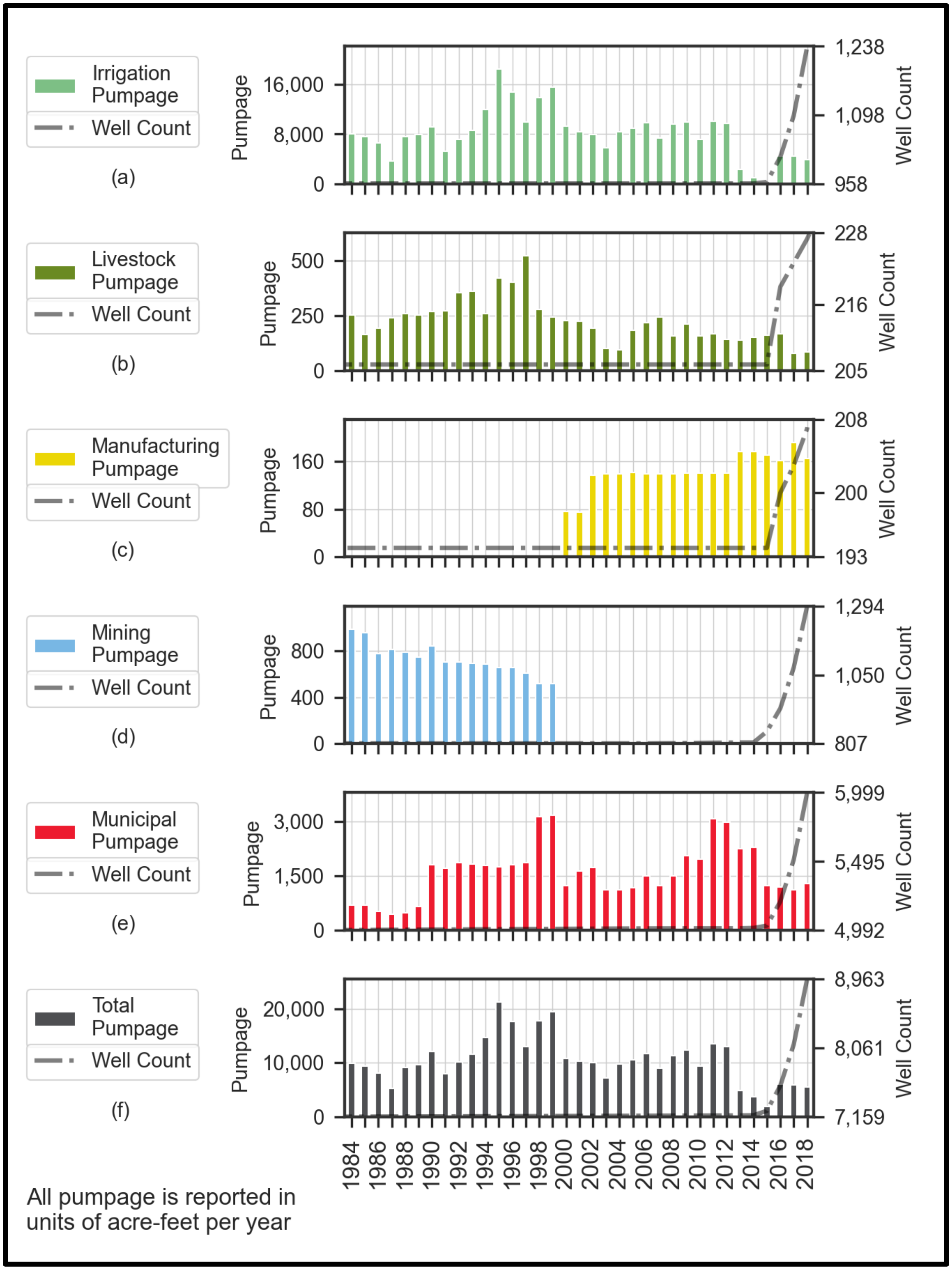


Figure 229. Midland County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and

the total number of wells completed in the aquifer as recorded in publicly available databases.

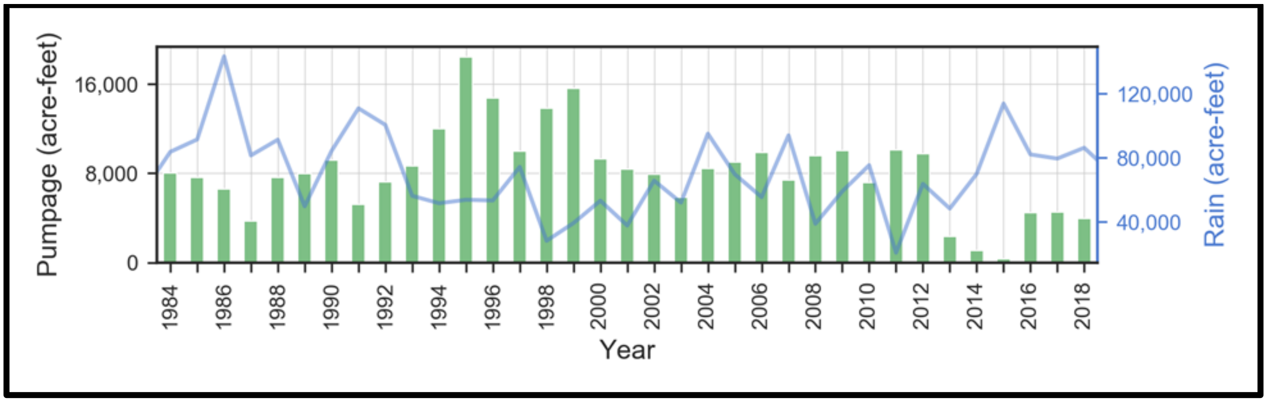


Figure 230. Midland County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

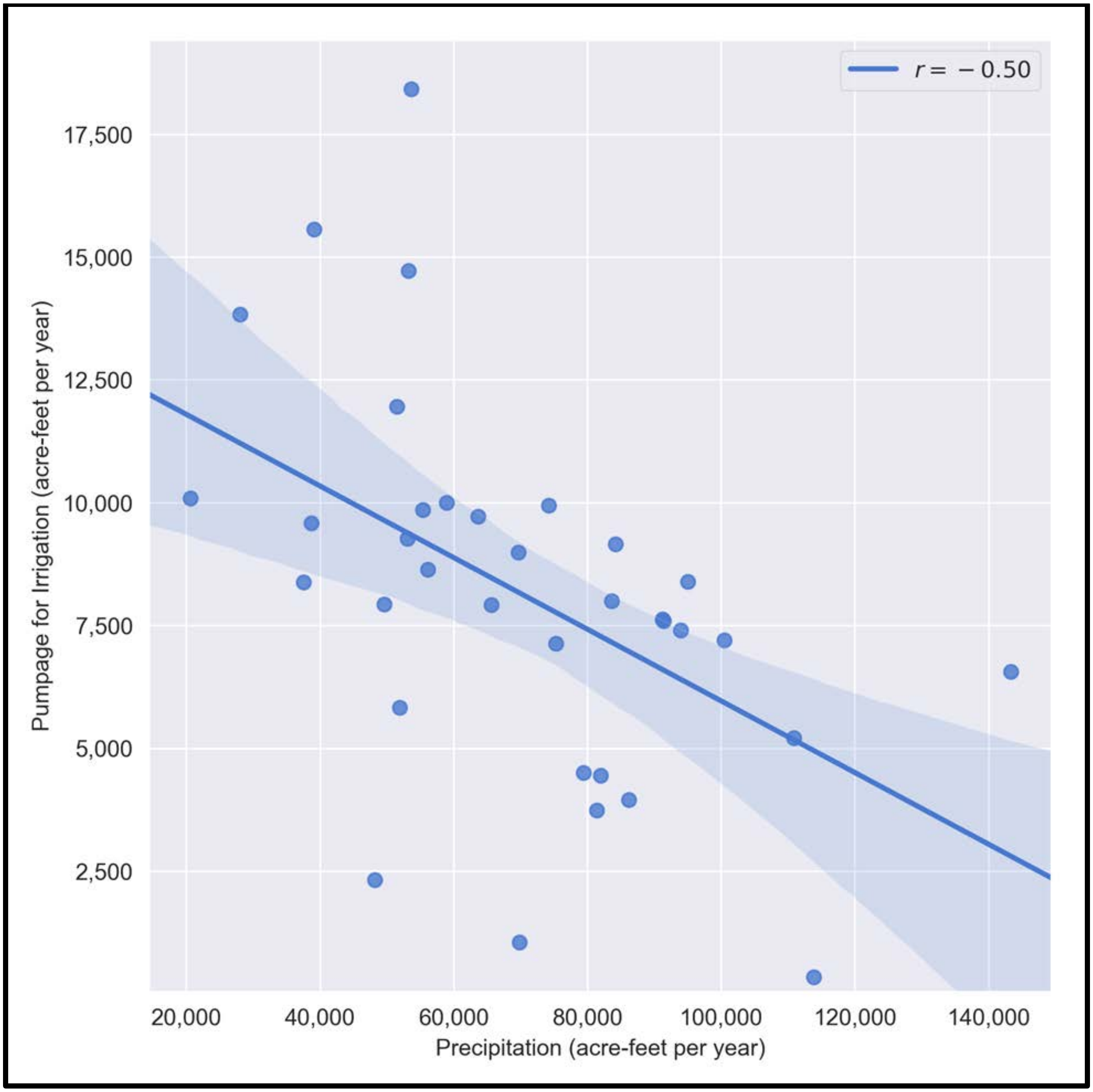


Figure 231. Midland County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

Table 41. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Midland County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1995, 2013-2015 new wells since 2015	1987, 1988, 1991, 1994-1998, 2000, 2010, 2011, 2013, 2016	1994, 1995, 2013, 2014
	Livestock	1997, 1998, 23 new wells since 2015	1984, 1985, 1992, 1994, 1995, 1997, 1998, 2003, 2005, 2008, 2017	1997-2000
	Manufacturing	1984-1999, 2002	1984-2000, 2002, 2013, 2017, 2018	1984-2000, 2002
	Mining	2000-2018	1986, 2000, 2008-2018	2000, 2001, 2008-2018
	Municipal	1990, 1998, 2000, 2011, 2015	1990, 1998, 2000, 2003, 2009, 2011, 2013, 2015	1990, 1998, 2000, 2011, 2015

3.3.35 Nolan County

The Edwards-Trinity (Plateau) Aquifer is present in the central portion of Nolan County, covering approximately 55 percent of the county area. Figure 232 illustrates the extent of the aquifer in Nolan County.

Groundwater pumping estimates from the Water Use Survey dataset indicate that the maximum total pumping from the Edwards-Trinity (Plateau) Aquifer within Nolan County was over 3,000 acre-feet in 2003 and 2006 through 2008 (Figure 233). As shown on Figure 233, reported pumpage data is for irrigation, livestock, manufacturing, mining, and municipal uses, with the majority of pumping supporting municipal use. Manual review of Figure 233 identified anomalies within the irrigation data, most notably the large difference between pumping in 1993 and 1999 with missing data between those years. There is also an abrupt increase in livestock water usage between 2004 and 2005 with higher pumpage continuing through 2018. Manufacturing pumpage was fairly stable from 1984 through 1997 after which it exhibited a gradual increase through 2007 followed by abrupt declines in 2009 and 2010. Mining data is not included in the Water Use Survey dataset after 1999. Municipal usage greatly increased in 2001 and the following years.

The year-to-year change analysis (Figure 234) and standard deviation analysis (Figure 235) flagged many anomalies in the data for the Edwards-Trinity (Plateau) Aquifer. These anomalies included those identified within the manual review, as well as additional years in which data was either missing or sufficiently different from adjacent years. Table 42 provides the years identified as having anomalous pumping amounts for Nolan County from the Edwards-Trinity (Plateau) Aquifer.

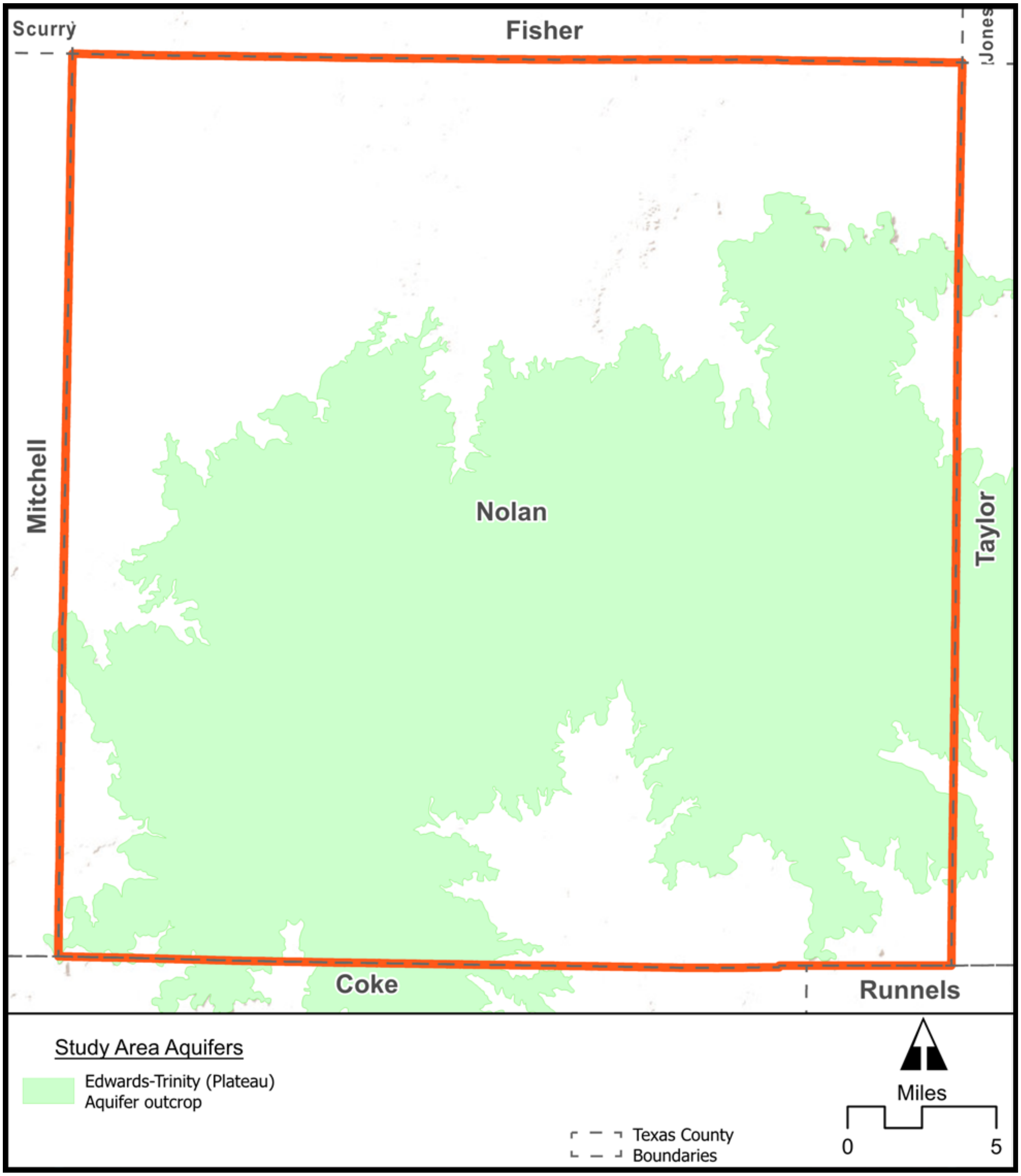


Figure 232. Nolan County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

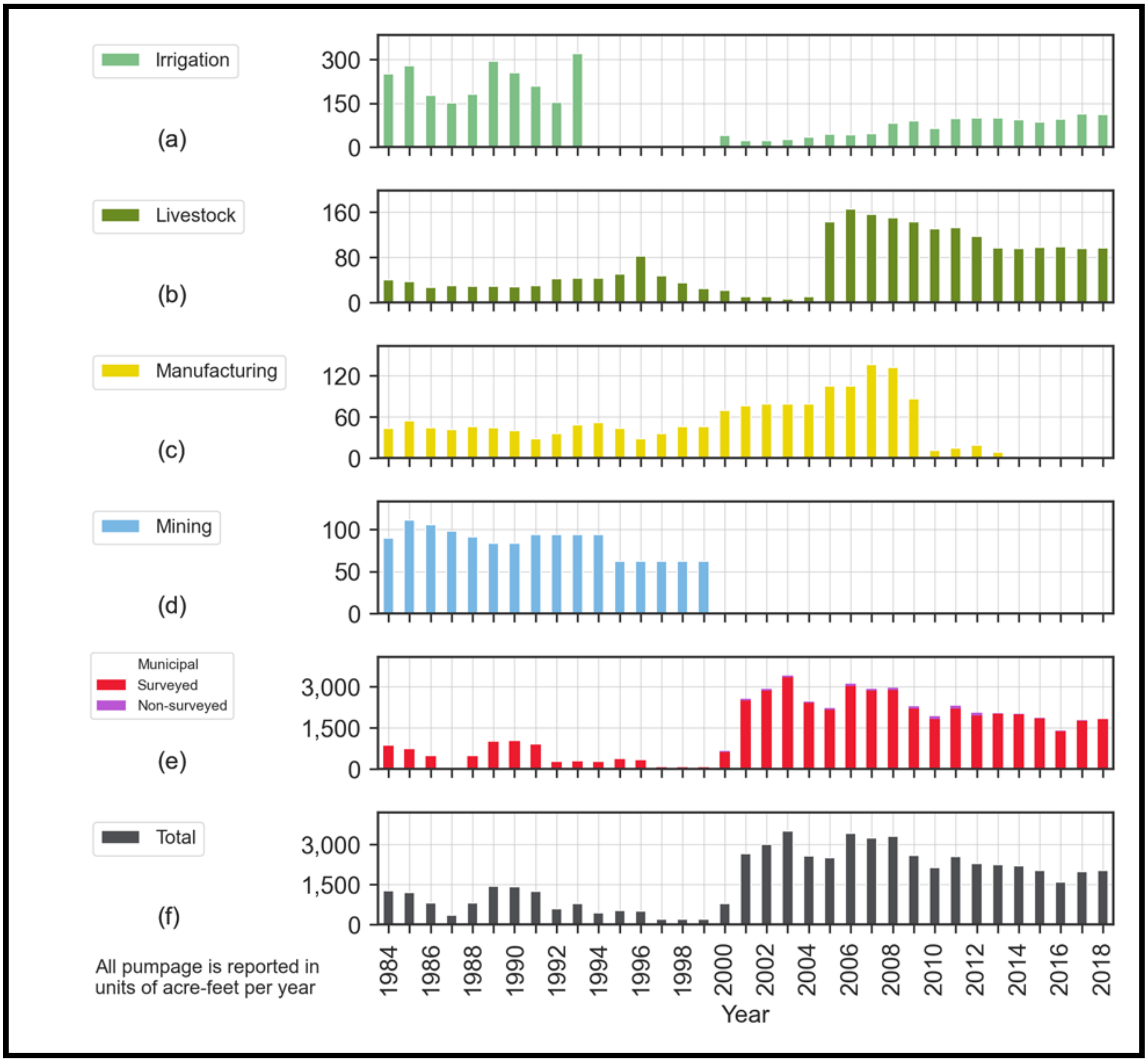


Figure 233. Nolan County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

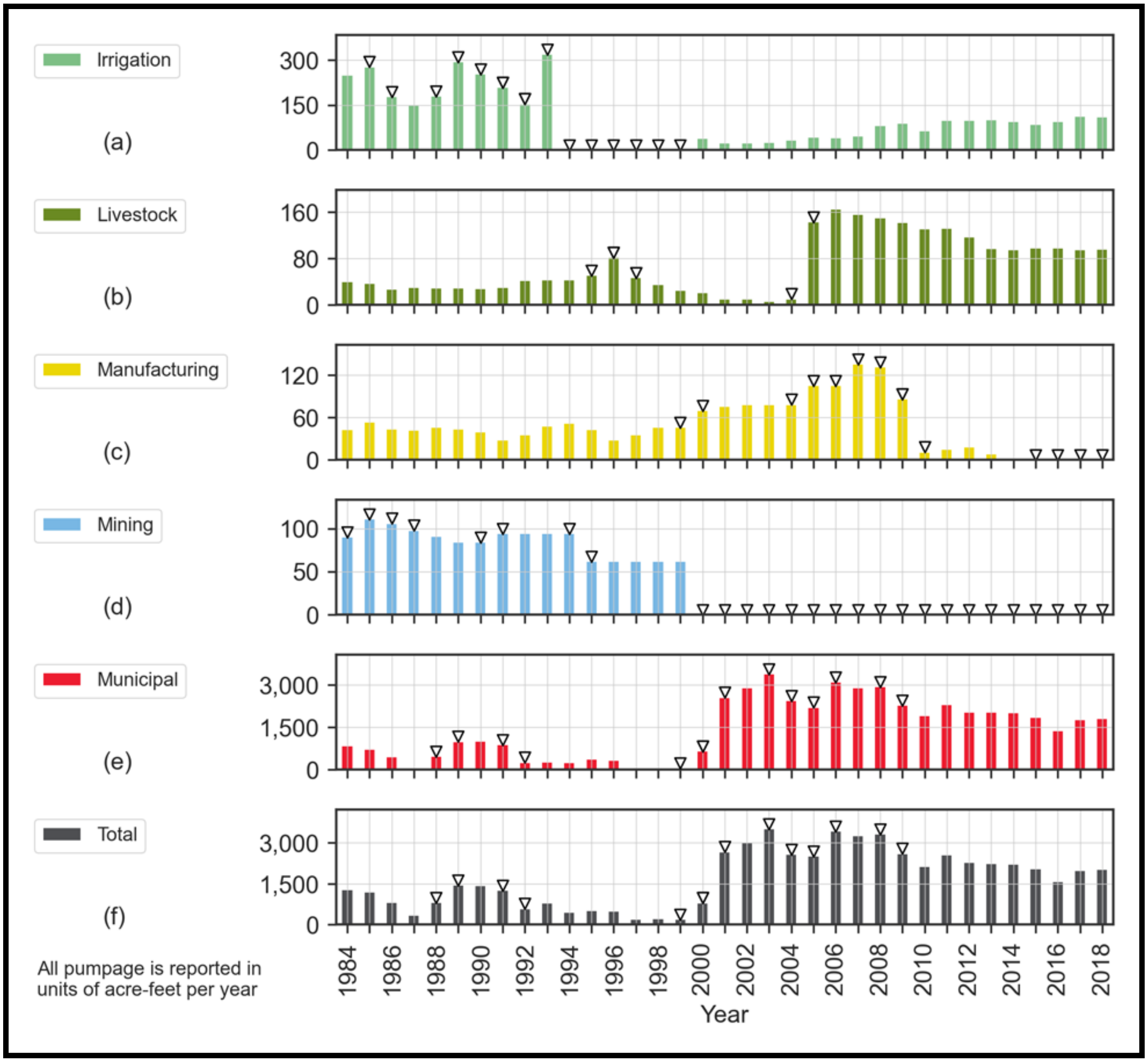


Figure 234. Nolan County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

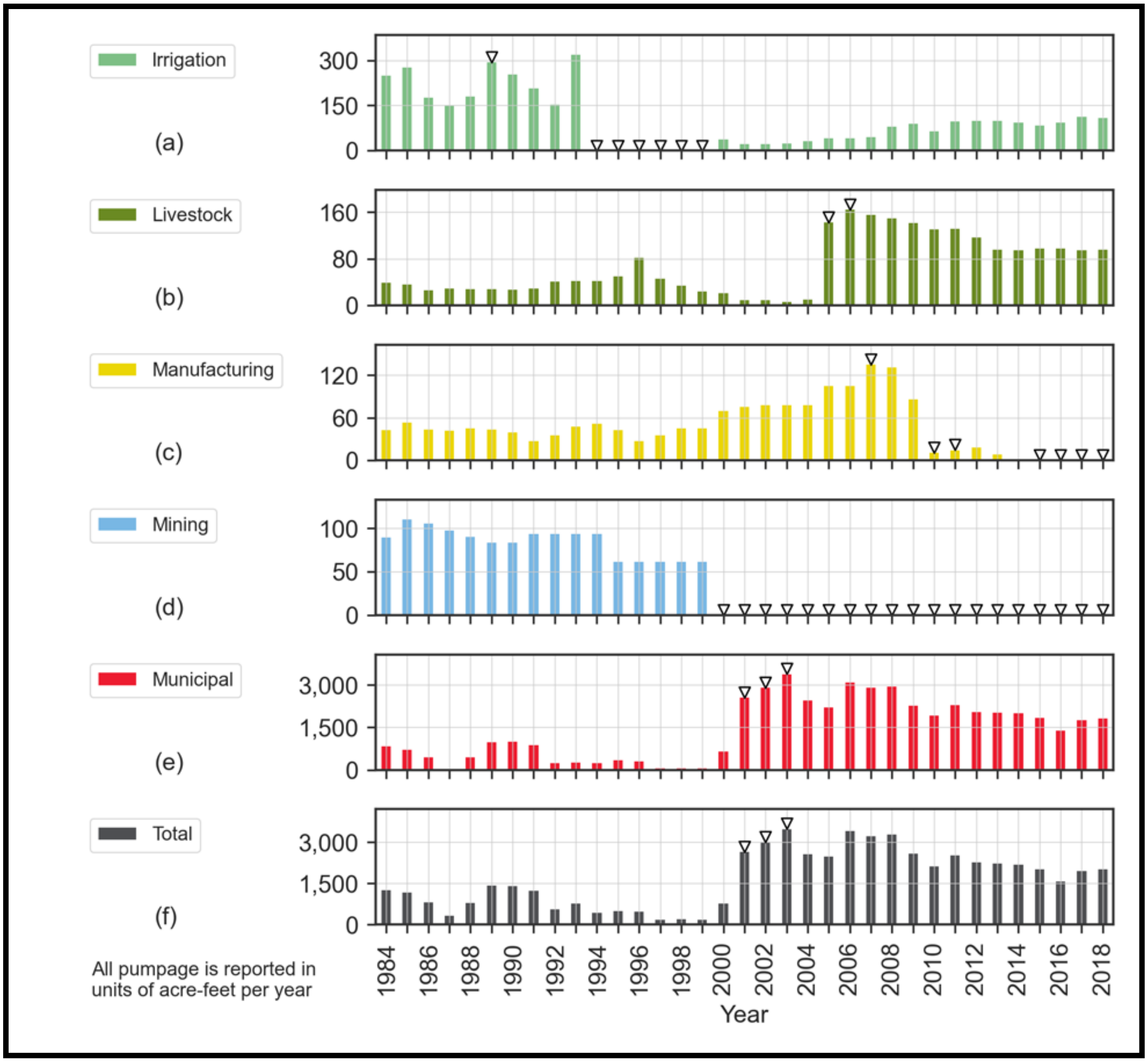


Figure 235. Nolan County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 42. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Nolan County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1993-1999	1986, 1989, 1991-1999	1989, 1994-1999
	Livestock	2005	1996, 1997, 2005	2005-2007
	Manufacturing	2009, 2010	2000, 2005, 2007, 2009, 2010, 2015-2018	2007, 2010, 2011, 2014-2018
	Mining	2000-2018	1984, 1985, 1987, 1991, 1995, 2000-2018	2000-2018
	Municipal	1984-1999, 2001	1989, 1992, 2000, 2001, 2004, 2006, 2009	2001-2003

3.3.36 Pecos County

The Edwards-Trinity (Plateau) Aquifer underlies approximately 98 percent of Pecos County with a smaller portion of the county (about 22 percent) being underlain by the Pecos Valley Aquifer (see Figure 236). As shown on Figure 237, the TWDB Water Use Survey data indicates total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer generally declined from 1984 through 2004. After 2004, reported pumping from the aquifer generally increased to a peak of approximately 100,000 acre-feet in 2014 where it subsequently declined. Based on the reported data, groundwater production from the aquifer for irrigation is the primary use.

Since 1984, reported pumping from the Edwards-Trinity (Plateau) Aquifer for irrigation ranged between 20,000 and 100,000 acre-feet per year. Pumping for livestock ranges from approximately 500 to 800 acre-feet per year during the study period. Reported pumping for manufacturing was nearly nonexistent until 2000 when the reported volumes abruptly increased. Estimated pumping for mining use in 1984 is nearly 5,000 acre-feet but was near zero or not estimated in subsequent years. Pumping for municipal use is the second highest use for the Edwards-Trinity (Plateau) Aquifer in Pecos County and ranges from approximately 3,000 to 6,000 acre-feet per year during the study period. Reported volumes of pumping for power use was more than 1,500 acre-feet in 1984 but generally declined through 2003 with no data reported after 2003.

For the estimated irrigation pumping, the data appear to follow relatively consistent trends. Applying our year-to-year change analysis we observed several anomalies in the data (Figure 238). In addition, the standard deviation analysis (Figure 239) flagged the increase in irrigation pumping beginning in 2009 as anomalous. We also observe changes in pumping for municipal use that the year-to-year change and standard deviation analyses flag as anomalous, such as in years 2000 and 2011. Almost all municipal use from both the Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer in Pecos County is surveyed.

Total reported groundwater pumping from the Pecos Valley Aquifer is not as high as the pumping from the Edwards-Trinity (Plateau) Aquifer but does follow a similar overall trend (Figure 240). Like the total pumping for the Edwards-Trinity (Plateau) Aquifer, the reported pumping for the Pecos Valley Aquifer peaks at about 40,000 acre-feet in 2014 and subsequently declines.

Pumping from the Pecos Valley Aquifer for irrigation ranges between about10,000 and 40,000 acre-feet per year. Estimated and reported pumping for other uses is relatively small compared to irrigation pumping at less the 500 acre-feet per year except for mining use in 1984. The year-to-year change (Figure 241) and standard deviation (Figure 242) analyses flagged several years of anomalous values for irrigation use. For example, in 1994 irrigation pumping abruptly increased relative to the previous year and trend in pumping.

Figure 243 shows that since 2015 approximately 16 new mining use wells were completed in Pecos County in the Pecos Valley Aquifer. However, pumping for mining from 2015 to 2017 is negligible suggesting the pumpage data is anomalous. We will research the cause of this observed anomaly as part of subsequent project phases.

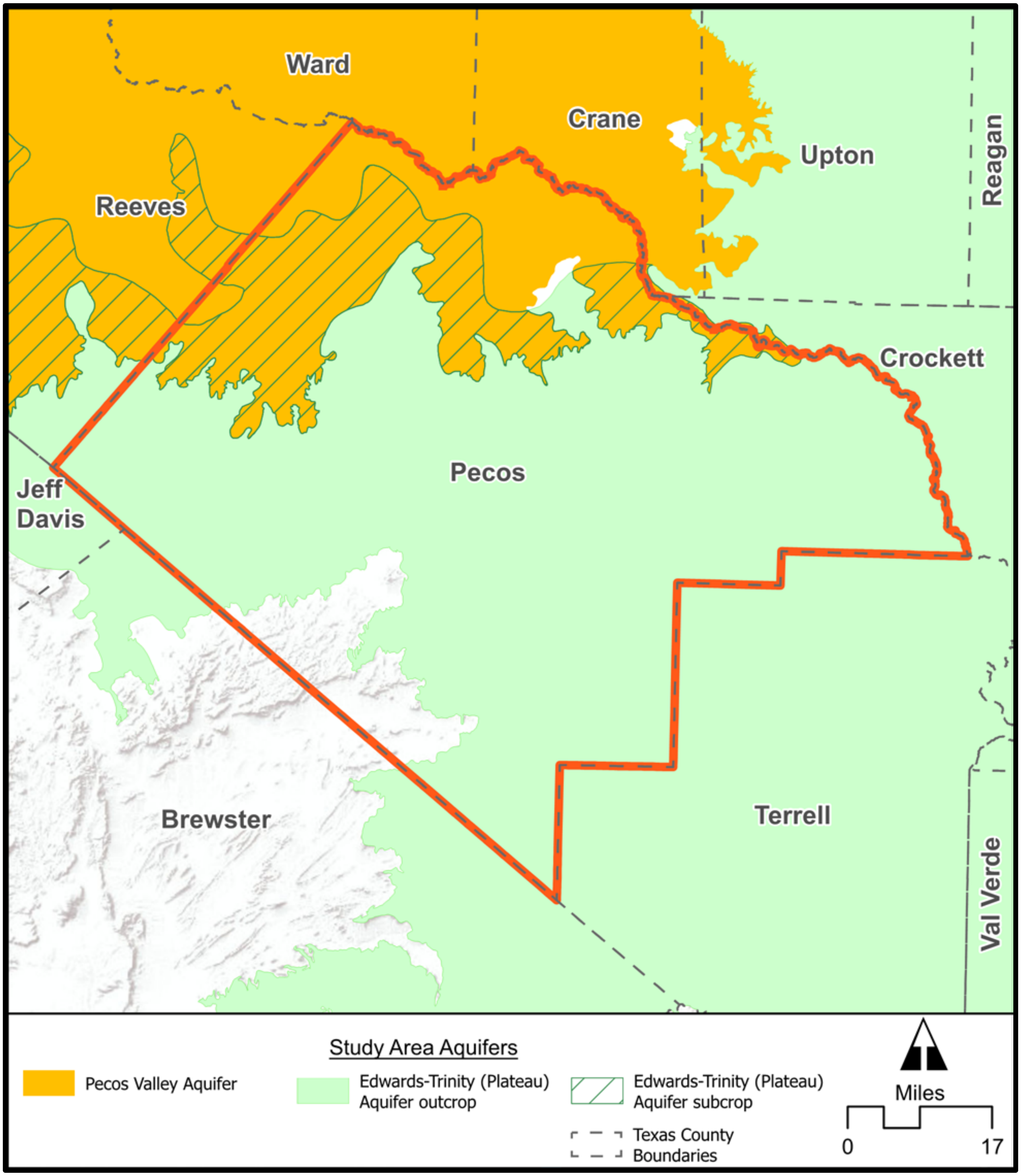


Figure 236. Pecos County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer.

We expect a positive linear correlation between the land potentially used for irrigation overlying the Pecos Valley Aquifer in Pecos County and groundwater pumpage from the Pecos Valley Aquifer used for irrigation. However, although the acres of potentially irrigated land appear to be decreasing since 1998, the reported pumping for irrigation has reportedly increased (see Figure 244). Figure 245 indicates a linear correlation value of -0.68 between the potentially irrigated land area and reported groundwater pumpage for irrigation from the Pecos Valley Aquifer. This strong negative correlation may suggest that pumpage for irrigation in Pecos County is anomalous after 1998. We will research alternative explanations for the strong negative correlation during subsequent project phases.

Table 43 provides the years identified as having anomalous pumping amounts for Pecos County for the Edwards-Trinity (Plateau) Aquifer and the Pecos Valley Aquifer based on our manual review, year-to-year change (Figure 238 and Figure 241), and standard deviation (Figure 239 and Figure 242) analyses.

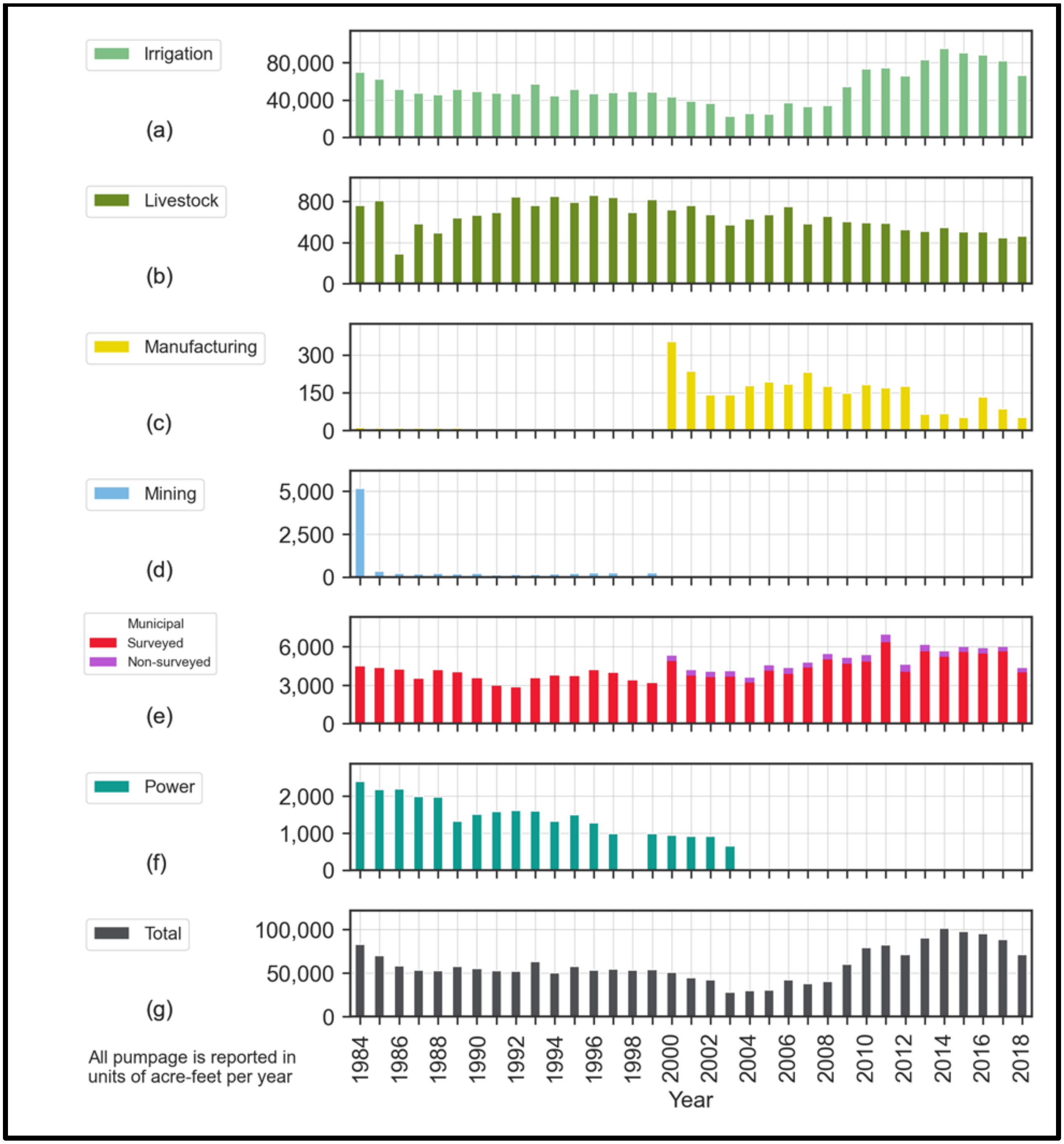


Figure 237. Pecos County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Figure 238. Pecos County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

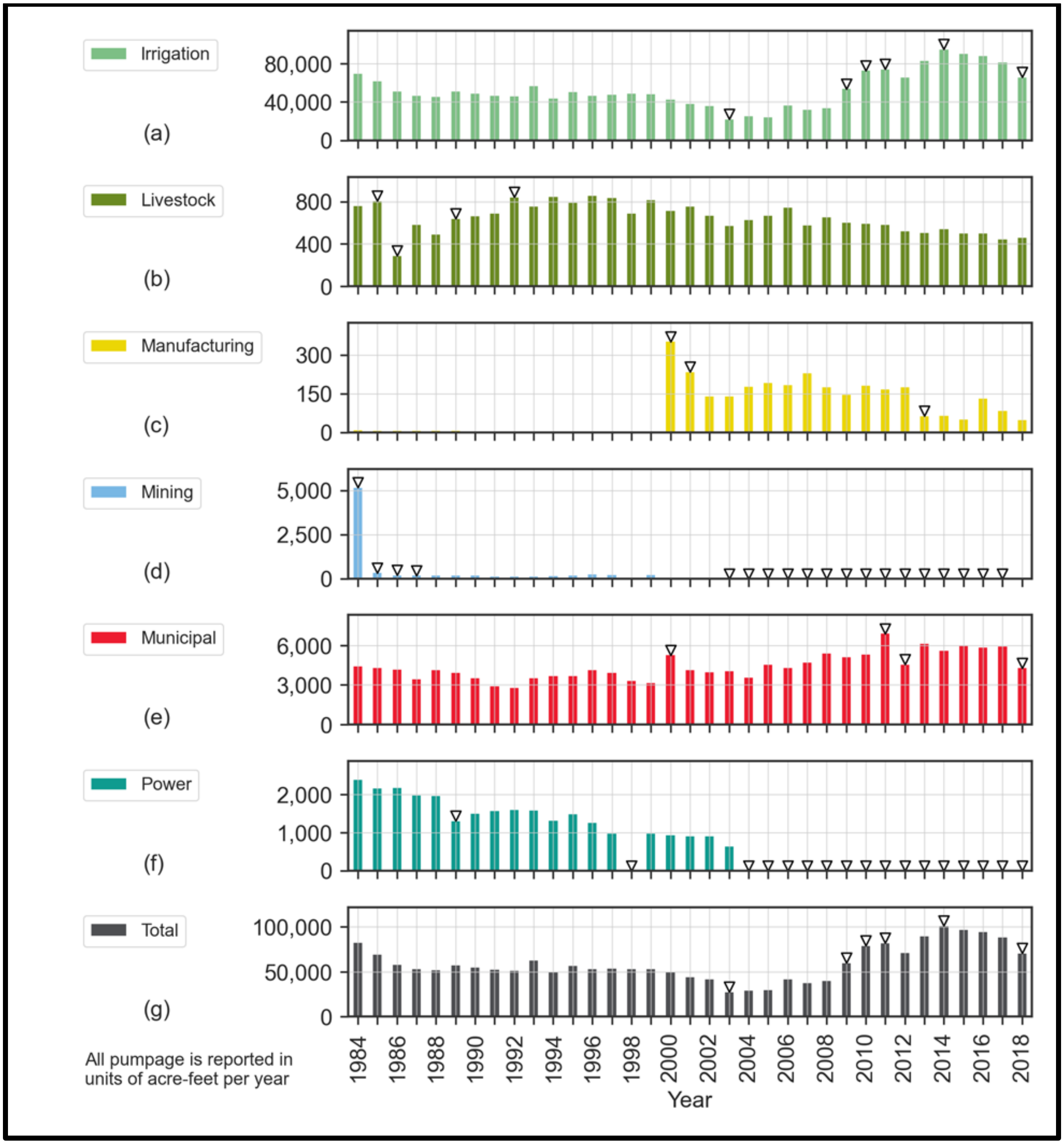


Figure 239. Pecos County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 240. Pecos County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

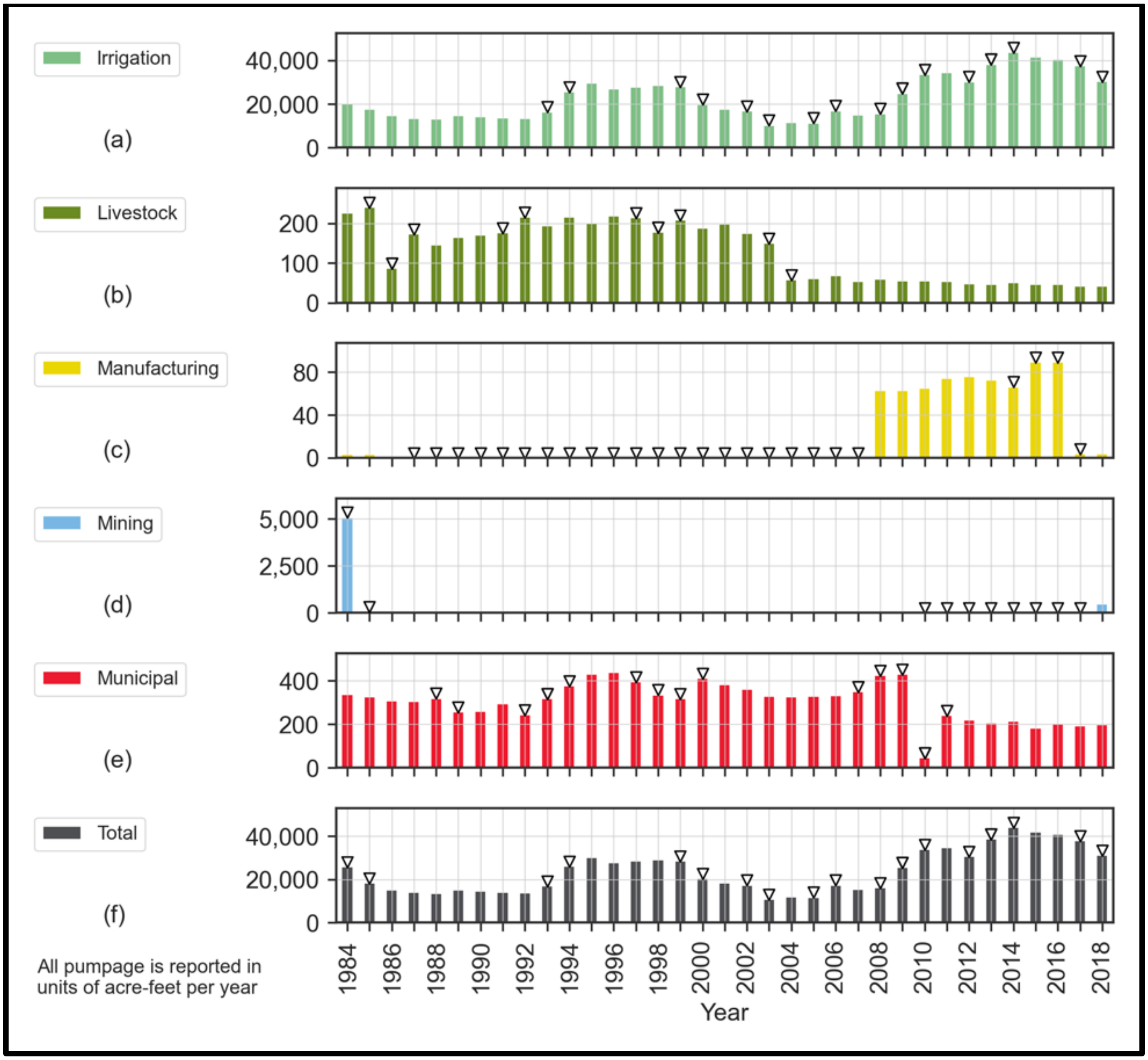


Figure 241. Pecos County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 242. Pecos County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

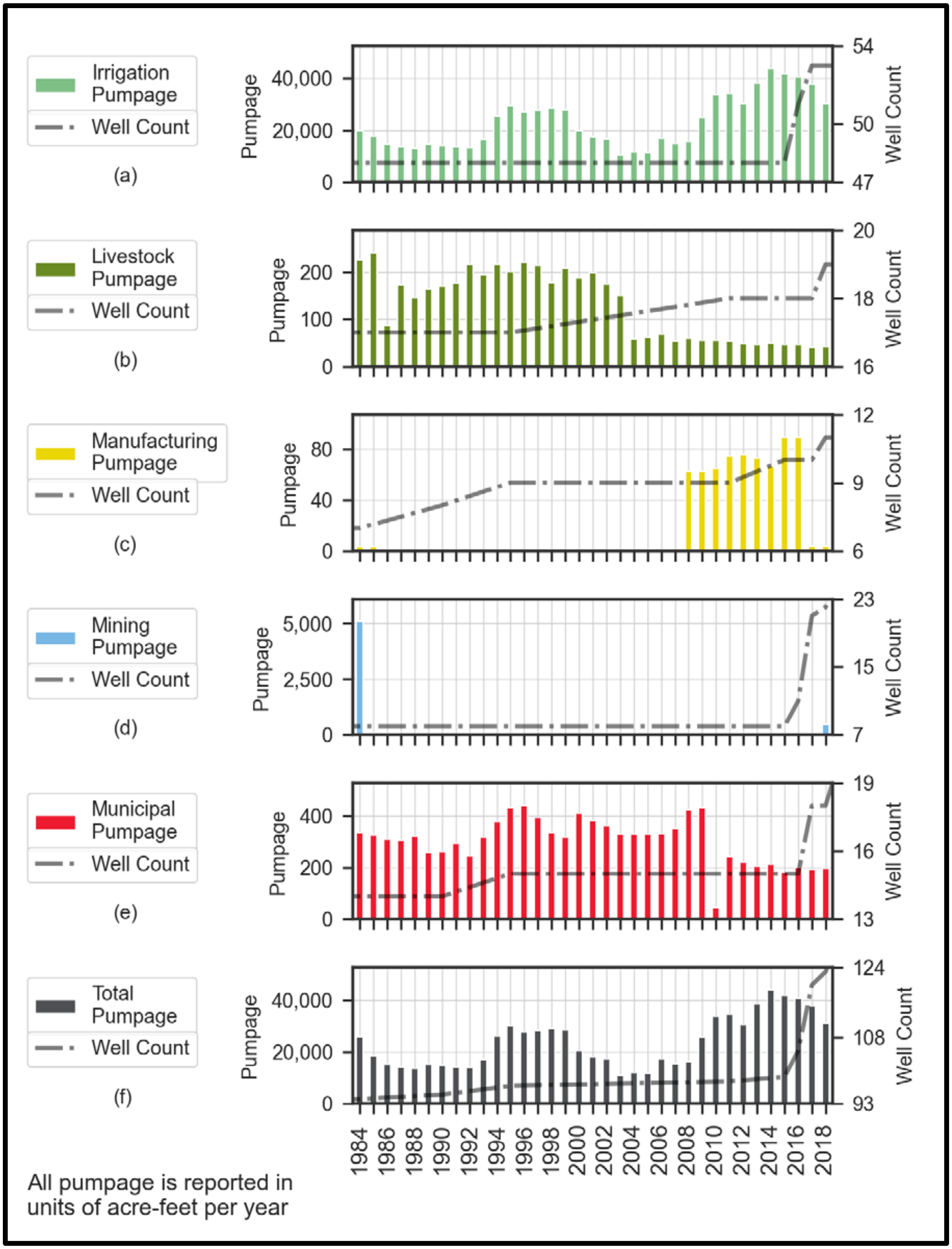


Figure 243. **Pecos County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer and county as recorded in publicly available databases.**

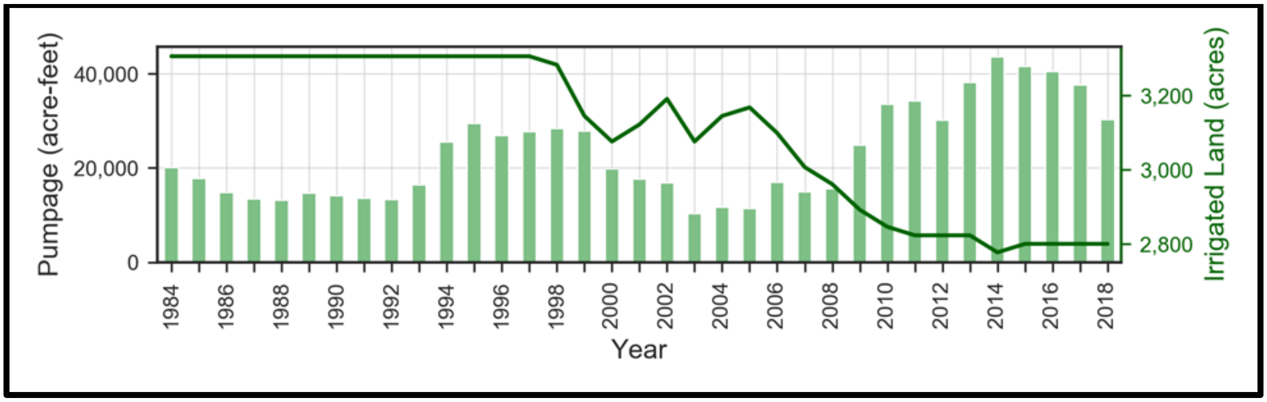


Figure 244. Pecos County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

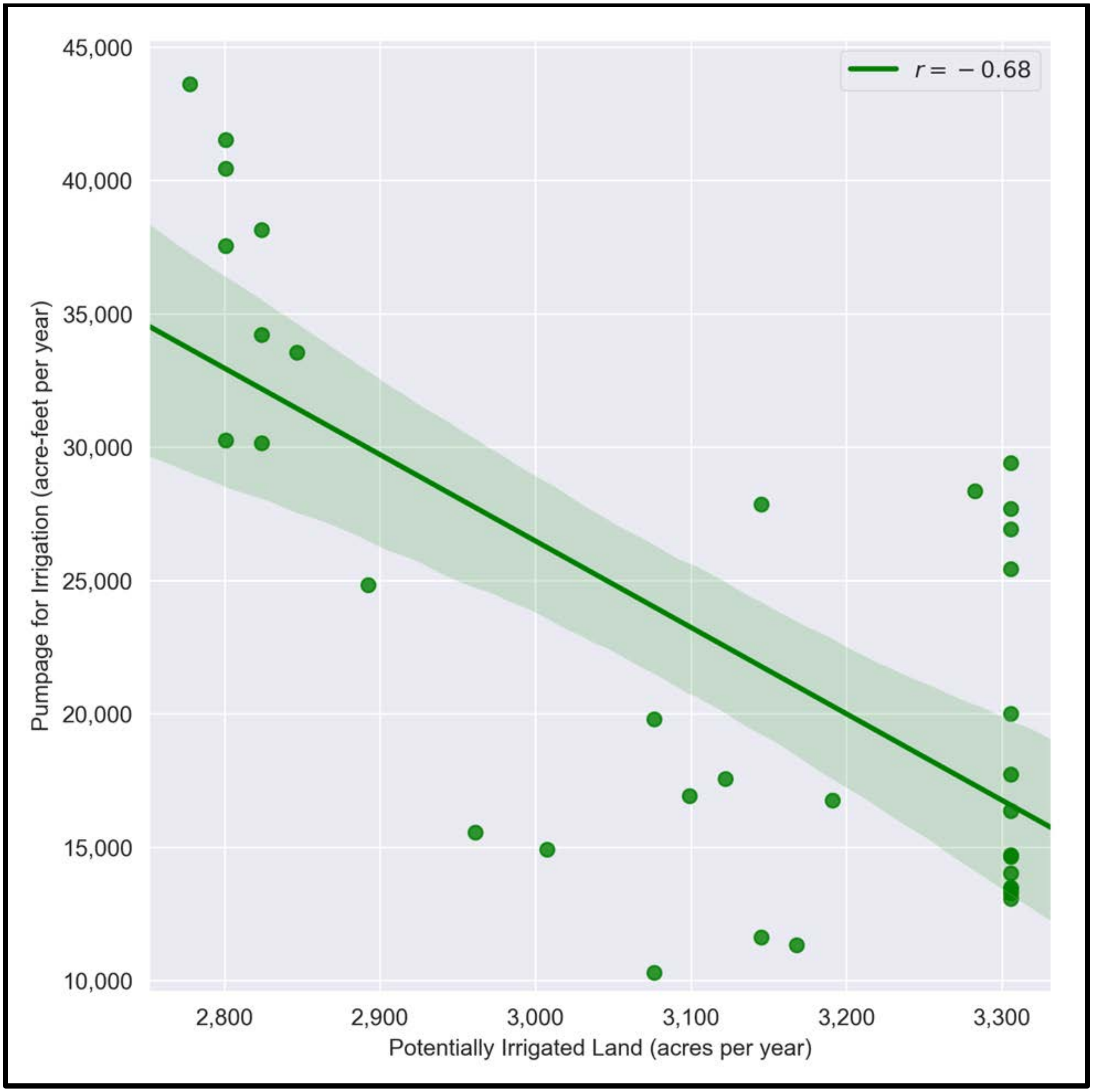


Figure 245. **Pecos County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.**

Table 43. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Pecos County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	None	1994, 2003, 2006, 2009, 2010, 2013, 2014, 2018	2003, 2009-2011, 2014, 2018
	Livestock	1986	1986-1989, 1992-1994, 1998-2000, 2002, 2003, 2007	1985, 1986, 1989, 1992
	Manufacturing	1984-2000, 2001	2000-2002, 2008, 2013, 2016	2000, 2001, 2013
	Mining	1984, well count increased since 2015	1984, 1985, 2003-2017	1984-1987, 2003-2017
	Municipal	2000, 2011	1987, 1988, 1993, 2000, 2001, 2005, 2008, 2011-2013, 2018	2000, 2011, 2012, 2018
	Power	1998, 2004-2018	1989, 1998, 1999, 2004-2018	1989, 1998, 2004-2018
Pecos Valley	Irrigation	None	1994, 2000, 2003, 2006, 2009, 2010, 2013, 2014, 2018	1994, 1995, 2000, 2010, 2018
	Livestock	1986, 2004	1986, 1987, 1992, 1998, 1999, 2004	1985, 1986, 1992, 2004, 2005
	Manufacturing	1984-2007, 2017-2018	1987-2008, 2015, 2017	1987-2008, 2017, 2018
	Mining	1984	1984, 1985, 2010-2017	1984-1987, 2010-2017
	Municipal	2010	1989, 1993, 1994, 1998, 2000, 2008, 2010, 2011	1995, 2010

3.3.37 Reagan County

The Edwards-Trinity (Plateau) Aquifer outcrop covers the entire area of Reagan County (see Figure 246). According to the TWDB Water Use Survey data, irrigation is the primary use of groundwater from the Edwards-Trinity (Plateau) Aquifer in Reagan County (Figure 247). The total reported annual volumes pumped from Reagan County range from about 20,000 acre-feet to a peak of more than 60,000 acre-feet.

Pumping for irrigation abruptly increased to more than 60,000 acre-feet in 1998 but typically ranged from 10,000 to 30,000 acre-feet per year. Irrigation pumping generally increased from 1984 through the peak in 1998. However, in 1999 irrigation pumping abruptly declined to less than 30,000 acre-feet and remained below that level through 2018.

Pumping for livestock use ranged from 100 to 200 acre-feet per year with a recent increase in reported volumes to over 300 acre-feet per year in 2017 and 2018. Pumping for manufacturing has several data gaps with pumping between 2000 and 2013 averaging around 80 acre-feet per year. Pumping for mining exceeds 1,600 acre-feet per year through 1999 with a data gap in from 2000 through 2013. After 2013, estimated pumping volumes for mining use are nearly zero. Pumping for municipal use averages approximately 800 acre-feet per year with abnormally low reported values in 2000 and 2017. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use constituted a relatively small portion of total municipal usage.

Figure 250 shows 146 new Edwards-Trinity (Plateau) Aquifer wells with a proposed irrigation use completed in the county since 2015. However, irrigation pumping since 2015 remained relatively constant through 2018. This discrepancy suggests the irrigation pumpage since 2015 is anomalous and may warrant further investigation. Similar discrepancies exist with respect to manufacturing, mining, and municipal wells compared to their use. In contrast, increasing wells for livestock use correspond well with reported increase in livestock usage in 2017 and 2018.

Table 44 provides the years identified as having anomalous pumping amounts for Reagan County from the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 248), and standard deviation (Figure 249) analyses.

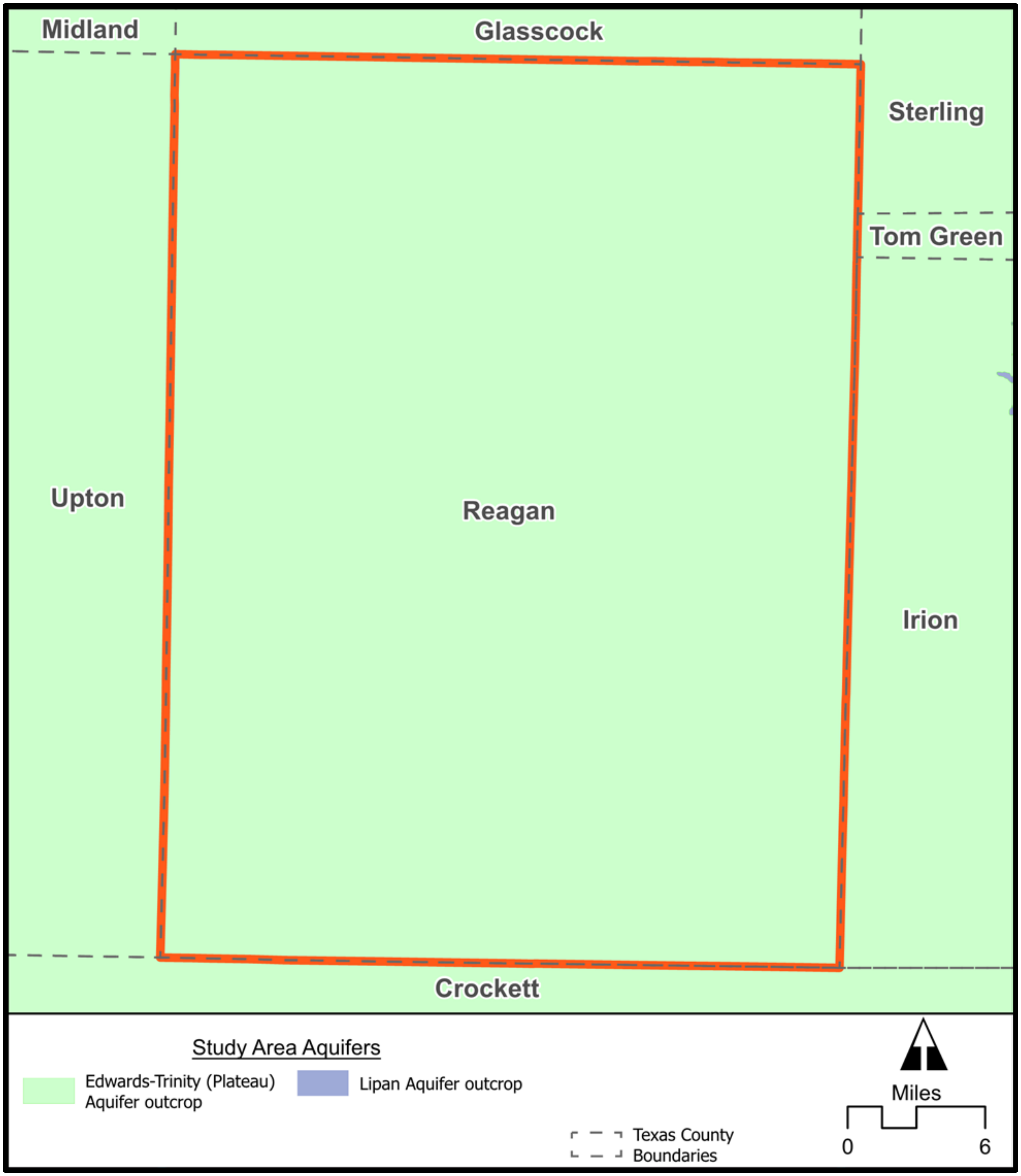


Figure 246. Reagan County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

Figure 247. Reagan County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

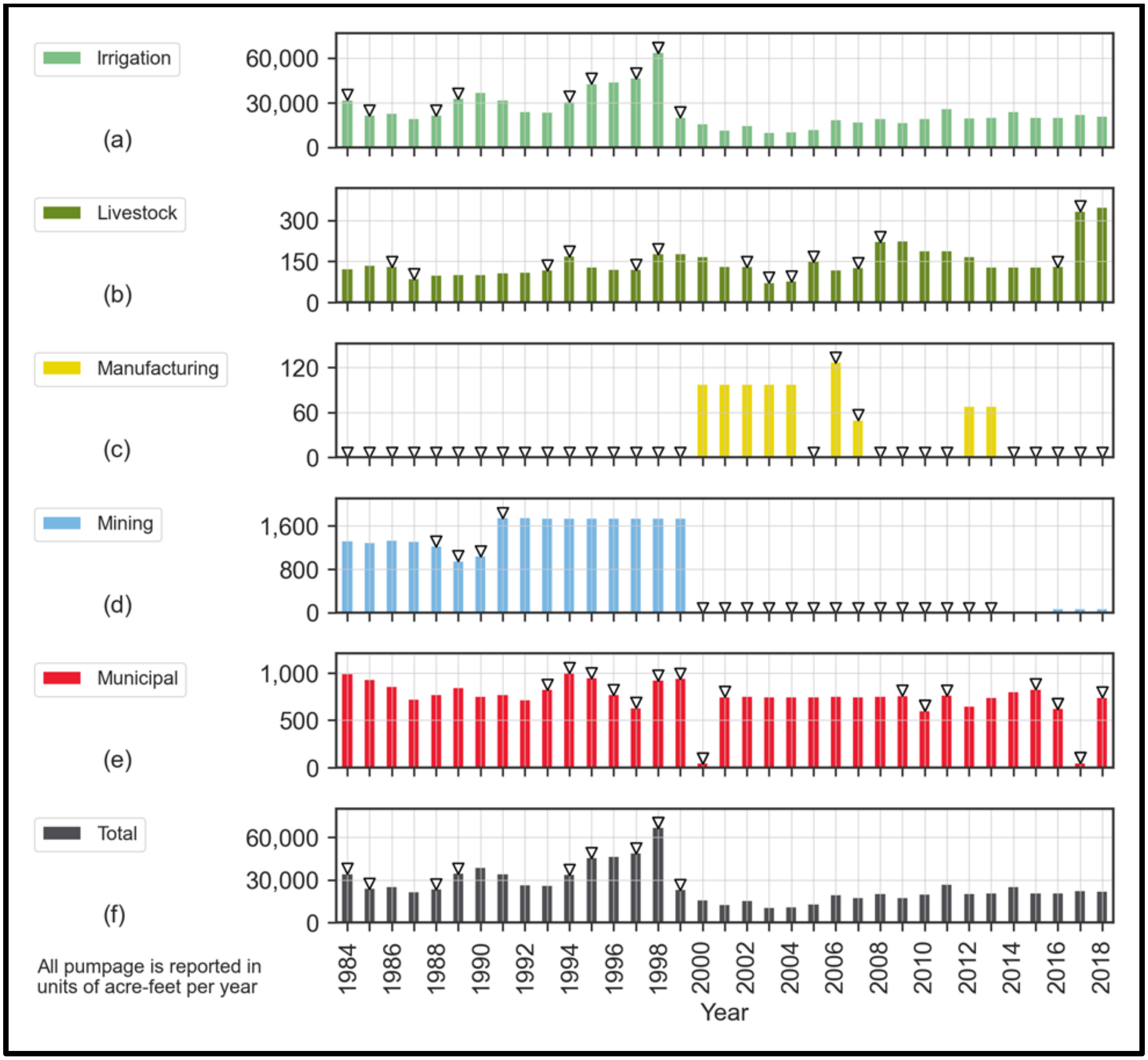


Figure 248. Reagan County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 249. Reagan County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

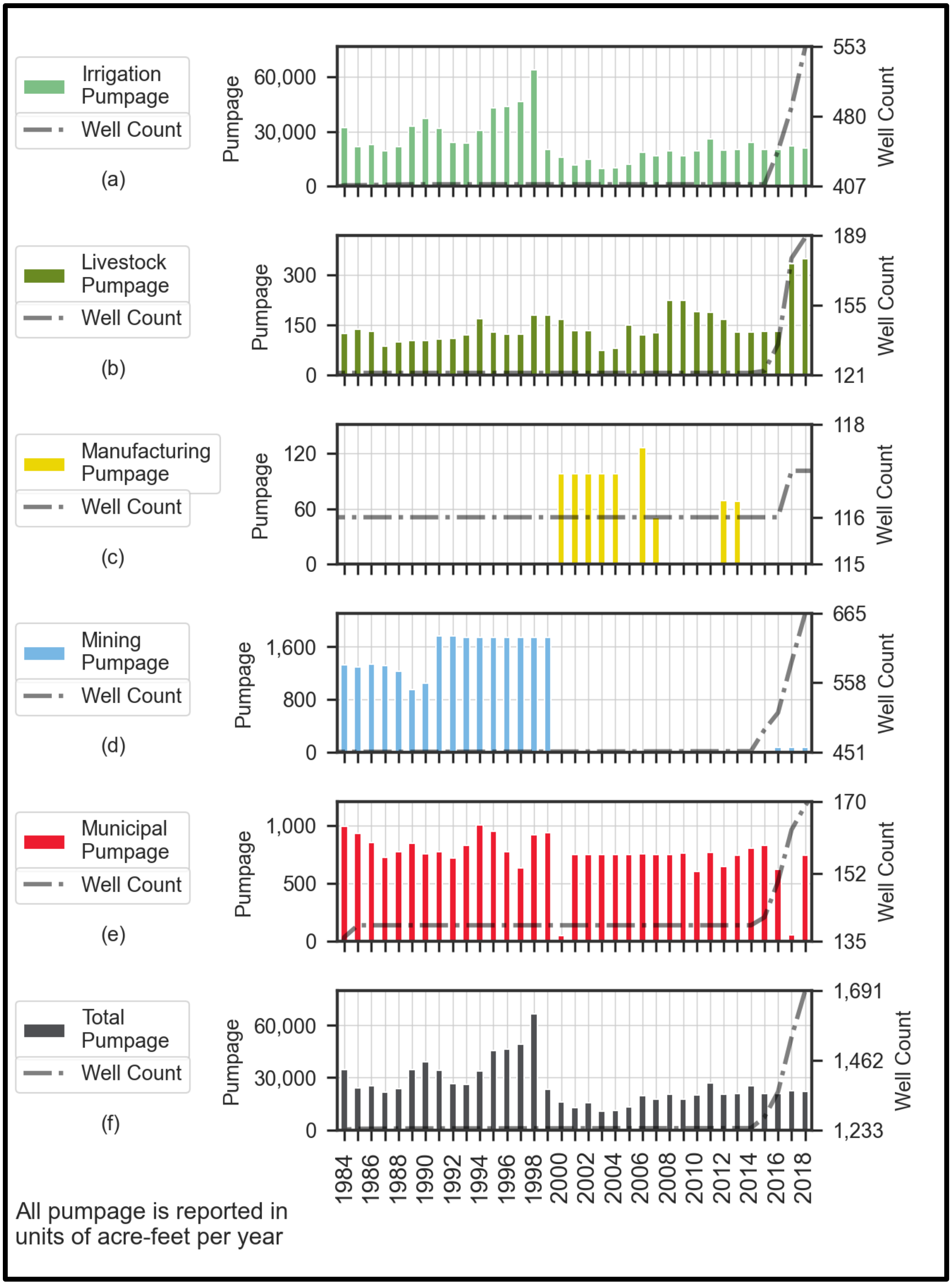


Figure 250. **Reagan County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the**

total number of wells completed in the aquifer as recorded in publicly available databases.

Table 44. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Reagan County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1998; 146 new wells since 2015	1984, 1985, 1989, 1995, 1998, 1999	1995, 1998-2001
	Livestock	2017-2018	1987, 1994, 1998, 2003, 2005, 2008, 2017	2017, 2018
	Manufacturing	1984-1999, 2005, 2008-2010, 2014-2018	1984-2000, 2005-2012, 2014-2018	1984-2000, 2005, 2008-2012, 2014-2018
	Mining	1991, 2000-2018	1989, 1991, 2000-2013	2000-2013
	Municipal	2000, 2017	1994, 1996, 1998, 2000, 2001, 2010, 2011, 2016-2018	2000, 2017

3.3.38 Real County

The TWDB defined footprint of the Edwards-Trinity (Plateau) aquifer covers nearly all of Real County with a small portion of the Trinity (Hill Country) Aquifer in the southeastern corner of the county (see Figure 251). As shown in Figure 252, total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer reached approximately 1,000 acre-feet in 2011. In the early part of the study period, irrigation and livestock were the primary uses of groundwater from the aquifer. However, in recent years the data indicate the pumping is primarily for municipal use.

Reported pumping from the Edwards-Trinity (Plateau) Aquifer for irrigation began in 1989 and generally ranged between 100 and 400 acre-feet per year until 1999. After 1999, there was an abrupt decrease lasting four consecutive years, until the pumpage increased again reaching almost 300 acre-feet in 2006. After 2006, estimated irrigation pumpage generally ranged between 100 and 200 acre-feet per year except for two years (2007 and 2009) with minimal reported pumpage. The oscillations in estimated irrigation pumping data resulted in many years being flagged as anomalous (Figure 253).

Pumpage for livestock appears steady and generally ranging between 100 and 160 acre-feet per year until 1999. From 2000 through 2018 reported livestock pumping is generally declining and typically ranging between 50 and 100 acre-feet per year except for two relatively higher pumpage years (2010 and 2011) which are noted as anomalies (Figure 254). Pumpage to meet municipal needs was relatively constant at approximately 100 acre-feet per year between 1984 and 2003, after which it generally increased to almost 500 acre-feet in 2011 before subsequently declining through 2018. Since 2000, non-surveyed municipal use constituted a significant portion of the total municipal water use.

Figure 253 identifies an abrupt decrease in pumpage from the Edwards-Trinity (Plateau) for irrigation in 1992 and in 2000, for livestock in 2012, for manufacturing in 1989, for mining in 2000, and an anomalous decreasing trend in municipal pumpage after 2014. Figure 254 also identifies an abrupt increase in irrigation pumpage in 1989 and 2006, for livestock in 2010 and 2011, for mining in 1991 and for municipal needs in 2004, 2010, and 2011.

As shown on Figure 255, reported groundwater pumping from the Trinity (Hill Country) Aquifer did not occur until the year 2000 where it reached a maximum of about 60 acre-feet in 2011. The Water Use Survey data indicate irrigation and livestock use are the primary uses of Trinity (Hill Country) Aquifer groundwater in Real County. Overall, the reported production is relatively small and is typically be less than 30 acre-feet per year. Figure 256 and Figure 257 present the year-to-year change and standard deviation analyses, respectively, of the limited Water Use Survey data for the Trinity (Hill Country) Aquifer in Real County.

Table 45 provides the years identified as having anomalous pumping amounts for Real County for the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer based on our manual review, year-to-year change (Figure 253 and Figure 256), and standard deviation (Figure 254 and Figure 257) analyses.

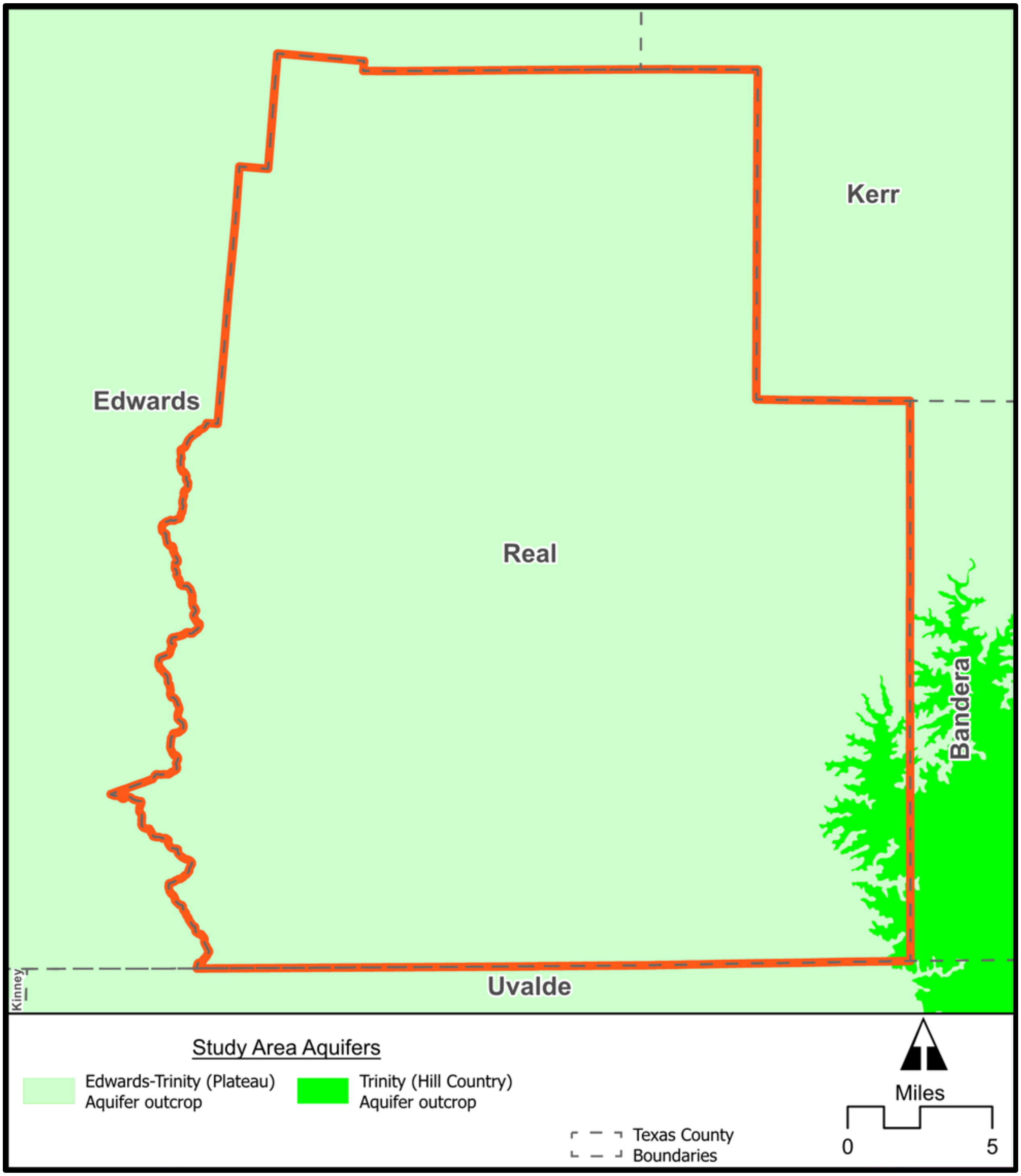


Figure 251. Real County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer.

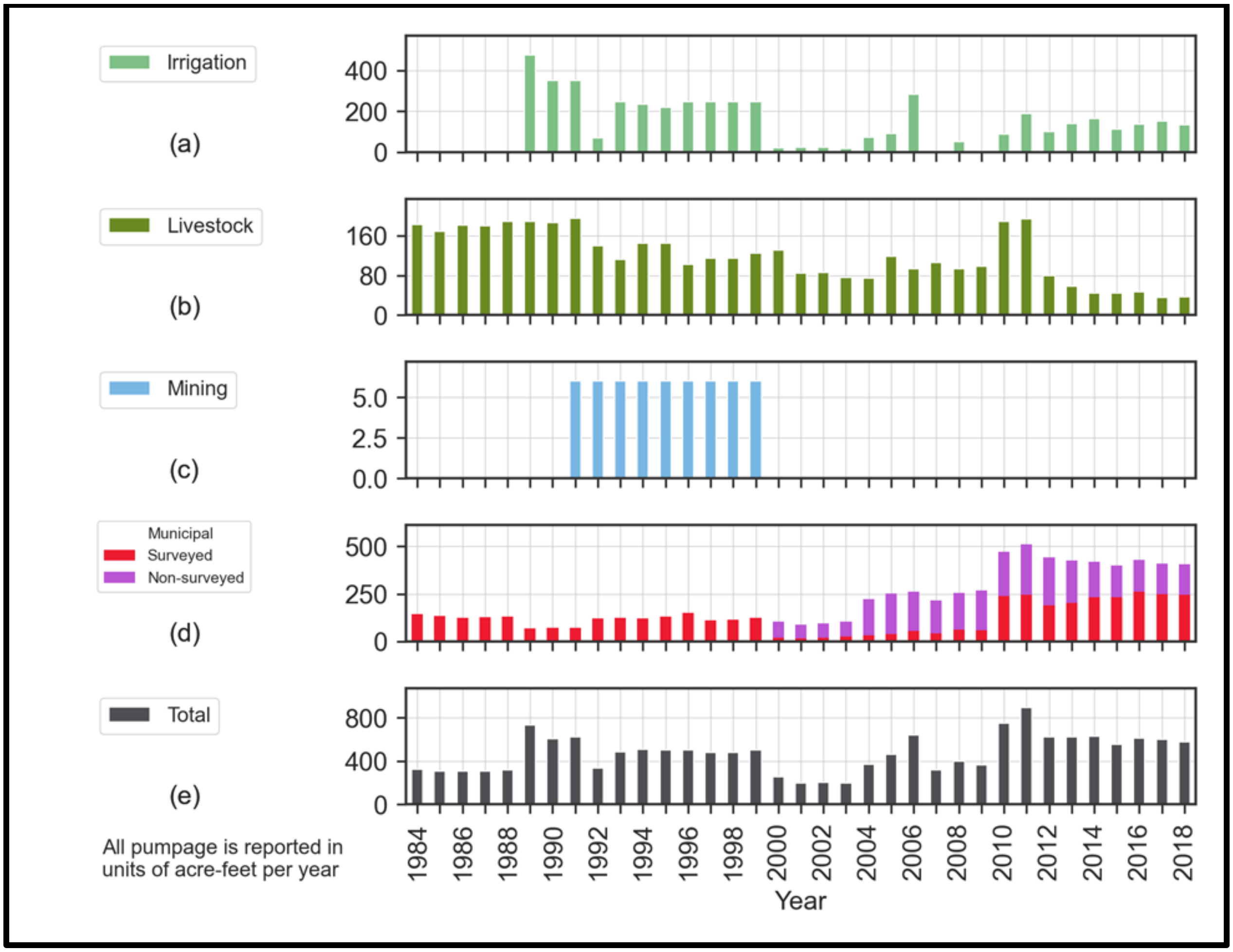


Figure 252. Real County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

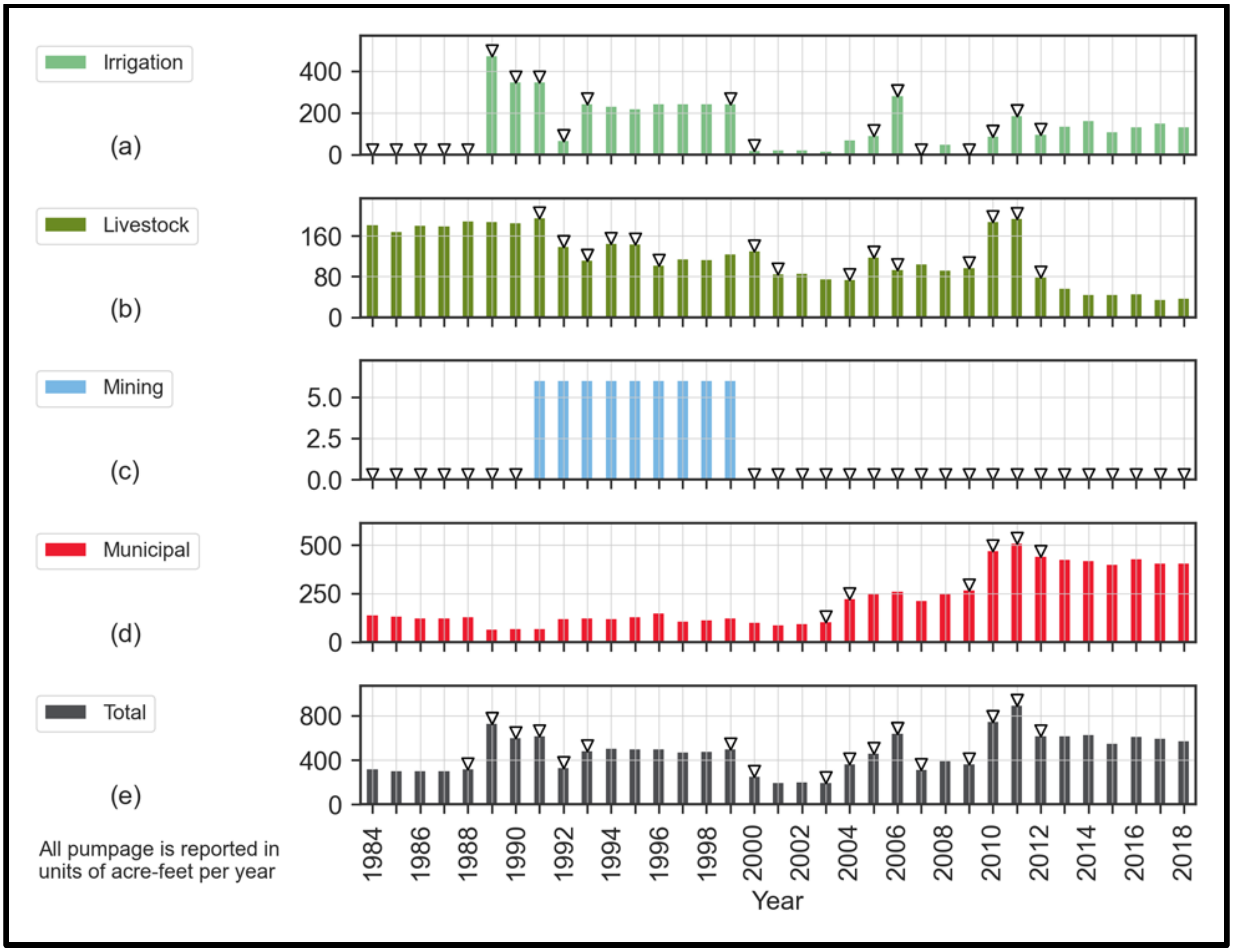


Figure 253. Real County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

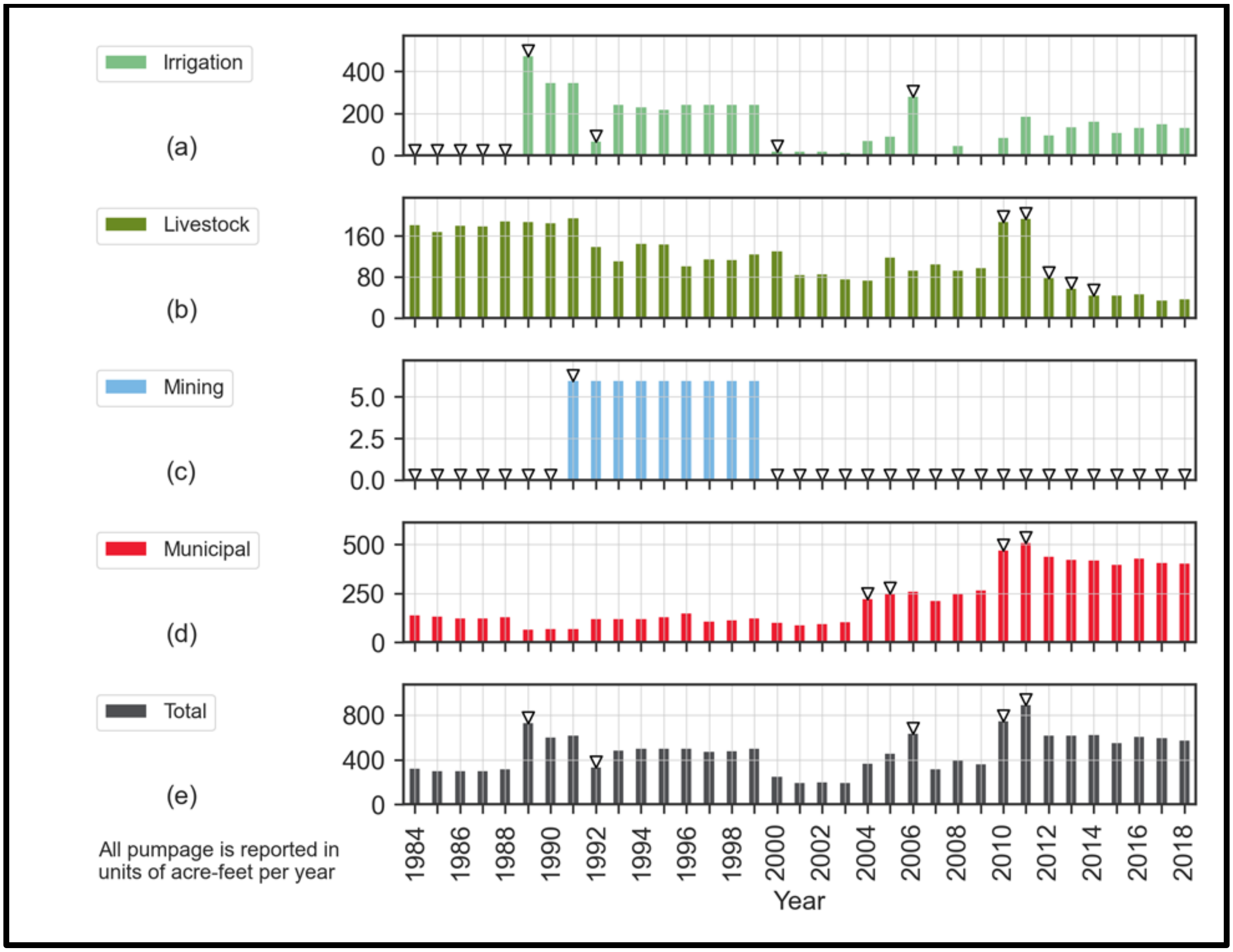


Figure 254. Real County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

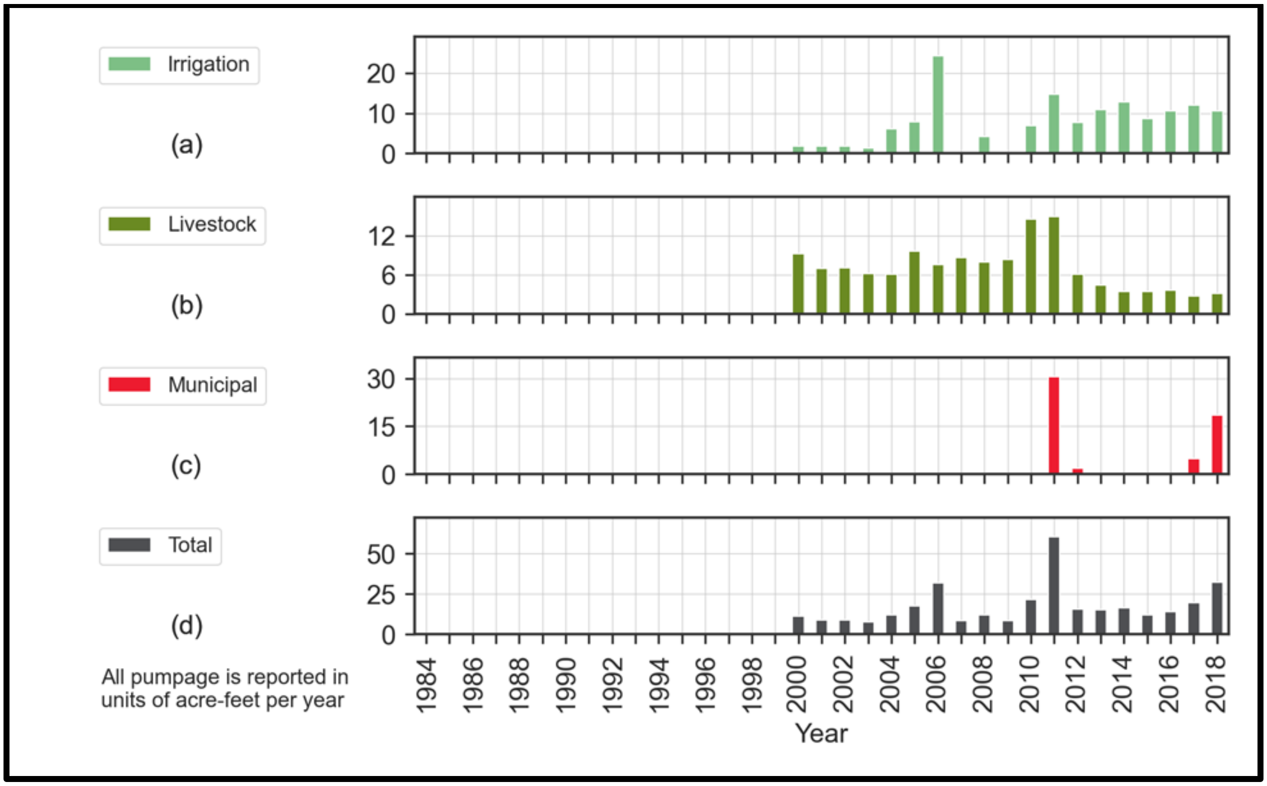


Figure 255. Real County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

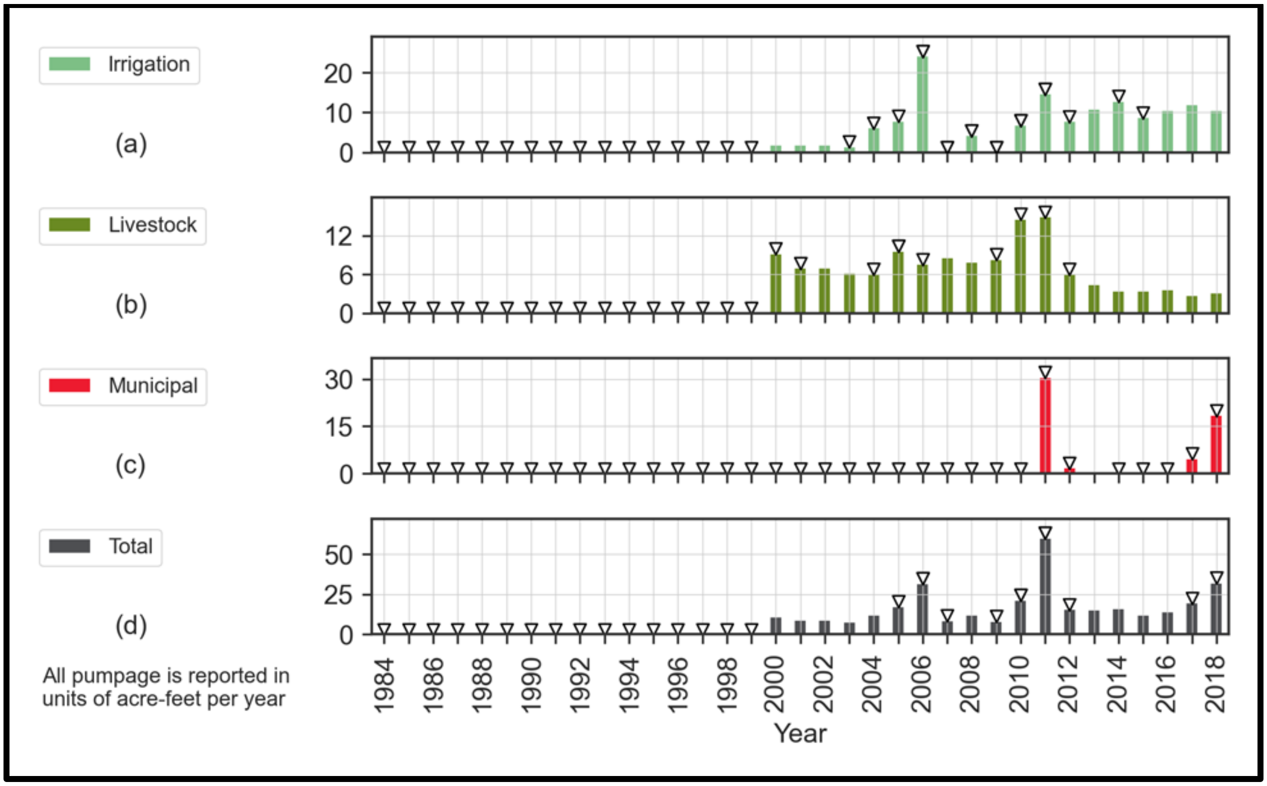


Figure 256. Real County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

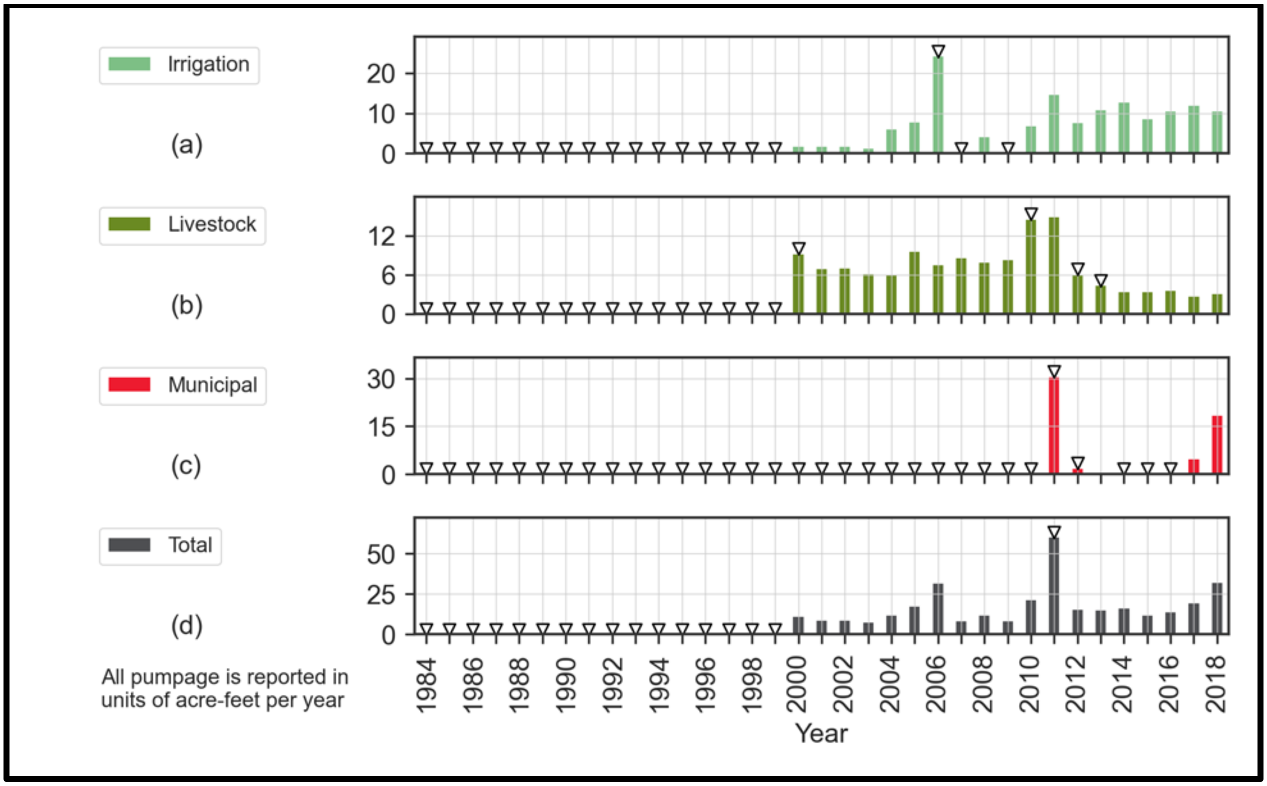


Figure 257. Real County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 45. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Real County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1984-1988, 1992, 2000-2003, 2007, 2009	1984-1990, 1992, 1993, 2000, 2006, 2007, 2010-2012	1984-1989, 1992, 2000, 2006, 2007, 2009-2011-2013
	Livestock	1992, 2010-2011	1992-1994, 1996, 2001, 2005, 2006, 2010, 2012	2010-2014
	Mining	1984-1990, 2000-2018	1984-1990, 2000-2018	1984-1991, 2000-2018
	Municipal	2004, 2010	2004, 2010, 2012	2004, 2005, 2010, 2011
Trinity (Hill Country)	Irrigation	2006	2004, 2006-2012, 2015	2006, 2007, 2009-2011-2013
	Livestock	2010-2011	2000, 2001, 2005, 2006, 2010, 2012	2010-2013
	Municipal	All except for 2011, 2012, 2017, 2018	2000-2012, 2014-2018	2000-2016

3.3.39 Reeves County

The Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer together underlie almost the entire area of Reeves County (see Figure 258). As shown on Figure 259, total groundwater pumping from the Pecos Valley Aquifer surpassed 300,000 acre-feet in 1993. Most of the total groundwater production from the Pecos Valley Aquifer is for irrigation.

As indicated in Figure 259, over the period from 1984 to 2018 groundwater pumping from the Pecos Valley Aquifer was for irrigation, livestock, manufacturing, mining and municipal use. Pumping for irrigation was consistently below 100,000 acre-feet except in 1993 when it exceeded 300,000 acre-feet. Pumpage for livestock was over 1,200 acre-feet between 1984 and 1987. After 1987, livestock pumping reduced by one-half for the next four consecutive years until 1991 when it increased to almost 1,000 acre-feet from 1992 through 1997. From 1998 to 2018, livestock pumpage gradually decreased from 300 acre-feet to a minimal amount in 2018.

Groundwater production from the Pecos Valley Aquifer in Reeves County for manufacturing gradually increased from 1984 to 1997 when it reached 1,200 acre-feet. In 1998 and 1999, pumping dropped to less than 600 acre-feet and in 2000 through 2012, pumping volumes remained consistently at minimal levels. Mining pumpage gradually decreased from almost 3,000 acre-feet in 1985 to approximately 300 acre-feet per year by 2009 with an abrupt decrease occurring in two years (1998 and 2008).

Reported groundwater pumping from the Pecos Valley Aquifer in Reeves County to meet municipal needs is from 1992 through 2018. The reported municipal use gradually increased from 100 acre-feet to almost 2,000 acre-feet by 2018. There was an abrupt increase in 2000 and an abrupt decrease in 2017. Since 2000, non-surveyed municipal use constituted a relatively small portion of the total municipal water usage. Figure 260 (year-to-year change analysis) and Figure 261 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Pecos Valley Aquifer in Reeves County.

Groundwater production from the Edwards-Trinity (Plateau) Aquifer helped meet the water needs for irrigation, livestock, mining, and municipal use from 1984 and 2018. Estimated pumping for irrigation, similarly to that from the Pecos Valley Aquifer, peaked in 1993 at almost 30,000 acre-feet, whereas the rest of the pumpage remained less than 10,000 acre-feet per year. Pumpage for livestock ranged between 100 and 800 acre-feet per year and mimics the livestock pattern from the pumpage from the Pecos Valley Aquifer. Pumping for mining was only reported in 1984. Groundwater production for municipal use minimal prior to 2010 and remained less than 500 acre-feet per year through 2018, except for 2013 where usage peaked at 3,000 acre-feet. Figure 263 (year-to-year change analysis) and Figure 264 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Reeves County.

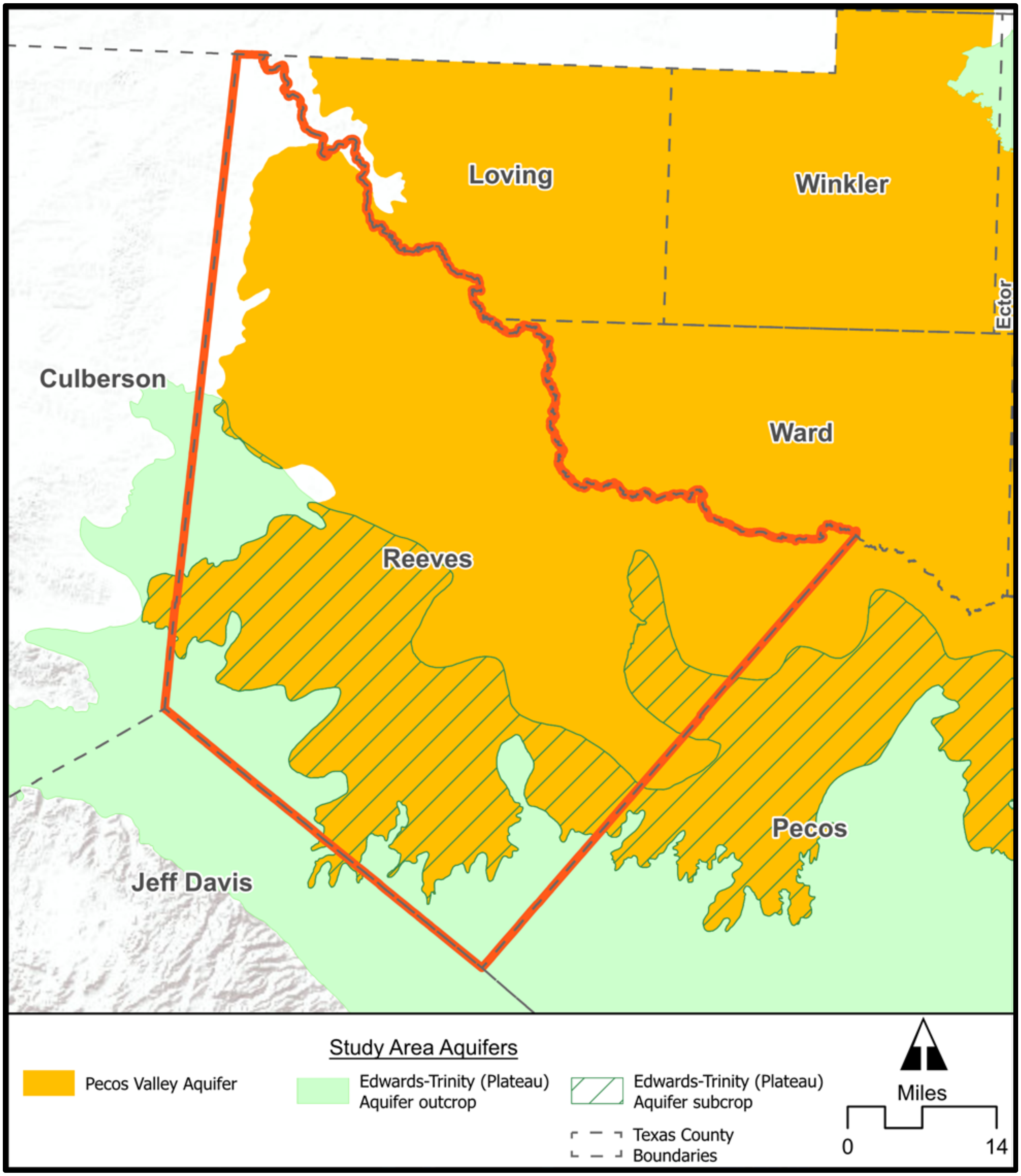


Figure 258. Reeves County showing the extent of the Pecos Valley and Edwards-Trinity (Plateau) aquifers.

We noted similarities between the patterns of irrigation and livestock data for Reeves County for the Pecos Valley Aquifer (Figure 259) and Edwards-Trinity (Plateau) Aquifer (Figure 260). We suspect these patterns result from the methodology utilized to estimate pumping for these use categories within this county. We will investigate the data estimation methods used in creating these datasets during subsequent project phases. Our investigation will include detailing the methods used by the TWDB Agricultural Water Conservation Group in estimating historical groundwater pumpage.

Land used for potential irrigation overlying the Pecos Valley Aquifer in Reeves County negatively correlates to groundwater pumpage from the Pecos Valley Aquifer for irrigation use. Figure 265 indicates that although the acres of potentially irrigated land overlying the aquifer have increased in the county by approximately 4,000 acres since 2000, the reported pumpage for irrigation use decreased. Figure 266 indicates a linear correlation value (“*r*”) of -0.51 between potentially irrigated land area and groundwater pumpage for irrigation. The observed moderate negative correlation suggests that pumpage for irrigation in Reeves County is anomalous. We will research alternative explanations for this negative correlation during subsequent project phases, along with researching the identified irrigation data anomalies used in computing the correlation.

Table 46 provides the years identified as having anomalous pumping amounts for Reeves County for the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 260 and Figure 263Figure 256), and standard deviation (Figure 261 and Figure 264) analyses.

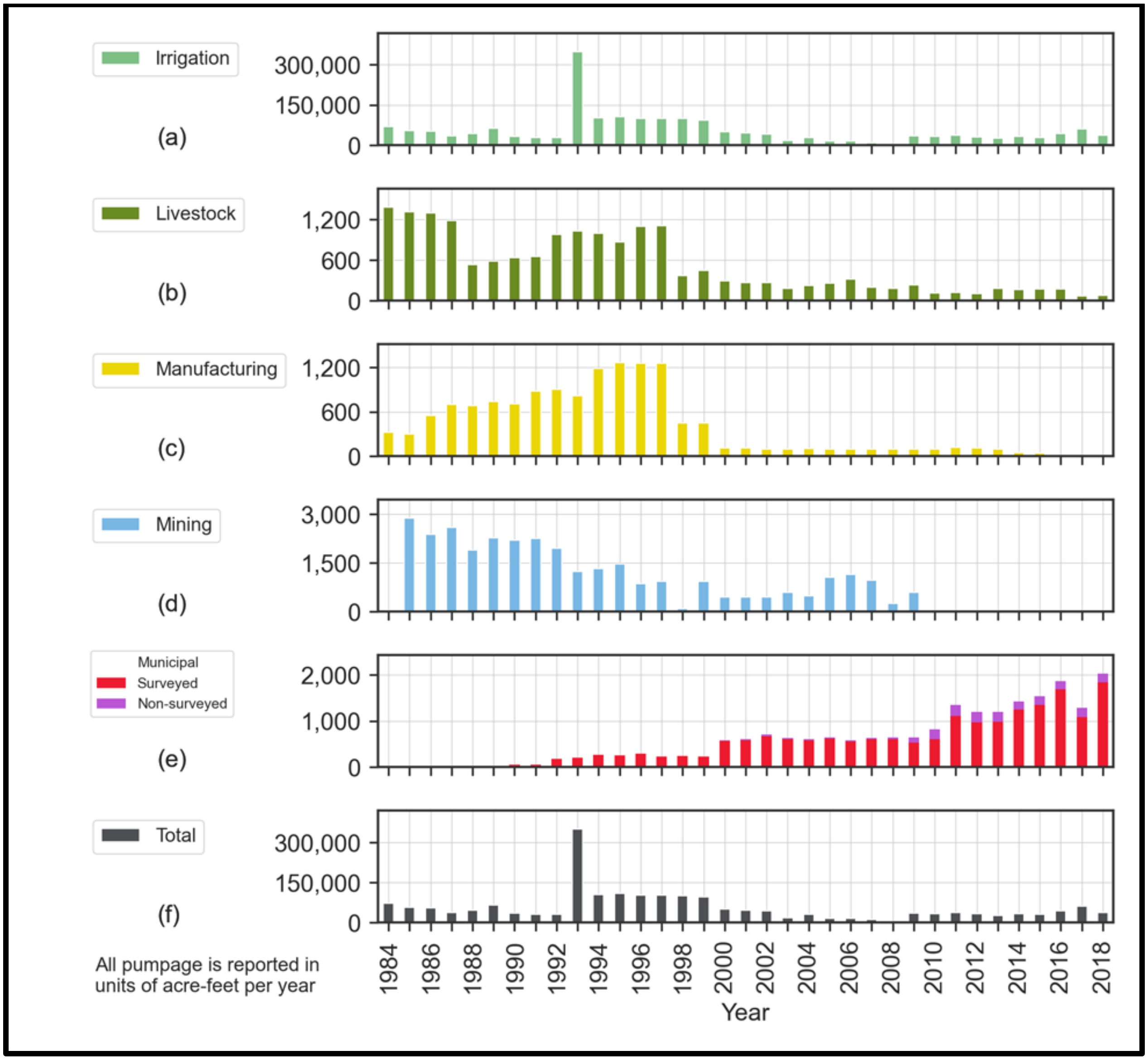


Figure 259. Reeves County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

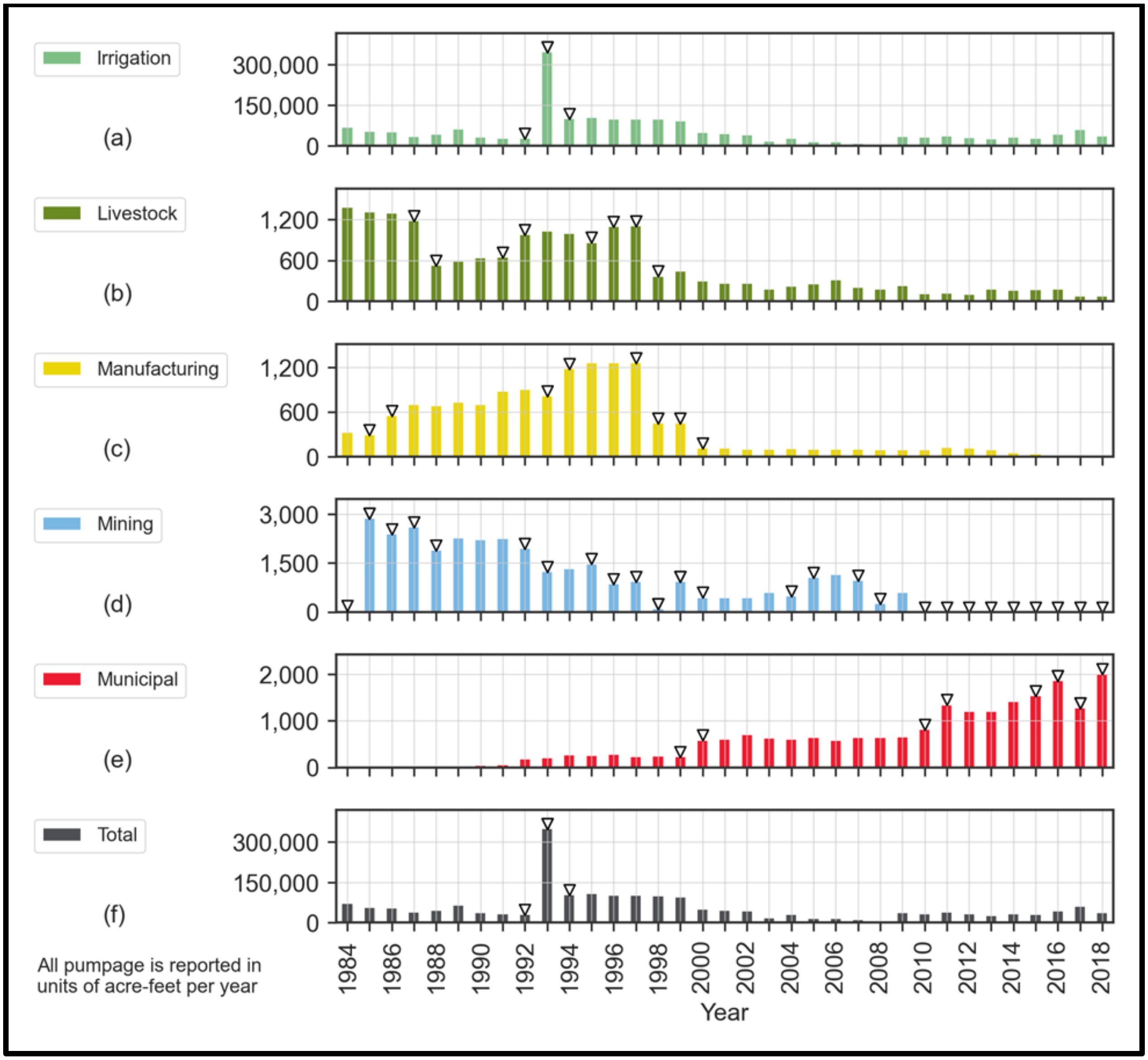


Figure 260. Reeves County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

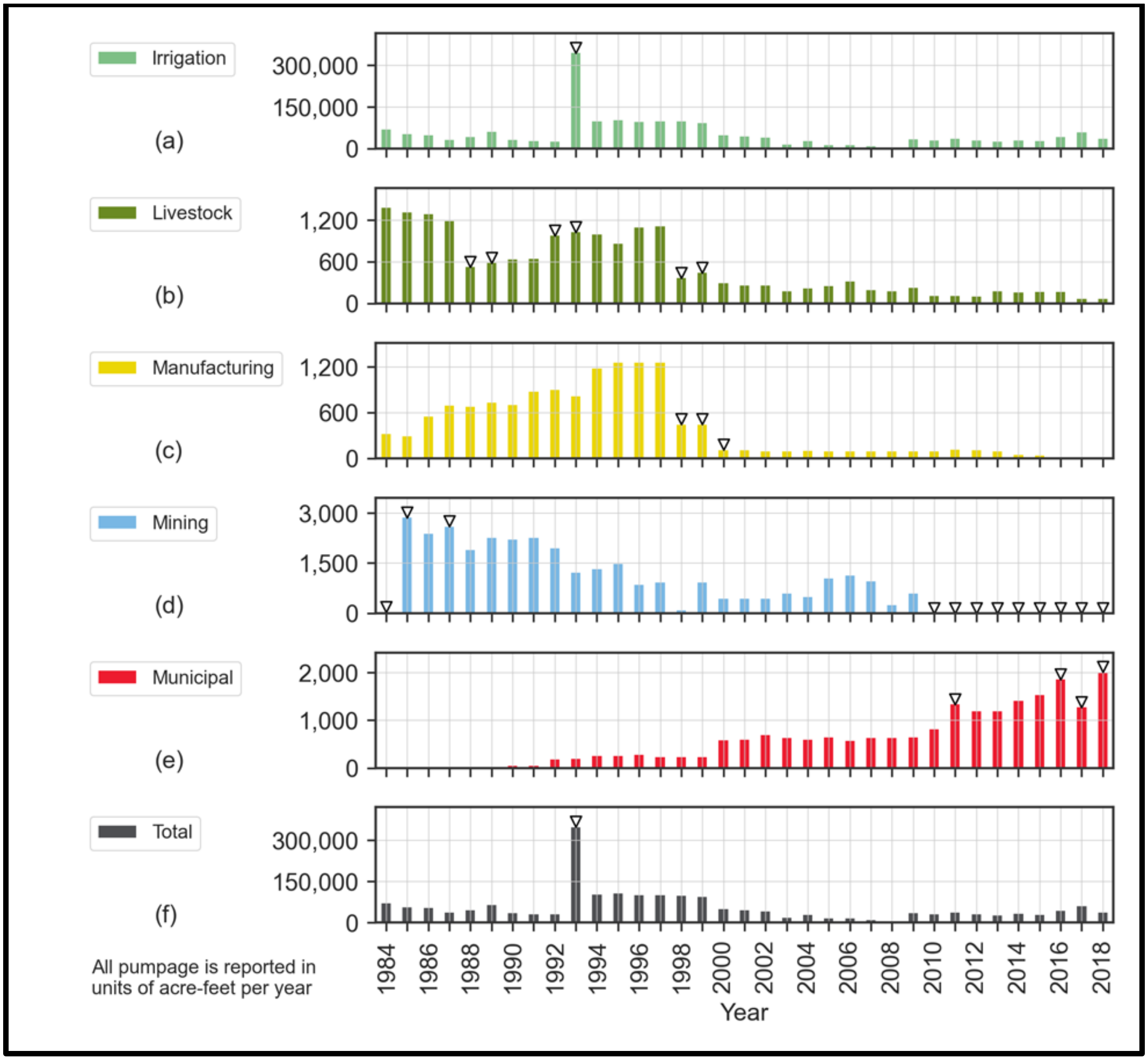


Figure 261. Reeves County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

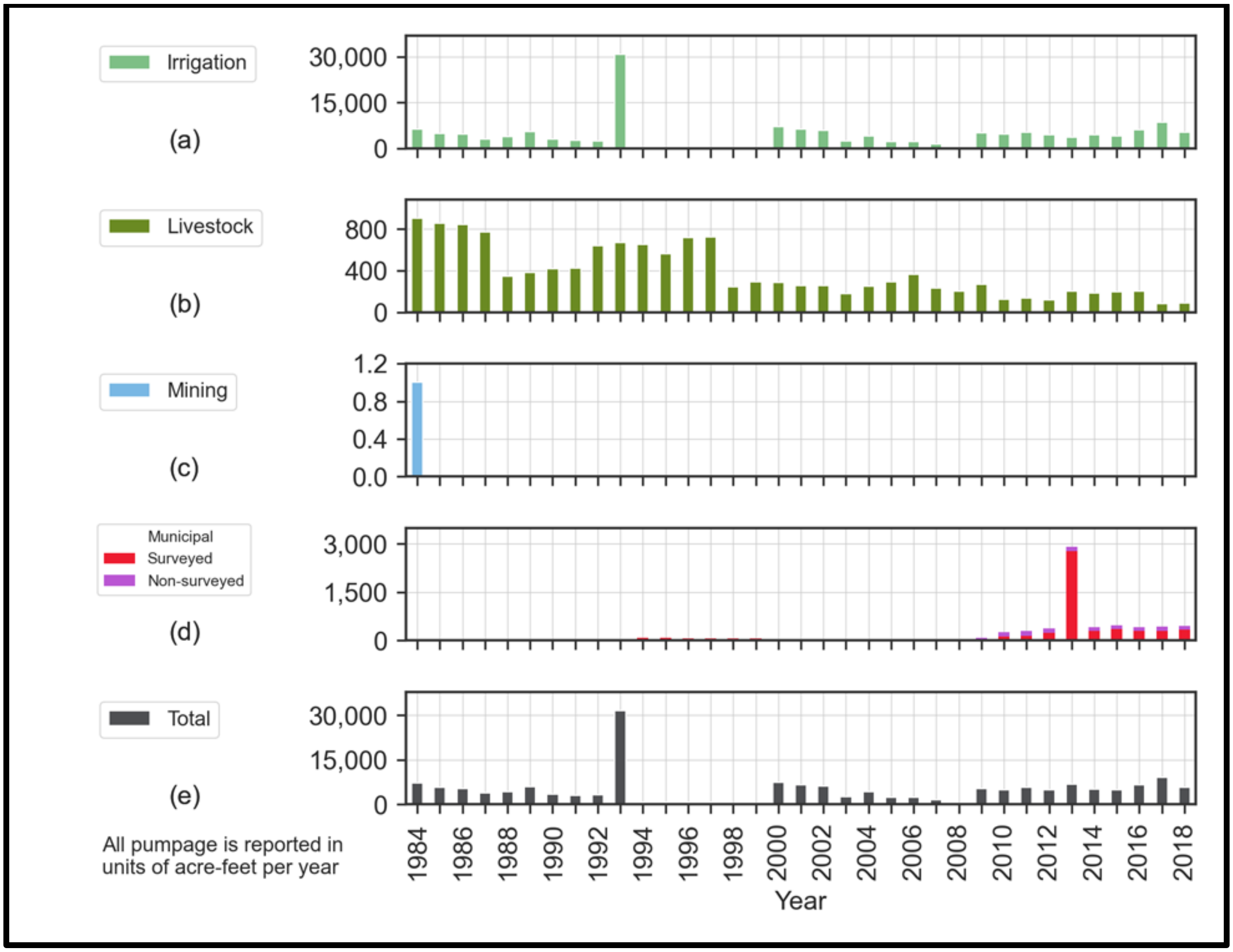


Figure 262. **Reeves County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

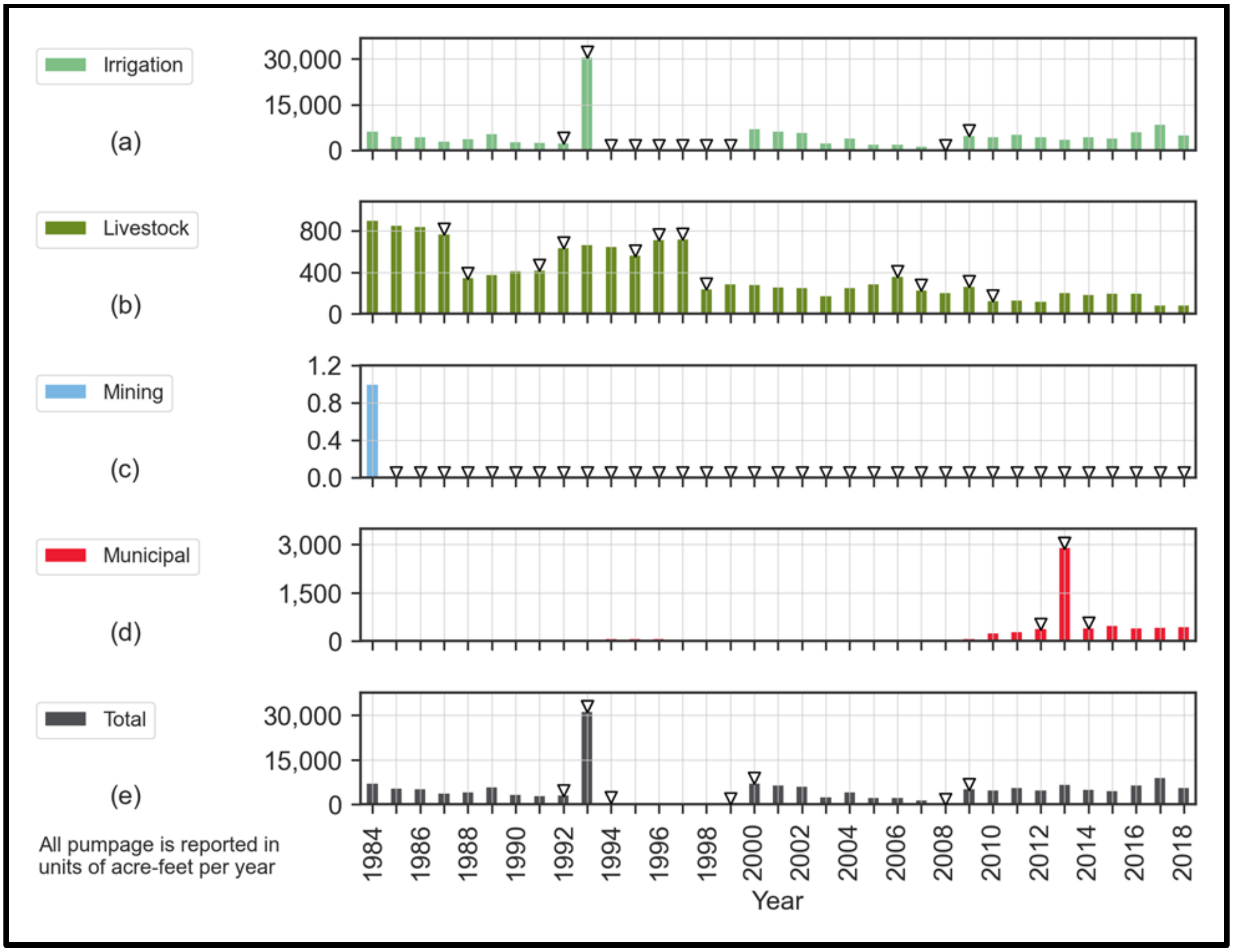


Figure 263. Reeves County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

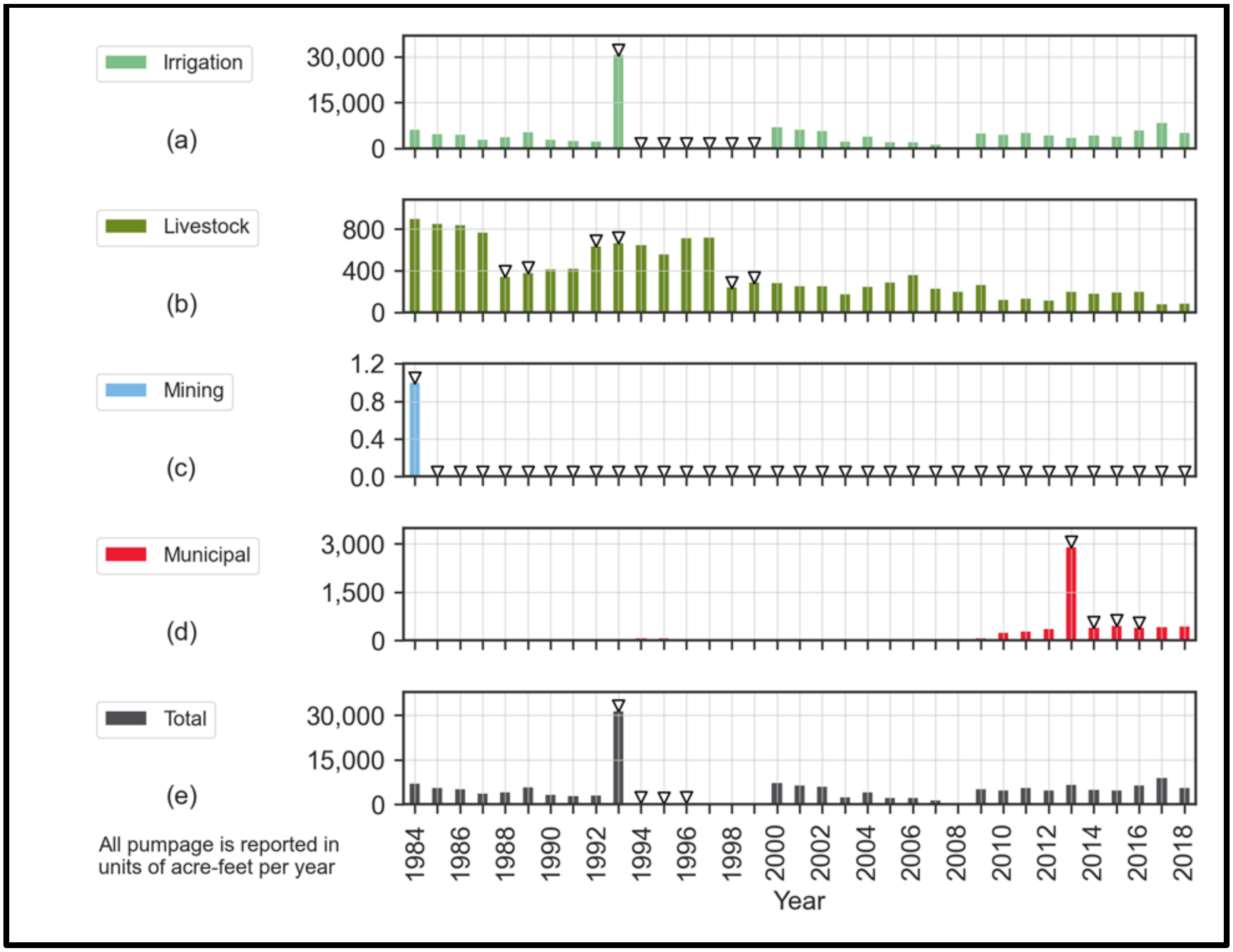


Figure 264. Reeves County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

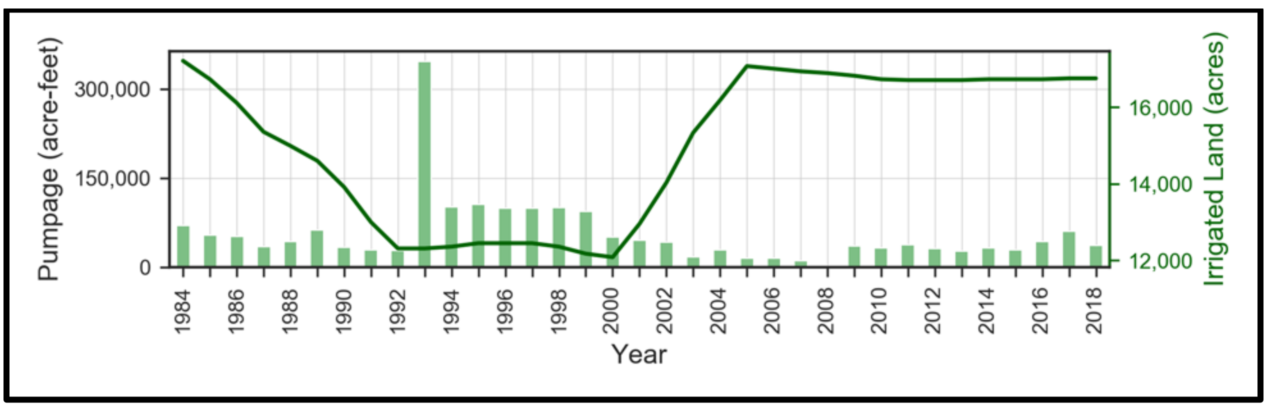


Figure 265. Reeves County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

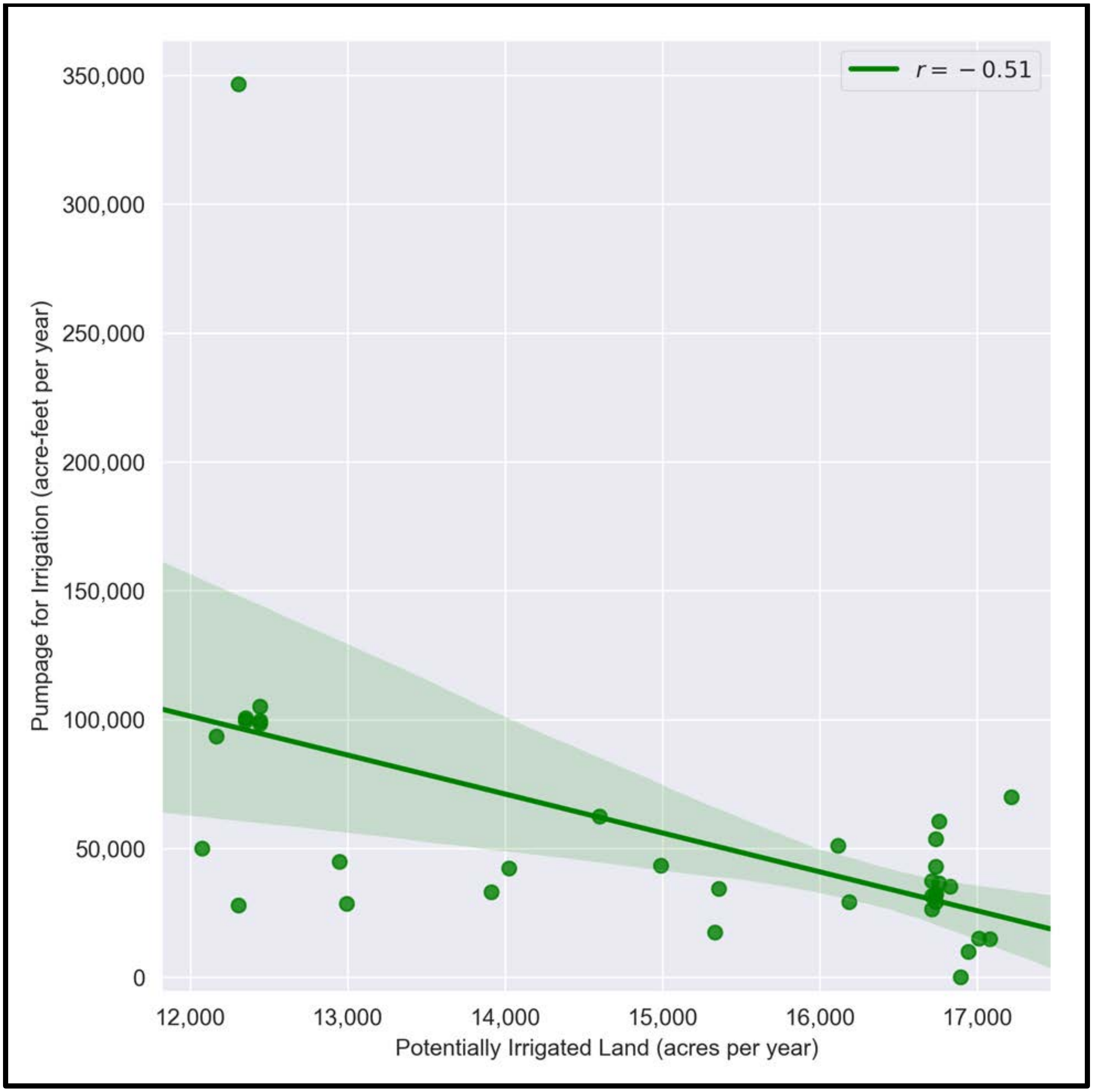


Figure 266. Reeves County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 46. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Reeves County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Pecos Valley	Irrigation	1993	1993, 1994	1993, 2008
	Livestock	1988, 1998	1988, 1992, 1996, 1998	1988, 1989, 1992, 1993, 1998, 1999
	Manufacturing	1998	1986, 1994, 1998, 2000	1998-2000
	Mining	1984, 1998, 2010-2018	1984-1986, 1988, 1993, 1996, 1998-2000, 2005, 2008, 2010-2018	1984, 1985, 1987, 2010-2018
	Municipal	2011	2000, 2011, 2016-2018	2011, 2016-2018
Edwards - Trinity (Plateau)	Irrigation	1993-1999, 2008	1993-2000, 2009	1993-1999, 2008
	Livestock	1988, 1998	1988, 1992, 1996, 1998, 2007, 2010	1988, 1989, 1992, 1993, 1998, 1999
	Mining	1984	1985-2018	1984-2018
	Municipal	2013	2013, 2014	2013-2016

3.3.40 Runnels County

The Lipan Aquifer underlies a portion of southwestern Runnels County (see Figure 267). As shown on Figure 268, total groundwater pumping from the Lipan Aquifer in Runnels County surpassed 200 acre-feet 2001, with the majority of the pumpage for municipal use. Pumpage was also reported for manufacturing and livestock uses.

Pumping data for the Lipan Aquifer in Runnels County was only reported between 2000 and 2018. Pumping for livestock was less than 10 acre-feet per year from 2000 through 2004, and increased to between 30 acre-feet per year to 40 acre-feet per year from 2005 through 2011. Pumpage decreased in 2012 and remained below 30 acre-feet per year through 2018. Groundwater pumping for manufacturing was reported as one acre-foot for three years (2002, 2003, and 2004) and was not reported during other years. Groundwater pumpage to meet municipal needs ranged between 100 and 200 acre-feet between 2000 and 2003, and was reported as minimal for 2013, 2014, 2017, and 2018 (with data not reported for all other years). Figure 269 (year-to-year change analysis) and Figure 270 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Lipan Aquifer in Runnels County.

The TWDB Water Use Survey database contains pumping records from the Edwards-Trinity (Plateau) Aquifer within Runnels County (Figure 271). We believe this attribution to Runnels County is in error, as the TWDB defined footprint of the Edwards-Trinity (Plateau) Aquifer does not extend into Runnels County. These pumping records could pertain to wells drawing from the Lipan Aquifer or other formations within Runnels County that are not part of the focus of this project. We will investigate the source of this pumpage data during subsequent project phases.

Table 47 provides the years identified as having anomalous pumping amounts for Runnels County for the Lipan Aquifer based on our manual review, year-to-year change (Figure 269), and standard deviation (Figure 270) analyses.

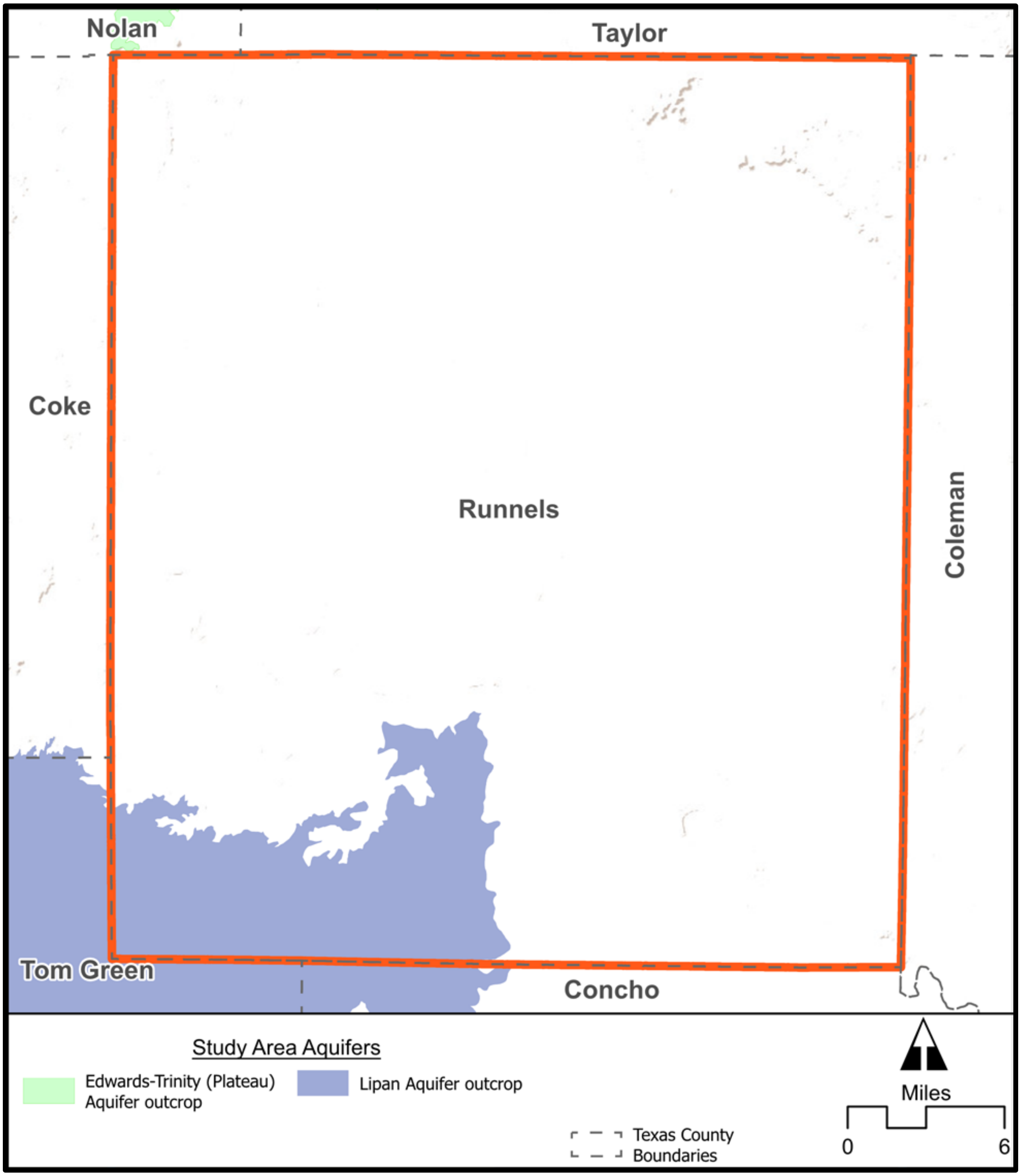


Figure 267. Runnels County showing the extent of the Lipan Aquifer.

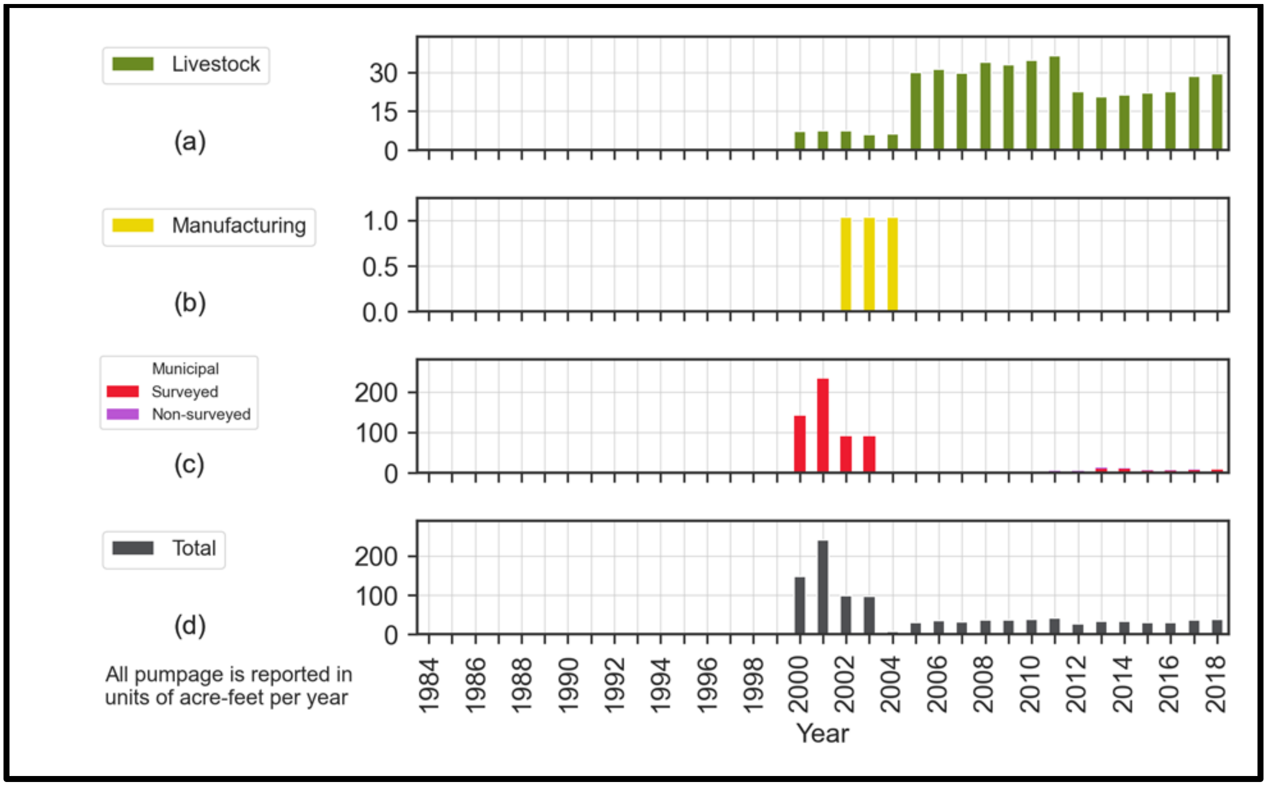


Figure 268. **Runnels County Lipan Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

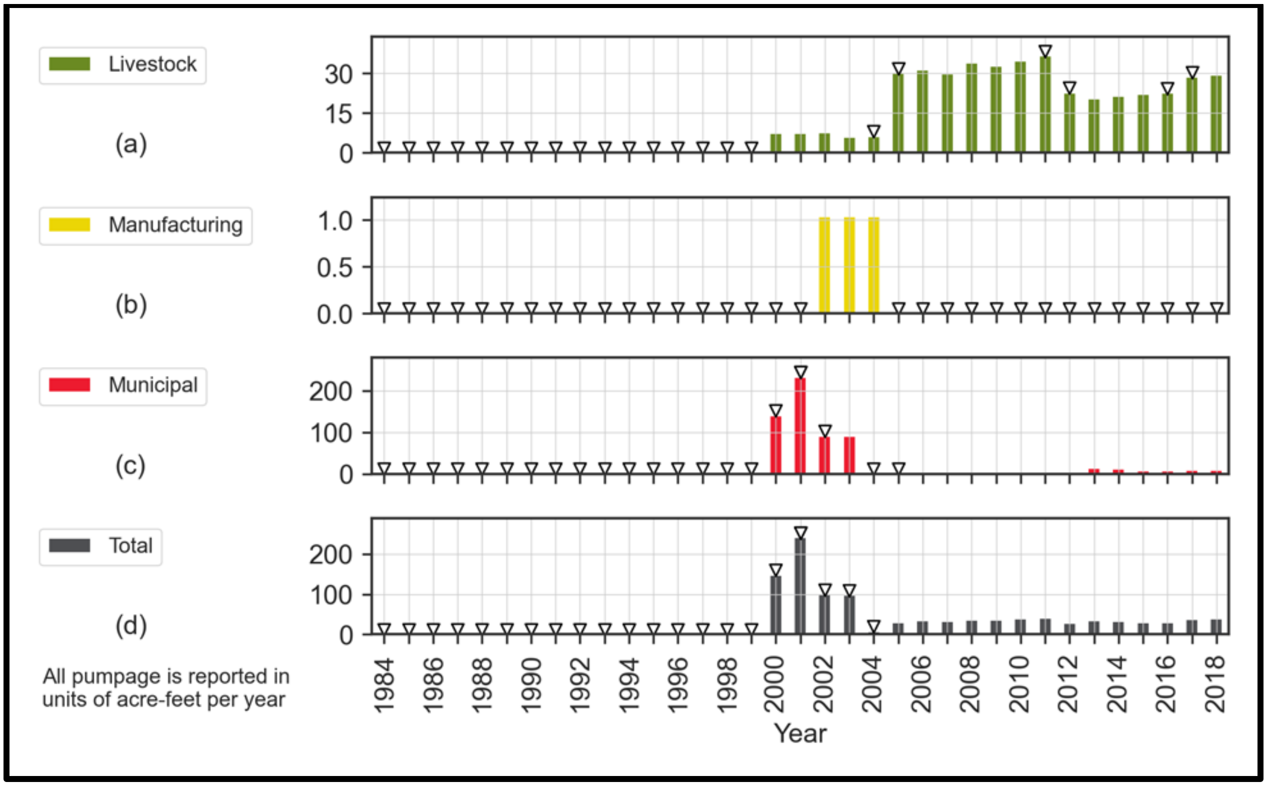


Figure 269. Runnels County Lipan Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

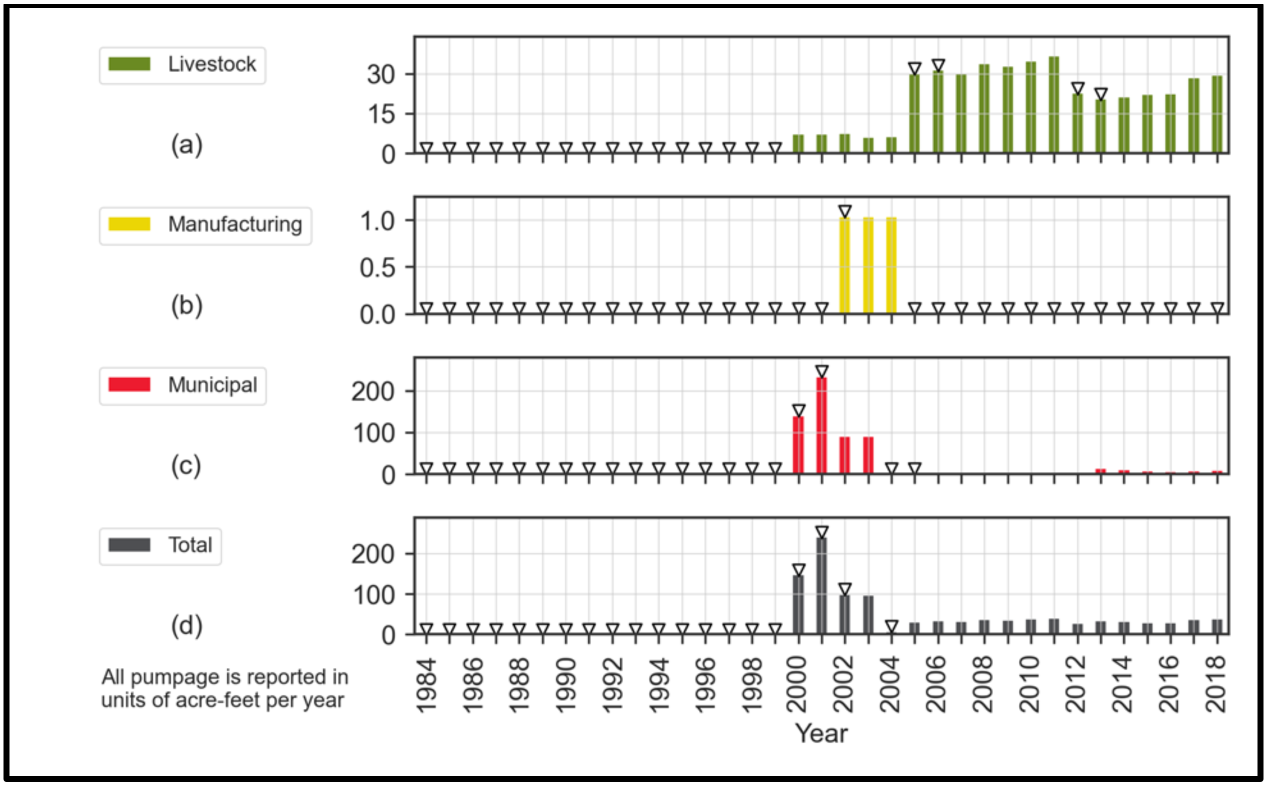


Figure 270. Runnels County Lipan Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

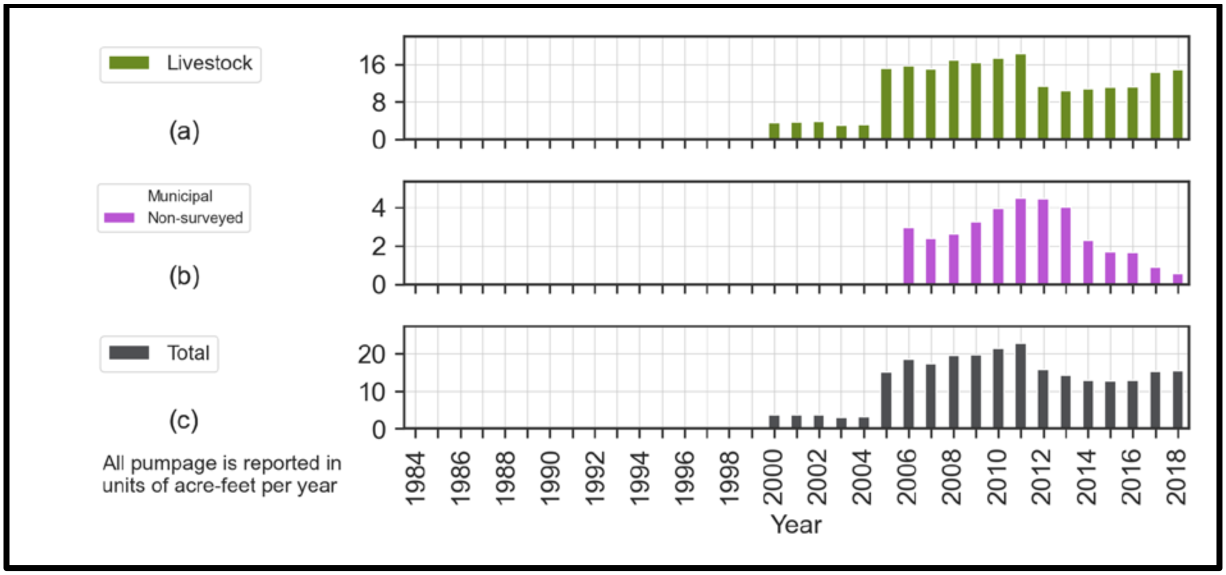


Figure 271. Runnels County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Table 47. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Runnels County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Lipan	Livestock	2005, 2012	2005, 2012, 2017	2005, 2006, 2012, 2013
	Manufacturing	2000-2018	2000, 2001, 2005-2018	2000, 2001, 2005-2018
	Municipal	2000-2004	2000-2002, 2004, 2005	2001, 2004, 2005

3.3.41 Schleicher County

The Edwards-Trinity (Plateau) Aquifer covers the entire area of Schleicher County (see Figure 272). A small portion of the Lipan Aquifer (subcrop) also is present along the northern border of the county. As shown on Figure 273, total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer during the study period generally ranged between 1,500 and 4,000 acre-feet per year. According to the Water Use Survey data, groundwater production is primarily for irrigation use, yet is also used for livestock, mining, and municipal purposes.

Pumping data for the Edwards-Trinity (Plateau) Aquifer for irrigation shows a general increase from 1984 to 1999 where pumpage peaked at approximately 3,000 acre-feet. Irrigation pumping declined between 2000 and 2007. After 2007 there was an increasing trend in irrigation pumping through 2018.

Pumping data for livestock use appears fairly steady and ranges between 200 and 500 acre-feet per year. Pumping for mining gradually increased between 1984 and 1996, then gradually decreased until 1999. There was an abrupt decrease in the year 2000 which caused pumpage to remain at minimal reported volumes from 2000 to 2007, after which the Water Use Survey dataset does not contain pumpage data. Pumping to meet municipal needs appears relatively stable at approximately 500 acre-feet except for anomalous high values in 1998, 2011, and 2014. Since 2000, non-surveyed municipal use constituted a relatively small portion of municipal usage compared to surveyed use.

Figure 274 and Figure 275 identify anomalous pumping amounts in the data for Schleicher County. These anomalies include an abrupt decrease in pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation in 1987 and in 2001, for livestock in 2001, for mining in 2000, and for municipal use in 2015. We also observe anomalies as abrupt pumping increases in irrigation in 1998 and 1999, for livestock in 2005, for mining in 1991, and for municipal use in 1998 and 2011. The TWDB Water Use Survey database did not contain any entries indicating pumpage from the Lipan Aquifer in Schleicher County.

Potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in Schleicher County correlates linearly to groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation use. Figure 276 indicates that from 2007 onward as the area of potentially irrigated land overlying the aquifer increased in the county, reported pumpage for irrigation also increased. Figure 277 indicates a linear correlation value ("r") of 0.42 between potentially irrigated land area and groundwater pumpage for irrigation use. This moderate positive correlation suggests that pumpage for irrigation in Schleicher County matches the trend in potentially irrigated land. This correlation does not indicate that the increase in potentially irrigated land overlying the aquifer caused or contributed to any observed increases in irrigation pumpage. We will investigate this identified correlation as part of subsequent project phases.

Table 48 provides the years identified as having anomalous pumping amounts for Schleicher County for the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 274), and standard deviation (Figure 275) analyses.

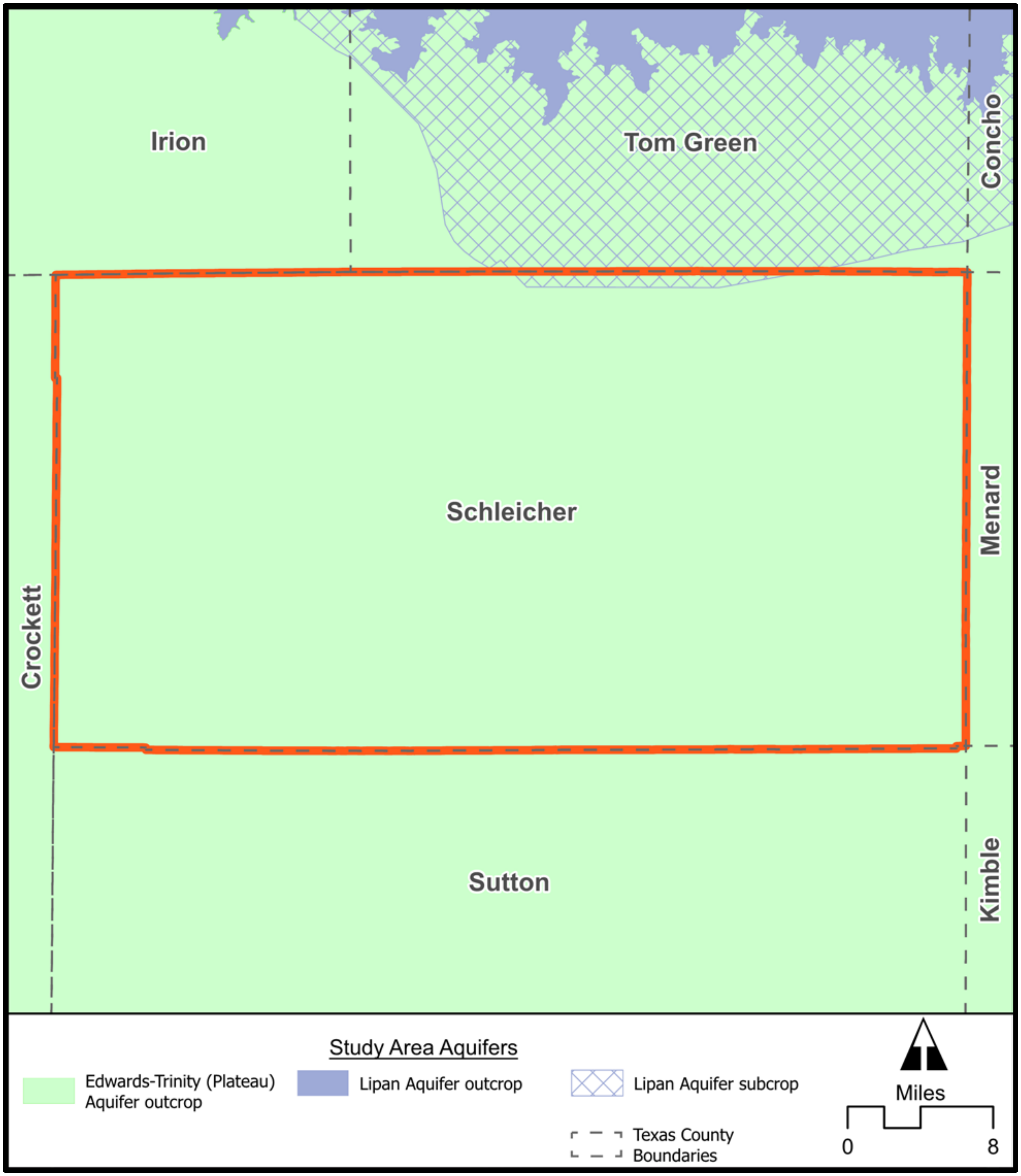


Figure 272. Schleicher County showing the extent of the Edwards-Trinity (Plateau) and Lipan aquifers.

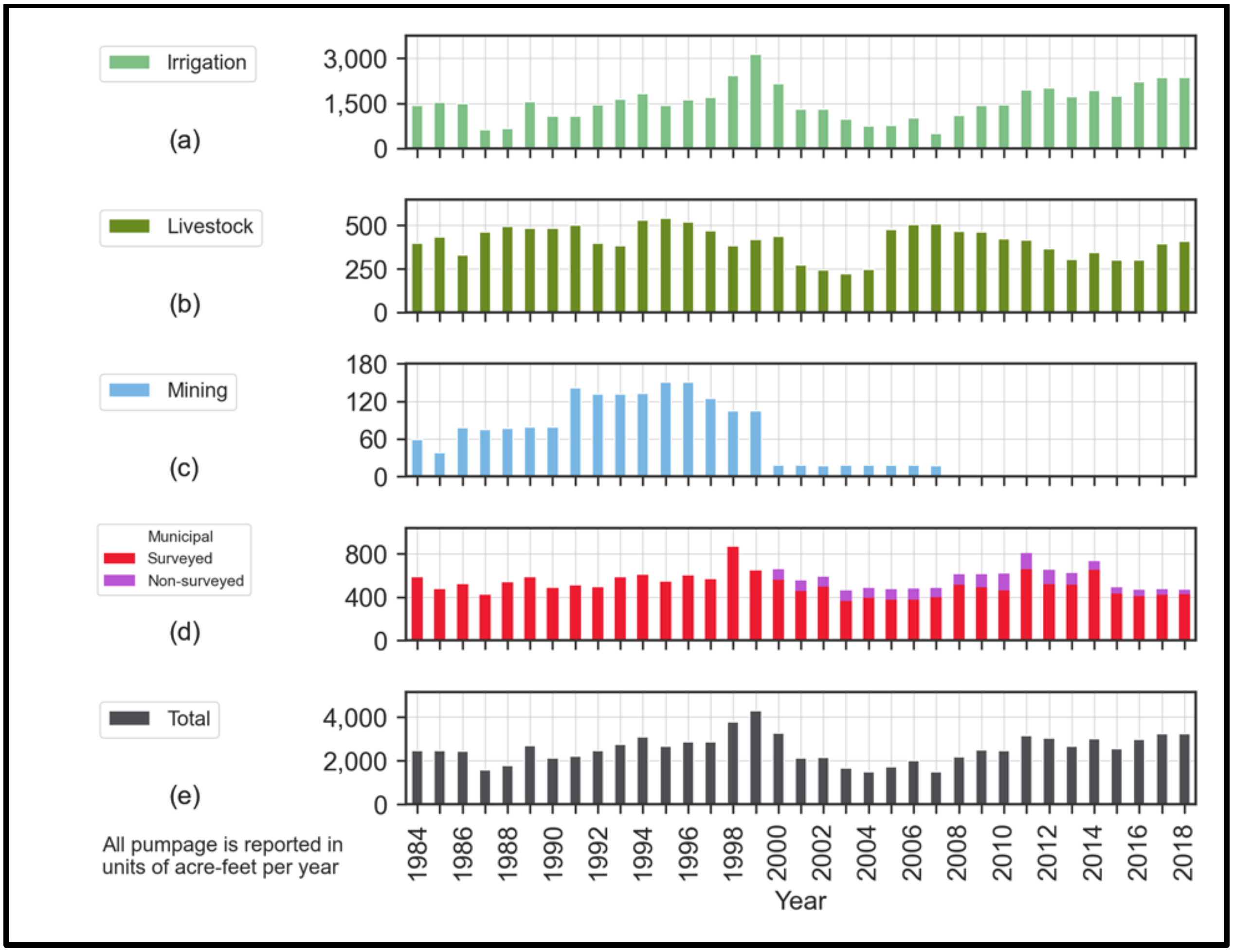


Figure 273. Schleicher County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

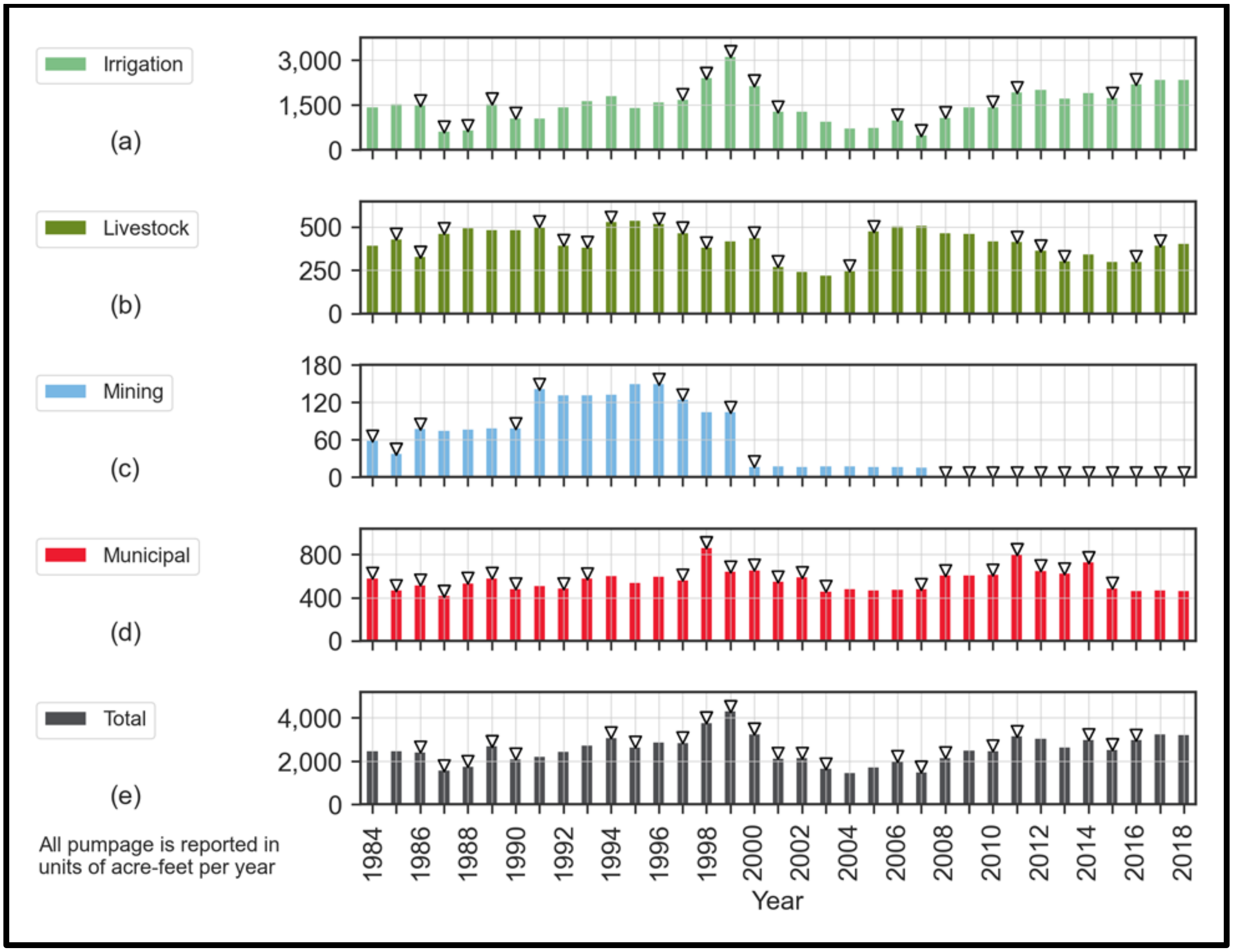


Figure 274. Schleicher County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

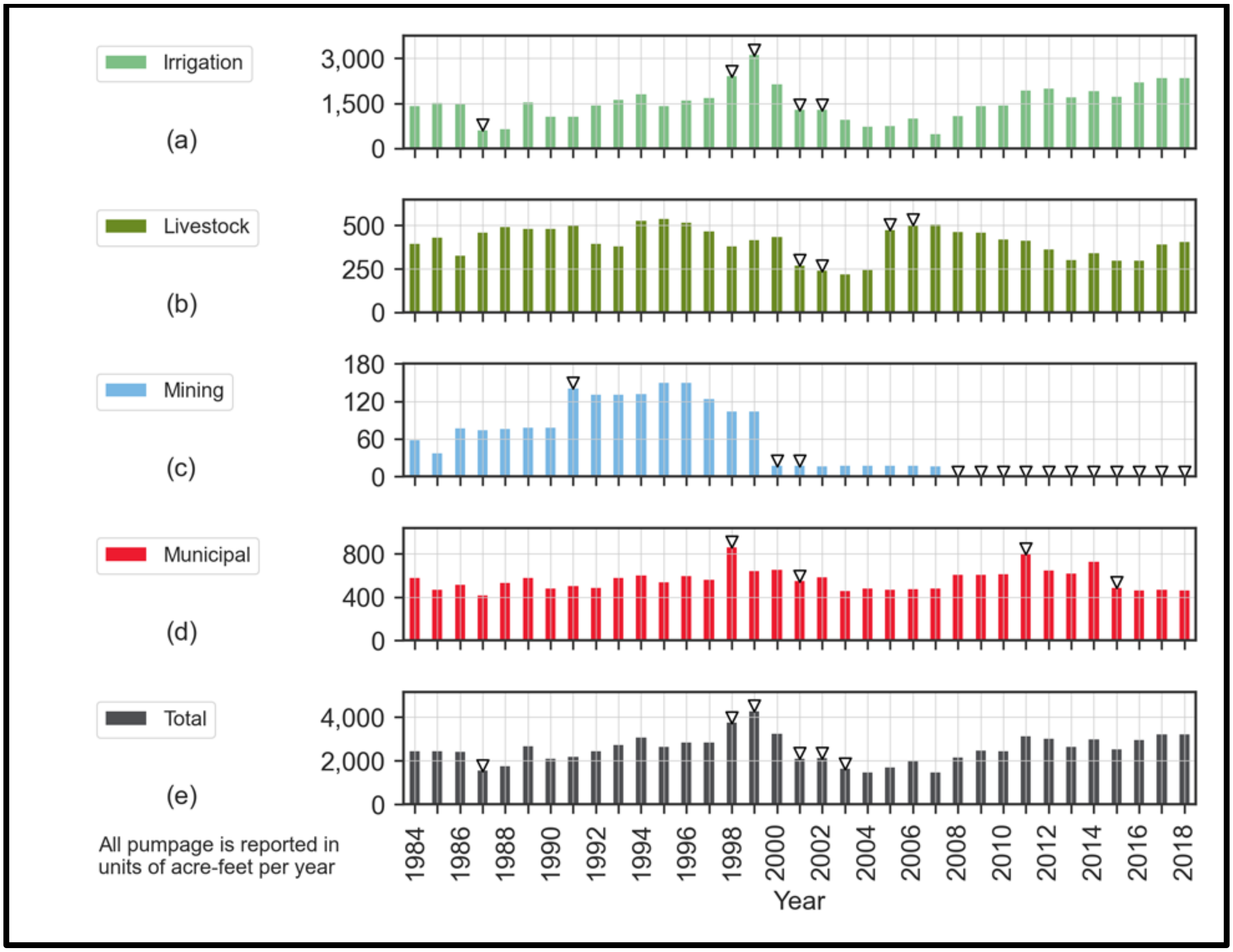


Figure 275. Schleicher County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

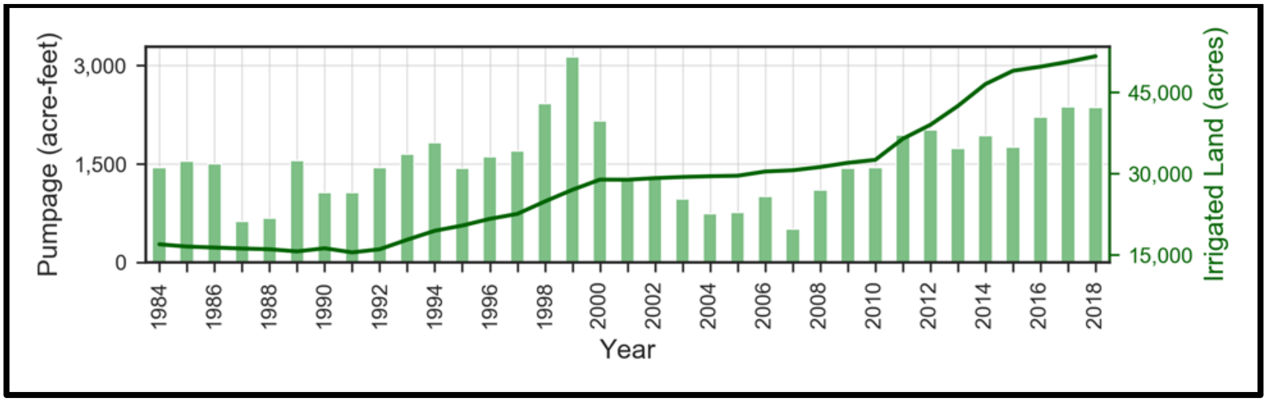


Figure 276. Schleicher County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

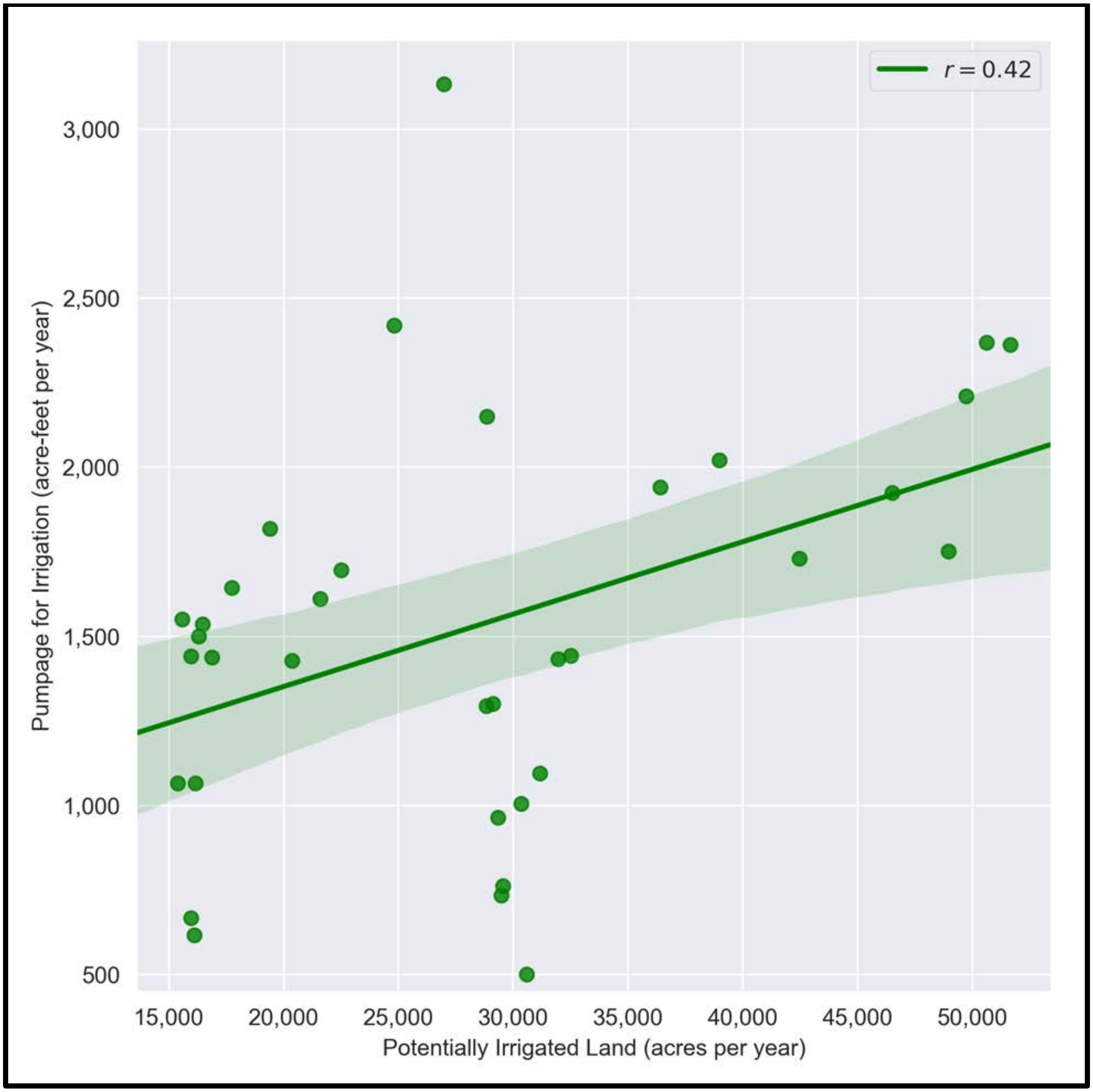


Figure 277. Schleicher County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 48. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Schleicher County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1987, 1989, 1998, 1999, 2001	1987, 1989, 1990, 1998-2001, 2007, 2008, 2011, 2016	1987, 1998, 1999, 2001, 2002
	Livestock	2001, 2005	1986, 1987, 1992, 1994, 1997, 1998, 2001, 2005, 2012, 2013, 2017	2001, 2002, 2005, 2006
	Mining	1991, 2000, 2008-2018	1984-1986, 1991, 1997, 2000, 2008-2018	1991, 2000, 2001, 2008-2018
	Municipal	1998, 2011, 2015	1984, 1985, 1987, 1988, 1990, 1993, 1998, 1999, 2001, 2003, 2008, 2011, 2012, 2014, 2015	1998, 2001, 2011, 2015

3.3.42 Sterling County

The Edwards-Trinity-Plateau Aquifer and the Lipan Aquifer together underlie nearly 90 percent of Sterling County by area (see Figure 278). As shown in Figure 279, total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer surpassed 1,000 acre-feet between 1991 and 1993. Most of the total groundwater production from the Edwards-Trinity (Plateau) Aquifer in Sterling County was for irrigation.

Reported groundwater pumping from the Edwards-Trinity (Plateau) Aquifer was for irrigation, livestock, mining, and municipal use. Groundwater pumping for irrigation started out high (approximately 500 acre-feet per year) from 1984 through 1986 then remained at approximately 250 acre-feet per year through 2009. During this period, there were two spans of anomalous lower pumpage (1987 and 1988, and 1994 through 1999). After 2009, irrigation pumpage was generally higher and approached 400 acre-feet per year.

Estimated pumping for livestock ranged between 150 and 300 acre-feet per year over the entire 1984 through 2018 period. Groundwater production for mining was only reported from 1984 through 1999 and shows an abrupt increase in pumping after 1990. Pumping for municipal use remained consistent at approximately 35 acre-feet annually from 1984 through 1999, after which it decreased to minimal pumpage from 2000 through 2005 and then remained at 20 acre-feet per year from 2006 through 2018. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, non-surveyed municipal use constituted all municipal usage. Figure 280 (year-to-year change analysis) and Figure 281 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Sterling County.

The TWDB Water Use Survey database indicates total pumping of up to about 90 acre-feet per year from the Pecos Valley Aquifer within Sterling County (see Figure 282); however, the TWDB footprint for the Pecos Valley Aquifer does not extend to Sterling County and we expect the pumping is likely from the Edwards-Trinity (Plateau) Aquifer or the Lipan Aquifer. We will investigate the source of this pumping data attribution to the Pecos Valley Aquifer during subsequent tasks of this project.

The TWDB Water Use Survey database does not contain records of groundwater production from the Lipan Aquifer in Sterling County. We will investigate this lack of usage data during subsequent project phases.

Table 49 provides the years identified as having anomalous pumping amounts for Sterling County for the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 280), and standard deviation (Figure 281) analyses.

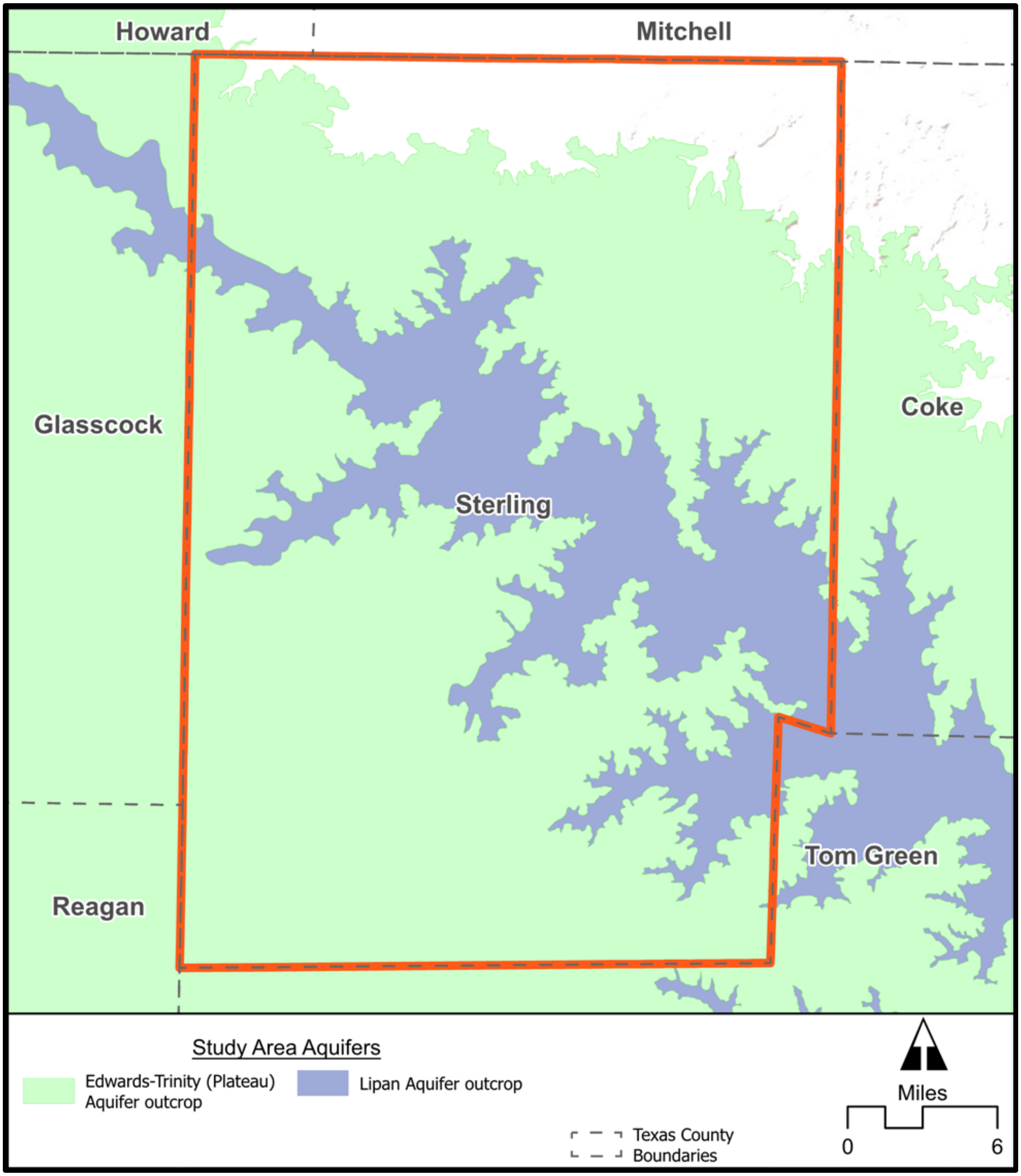


Figure 278. Sterling County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer.

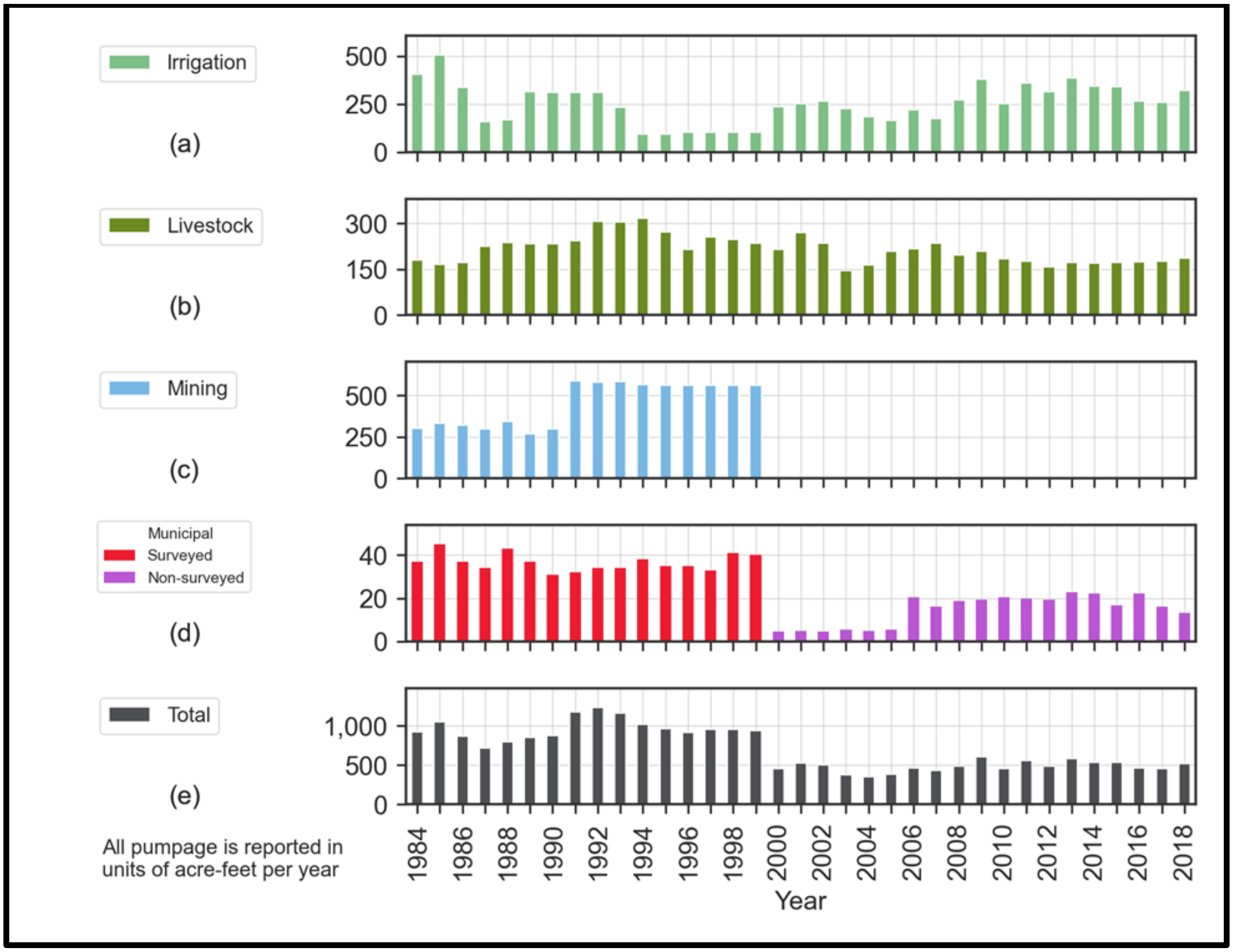


Figure 279. Sterling County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

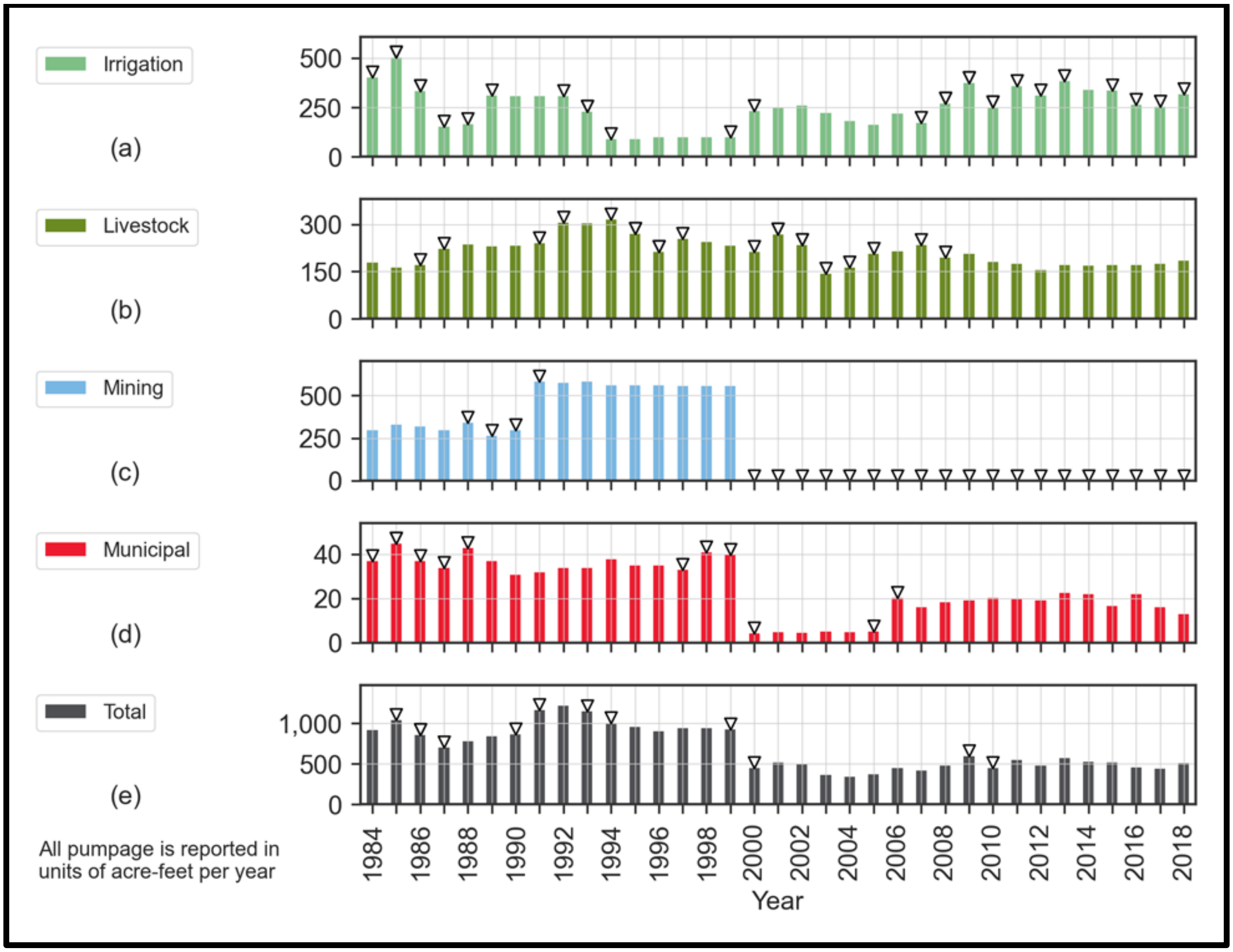


Figure 280. **Sterling County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

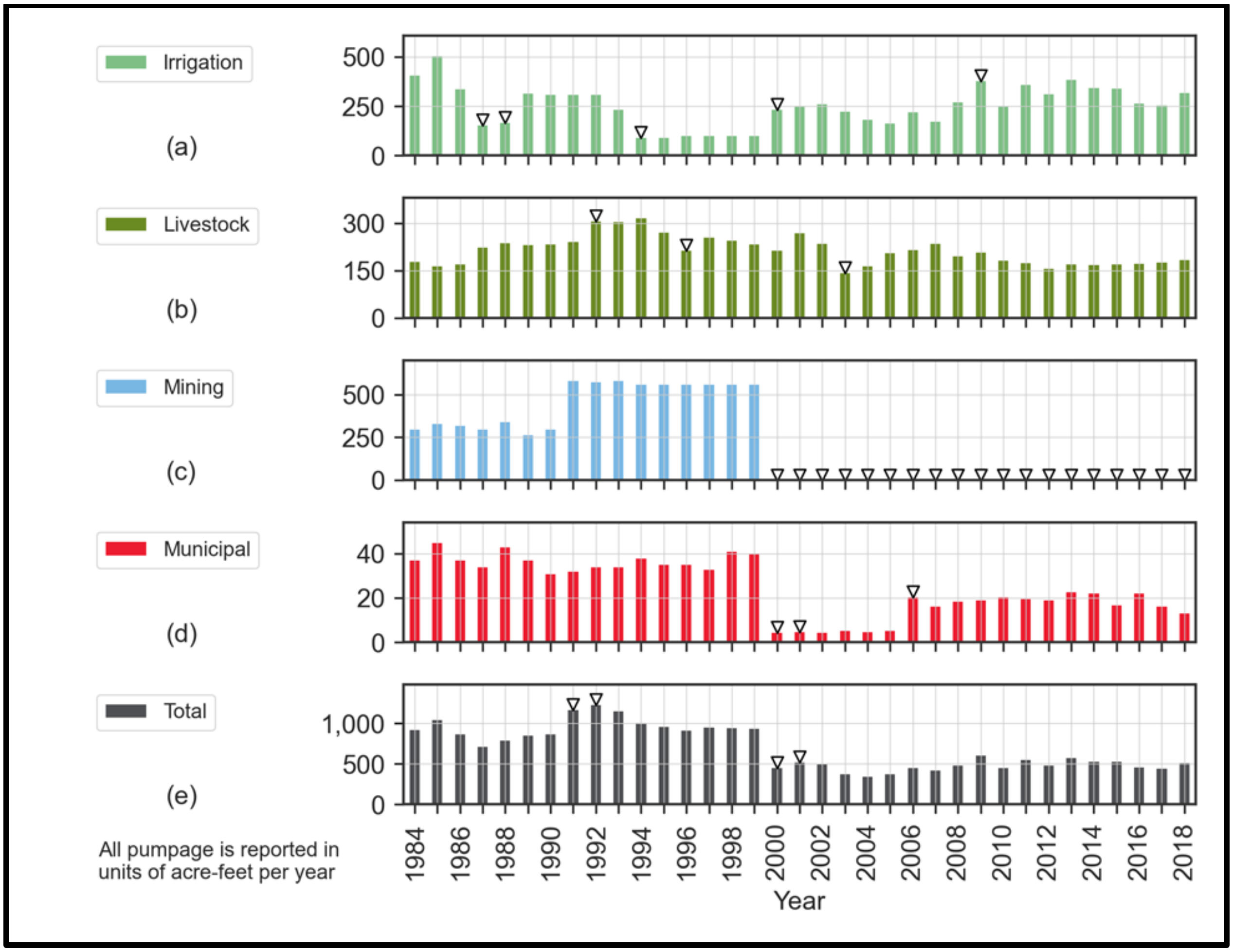


Figure 281. Sterling County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

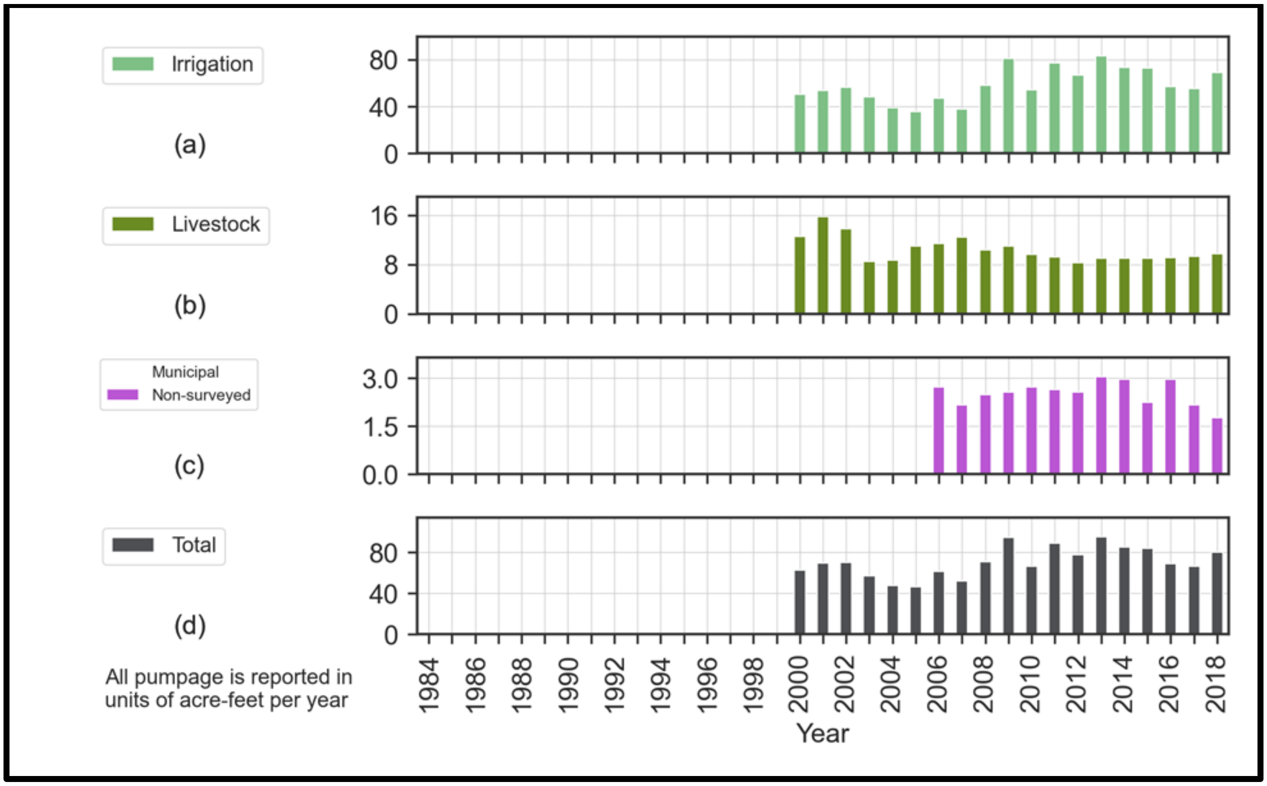


Figure 282. Sterling County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Table 49. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Sterling County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1987, 1989, 1994-2000	1984-1987, 1989, 1993, 1994, 2000, 2008-2011, 2013, 2016, 2018	1987, 1988, 1994, 2000, 2009
	Livestock	2005	1987, 1992, 1995-1997, 2001-2003, 2005, 2008	1992, 1996, 2003
	Mining	1991, 2000-2018	1989, 1991, 2000-2018	2000-2018
	Municipal	2000-2006	1984-1986, 1988, 1998, 2000, 2006	2000, 2001, 2006
Pecos Valley	All	Not present in county	None	None

3.3.43 Sutton County

The Edwards-Trinity (Plateau) Aquifer underlies the entire area of Sutton County (see Figure 283). As shown on Figure 284, total groundwater pumping within the county from the Edwards-Trinity (Plateau) Aquifer during the study period typically ranges between 1,500 and 3,000 acre-feet per year. Irrigation and municipal are the primary uses of groundwater from the Edwards-Trinity (Plateau) Aquifer in Sutton County.

Pumping data from the Edwards-Trinity (Plateau) Aquifer for irrigation shows a general increase from 1984 through 1999. After 1999, estimated irrigation pumping slowly declined for three years with an abrupt decline in 2003. Following a brief rise from 2005 through 2007, estimated irrigation pumping remained relatively stable at about 800 acre-feet per year. The abrupt changes in pumping are noted from the year-to-year change (Figure 285) and standard deviation (Figure 286) analyses.

Pumping for livestock appears steady and typically ranges between 300 and 500 acre-feet per year. However, from 2001 through 2004 pumping for livestock use anomalously dipped below 200 acre-feet per year. Reported pumping for manufacturing was only for 1989 at approximately 50 acre-feet. Pumping for mining fluctuated between 30 and 70 acre-feet per year prior to 1991 then remained relatively steady at about 70 acre-feet per year from 1992 through 1999. After 1999, there is not any reported mining use pumping from the Edwards-Trinity (Plateau) Aquifer in Sutton County. Pumping to meet municipal needs appears relatively stable with an average rate of approximately 1,000 acre-feet per year. Since 2000, non-surveyed municipal use constituted only a relatively small portion of the total municipal usage.

Upon review of the data and application of the year-to-year change analysis (Figure 285) and standard deviation analysis (Figure 286), we observed numerous data anomalies. These anomalies consisted of an abrupt decrease in pumpage for irrigation in 1998, 2003, 2004, and 2008, for livestock in 2001, for mining in 2000, and for municipal pumpage in 2015. In addition, we also observed anomalies as an abrupt increase in pumpage for livestock in 2005 and for municipal use in 2011 and 2012. Table 50 provides the years identified as having anomalous pumping amounts for Sutton County based on our manual review, year-to-year change (Figure 285), and standard deviation (Figure 286) analyses.

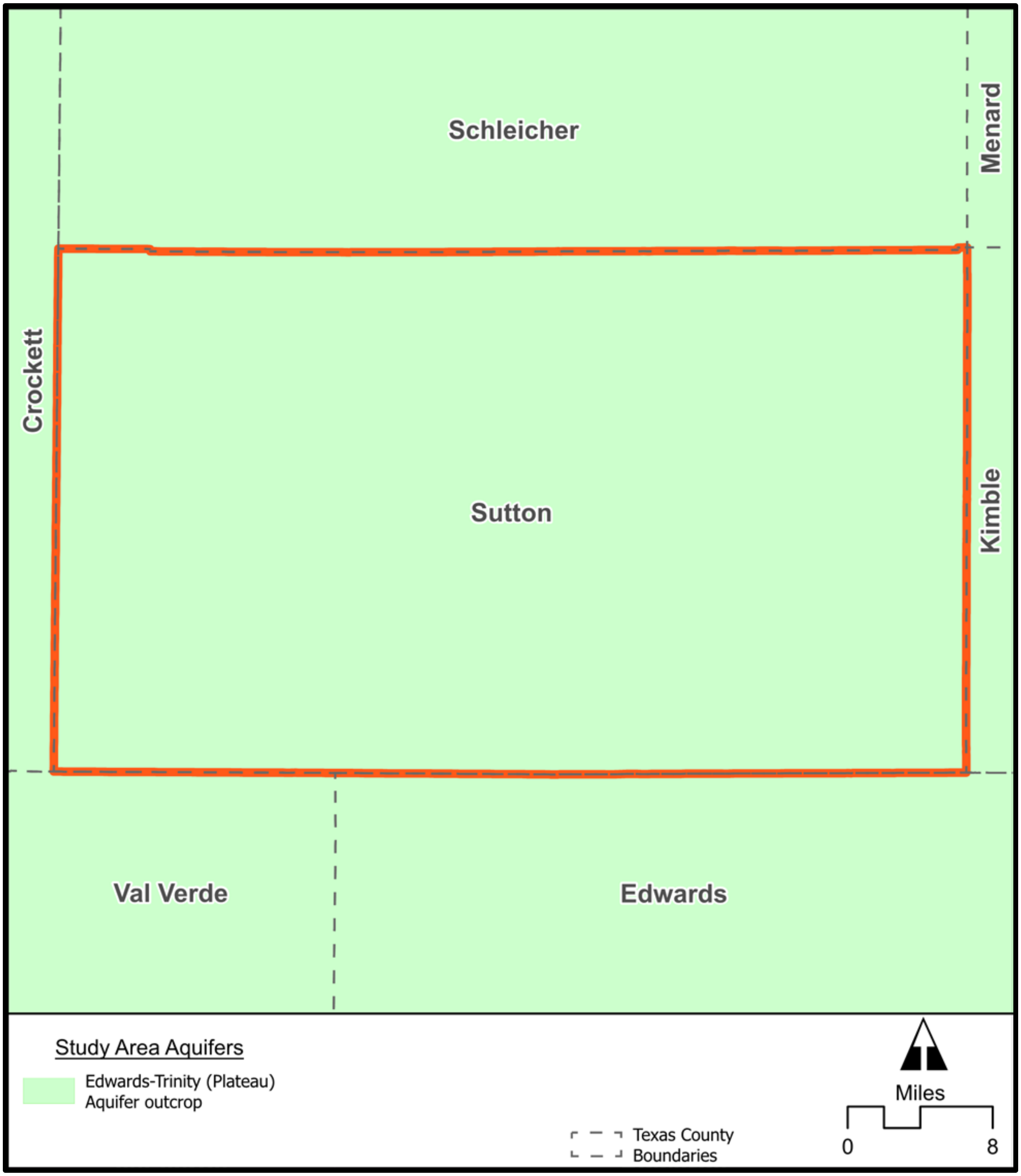


Figure 283. Sutton County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

Figure 284. Sutton County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

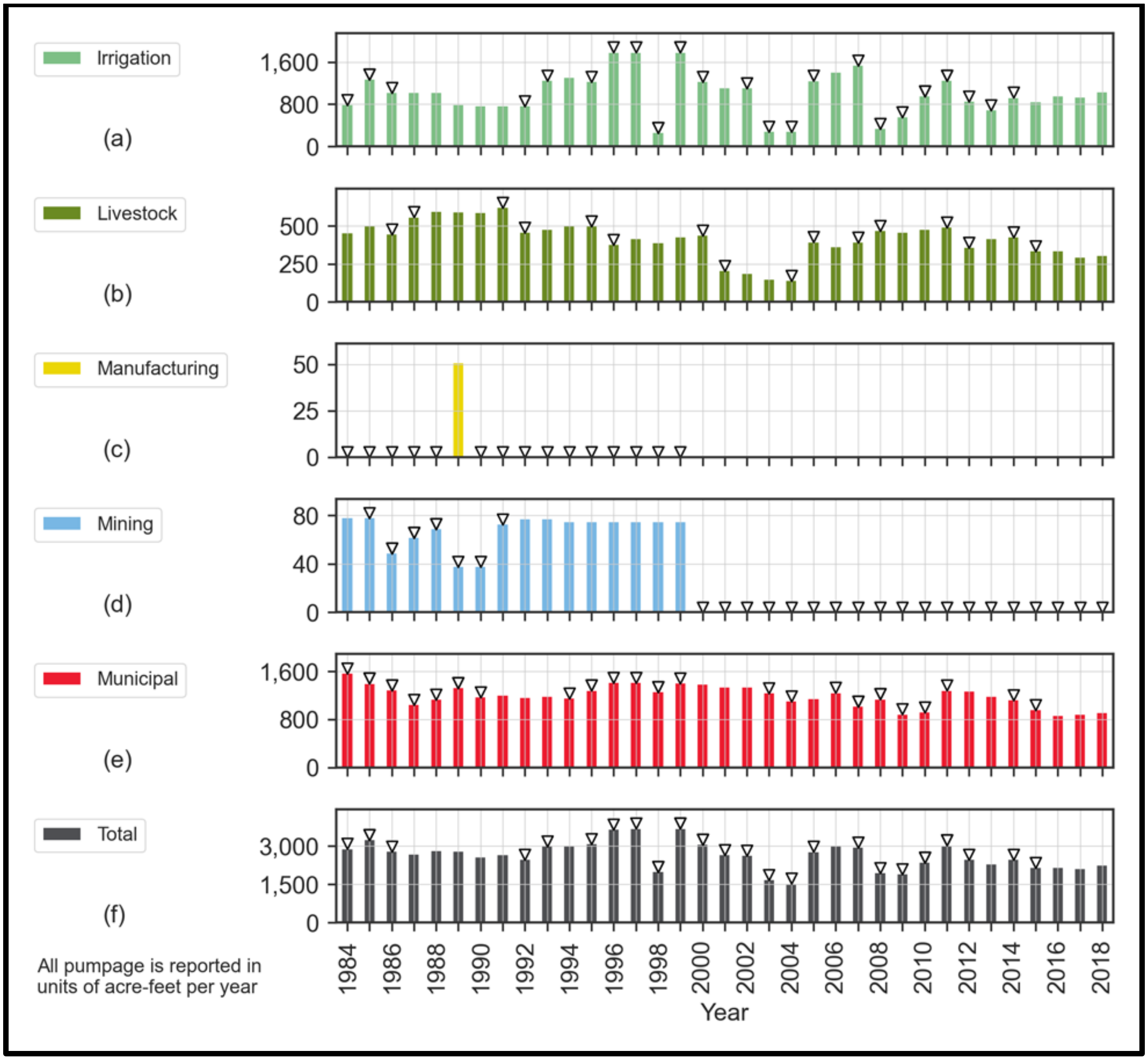


Figure 285. Sutton County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

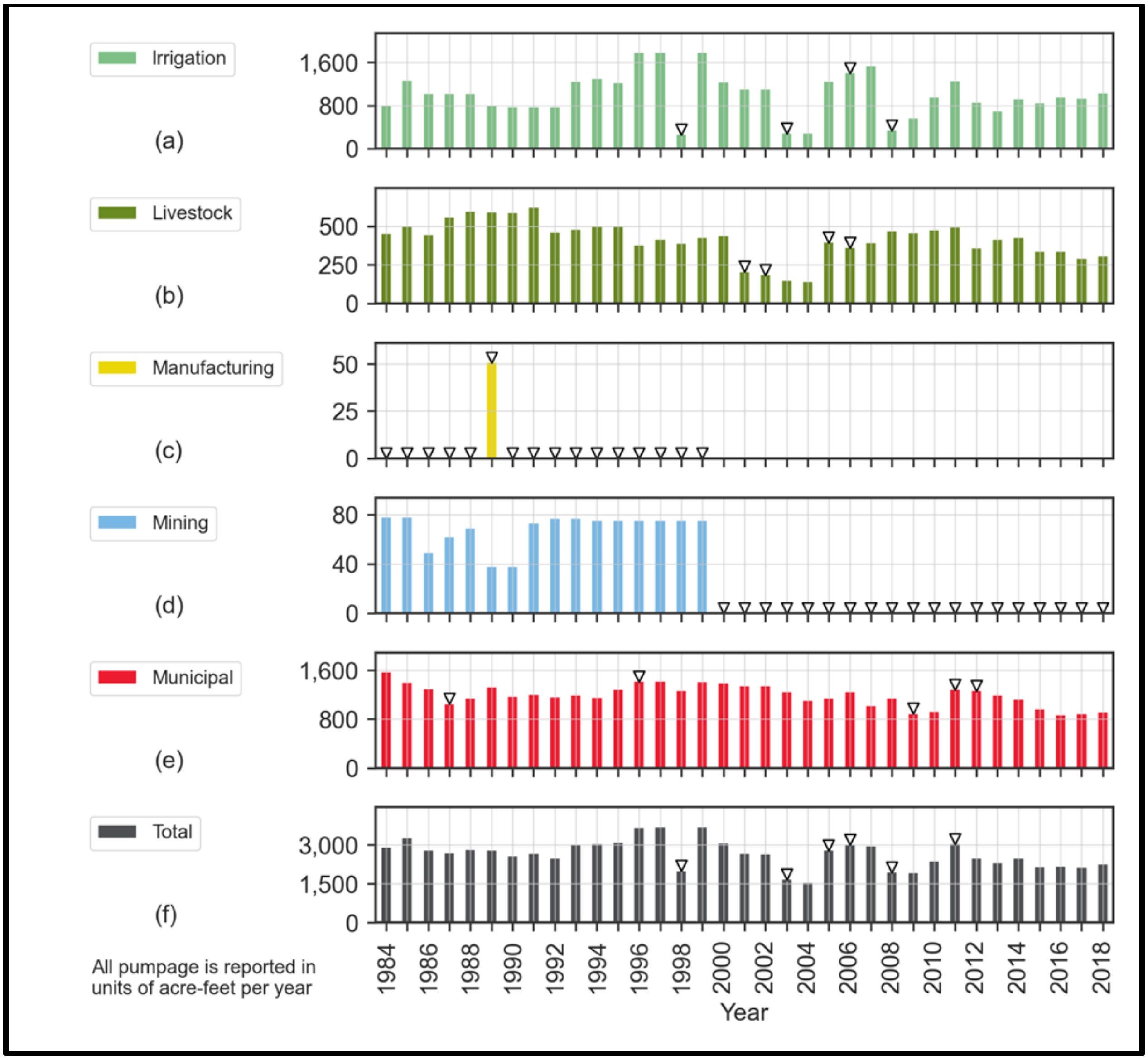


Figure 286. Sutton County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Table 50. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Sutton County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1998, 2003, 2004, 2008	1984-1986, 1993, 1996, 1998-2000, 2003, 2005, 2008, 2010-2012, 2014	1998, 2003, 2006, 2008
	Livestock	2001-2005	1987, 1992, 1996, 2001, 2005, 2008, 2012, 2015	2001, 2002, 2005, 2006
	Manufacturing	1989	1984-1999	1984-1999-2001-2003-2005-2007-2009-2011-2013-2015-2017
	Mining	1989-1990, 2000-2018	1986-1989, 1991, 2000-2018	2000-2018
	Municipal	2011	1984-1987, 1989, 1990, 1995, 1996, 1998, 1999, 2004, 2007-2009, 2011, 2015	1987, 1996, 2009, 2011, 2012

3.3.44 Taylor County

The Edwards-Trinity (Plateau) Aquifer underlies the central western portion of Taylor County (see Figure 287). As shown on Figure 288, total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer within Taylor County exceeded 300 acre-feet per year from 2009 to 2012. Municipal use comprises most of the total groundwater production from the Edwards-Trinity (Plateau) Aquifer within Taylor County.

Groundwater pumping from the Edwards-Trinity (Plateau) Aquifer was for irrigation, livestock, and municipal use. Groundwater pumping for irrigation appears to stay lower than 30 acre-feet per year throughout the study period except for two years where it reached almost 50 acre-feet (1992 and 2011). The TWDB Water Use Survey database does not contain irrigation pumping data for the county and aquifer for 1994 through 1999, 2003, 2004, 2008, and 2014.

Pumping for livestock use averaged approximately 50 acre-feet per year from 1984 through 2018, with two years exceeding 100 acre-feet and several years reporting minimal pumpage. The TWDB Water Use Survey database reports groundwater pumping for non-surveyed municipal use after 1999 with it gradually increasing from 100 acre-feet in 2000 to 300 acre-feet in 2010. Municipal use then decreased to less than 100 acre-feet per year by 2014 and remained near this level through 2018. Figure 289 (year-to-year change analysis) and Figure 290 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Taylor County.

Groundwater production from the Trinity (Hill Country) aquifer (Figure 291) was reported to help meet the Taylor County water needs for irrigation, livestock and municipal use from 2000 through 2018. We believe this pumping was incorrectly attributed to either Taylor County or to the Trinity (Hill Country) Aquifer, as the TWDB defined footprint for the aquifer is not present within the county boundary. We will investigate the source of this pumping data during subsequent project phases.

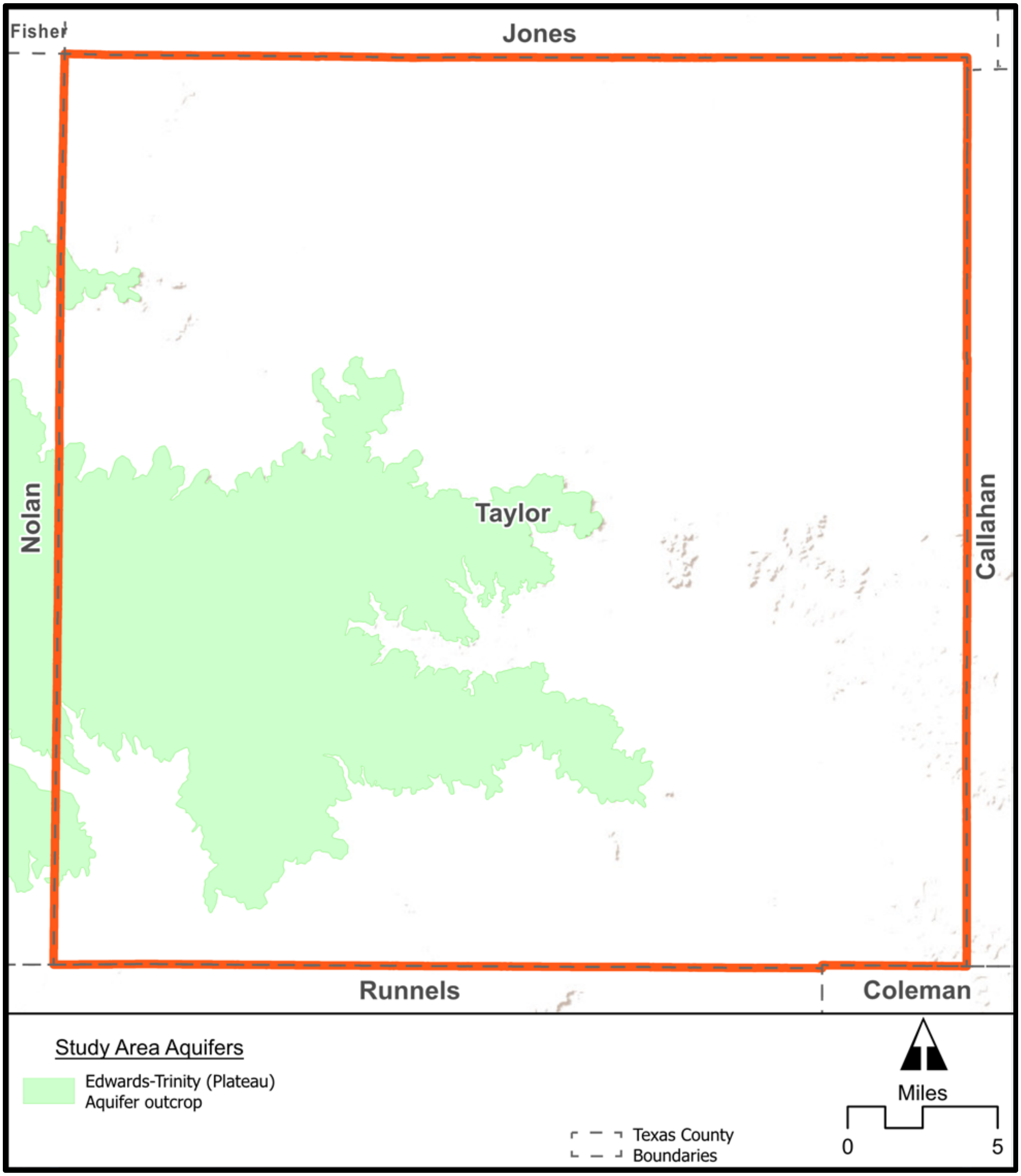


Figure 287. Taylor County showing the extent of the Edwards-Trinity (Plateau) aquifer.

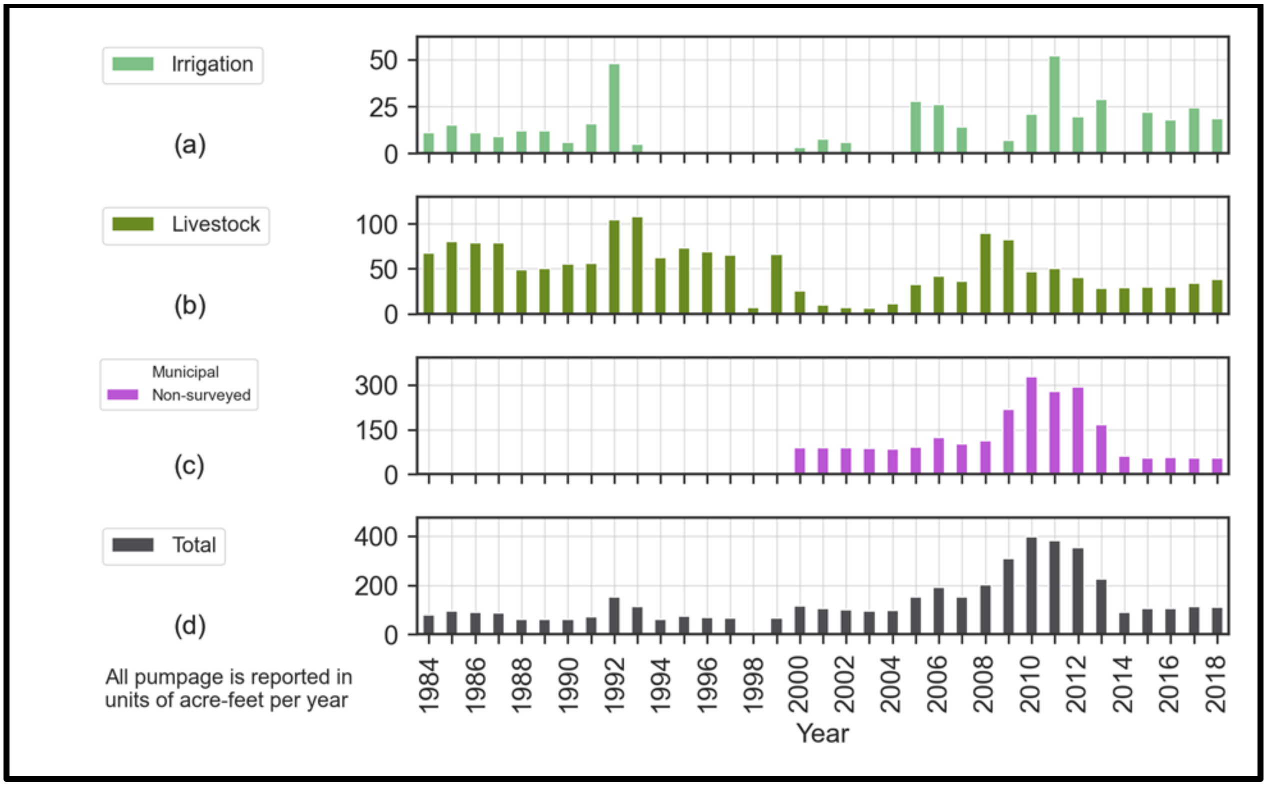


Figure 288. Taylor County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

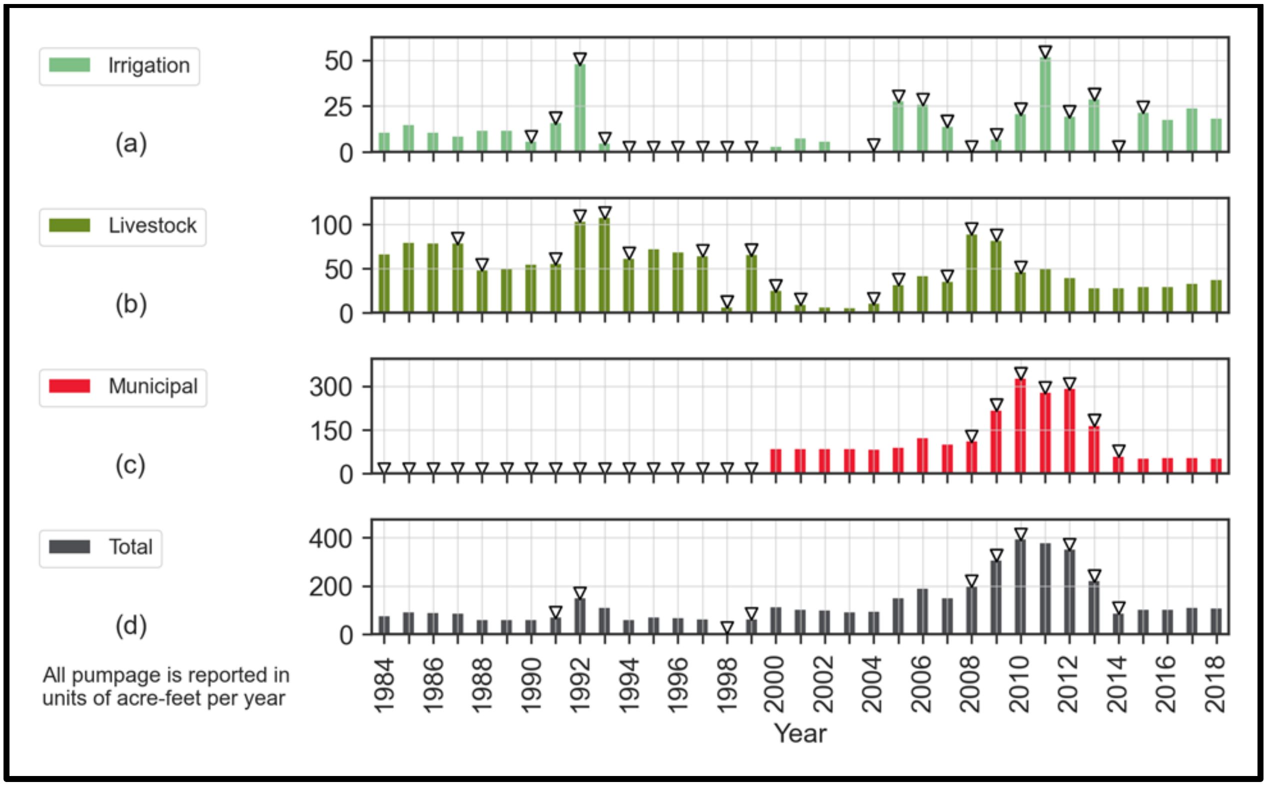


Figure 289. Taylor County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

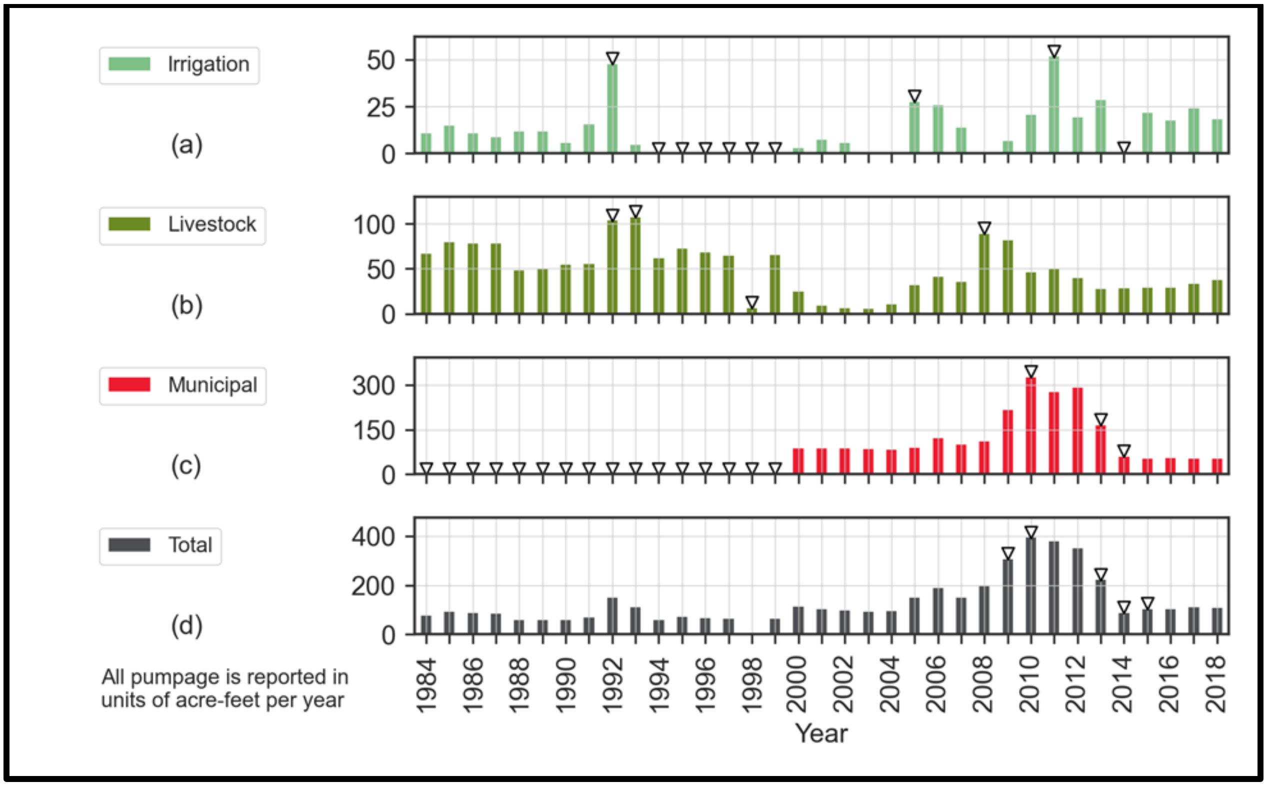


Figure 290. Taylor County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

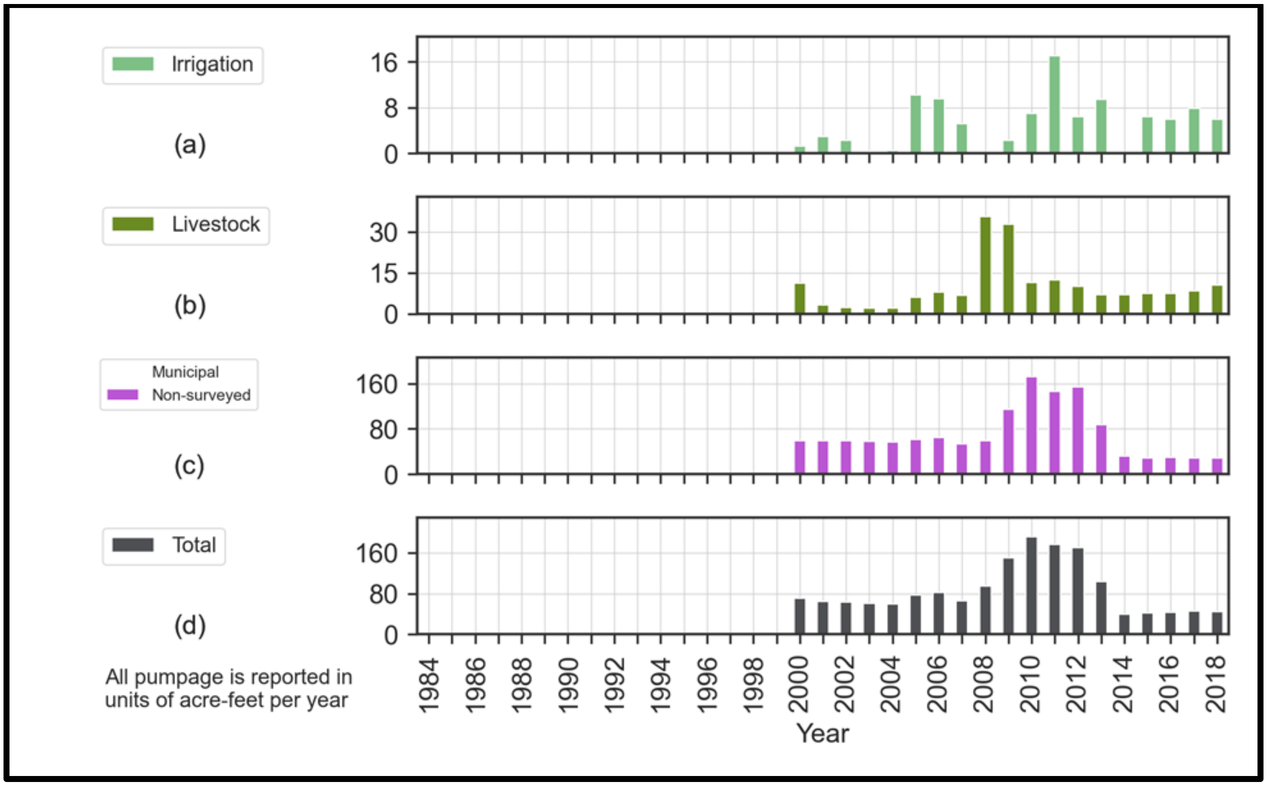


Figure 291. Taylor County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Table 51. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Taylor County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	1991, 1992, 1994-2005, 2011, 2014	1991-1999, 2005, 2007, 2008, 2010-2015	1992, 1994-1999, 2005, 2011, 2014
	Livestock	1998, 2008, 2010	1988, 1992, 1994, 1998-2001, 2005, 2008, 2010	1992, 1993, 1998, 2008
	Municipal	1984-1999, 2010-2014	1984-2000, 2009-2011, 2013, 2014	1984-1999, 2010, 2013, 2014
Trinity (Hill Country)	All	Not present in county	None	None

3.3.45 Terrell County

The Edwards-Trinity (Plateau) Aquifer underlies the entire area of Terrell County (see Figure 292). According to the TWDB Water Use Survey data, the total reported pumping from the Edwards-Trinity (Plateau) Aquifer since 2000 is typically less than 600 acre-feet per year (see Figure 293). However, from 1984 through 1999 the total pumping was nearly 1,200 acre-feet per year.

A significant contributor to the decrease in total pumping is the data gap from 2000 through 2006 for irrigation use pumping. We also observed a steady decline in pumping for livestock use over the entire study period. Pumping for mining typically ranged from nearly zero to 30 acre-feet per year between 1985 and 1999. Mining pumpage increased abruptly, however, in 2017. Similar to livestock use, we observe steady decline in pumping for municipal use from nearly 400 acre-feet per year in the early 1984 to just over 100 acre-feet in 2018. Since 2000, non-surveyed municipal use constituted a relatively small portion of the total municipal use. Figure 294 (year-to-year change analysis) and Figure 295 (standard deviation analysis) identify anomalous pumping amounts in the TWDB Water Use Survey data for Terrell County from the Edwards-Trinity (Plateau) Aquifer.

We would expect groundwater pumping for irrigation from the Edwards-Trinity (Plateau) Aquifer in Terrell County to correlate negatively to precipitation on potentially irrigated land overlying the aquifer such that there would be less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 296 indicates that as precipitation increased on the potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in Terrell County, the reported pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer decreased. Figure 297 indicates a negative correlation value (*"r"*) of -0.55 between precipitation and groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer. This moderate negative correlation suggests that the reported pumpage for irrigation in Terrell County inversely follows the trend in precipitation. We note, however, that irrigation data is missing for many years of the study period, and the missing years are the years with the greatest rainfall. We will revise this correlation during subsequent project phases, after researching the irrigation pumpage within Terrell County and addressing the missing and anomalous irrigation data shown in Figure 294 and Figure 295.

Table 52 provides the years identified as having anomalous pumping amounts for Terrell County from the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 294), and standard deviation (Figure 295) analyses.

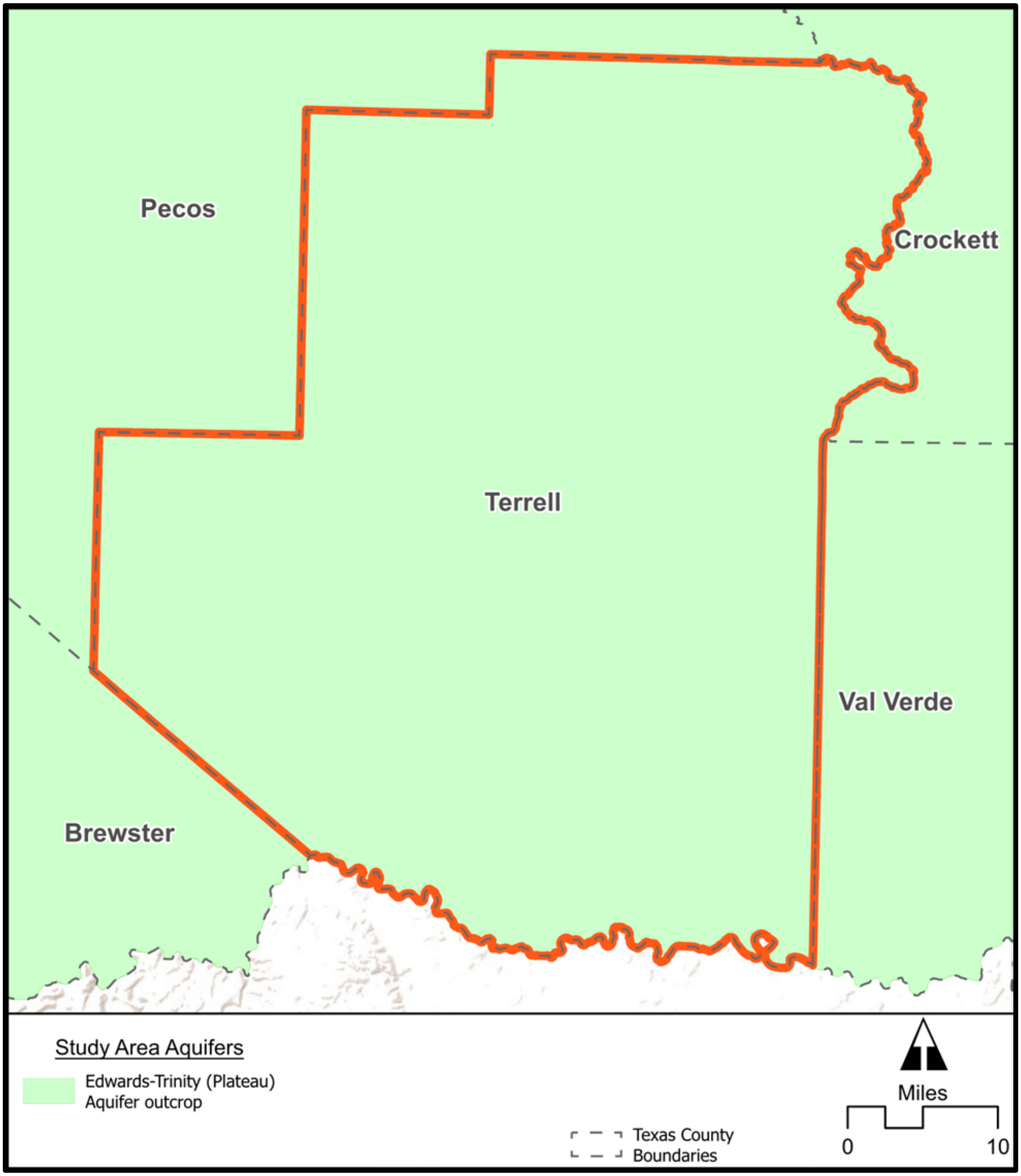


Figure 292. Terrell County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

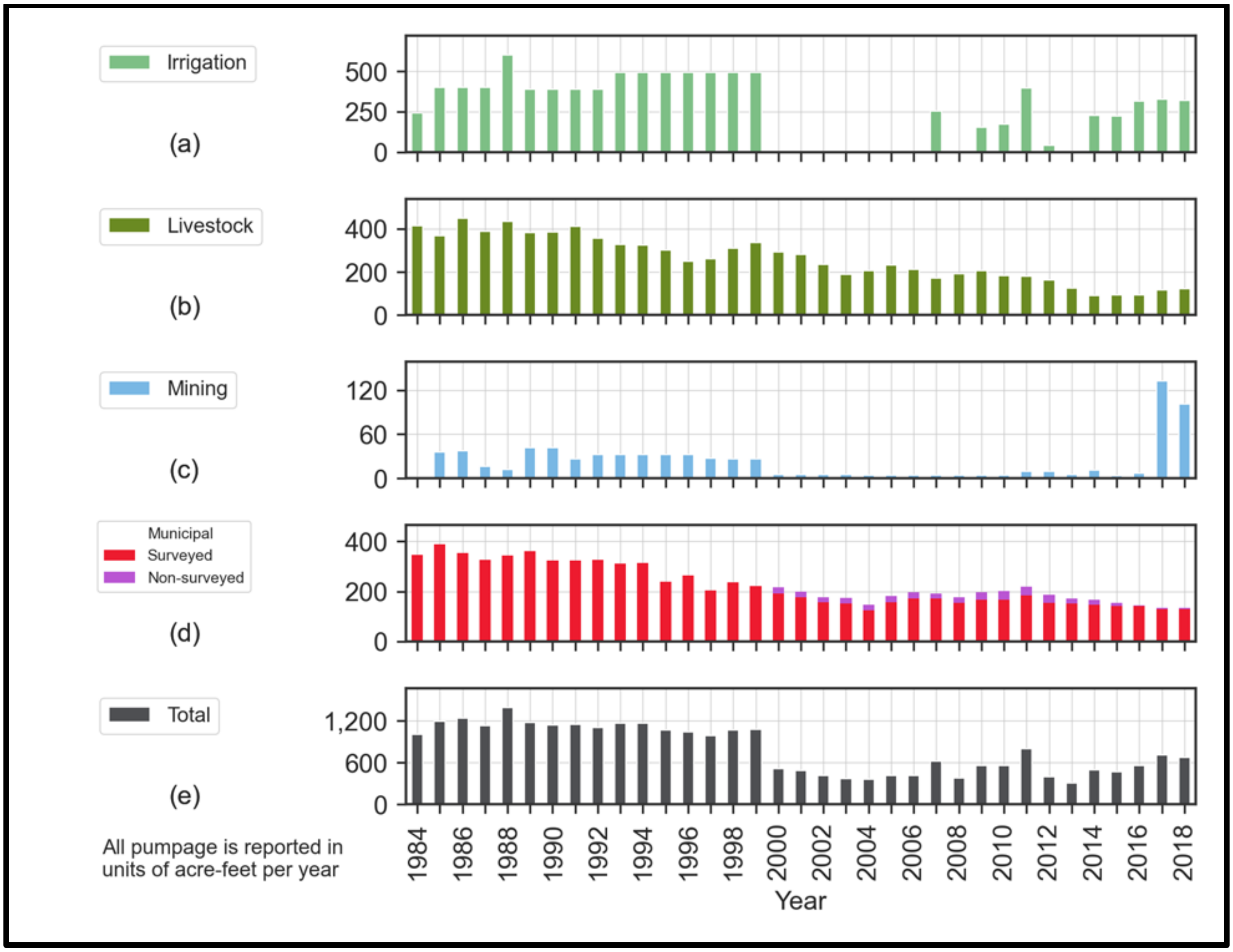


Figure 293. Terrell County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

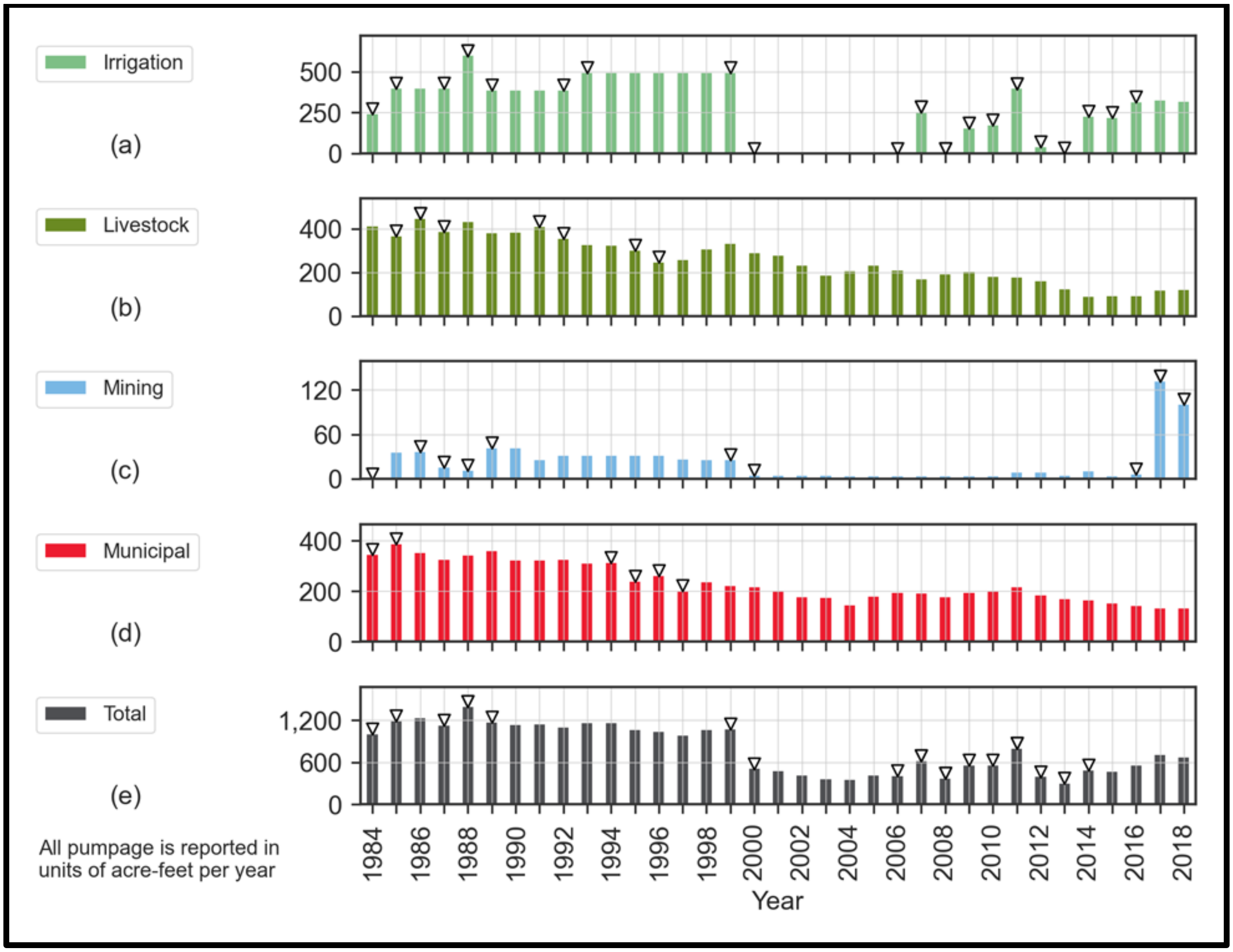


Figure 294. Terrell County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

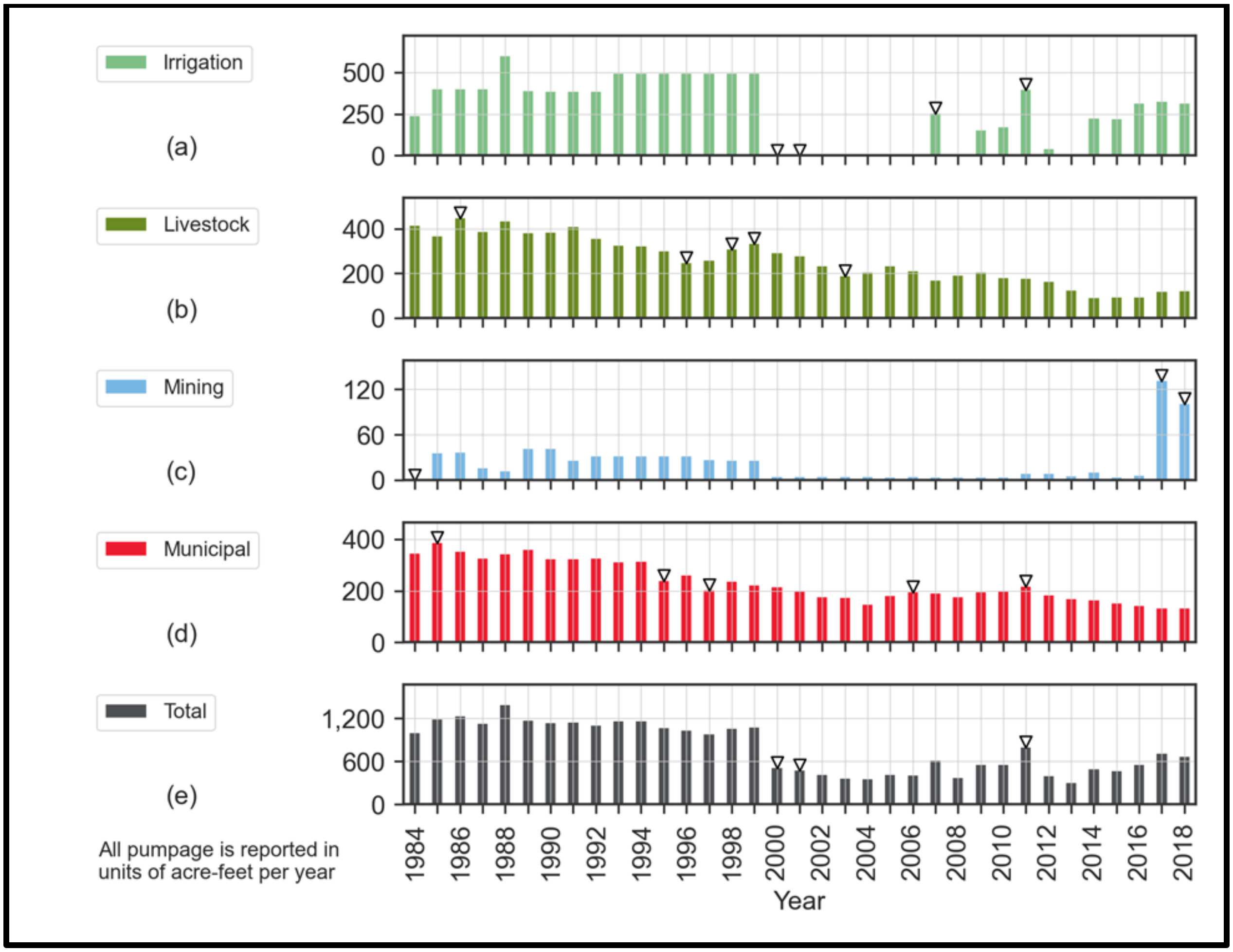


Figure 295. Terrell County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

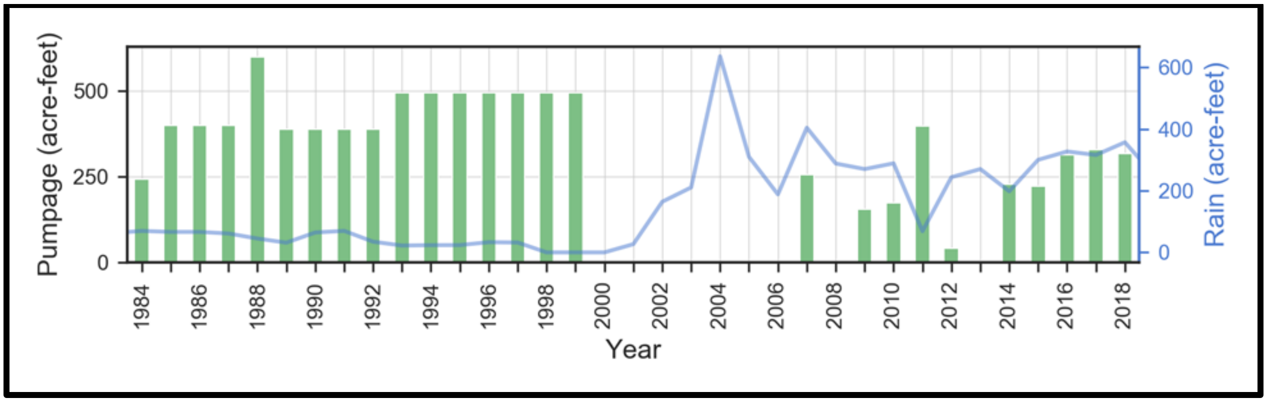


Figure 296. **Terrell County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.**

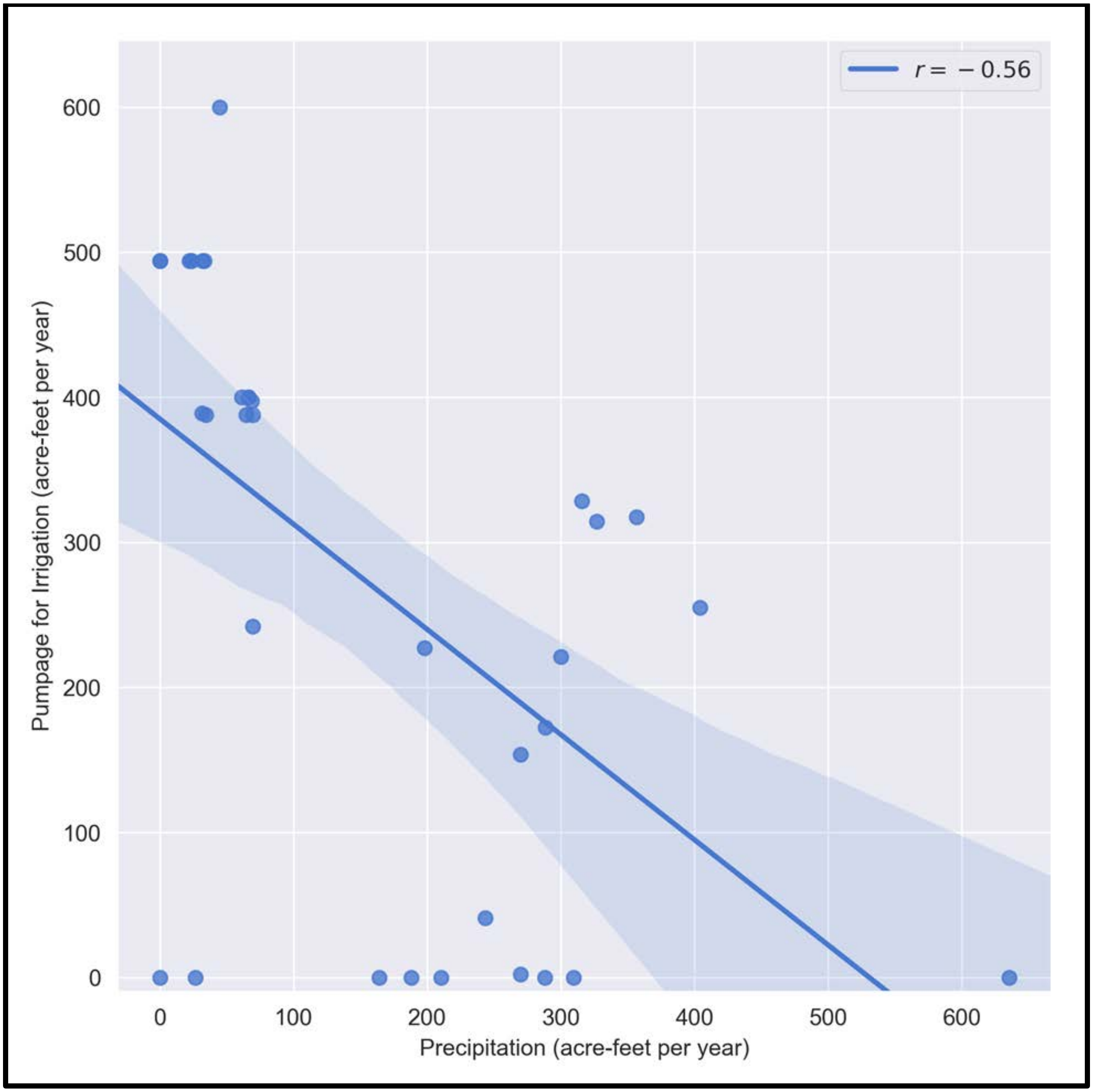


Figure 297. Terrell County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

Table 52. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Terrell County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards - Trinity Plateau	Irrigation	2000-2006, 2008, 2012-2013	1984, 1985, 1988, 1989, 1993, 2000, 2007-2009, 2011, 2012, 2014, 2016	2000-2008, 2011
	Livestock	None	1986, 1987, 1992, 1996	1986, 1996, 1998, 1999, 2003
	Mining	1984, 2017, 2018	1984, 1985, 1987, 1989, 2000, 2017, 2018	1984, 2017, 2018
	Municipal	None	1984, 1985, 1995, 1997	1985, 1995, 1997, 2006, 2011

3.3.46 Tom Green County

The Lipan Aquifer (outcrop and subcrop) as well as the Edwards-Trinity (Plateau) Aquifer together underlie nearly the entirety of Tom Green County (see Figure 298). As shown on Figure 299, total groundwater pumping from the Lipan Aquifer reached a peak of almost 70,000 acre-feet in 1995. Most of the total groundwater production from the Lipan Aquifer is for irrigation use.

Pumping of groundwater from the Lipan Aquifer was for irrigation, livestock, manufacturing, mining, and municipal use. Groundwater pumping for irrigation remained under 30,000 acre-feet per year from 1984 until 1992, after which usage peaked at over 60,000 acre-feet annually for four of the next five years. From 1998 through 2018, groundwater pumping from the Lipan Aquifer in the county for irrigation remained below 60,000 acre-feet per year and oscillated gradually except for a minimal pumpage value reported in 2011.

Estimated pumping for livestock was relatively stable with pumping below 40 acre-feet per year from 1984 through 2004. After this period, pumping increased abruptly to approximately 150 acre-feet per year from 2005 through 2012, followed by a drop down to about 80 acre-feet per year through 2018. Reported groundwater pumping for manufacturing lacks data from 1984 through 2001, except for data provided for 1994 and 1995. Manufacturing pumping increased gradually from 2002 through 2018.

Reported pumpage for mining use was for the years prior to 2000 at approximately less than 40 acre-feet per year with an anomalous high in 1984 surpassing 80 acre-feet. Groundwater pumpage for municipal use shows a steady increase from 1,000 acre-feet per year early in the study period to 2,000 acre-feet in 2011. From 2012 through 2018, municipal pumping gradually declined to 800 acre-feet per year. Since 2000, when inclusion of the non-surveyed municipal use in the TWDB Water Use Survey database began, it constituted a significant portion of the total municipal usage. Figure 300 (year-to-year change analysis) and Figure 301 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Lipan Aquifer in Tom Green County.

Groundwater production from the Edwards-Trinity (Plateau) Aquifer helped meet the Tom Green County water needs for irrigation, livestock, and municipal use. Reported irrigation use starts in 1994 and increases gradually through 2008 where it peaked at over 1,600 acre-feet. Groundwater pumping for irrigation use decreased sharply to minimal pumpage by 2011 and then abruptly increased and remained stable at approximately 800 acre-feet per year through 2018.

Estimated groundwater pumping for livestock remained fairly constant around 100 acre-feet per year from 1984 through 2004. From 2005 through 2012, livestock pumpage increased to approximately 800 acre-feet per year, and from 2013 to 2018 pumpage reduced to approximately 400 acre-feet per year. Pumping to meet municipal needs was relatively stable at 400 acre-feet per year from 1984 through 1999, followed by reduced pumpage from 2000 through 2007. Municipal pumpage then increased from 2008 through 2011 when it peaked at over 800 acre-feet. From 2012 through 2018 pumping gradually decreased back to the 400 acre-feet per year level. Since 2000, non-surveyed municipal use constituted most of the municipal usage. Figure 303 (year-to-year change analysis) and Figure 304 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Tom Green County.

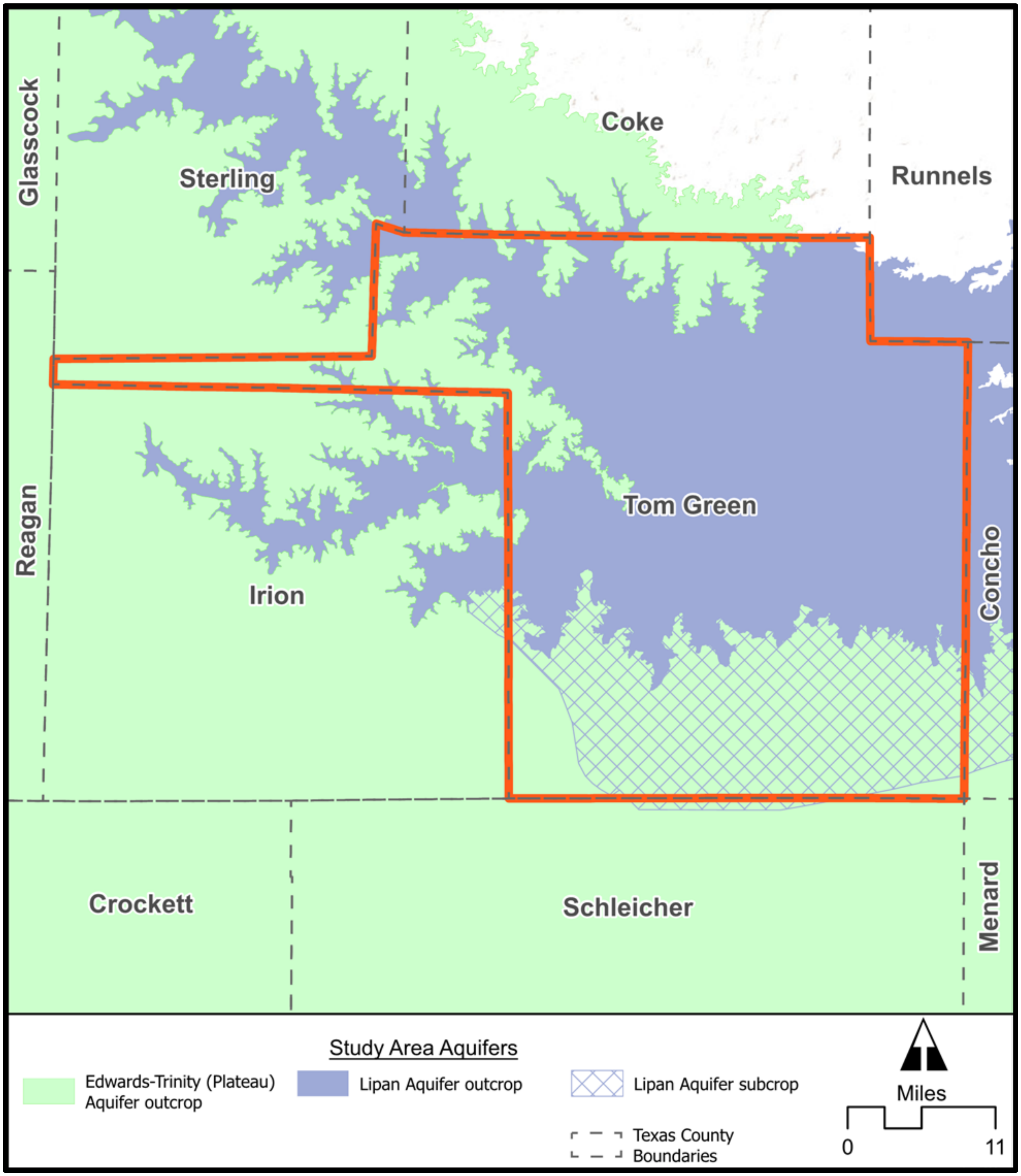


Figure 298. Tom Green County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer.

We would expect groundwater pumping for irrigation in Tom Green County to correlate negatively to precipitation on potentially irrigated land such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 305 indicates that as precipitation on potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in the county increased, the reported pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer also tended to increase, contrary to our expectations Figure 306 indicates a positive correlation value (“*r*”) of 0.46 between precipitation on potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer and groundwater pumpage for irrigation from the aquifer in Tom Green County. This moderate positive correlation suggests that the reported pumpage for irrigation in Tom Green County follows the trend in precipitation and may potentially be anomalous. We note, however, that irrigation data is missing for many years of the study period and analyses flagged some of the existing data as anomalous. We will revise this correlation during subsequent project phases, after researching the irrigation pumpage within Tom Green County and addressing the missing and anomalous irrigation data shown in Figure 303 and Figure 304.

Table 53 provides the years identified as having anomalous pumping amounts for Tom Green County from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 300 and Figure 303), and standard deviation (Figure 301 and Figure 304) analyses.

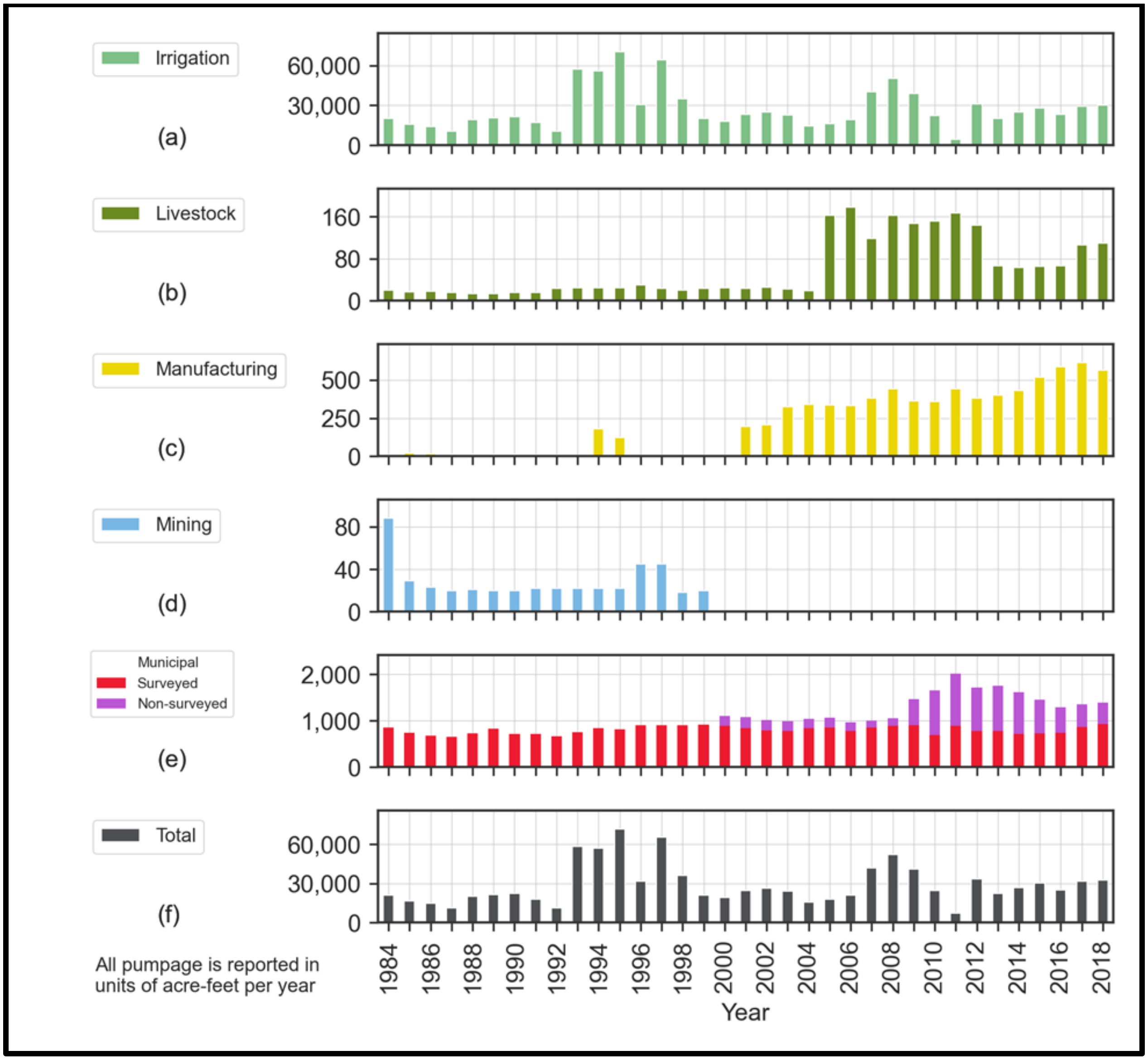


Figure 299. Tom Green County Lipan Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

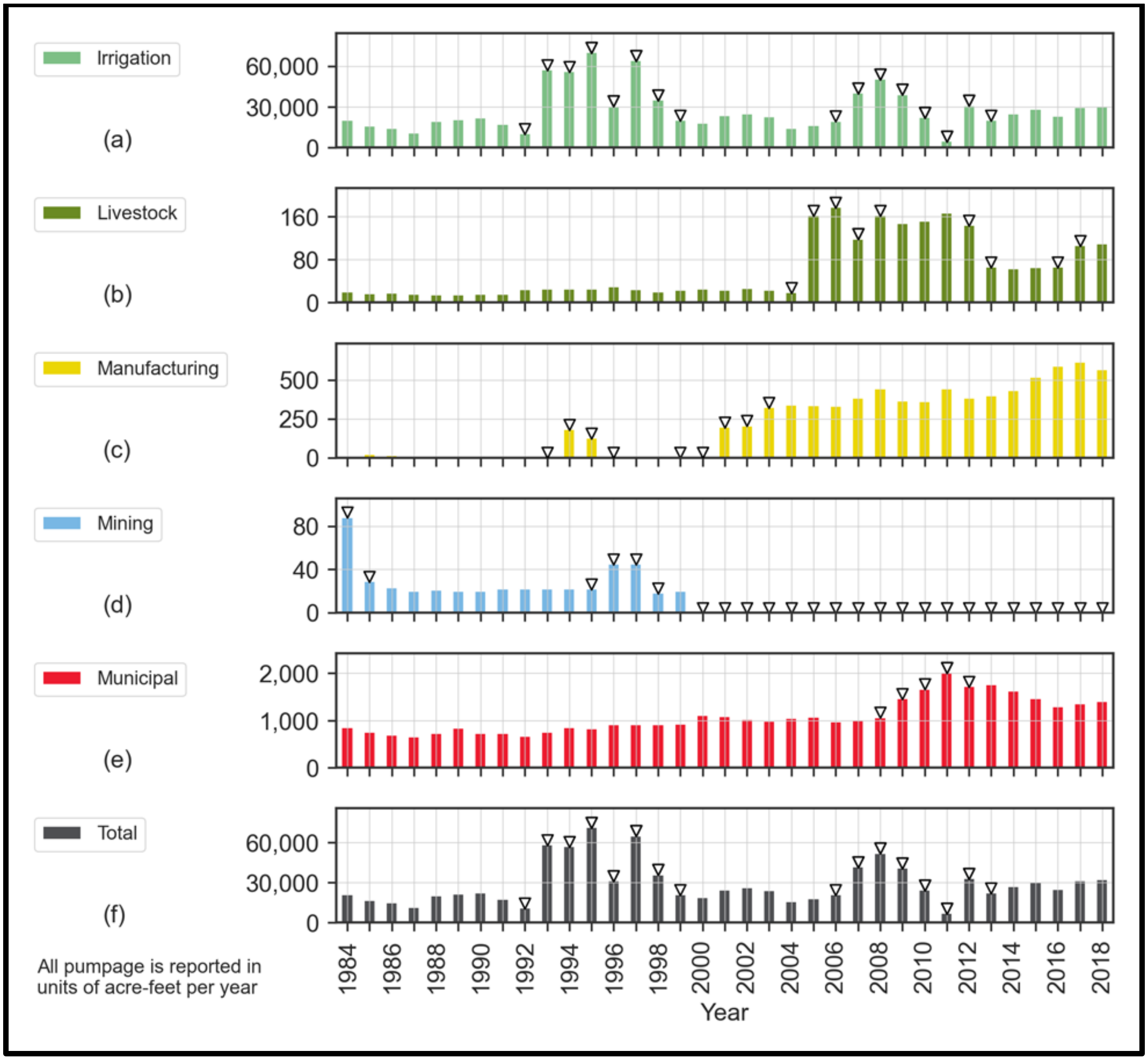


Figure 300. Tom Green County Lipan Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 301. **Tom Green County Lipan Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

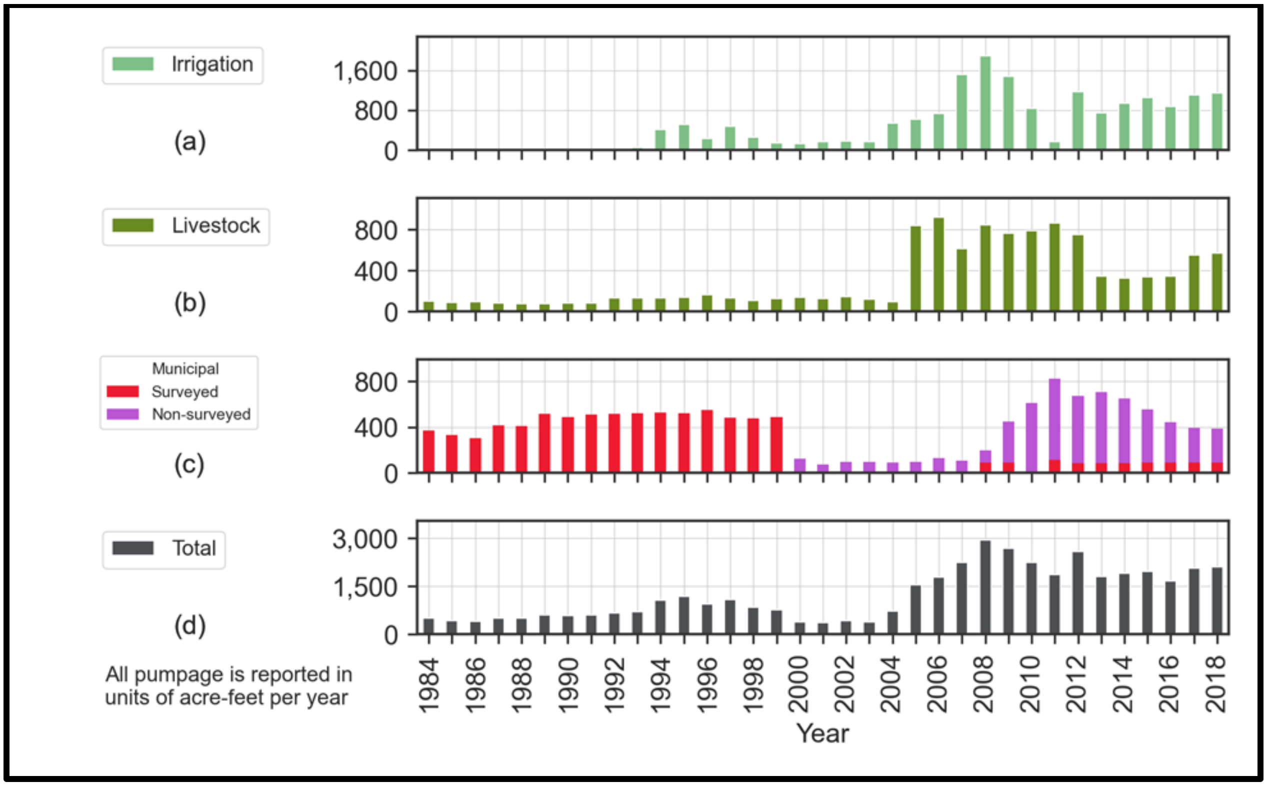


Figure 302. Tom Green County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

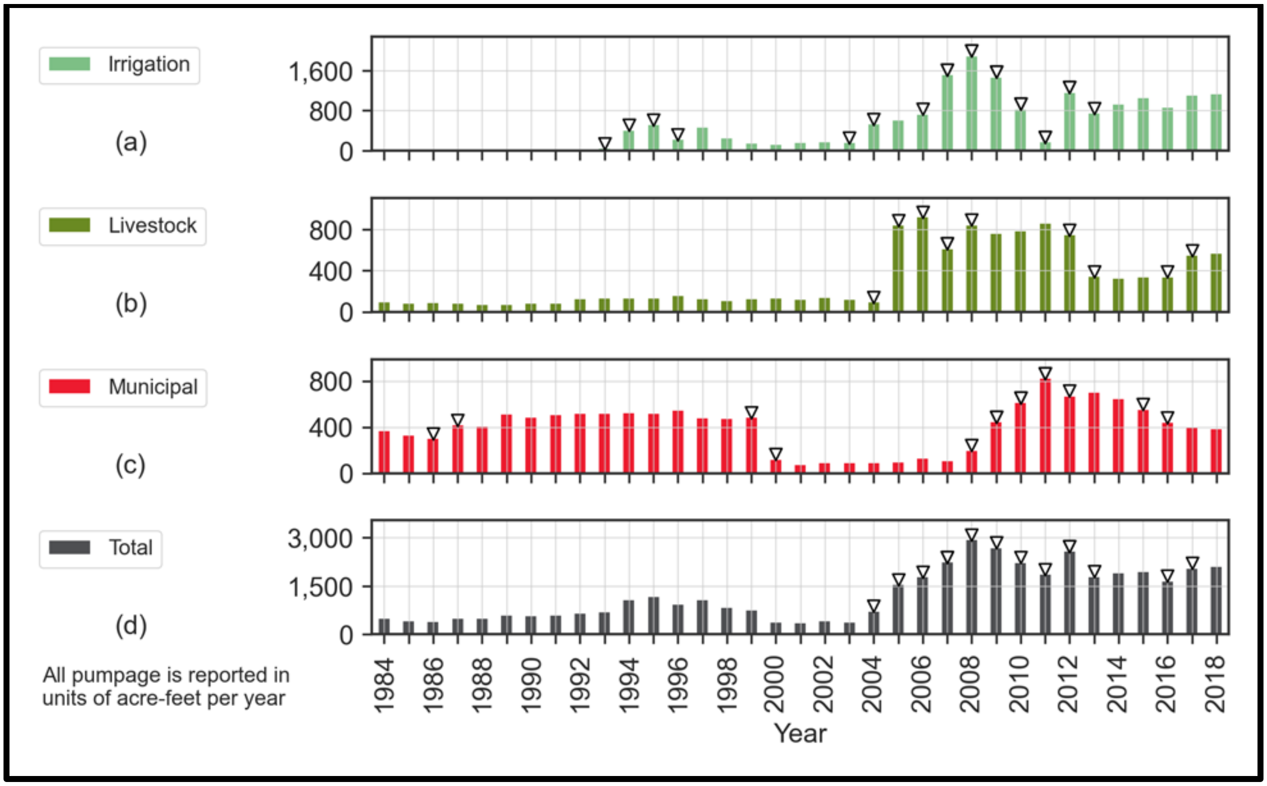


Figure 303. Tom Green County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

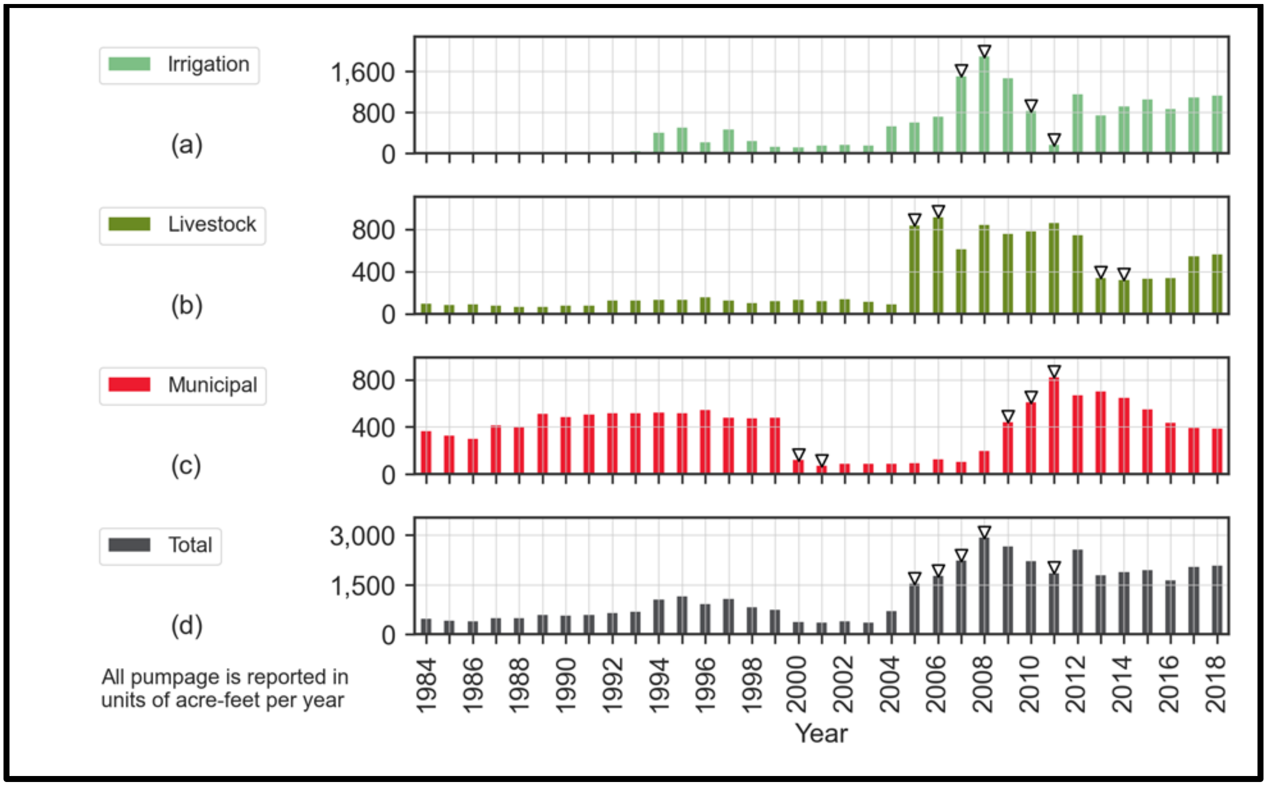


Figure 304. Tom Green County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

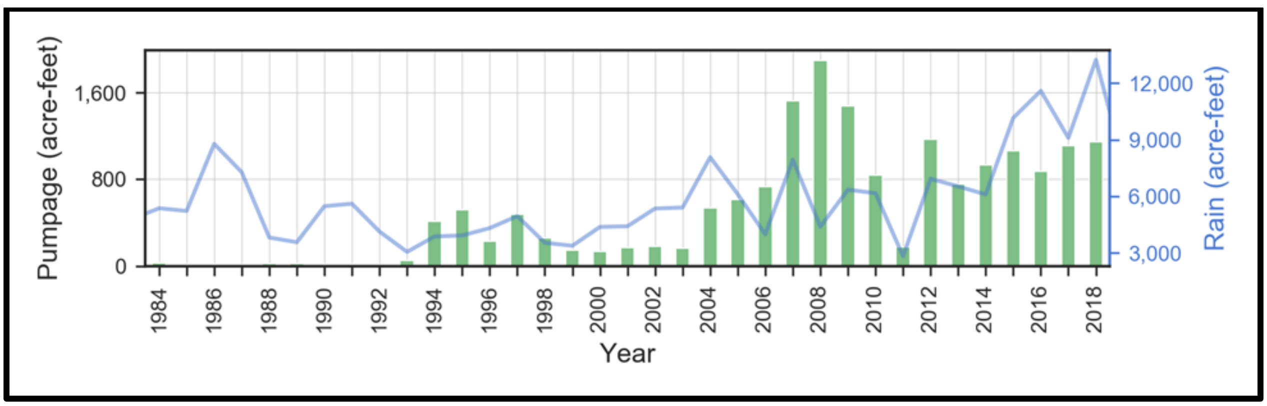


Figure 305. Tom Green County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

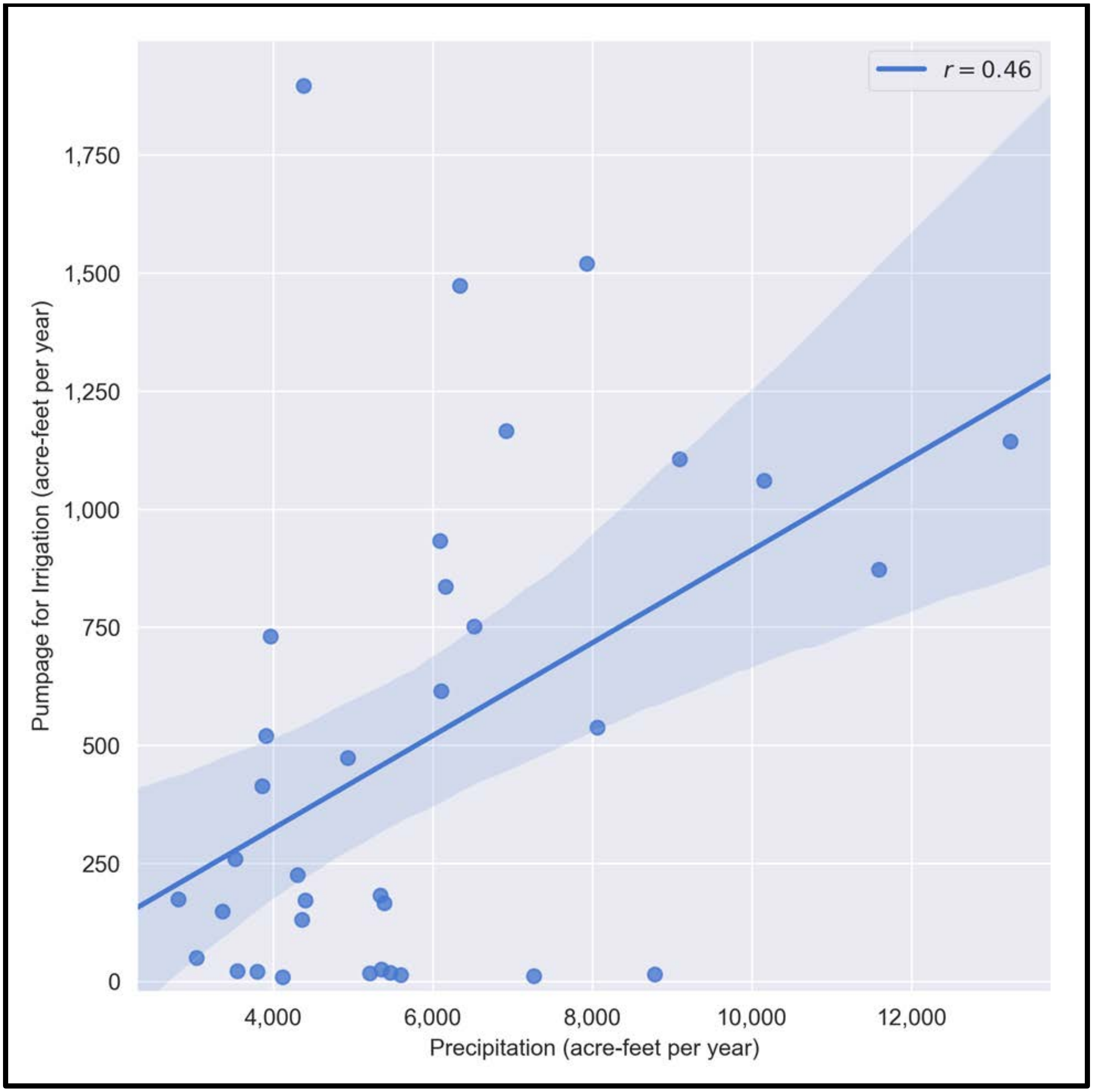


Figure 306. Tom Green County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

Table 53. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Tom Green County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Lipan	Irrigation	1993, 1996, 1998, 1999, 2007, 2011	1993, 1995-1999, 2007-2013	1993-1996, 2011
	Livestock	2005, 2013	2005, 2007, 2008, 2013, 2017	2005, 2006, 2013, 2014
	Manufacturing	1984-1994, 1996-2000	1994, 1996, 1999, 2001, 2003	1994, 1996, 1997, 1999, 2001, 2003
	Mining	1984, 1996, 1997, 2000-2018	1984, 1985, 1996, 1998, 2000-2018	1984, 1996, 2000-2018
	Municipal	2011	2009, 2011, 2012	2009-2011, 2016
Edwards - Trinity (Plateau)	Irrigation	1984-1993, 2007, 2011	1994, 1996, 2004, 2007-2013	2007, 2008, 2010, 2011
	Livestock	2005, 2013-2016	2005, 2007, 2008, 2013, 2017	2005, 2006, 2013, 2014
	Municipal	2000-2008, 2011	1987, 2000, 2009-2012, 2016	2000, 2001, 2009-2011

3.3.47 Travis County

The Trinity (Hill Country) Aquifer as well as the overlying Edwards (Balcones Fault Zone) Aquifer together underlie almost all of the portion of Travis County within our study area (see Figure 307), defined as the portion south of the Colorado River. Both the Trinity (Hill Country) Aquifer and the Edwards (Balcones Fault Zone) Aquifer extend north of the Colorado River within Travis County, and as a result the pumping data from the TWDB Water Use Survey contains only data for the entire county. As such, our evaluations reflect observations on a dataset that represents an area beyond the boundary of our study area. For subsequent phases of the project, we will work to isolate the pumping amounts from the aquifers in Travis County that are within our defined study area.

As shown on Figure 308, total groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer within Travis County reached a peak of almost 16,000 acre-feet in 2005. Most of the total groundwater production from the Edwards (Balcones Fault Zone) Aquifer in Travis County is for municipal use. Since 2000, most municipal pumpage represents surveyed amounts and non-surveyed municipal use constituted a relatively small portion of the total municipal usage.

With respect to the Edwards (Balcones Fault Zone) Aquifer within Travis County, pumping for municipal use generally increased from 1984 through 2005. Following an abrupt decline in 2007, reported municipal pumping was relatively stable at just over 6,000 acre-feet per year. Reported pumping for irrigation started in 2000 and ranged between 500 and 1,000 acre-feet per year, except for 2011 where usage peaked at over 1,200 acre-feet. Estimated pumping for livestock remained at approximately 100 acre-feet per year from 1984 through 2004, except for 1996 when 300 acre-feet of pumping occurred. After 2004, livestock pumpage gradually decreased to less than 50 acre-feet per year by 2018. Reported pumping for manufacturing was relatively low from 1984 through 1998. In 1999, there was an abrupt decrease in manufacturing use followed by an increase in 2000. After 2000, groundwater withdrawals for manufacturing use ranged between approximately 500 and 750 acre-feet per year. Figure 309 (year-to-year change analysis) and Figure 310 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer in Travis County.

With respect to the Trinity (Hill Country) Aquifer within Travis County, from 1984 through 2007, total groundwater pumping was always less than 4,000 acre-feet per year and often was less than 2,000 acre-feet per year (Figure 311). Beginning in 2007, total pumping increased to a peak of more than 10,000 acre-feet in 2011.

Pumping for municipal use remained generally below 2,500 acre-feet per year from 1984 through 2005. In 2006, annual municipal use withdrawals began increasing until 2011 when pumpage peaked at almost 10,000 acre-feet. From 2011 onwards, reported municipal pumpage declined to about 5,000 acre-feet in 2018. Since 2000, non-surveyed municipal use constituted only a relatively small portion of the municipal usage until 2006, after which it constituted a significant portion of total municipal usage. The TWDB Water Use Survey first reports values for irrigation pumping in 2000 and they generally range between 250 and 500 acre-feet per year. Pumping for livestock remained stable at approximately 300 acre-feet per year from 1984 through 2004, after which pumping decreased to less than 100 acre-feet per year and remained relatively constant through the end of the study period. Figure 312 (year-to-year change analysis) and Figure 313 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Trinity (Hill Country) Aquifer in Travis County.

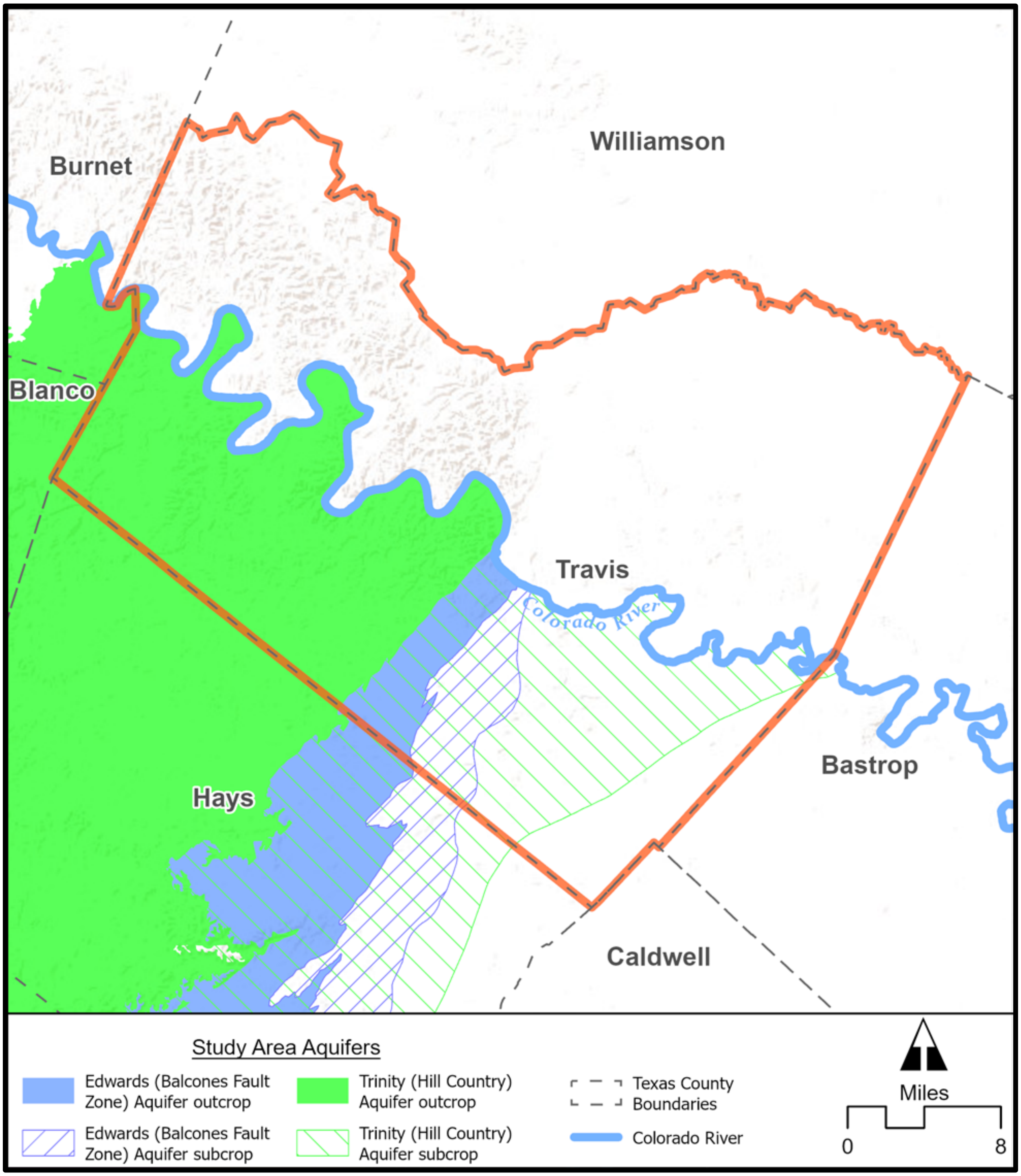


Figure 307. Travis County showing the extent of the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer within the study area.

Figure 314 presents Travis County Water User Survey data for the Edwards (Balcones Fault Zone) Aquifer along with time-series plots of the number of wells within the county for the specified water use category. In general, the number of wells for each water use category increased over time, which could suggest that pumpage for each water use category should correspondingly increase. This corresponding increase assumes, however, that all wells are continuously producing and that production per well does not decrease over time. Even with these assumptions, we may glean insight through comparisons of pumpage versus number of existing wells. For example, Figure 314 indicates that there were approximately 37 irrigation use wells completed in the Edwards (Balcones Fault Zone) Aquifer prior to 2000. Assuming some of these 37 wells were operational and producing would suggest that the lack of pumpage data for this period is incongruous. We will further investigate this relationship between wells and pumpage for Travis County under subsequent tasks of this project.

We would expect groundwater pumping for irrigation in Travis County to correlate negatively to precipitation on potentially irrigated land overlying the aquifer such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 315 indicates that as precipitation increased in the county, the reported pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer did often decrease. Similarly, as precipitation decreased (as in 2011), pumping for irrigation did often increase. Figure 316 indicates a negative correlation value (“*r*”) of -0.41 between precipitation on potentially irrigated land overlying the Edwards (Balcones Fault Zone) Aquifer within Travis County and groundwater pumpage for irrigation from the aquifer within the county. This moderate negative correlation suggests that the reported pumpage for irrigation in Travis County inversely follows the trend in precipitation. We will revise this correlation during subsequent project phases, including after fully researching irrigation usage in Travis County and limiting the usage only to portions of our project study area (rather than to the entire county).

Table 54 provides the years identified in the TWDB Water Use Survey as having anomalous pumping amounts for Travis County from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer based on our manual review, year-to-year change (Figure 309 and Figure 312), and standard deviation (Figure 310 and Figure 313) analyses.

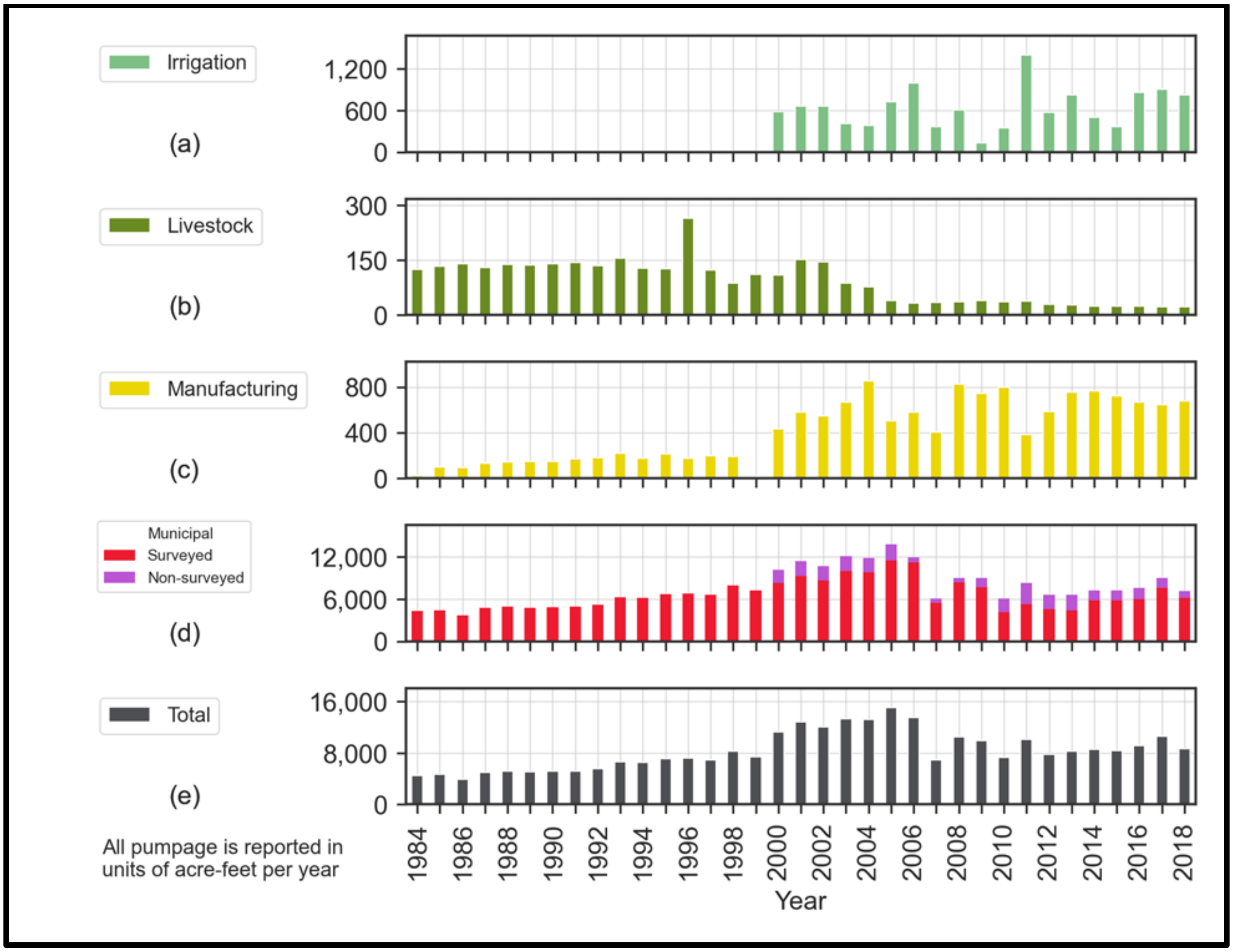


Figure 308. **Travis County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

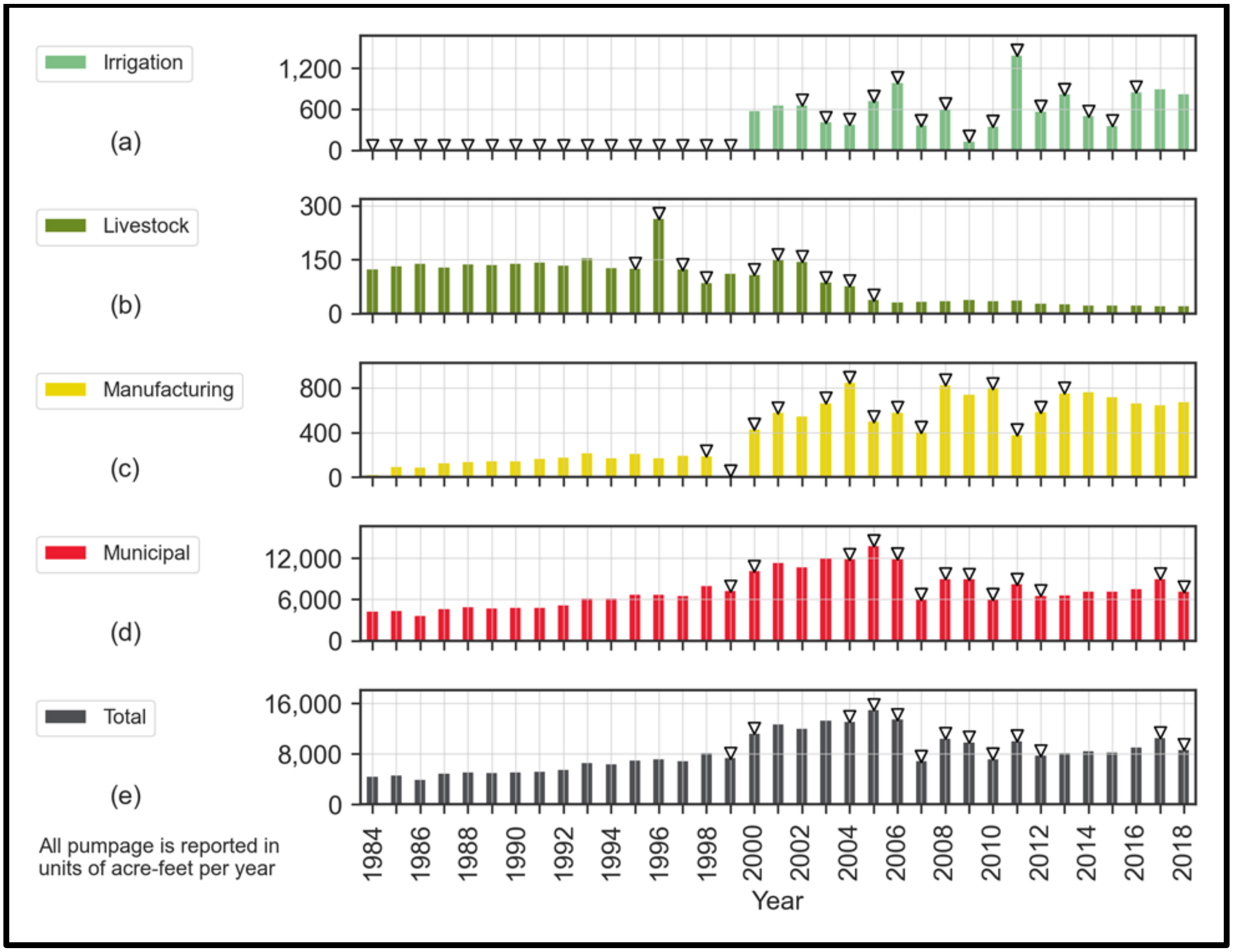


Figure 309. Travis County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

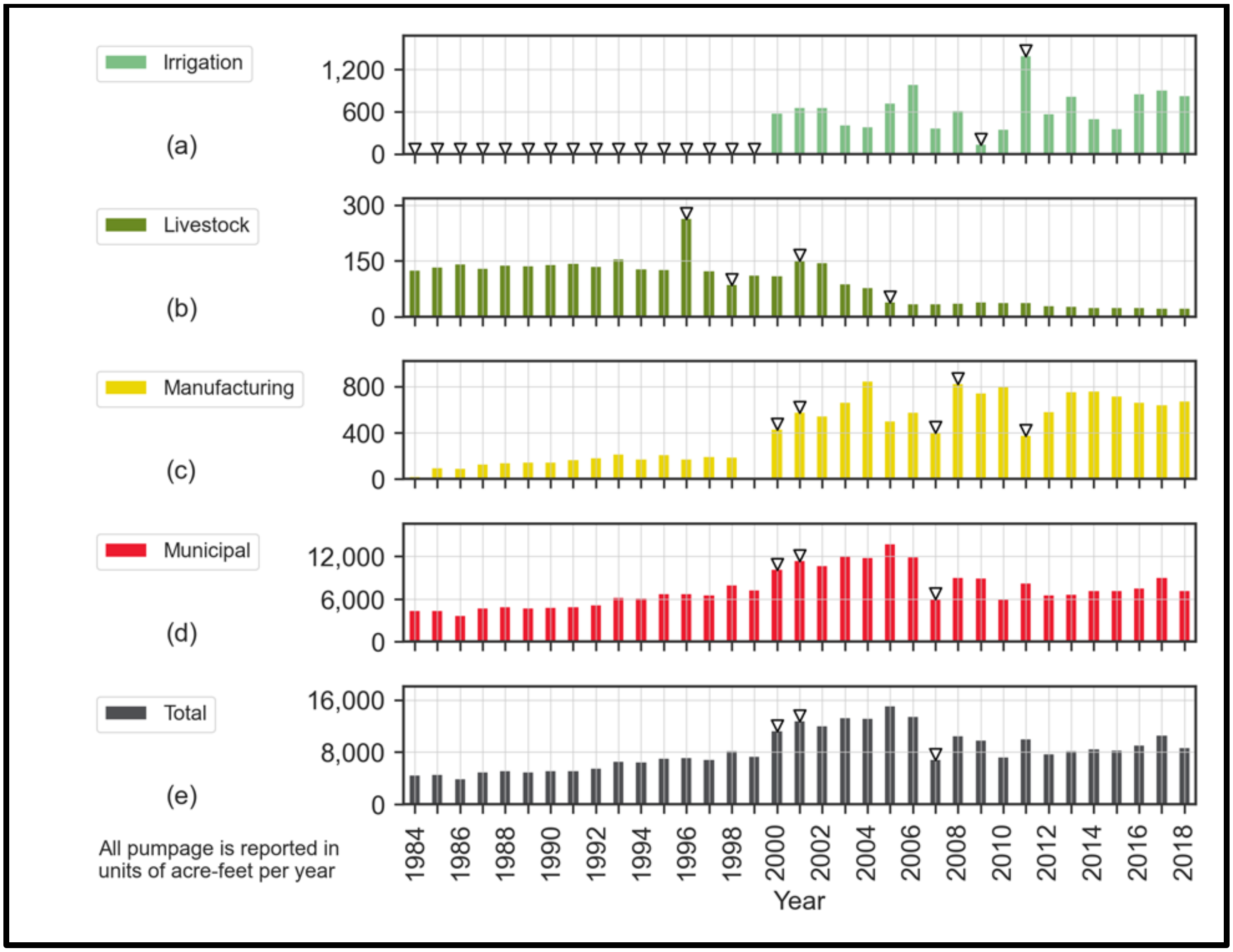


Figure 310. Travis County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

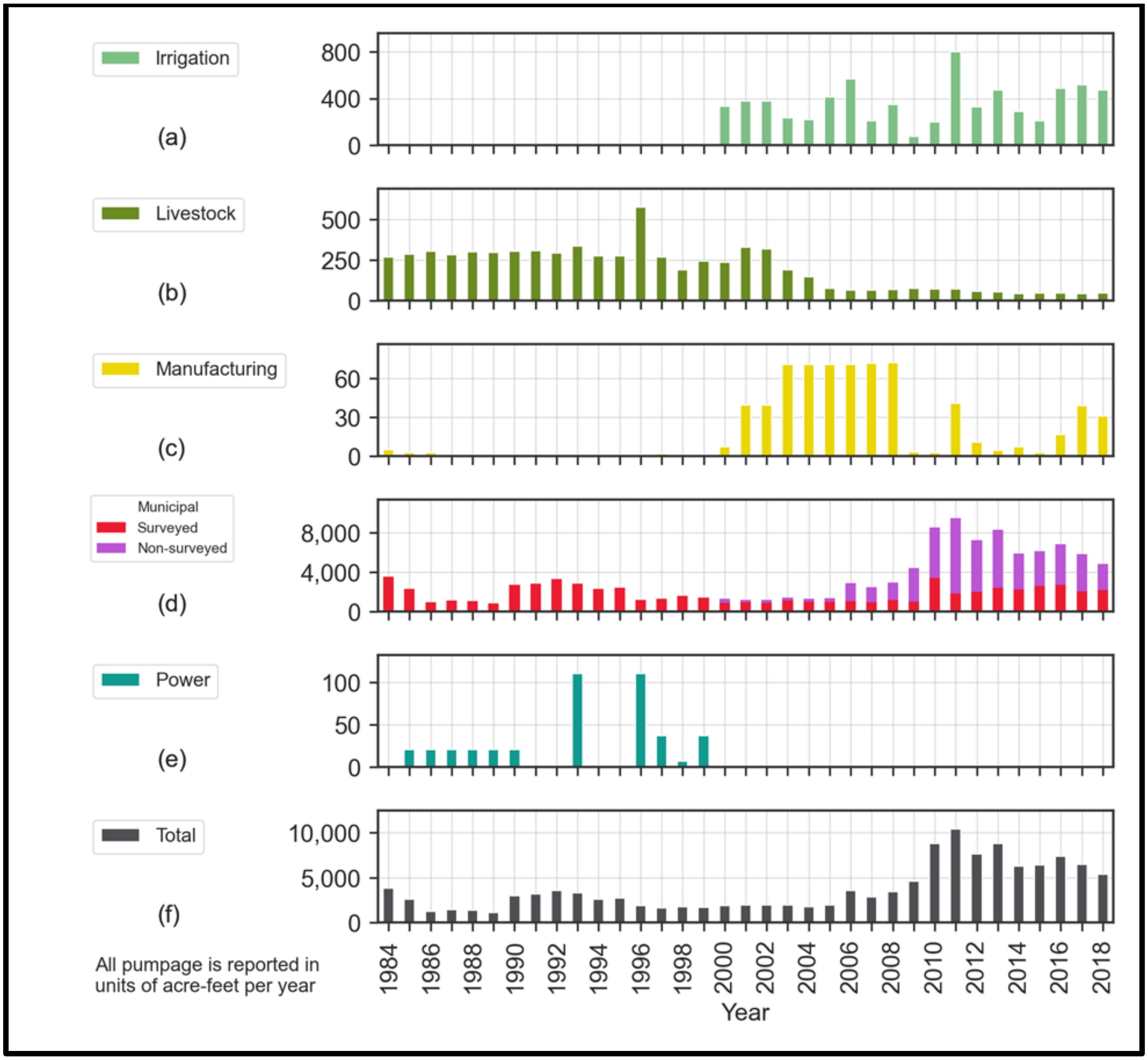


Figure 311. Travis County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

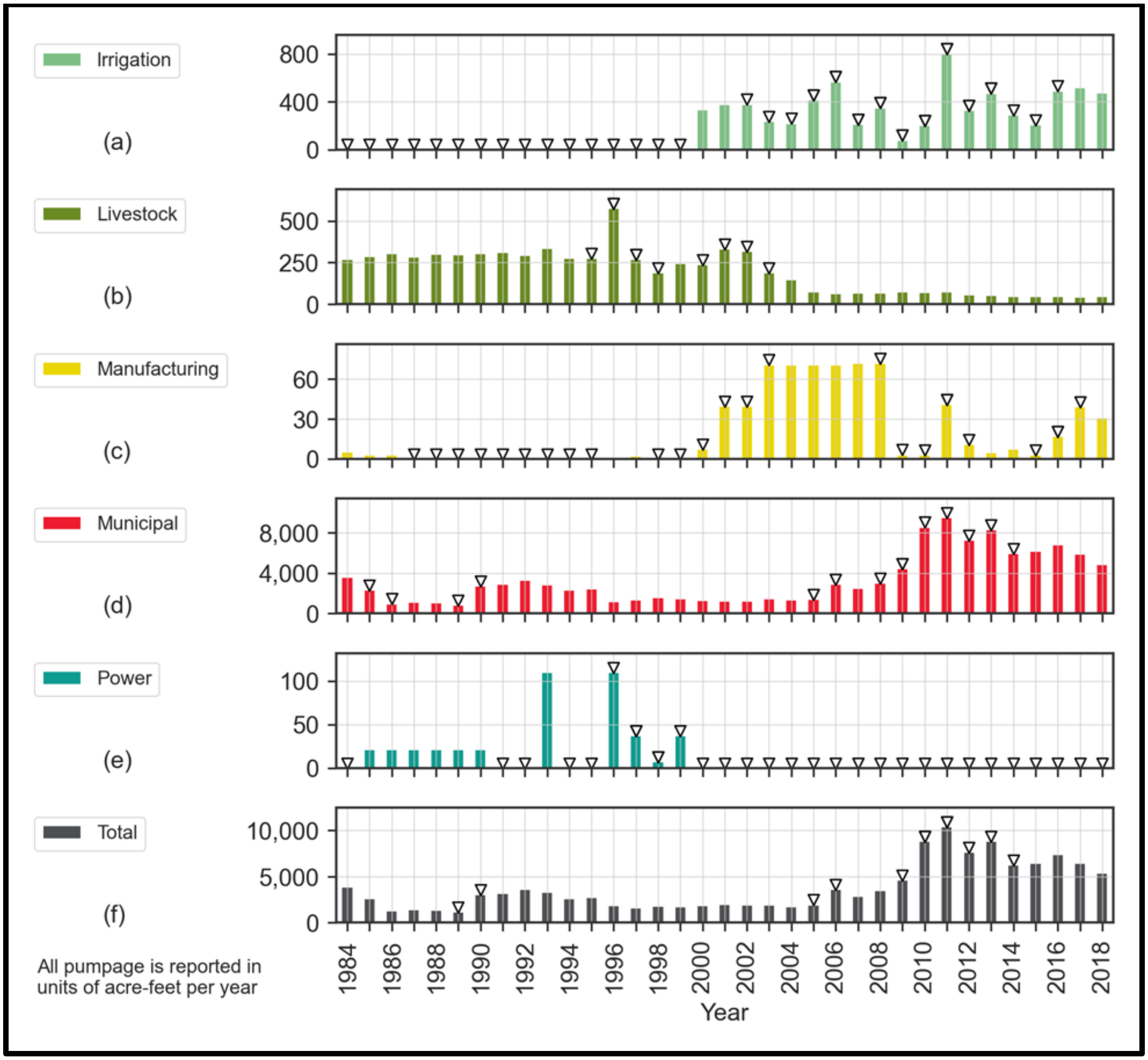


Figure 312. Travis County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 313. Travis County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

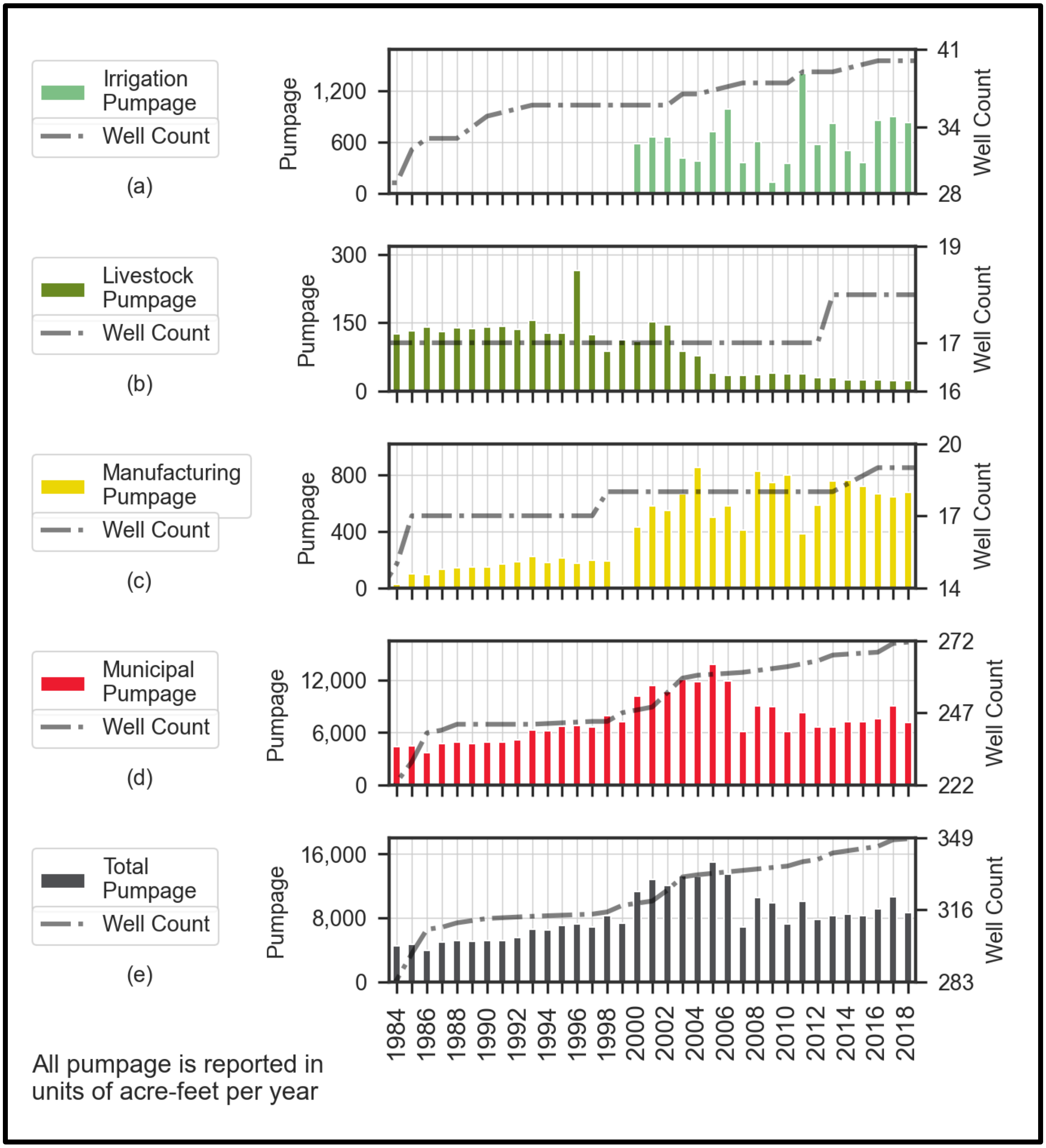


Figure 314. Travis County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer as recorded in publicly available databases.

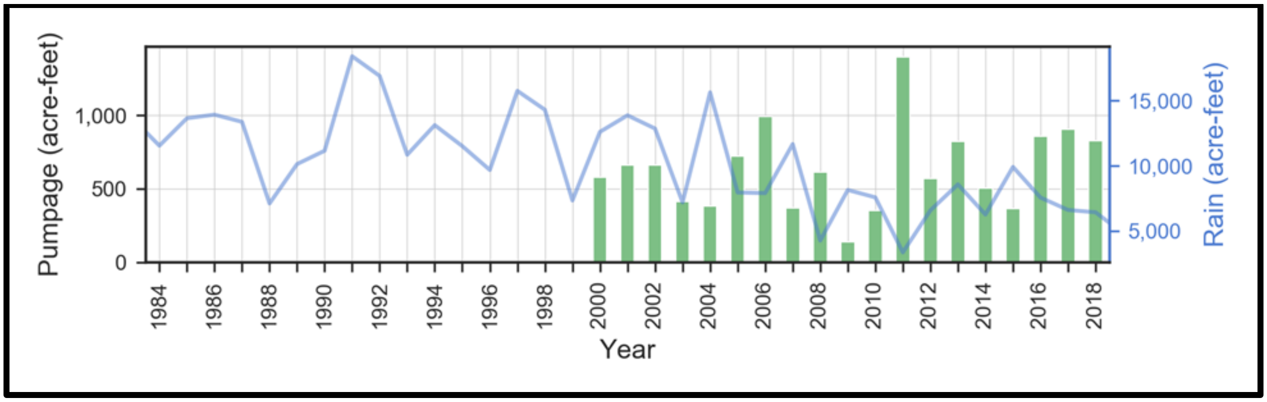


Figure 315. Travis County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

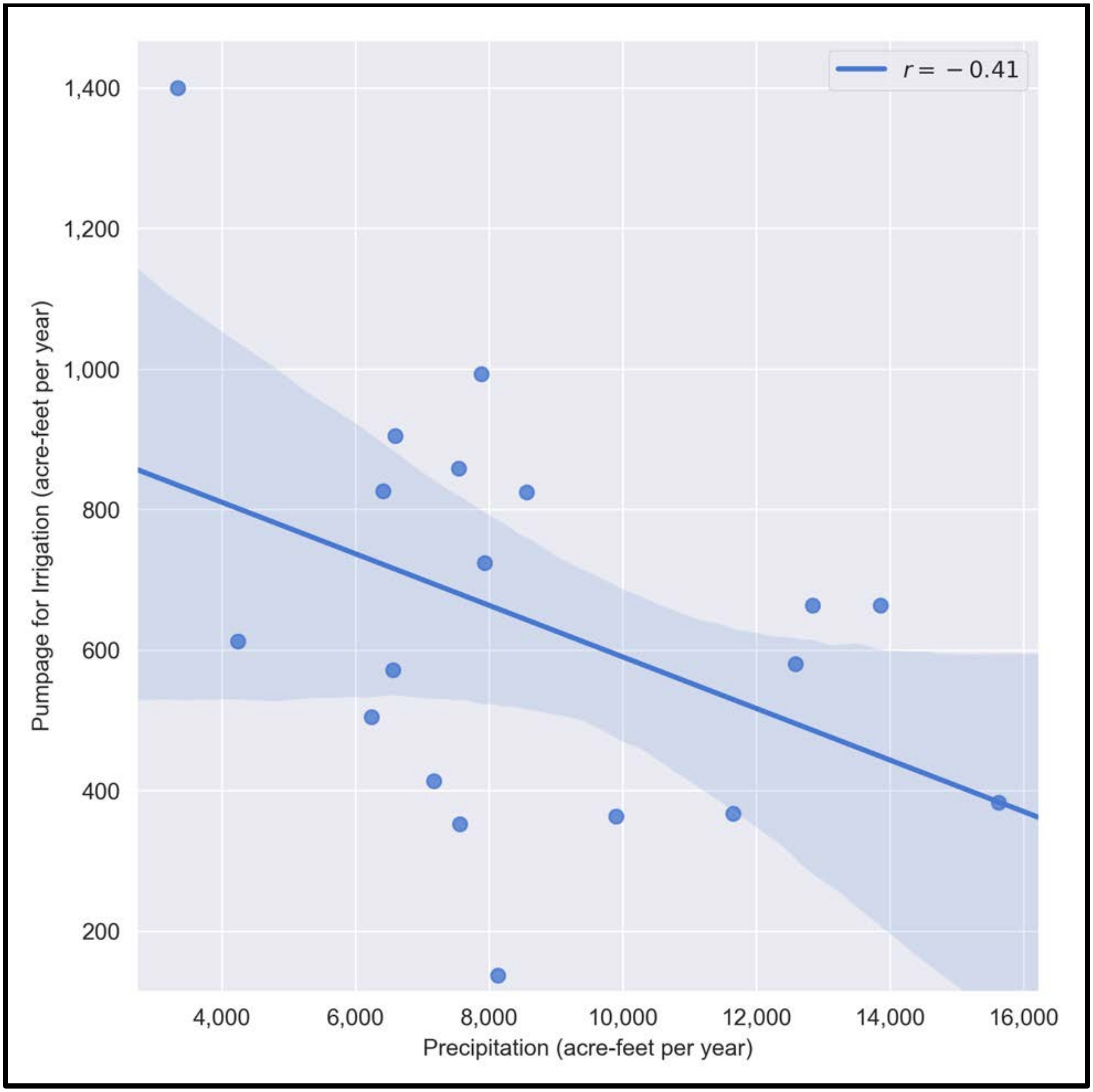


Figure 316. Travis County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers, in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

Table 54. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Travis County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	1984-1999, 2009,2011 wells completed prior to 2000, 2009, 2011	1984-2000, 2003, 2005-2014, 2016	1984-1999, 2009, 2011
	Livestock	1996	1996-1998, 2001, 2003, 2005	1996, 1998, 2001, 2005
	Manufacturing	1999, 2008, 2011	1999-2001, 2004, 2005, 2007, 2008, 2011-2013	2000, 2001, 2007, 2008, 2011
	Municipal	2000, 2007	2000, 2005-2008, 2010-2012, 2018	2000, 2001, 2007
Trinity (Hill Country)	Irrigation	1984-1999, 2009, 2011	1984-2000, 2003, 2005-2014, 2016	1984-1999, 2009, 2011
	Livestock	1996	1996-1998, 2001, 2003	1996, 1998, 2001, 2004, 2005
	Manufacturing	1988-1999, 2003, 2009, 2011, 2016	1987-1995, 1998, 1999, 2001, 2003, 2009, 2011, 2012, 2016, 2017	1987-1995, 1998, 1999, 2003, 2009, 2010
	Municipal	2006, 2010, 2011	1986, 1990, 2006, 2009, 2010, 2012, 2014	2010, 2011, 2014
	Power	1984, 1991-1996, 2000-2018	1984, 1985, 1991-2018	1984, 1991-1995, 2000-2018

3.3.48 Upton County

The Edwards-Trinity (Plateau) Aquifer underlies almost the entire area of Upton County with the exception of a small portion of the Pecos Valley Aquifer along the western side (see Figure 317). As shown on Figure 318, total groundwater pumping from the Edwards-Trinity (Plateau) Aquifer within Upton County reached approximately 30,000 acre-feet in 1998, but is typically less than 15,000 acre-feet per year. The TWDB Water Use Survey also indicates less than one acre-foot per year of pumping from the Pecos Valley Aquifer in Upton County for livestock use. During subsequent project tasks we will assess the potential production from the Pecos Valley Aquifer in Upton County, but further discussion of production from this aquifer will not be included in this section.

Most of the production from the Edwards-Trinity (Plateau) Aquifer in Upton County is for irrigation use. Estimated irrigation pumping appears to generally oscillate between 10,000 and 15,000 acre-feet per year. Irrigation use peaked in 1998 then abruptly declined to less than 10,000 acre-feet per year for most years through 2018. Pumpage for livestock use followed a similar oscillating trend and ranged between 50 and 150 acre-feet per year. Reported groundwater withdrawals for manufacturing use were not available prior to 2000. For 2000 and the following years, manufacturing use ranged between 50 and 150 acre-feet per year with abrupt declines in 2002, 2006, and 2016. Pumpage for mining use ranged from 1,000 to 3,000 acre-feet per year from 1984 through 1999, without any reported data for most of the remaining years of the study period. Pumping for municipal use ranged between 250 and 1,000 acre-feet per year except for three years when volumes decreased abruptly (1993, 1994, and 1995). Since 2000, non-surveyed municipal use constituted only a relatively small portion of the total municipal usage. Report groundwater pumpage for unknown use occurred from 2000 through 2009 with annual volumes ranging between 100 and 200 acre-feet. Figure 319 (year-to-year change analysis) and Figure 320 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Upton County.

The area of potentially irrigated land overlying the Edwards-Trinity (Plateau) Aquifer in Upton County correlates linearly to groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation use. Figure 321 indicates that as the area of potentially irrigated land overlying the aquifer decreased in the county, so did the reported pumpage for irrigation. Figure 322 indicates a linear correlation value ("*r*") of 0.52 between potentially irrigated land area and groundwater pumpage for irrigation. This moderate positive correlation suggests that pumpage for irrigation in Upton County matches the trend in potentially irrigated land. We will revise this correlation during subsequent project tasks, after researching anomalies identified within the Upton County irrigation use dataset.

Table 55 provides the years identified in the TWDB Water Use Survey as having anomalous pumping amounts for Upton County for the Edwards-Trinity (Plateau) Aquifer based on our manual review, year-to-year change (Figure 319), and standard deviation (Figure 320) analyses.

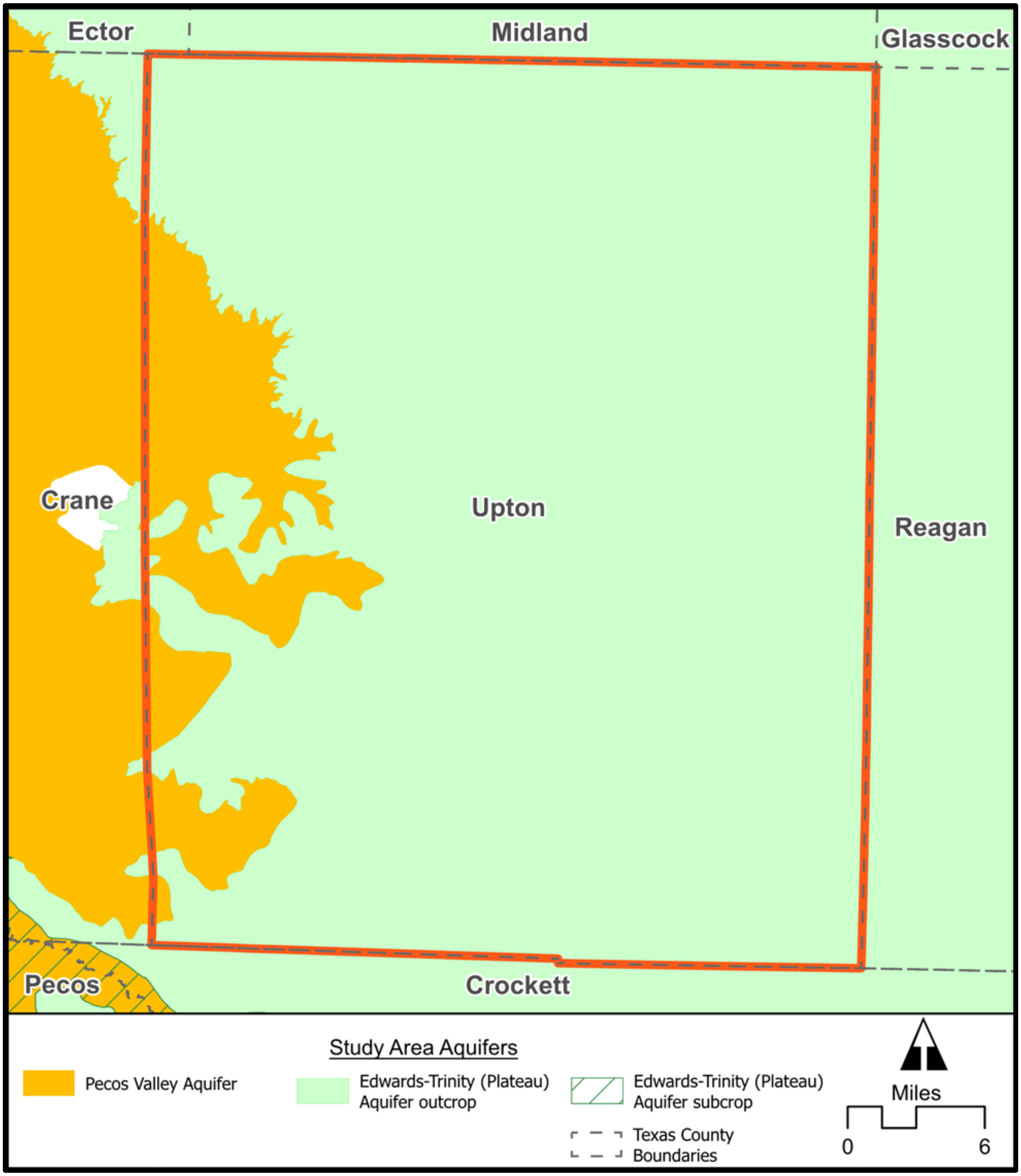


Figure 317. Upton County showing the extent of the Edwards-Trinity (Plateau) and Pecos valley aquifers.

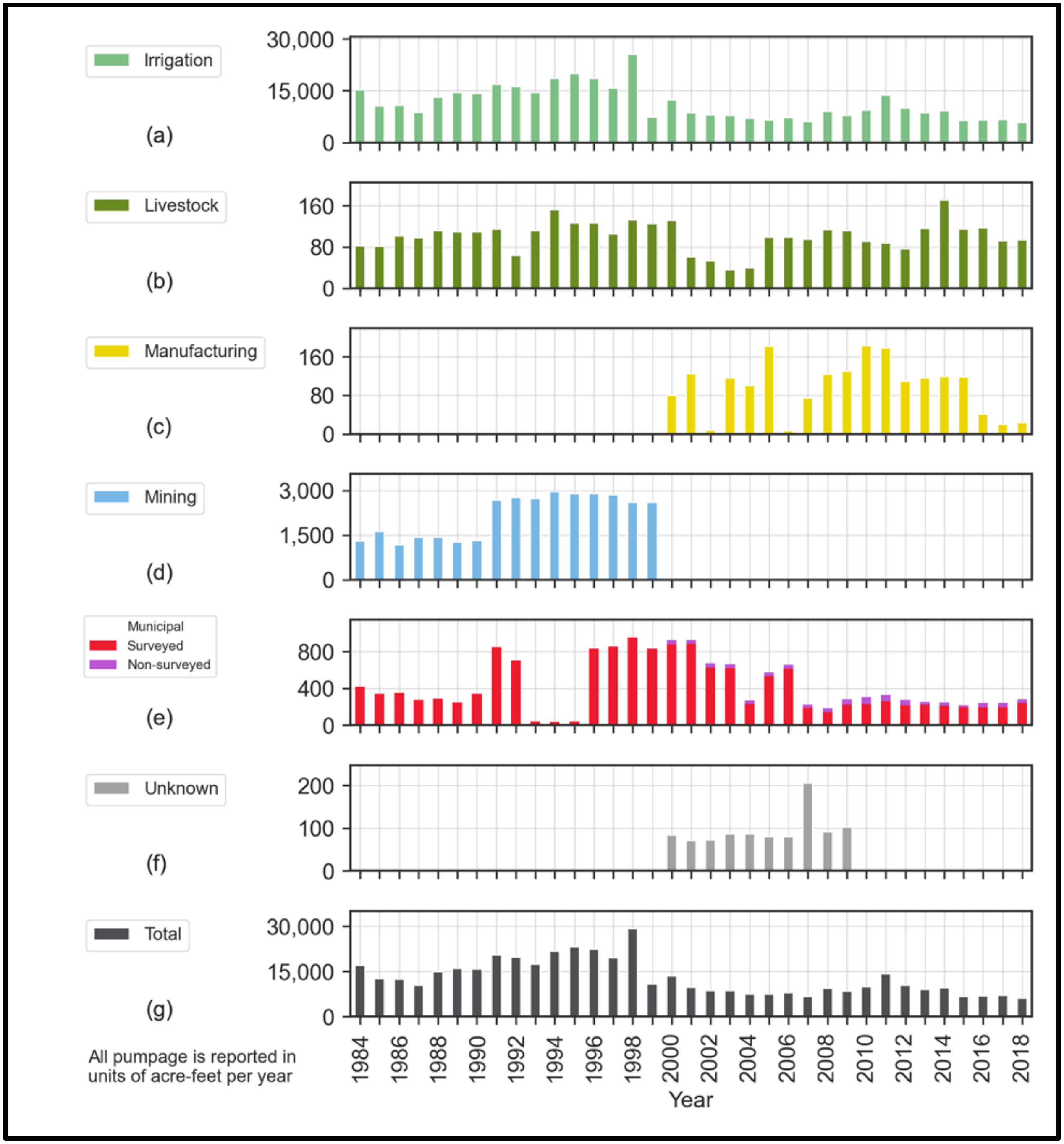


Figure 318. Upton County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

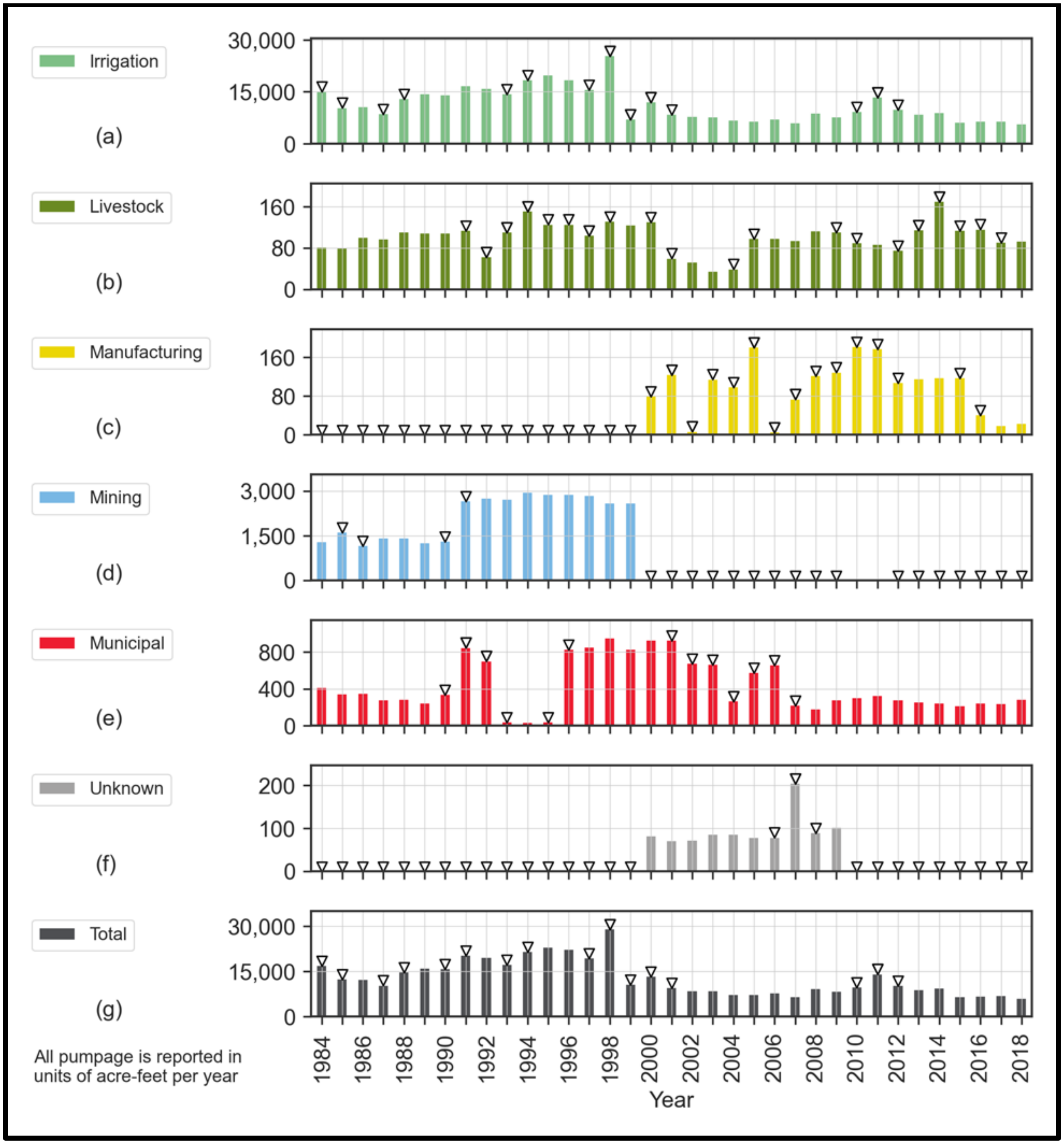


Figure 319. Upton County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 320. Upton County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

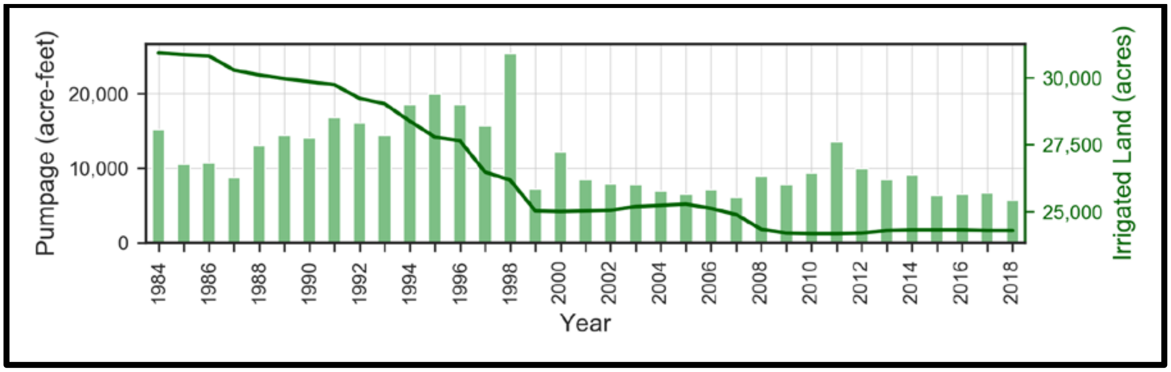


Figure 321. Upton County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

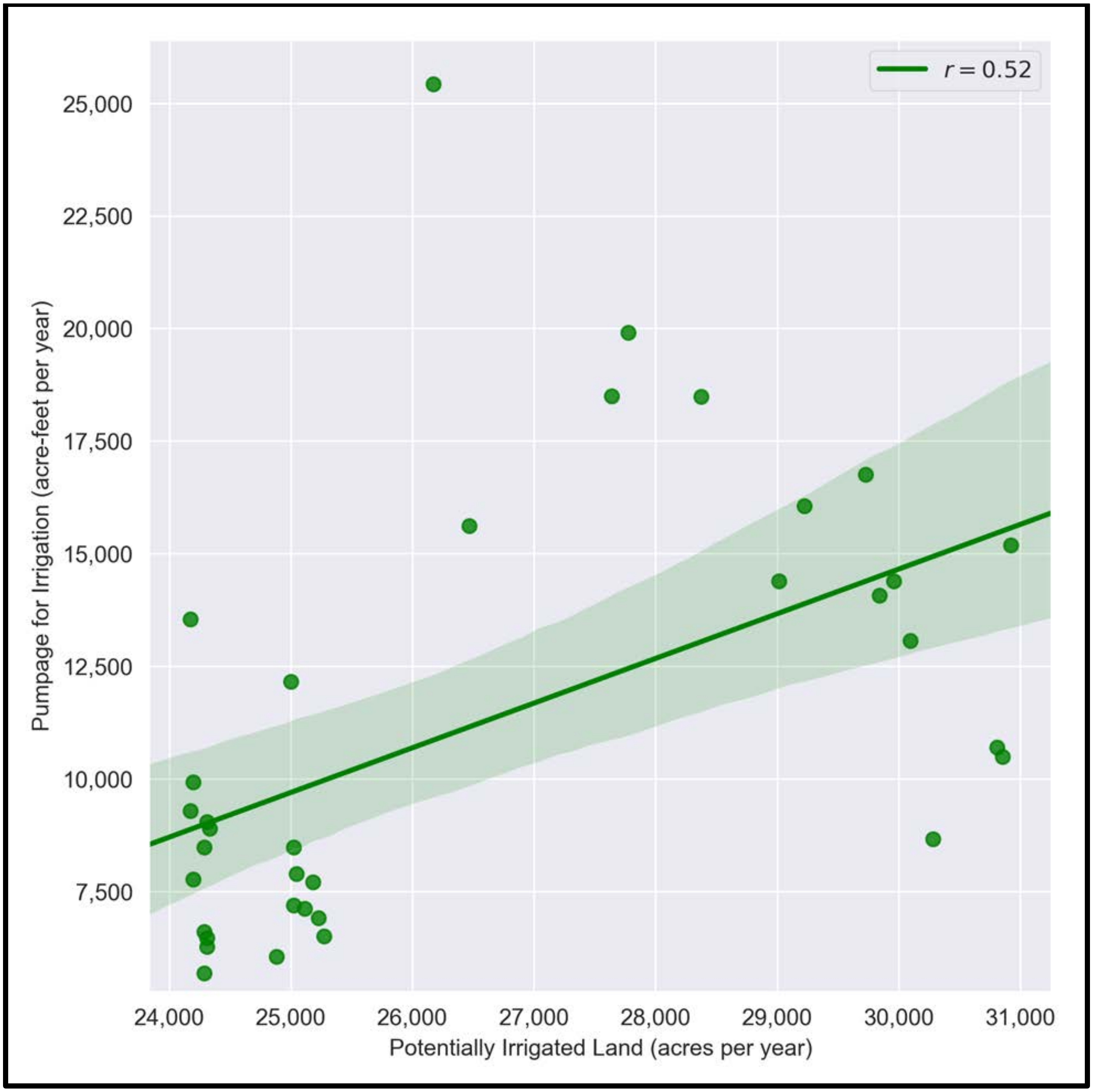


Figure 322. Upton County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 55. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Upton County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1998, 1999	1984, 1985, 1988, 1994, 1998-2001, 2011, 2012	1998, 1999, 2001
	Livestock	1992, 1994, 2001, 2005, 2014	1992-1995, 1997, 1998, 2001, 2005, 2010, 2013-2015, 2017	1992, 1994, 2001, 2002, 2005, 2014
	Manufacturing	1984-1999, 2002, 2005, 2006	1984-2003, 2005-2008, 2010, 2012, 2016	1984-1999, 2005, 2006
	Mining	1991, 2000-2018	1986, 1991, 2000-2009, 2012-2018	1991, 2000-2009, 2012-2018
	Municipal	1991, 1993-1995, 2004, 2007	1991-1993, 1996, 2002, 2004, 2005, 2007	1991, 1993, 1994, 1996, 1997, 2004
	Unknown	1984-1999, 2007, 2010-2018	1984-2000, 2007, 2008, 2010-2018	1984-1999, 2007, 2010-2018

3.3.49 Uvalde County

Uvalde is the only county in the study area in which three of the five study area aquifers are present. As Figure 323 illustrates, the Edwards-Trinity (Plateau) Aquifer is present in the northern part of the county covering about 20 percent of the county area. The Trinity (Hill Country) Aquifer is present in the northeast corner of the county covering about 12 percent of the county area. Lastly, the Edwards (Balcones Fault Zone) Aquifer is present across the central part of the county covering about 55 percent of the county area. Of the three aquifers, most of the production within Uvalde County occurs from the Edwards (Balcones Fault Zone) Aquifer.

With regard to the Edwards (Balcones Fault Zone) Aquifer in Uvalde County, total groundwater pumping reached approximately 150,000 acre-feet in 1989 but is generally much less, especially in recent years (Figure 324). Pumping for irrigation use declined from approximately 150,000 acre-feet per year in the 1980’s to about 40,000 acre-feet per year since 2015. Pumping for livestock use was minimal up to 2000 when it escalated to over 1,000 acre-feet per year. After 2000, livestock use again declined to relatively low levels except for five reportedly high pumping years (2005, 2007 through 2009, and 2012). Groundwater withdrawals for manufacturing use ranged between 300 and 700 acre-feet per year from 1984 through 2003, after which there were no reported pumping data. Pumpage for mining was typically less than 400 acre-feet per year except for during two high years (1993 and 1994). Pumpage for municipal use appears generally steady at 5,000 acre-feet per year with a declining trend since 2011. Figure 325 (year-to-year change analysis) and Figure 326 (standard deviation analysis) identify these and other potentially anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer in Uvalde County.

Estimated total pumping from the Edwards-Trinity (Plateau) Aquifer within Uvalde County is typically less than 800 acre-feet per year throughout the study period (Figure 327). Pumpage for livestock use reached 600 acre-feet in 1996 but generally stayed at approximately 400 acre-feet per year from 1984 through 2003. After 2003, estimated livestock pumpage decreased abruptly to minimal volumes. Pumping for municipal use generally ranged between 200 and 400 acre-feet per year although it decreased abruptly after 1999 and remained low through 2009. Figure 328 (year-to-year change analysis) and Figure 329 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Uvalde County.

With respect to the Trinity (Hill Country) Aquifer in Uvalde County, estimated total pumping was typically less than 150 acre-feet per year from 2000 through 2018 (Figure 330). Municipal usage was the largest recent use of groundwater from the aquifer in the county, reaching 200 acre-feet in 2011. However, prior to 2006 the Water Use Survey dataset does not contain municipal use for the Trinity (Hill Country) Aquifer in Uvalde County. Estimated pumping for livestock use was relatively consistent at approximately 40 acre-feet per year from 2000 through 2018. Figure 331 (year-to-year change analysis) and Figure 332 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Trinity (Hill Country) in Uvalde County.

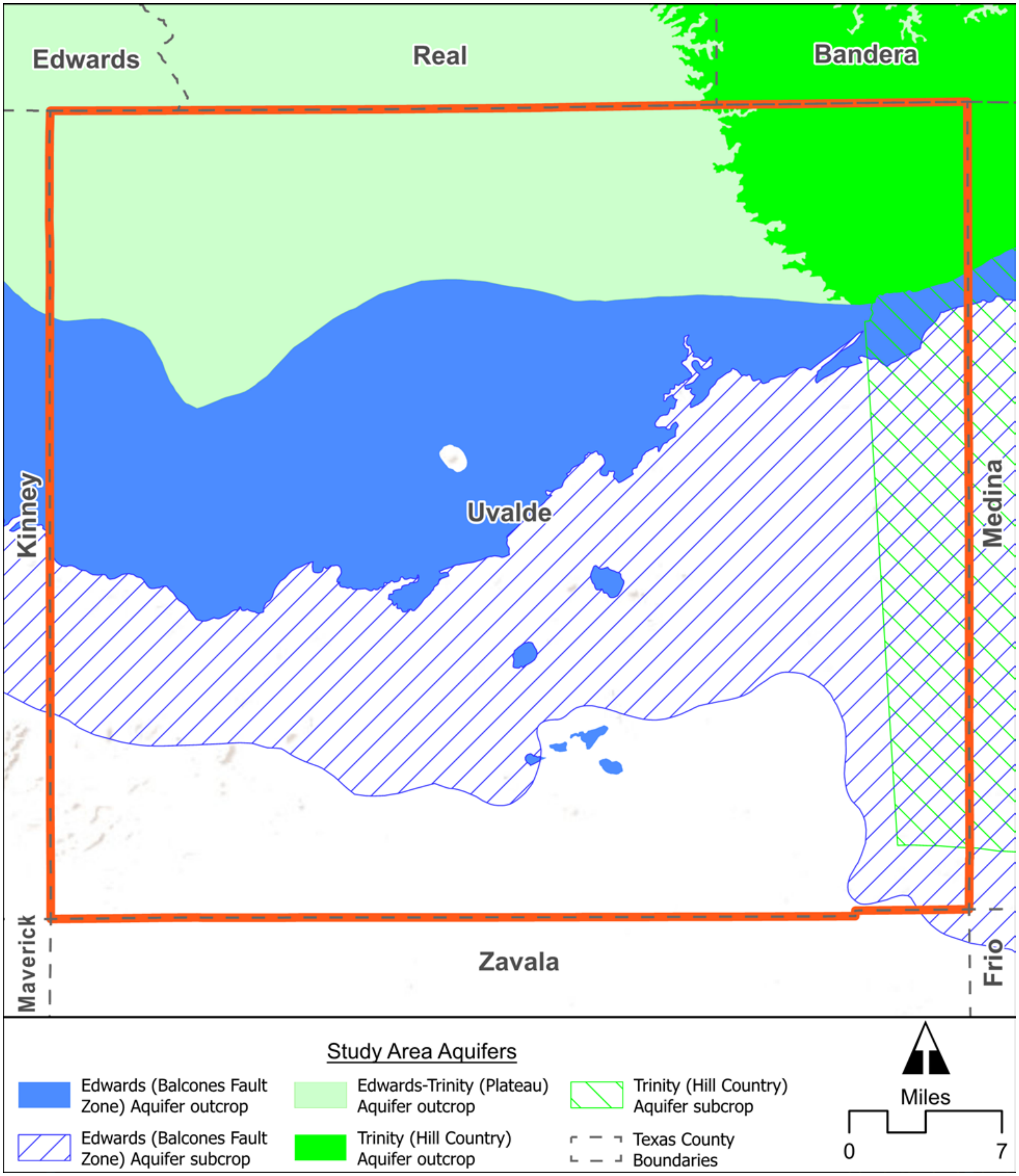


Figure 323. Uvalde County showing the extent of the Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone) and Trinity (Hill Country) aquifers.

We would expect the potentially irrigated land overlying the Edwards (Balcones Fault Zone) in Uvalde County to correlate linearly to groundwater pumpage from the Edwards (Balcones Fault Zone) for irrigation use. However, Figure 333 indicates that although the acres of potentially irrigated land overlying the aquifer have increased in the county, the reported pumpage for irrigation has decreased. Figure 334 indicates a linear correlation value (*"r"*) of -0.80 between potentially irrigated land area overlying the aquifer and groundwater pumpage for irrigation. This very strong negative correlation suggests that pumpage for irrigation from Edwards (Balcones Fault Zone) in Uvalde County may be anomalous. Alternative explanations for this observed correlation include: 1) the usage of different crops (potentially requiring less water), 2) improved irrigation water delivery practices, or 3) other unknown factors. We will revise this correlation after researching Uvalde County irrigation practices during subsequent project phases.

Table 56 provides the years identified in the TWDB Water Use Survey as having anomalous pumping amounts for Uvalde County based on our manual review, year-to-year change (Figure 325, Figure 328, and Figure 331), and standard deviation (Figure 326, Figure 329, and Figure 332) analyses.

Figure 324. Uvalde County Edwards (Balcones Fault Zone) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

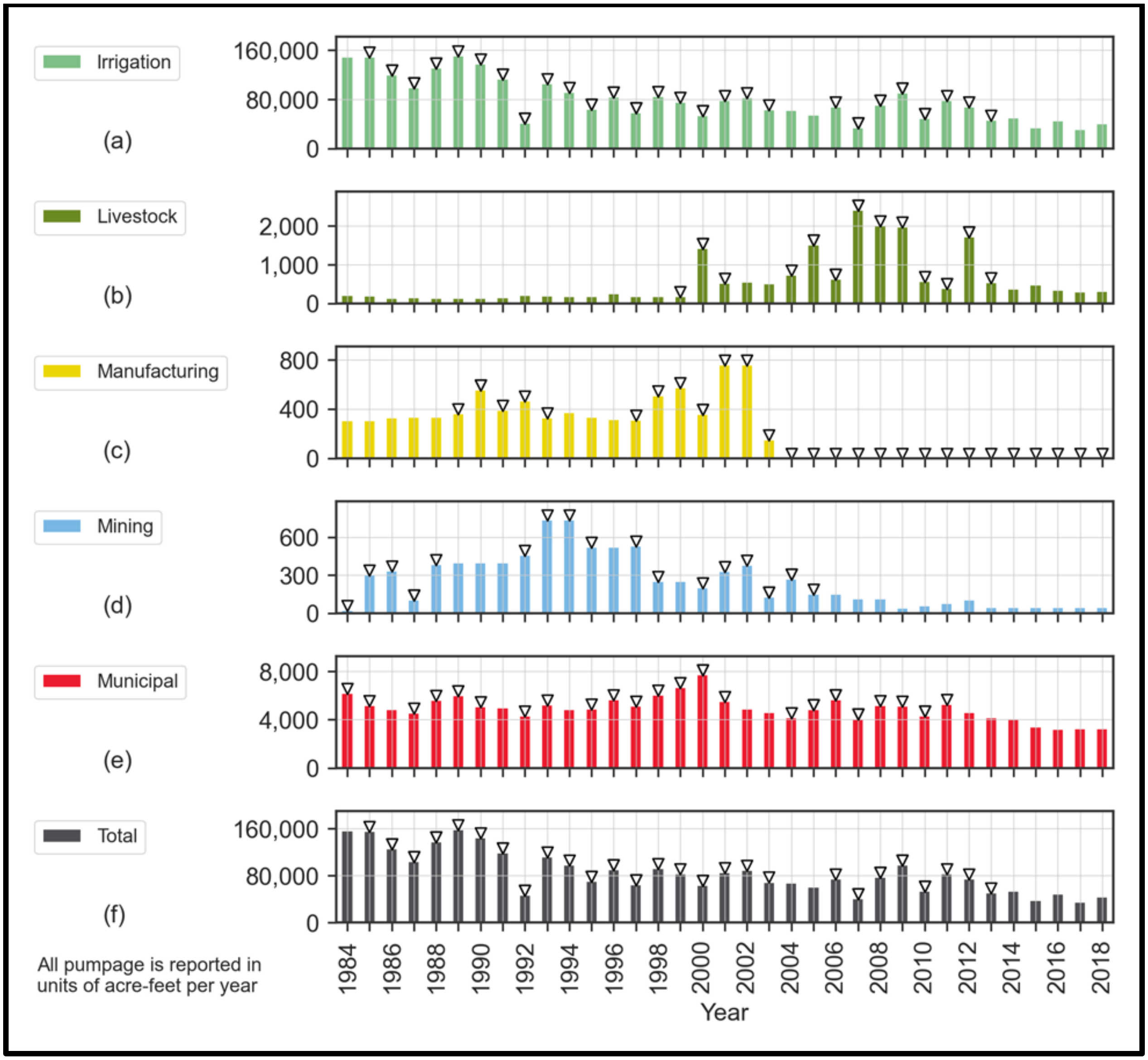


Figure 325. Uvalde County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

Figure 326. Uvalde County Edwards (Balcones Fault Zone) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

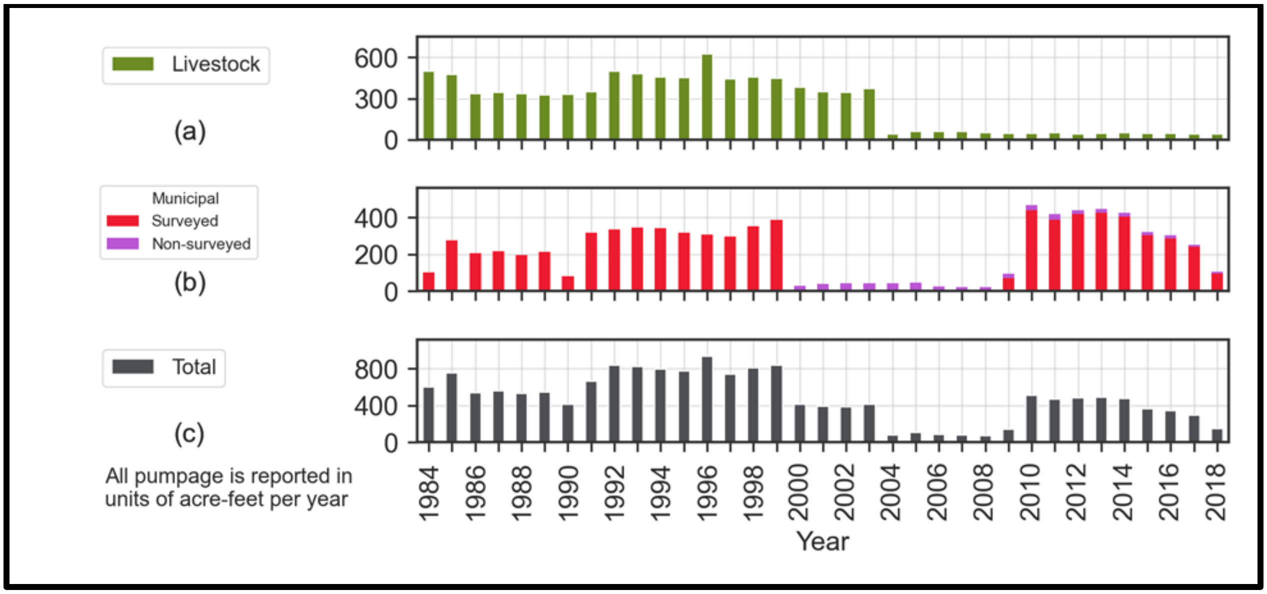


Figure 327. **Uvalde County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.**

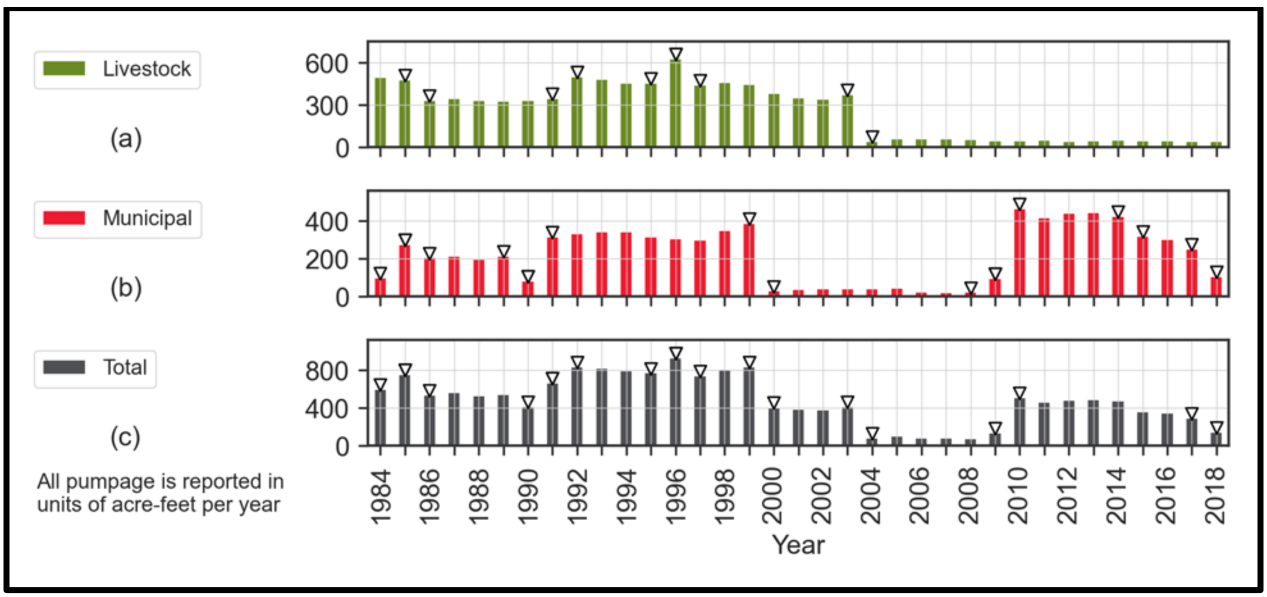


Figure 328. **Uvalde County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

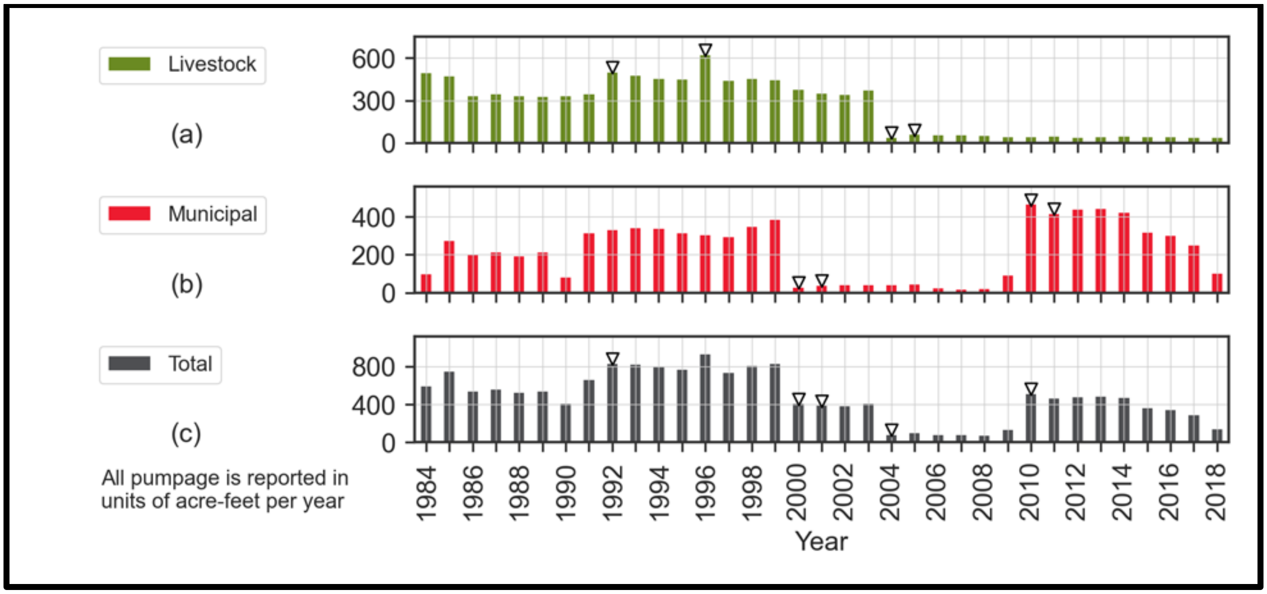


Figure 329. Uvalde County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

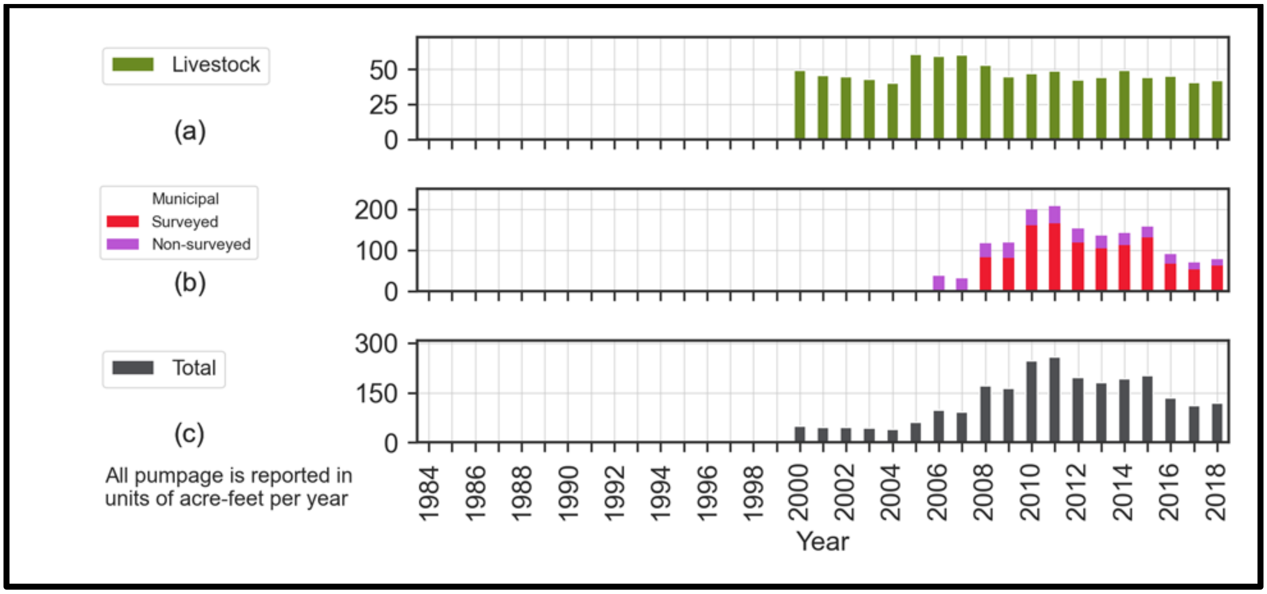


Figure 330. Uvalde County Trinity (Hill Country) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

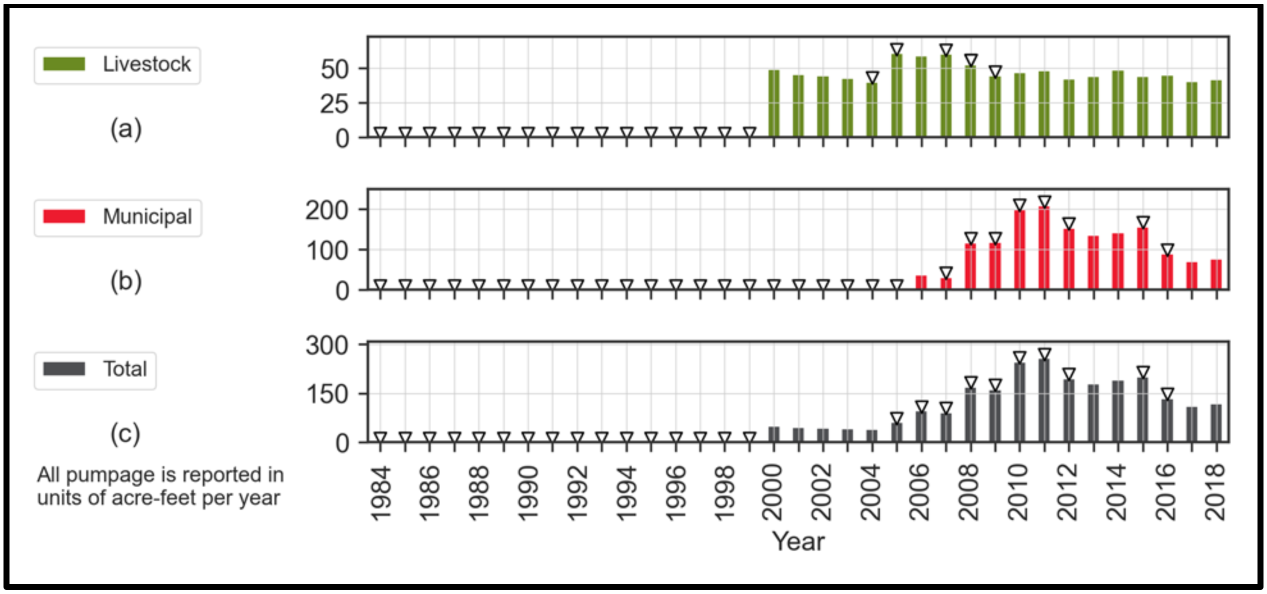


Figure 331. Uvalde County Trinity (Hill Country) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

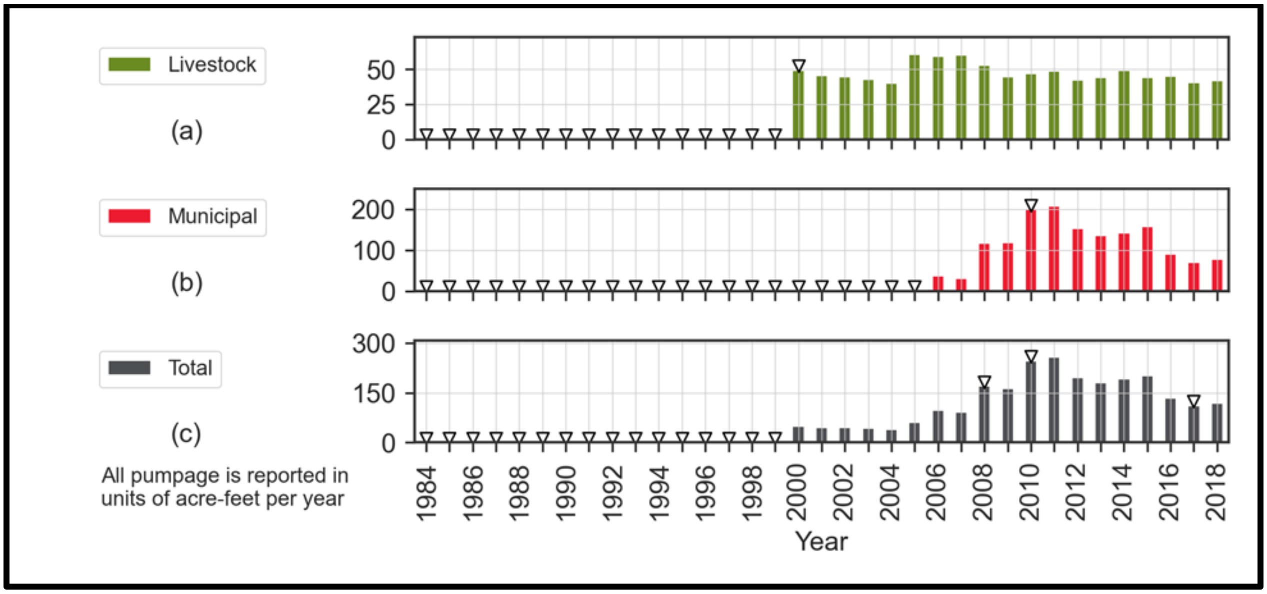


Figure 332. Uvalde County Trinity (Hill Country) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

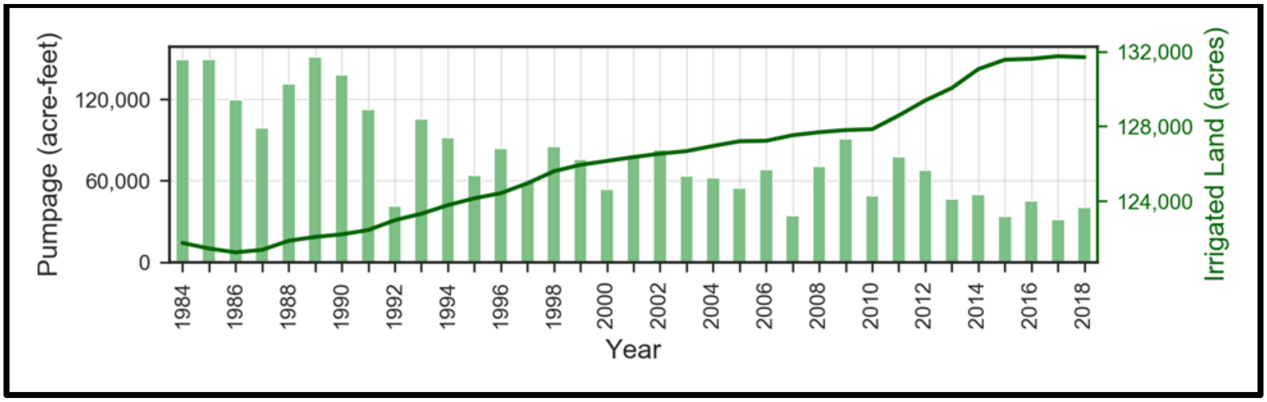


Figure 333. Uvalde County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

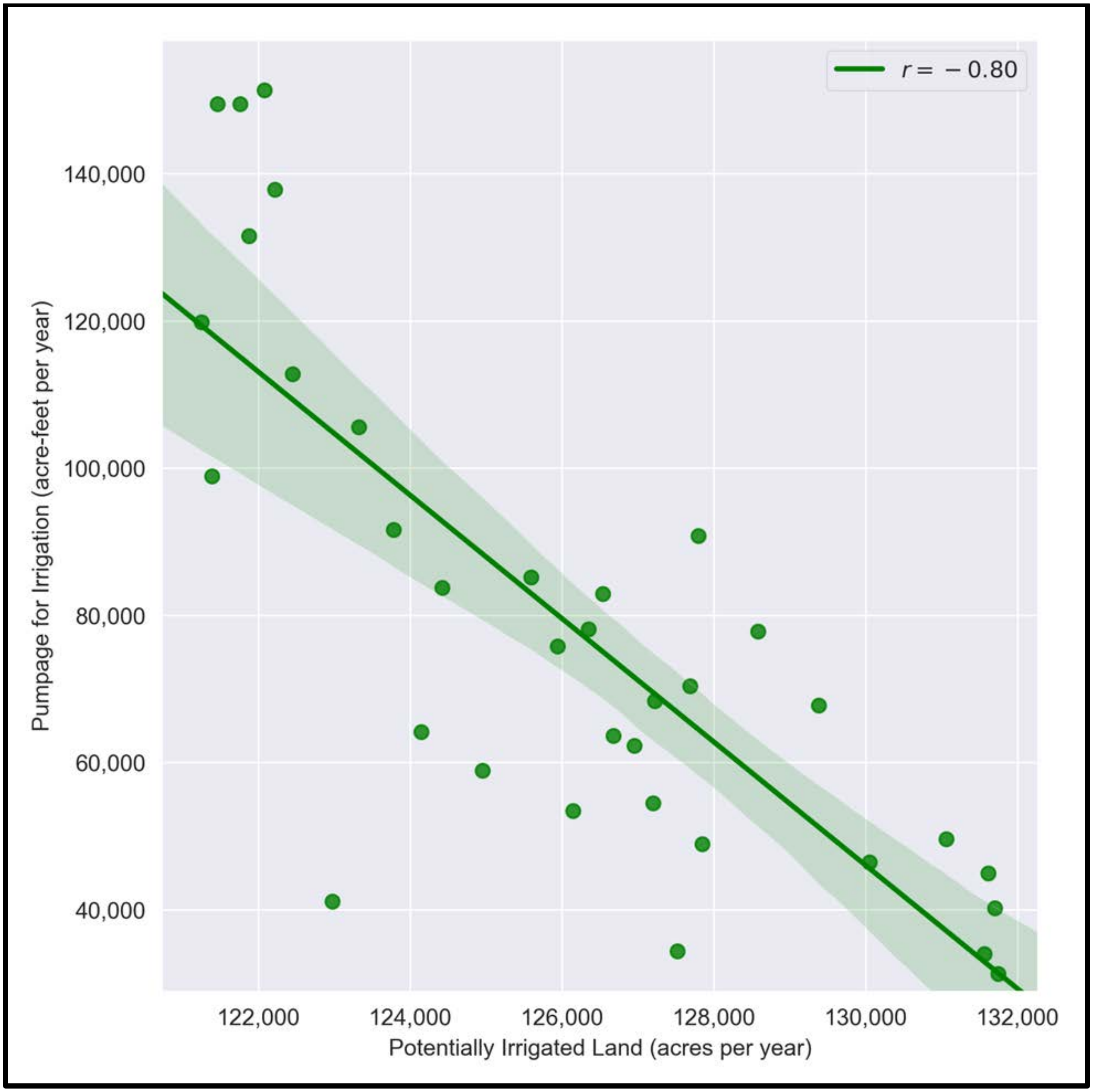


Figure 334. Uvalde County Edwards (Balcones Fault Zone) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 56. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Uvalde County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards (Balcones Fault Zone)	Irrigation	1987, 1989, 1992, 2009	1986-1989, 1991-1993, 1995-1998, 2000, 2001, 2003, 2007-2011, 2013	1987, 1989, 1992, 2009
	Livestock	2000, 2005, 2007, 2010, 2011	2000, 2001, 2005-2008, 2010, 2012, 2013	2000, 2005, 2007, 2010, 2011
	Manufacturing	2003, 2003-2018	1990, 1991, 1993, 1998, 2000, 2001, 2003-2018	2003-2018
	Mining	1984, 1987, 1993, 1995, 1998	1984, 1985, 1987, 1988, 1993, 1995, 1998, 2001, 2003-2005	1984, 1993, 1994, 1998
	Municipal	2000, 2002	1984, 1985, 1988, 1990, 1993, 1996, 1998, 2000, 2001, 2005-2008, 2010, 2011	2000, 2002, 2003, 2006
Edwards-Trinity (Plateau)	Livestock	1986, 1992, 1996, 2004	1986, 1992, 1996, 1997, 2004	1992, 1996, 2004, 2005
	Municipal	1984, 1990, 2000-2009	1984-1986, 1990, 1991, 2000, 2009, 2010, 2015, 2018	2000, 2001, 2010, 2011
Trinity (Hill Country)	Livestock	1984-1999	2005, 2008, 2009	2005, 2006, 2009
	Municipal	1984-2005	2000-2006, 2008, 2010, 2012, 2016	2000-2005, 2010

3.3.50 Val Verde County

The Edwards-Trinity (Plateau) Aquifer underlies nearly all of Val Verde County, except for two percent of the county area located at the southern tip of the county along the border with Mexico and Kinney County (see Figure 335). As illustrated in Figure 336, the TWDB Water Use Survey data indicate that water from the Edwards-Trinity (Plateau) Aquifer in Val Verde County was used for irrigation, livestock, mining, and municipal purposes, with most of the pumpage for municipal uses. Reported municipal use reached nearly 16,000 acre-feet per year in 2000 and remained relatively constant through 2005. Since 2000, surveyed municipal use constituted most municipal use. Reported groundwater uses for irrigation, livestock, and mining are relatively minor compared to municipal use.

With respect to Val Verde County usage from the Edwards-Trinity (Plateau) Aquifer, the essentially constant pumping for municipal use from 2000 through 2005 is anomalous (Figure 336). The year-to-year change analysis (Figure 337) flagged 1998 through 2000 as anomalous, but did not capture the 2001 through 2005 period. Similarly, the standard deviation analysis (Figure 338) did not flag any of the years from 2001 through 2005 as anomalous, as they suggest only minor deviations from the previous three-year average use. Nonetheless, the consistency of the data compared to data from other counties raises questions about the reported values. Another anomaly identified in the municipal data is the abrupt decline from over 10,000 acre-feet in 2006 to less than 1,000 acre-feet in 2007, followed by the increase of a similar magnitude from 2009 to 2010.

Figure 339 shows approximately 24 new wells completed in the county since 2015 with a proposed livestock use. However, groundwater pumpage for livestock use since 2015 has remained constant. Intuitively, we would expect some increase in pumping with the additional wells, suggesting a potential anomaly in the data for livestock use. Alternative explanations for this observation could be that newly installed wells are replacing older wells that are under performing or not in service. We will investigate the relationship between well numbers and pumpage during subsequent tasks of this project.

Potentially irrigated land in Val Verde County correlates linearly to groundwater pumpage from the Edwards-Trinity (Plateau) Aquifer for irrigation use. Figure 340 depicts pumpage for irrigation along with the number of acres of potentially irrigated land overlying the aquifer in the county and shows a potential correlation from 1984 through 2011; data from 2012 through 2018, however, suggest an opposite correlation, thereby potentially invalidating any relationship between potentially irrigated land and irrigation pumpage for Val Verde County. Figure 341 indicates a linear correlation value of 0.51 between potentially irrigated land area and groundwater pumpage for irrigation use, as calculated using data for the entire 1984 through 2018 period of record. This moderate positive correlation suggests that pumpage for irrigation in Val Verde County may loosely match temporal trends in potentially irrigated land overlying the aquifer. We will revise this correlation during subsequent project phases, including after researching and potentially revising anomalous irrigation pumping data identified for Val Verde County.

Table 57 provides the years identified as having anomalous pumping amounts for the Edwards-Trinity (Plateau) Aquifer in Val Verde County based on our manual review, year-to-year change (Figure 337), and standard deviation (Figure 338) analyses.

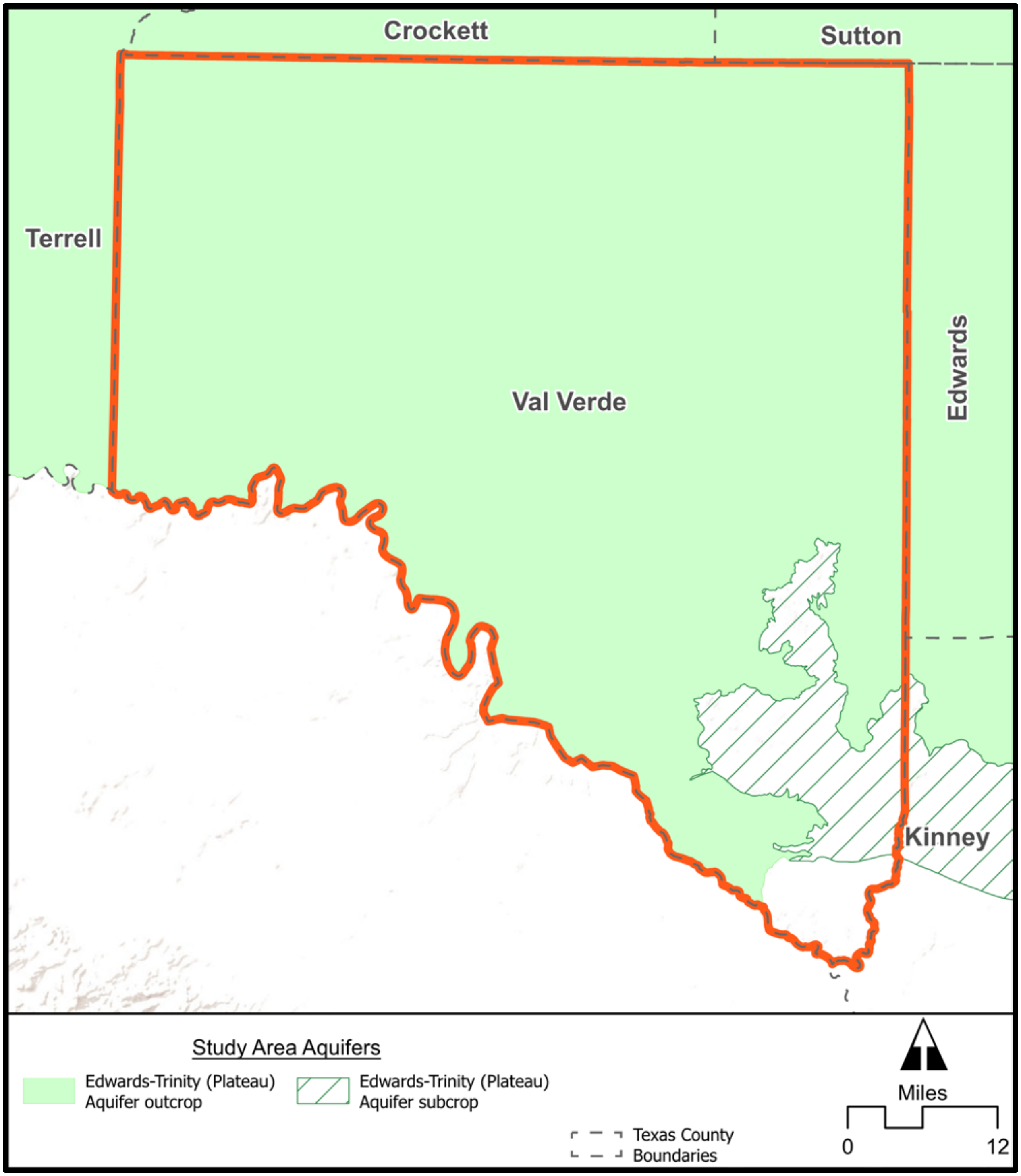


Figure 335. Val Verde County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

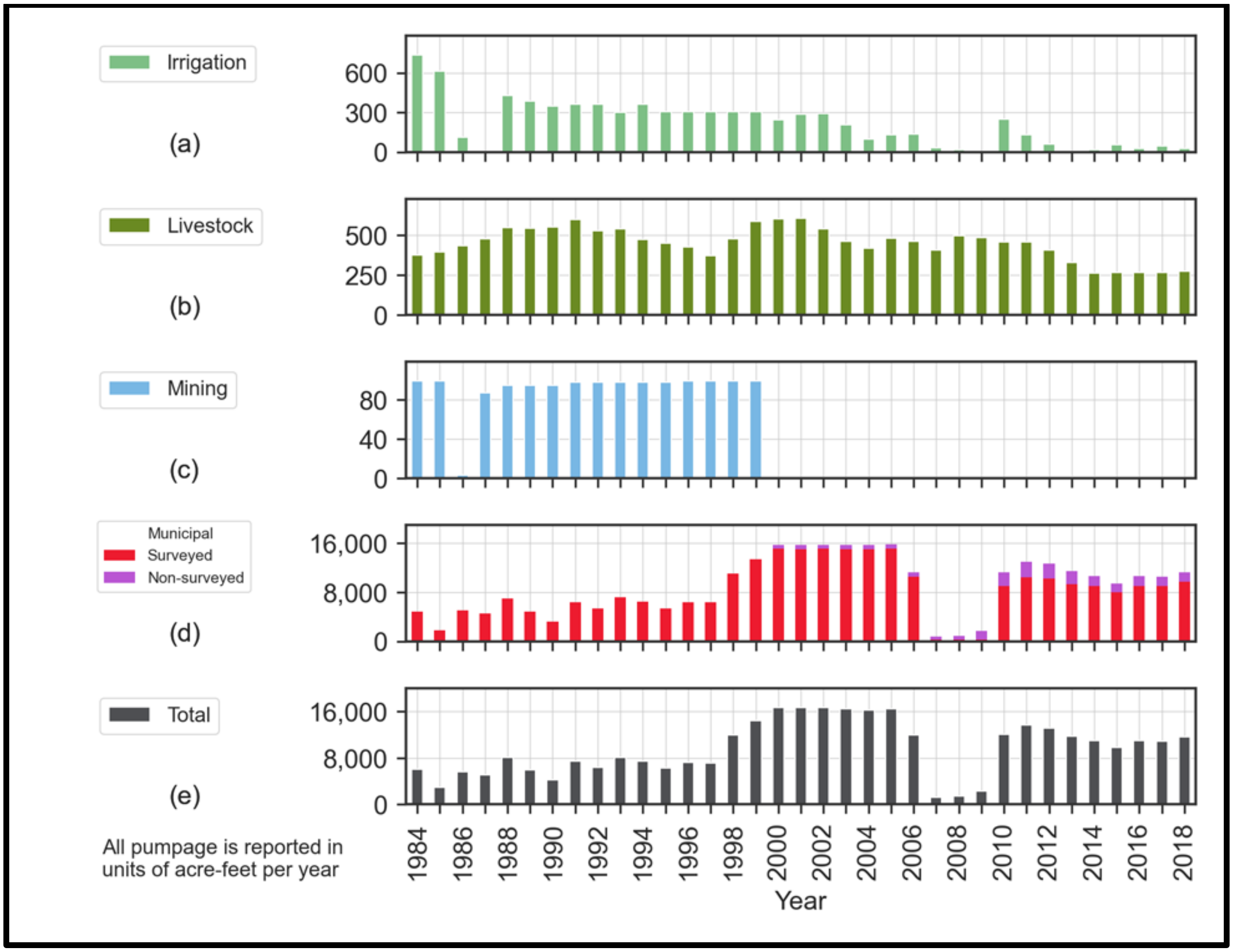


Figure 336. Val Verde County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

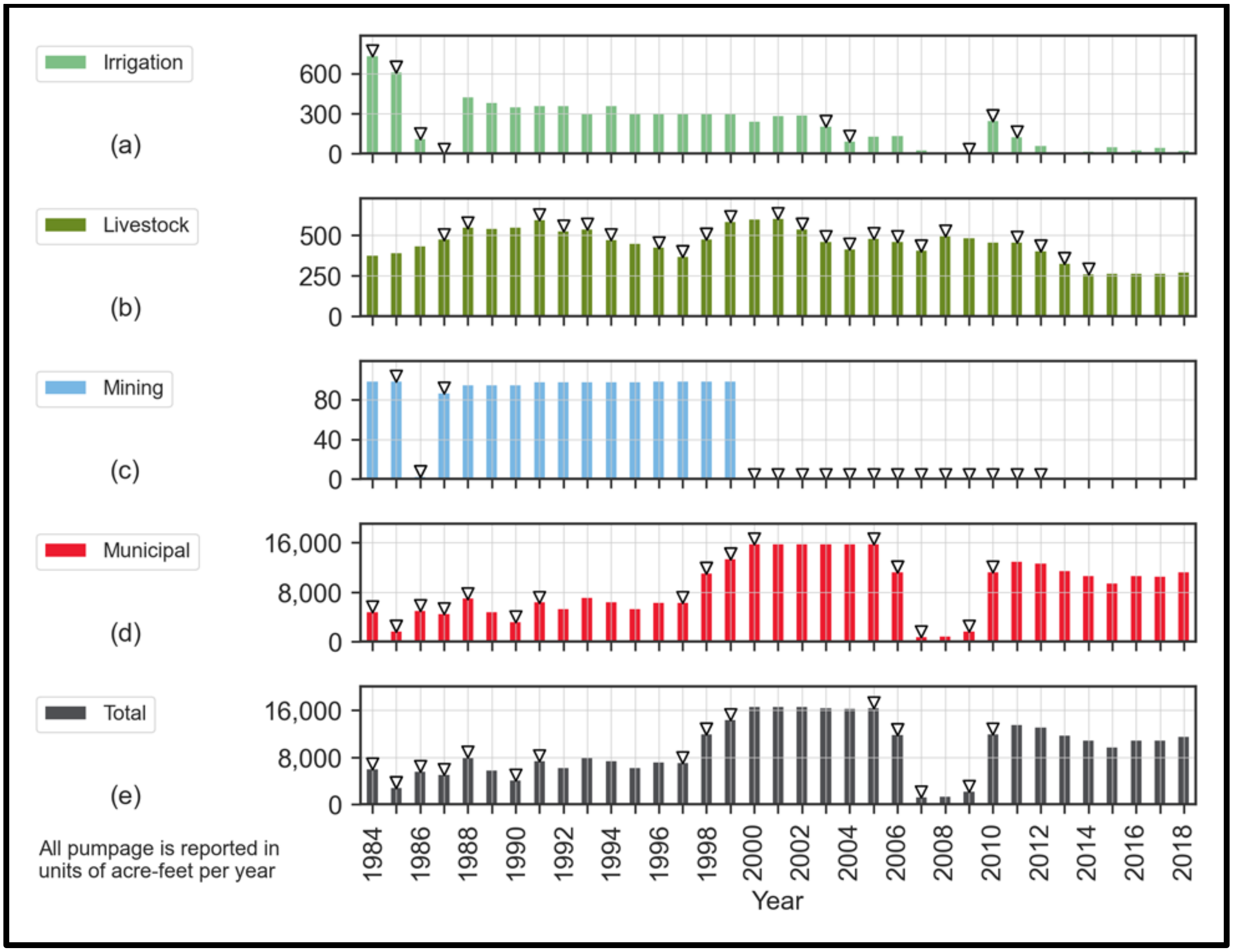


Figure 337. Val Verde County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

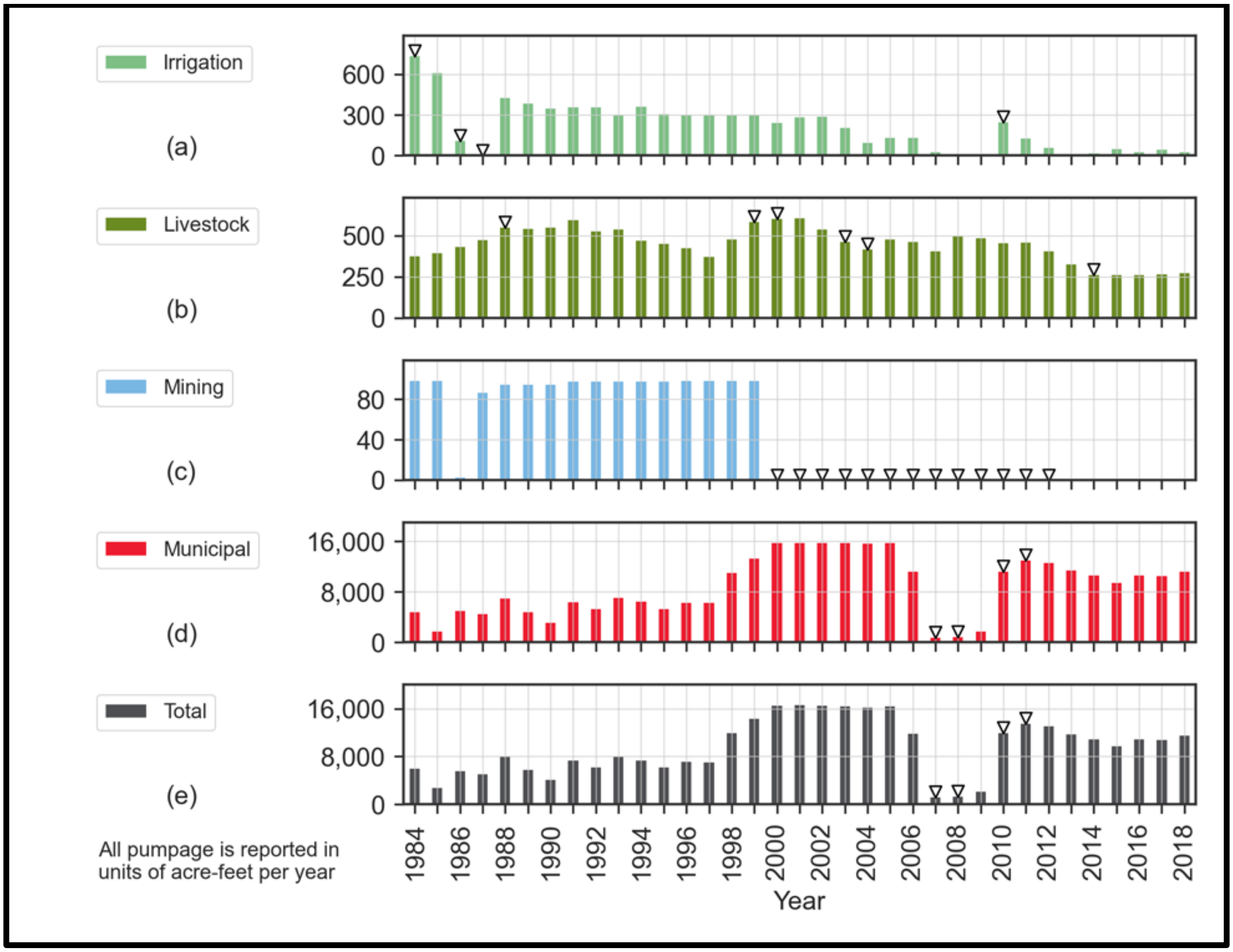


Figure 338. **Val Verde County Edwards-Trinity (Plateau) Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.**

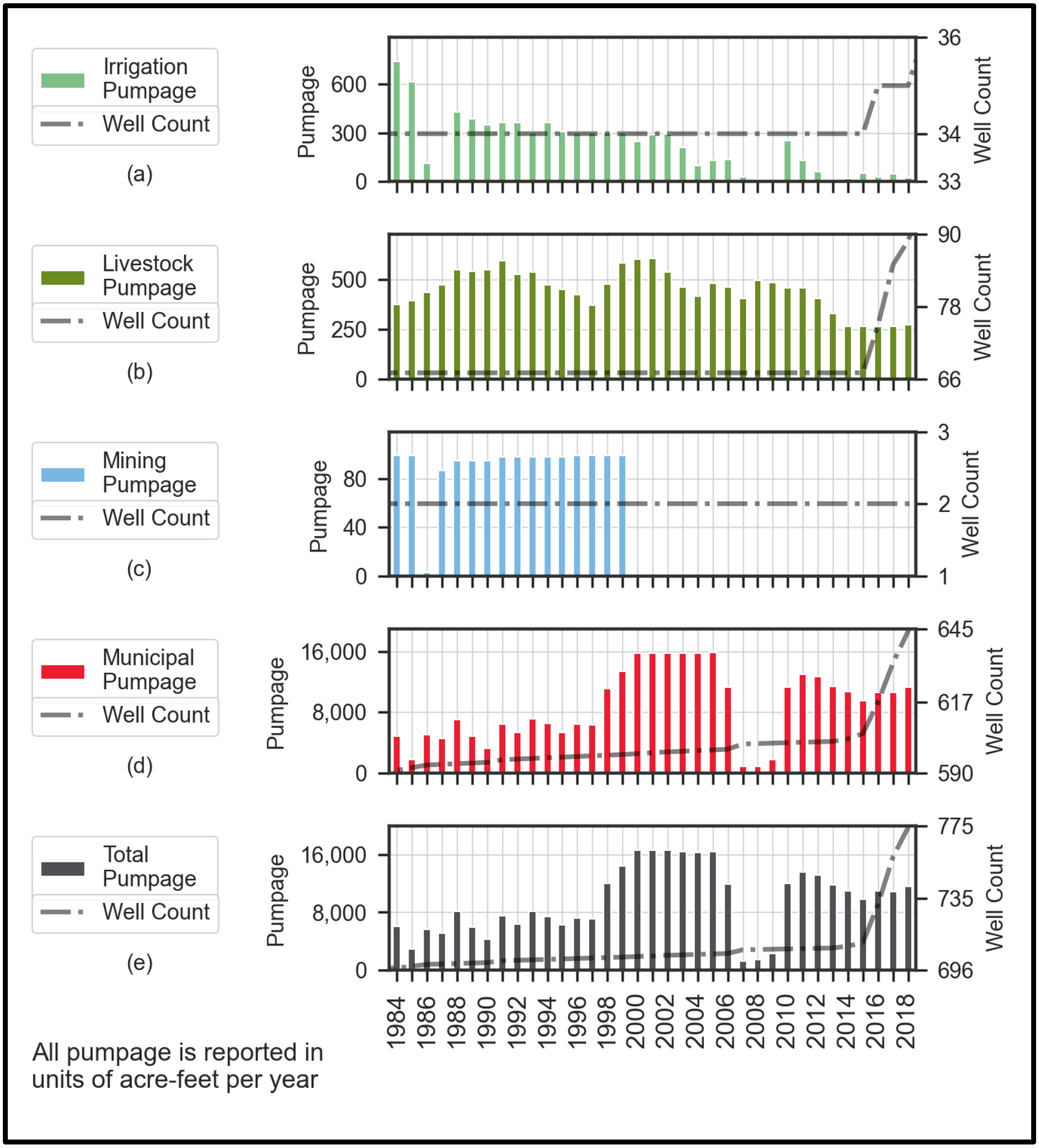


Figure 339. Val Verde County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer as recorded in publicly available databases.

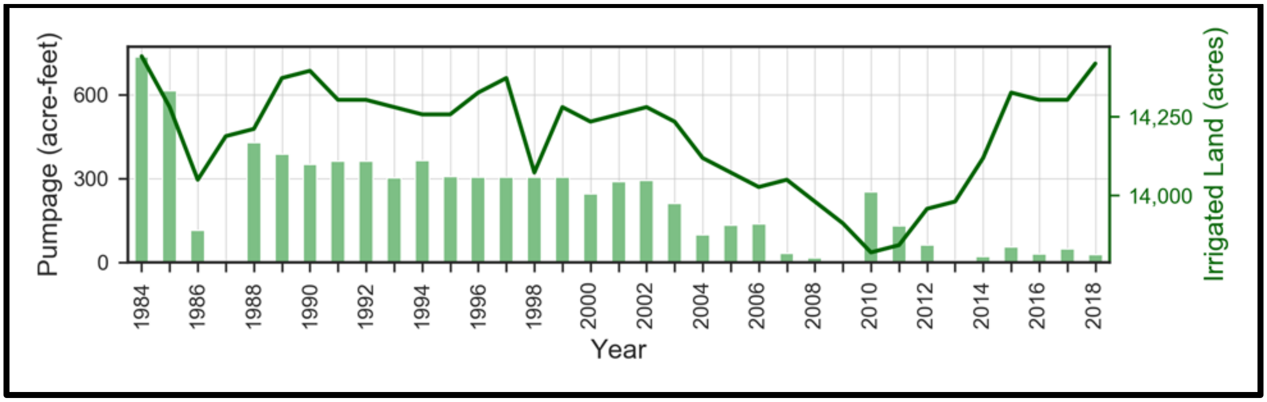


Figure 340. Val Verde County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

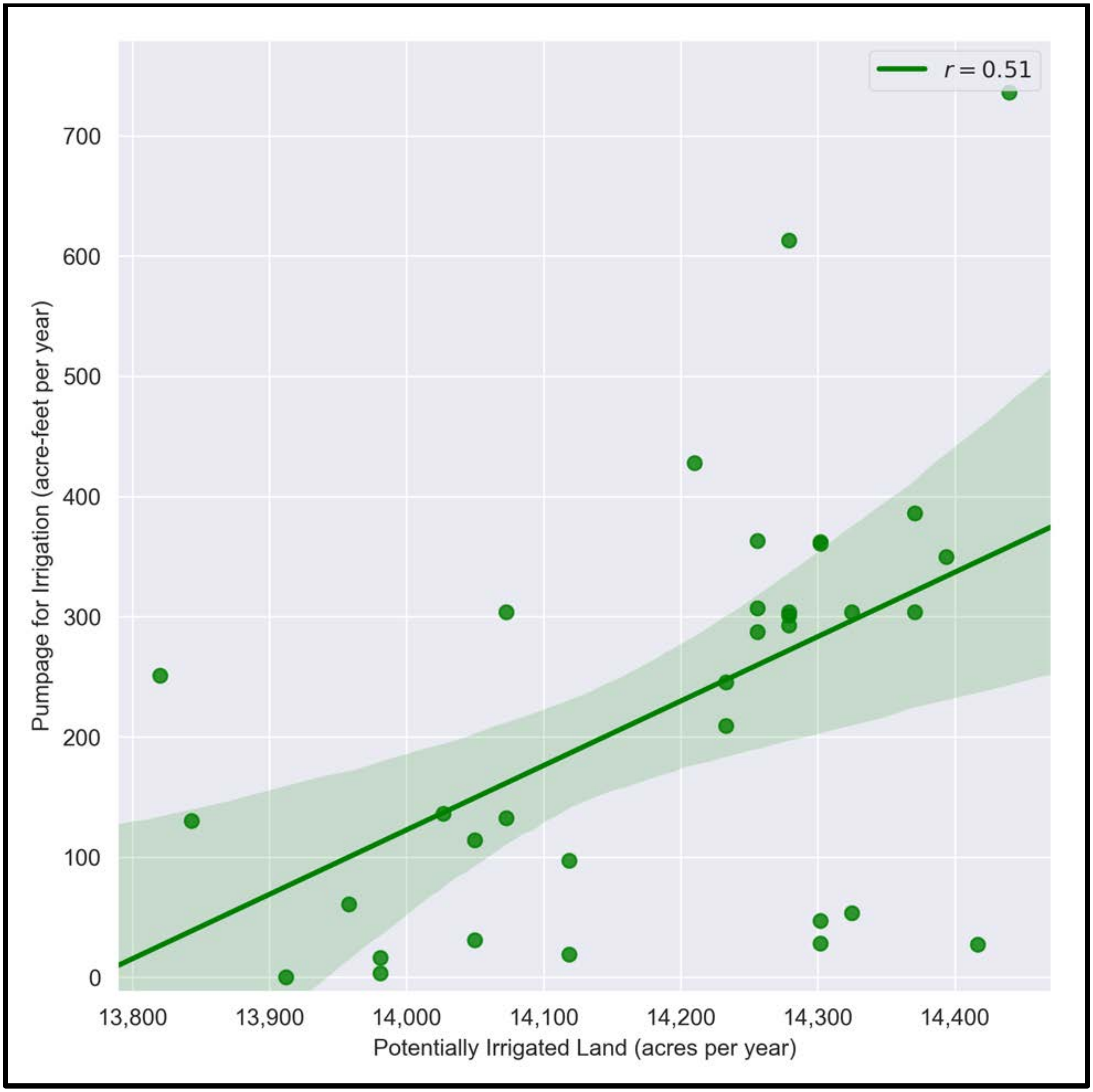


Figure 341. **Val Verde County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.**

Table 57. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Val Verde County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Edwards-Trinity (Plateau)	Irrigation	1986-1987, 2010	1984-1988, 2004, 2010, 2011	1984, 1986, 1987, 2009, 2010
	Livestock	2014-2018	1988, 1992, 1994, 1997-1999, 2002, 2003, 2005, 2007, 2008, 2012-2014	1988, 1999, 2000, 2003, 2004, 2014
	Mining	1986, 2000-2018	1986, 1987, 2000-2012	2000-2012
	Municipal	2000-2005, 2007-2009	1984-1986, 1988, 1991, 1998-2000, 2006, 2007, 2010	2007, 2008, 2010, 2011

3.3.51 Ward County

The Pecos Valley Aquifer underlies the entire area of Ward County (see Figure 342). As shown on Figure 343, total groundwater pumping from the Pecos Valley Aquifer fluctuated between about 10,000 and 20,000 acre-feet per year from 1984 through 2001. After 2001, total groundwater pumping has generally declined, with less than 8,000 acre-feet of pumpage in 2018.

With respect to the Pecos Valley Aquifer within Ward County, groundwater pumping is primarily for municipal and power use. Pumpage for municipal use was practically entirely surveyed and generally ranged between 10,000 and 15,000 acre-feet per year from 1984 through 2001 with a gradual decrease after 2001 to about 5,000 acre-feet in 2018. Pumping for power use generally ranged between 4,000 and 6,000 acre-feet between 1984 and 2003 except for 1988 when pumpage decreased abruptly to less than 2,000 acre-feet. From 2003 through 2012, pumpage for power use decreased gradually. After 2012, the Water Use Survey dataset does not contain data for power use.

Pumping for irrigation generally ranged between 1,000 and 2,000 acre-feet per year after 1999, whereas it ranged between minimal pumpage to 1,000 acre-feet per year from 1984 through 1999. In 2000, estimated irrigation pumpage increased abruptly to almost 3,000 acre-feet. Pumping for livestock use remained relatively consistent, between about 50 and 100 acre-feet per year, with anomalous increases in pumpage in 1992 and 1993. Reported pumping for manufacturing use is not available or is minimal for all years except 2004 when it was about 400 acre-feet. Pumping for mining ranged between 200 and 600 acre-feet per year except for multiple years without reported pumpage (1986 and 2000 through 2018). Figure 344 (year-to-year change analysis) and Figure 345 (standard deviation analysis) identify these and other potentially anomalous pumping amounts in the TWDB Water Use Survey data for the Pecos Valley Aquifer in Ward County.

Figure 346 compares pumping with the number of wells designated for each water use category. Datasets indicate the completion of approximately 20 new municipal wells in the Pecos Valley Aquifer in Ward County since 2003. The completion of these new wells suggests municipal pumpage would correspondingly increase. However, as shown in Figure 346, groundwater pumpage for municipal use since 2003 is significantly lower than amounts in previous years. The addition of wells with a decrease in pumping may indicate anomalies in the pumping and or well data. Alternative explanations for this observation could be that newly installed wells are replacing older wells that are under performing or not in service. We will investigate the relationship between well numbers and pumpage during subsequent tasks of this project. Note: the well type database does not include a power designation, and as such well information is not included in Figure 346-f.

We would expect groundwater pumping for irrigation in Ward County to correlate negatively to precipitation such that there is less groundwater pumped for irrigation during wet years and more groundwater pumped for irrigation during dry years. Figure 347 indicates that as precipitation over potentially irrigated land in the county increases, the reported pumpage for irrigation from the Pecos Valley Aquifer tended to increase. Figure 348 indicates a positive correlation value (“r”) of 0.46 between precipitation and groundwater pumpage for irrigation from the Pecos Valley Aquifer in Ward County. This moderate positive correlation suggests that the reported pumpage for irrigation in Ward County follows the trend in precipitation and may potentially be anomalous. We will revise this correlation during subsequent tasks of this project, including after researching and potentially revising anomalous irrigation pumping data identified for Ward County. It is also arguable that livestock usage (Figure 347–b), municipal usage (Figure 347–e), and even power usage (Figure 347–f) exhibit a similar correlation with precipitation.

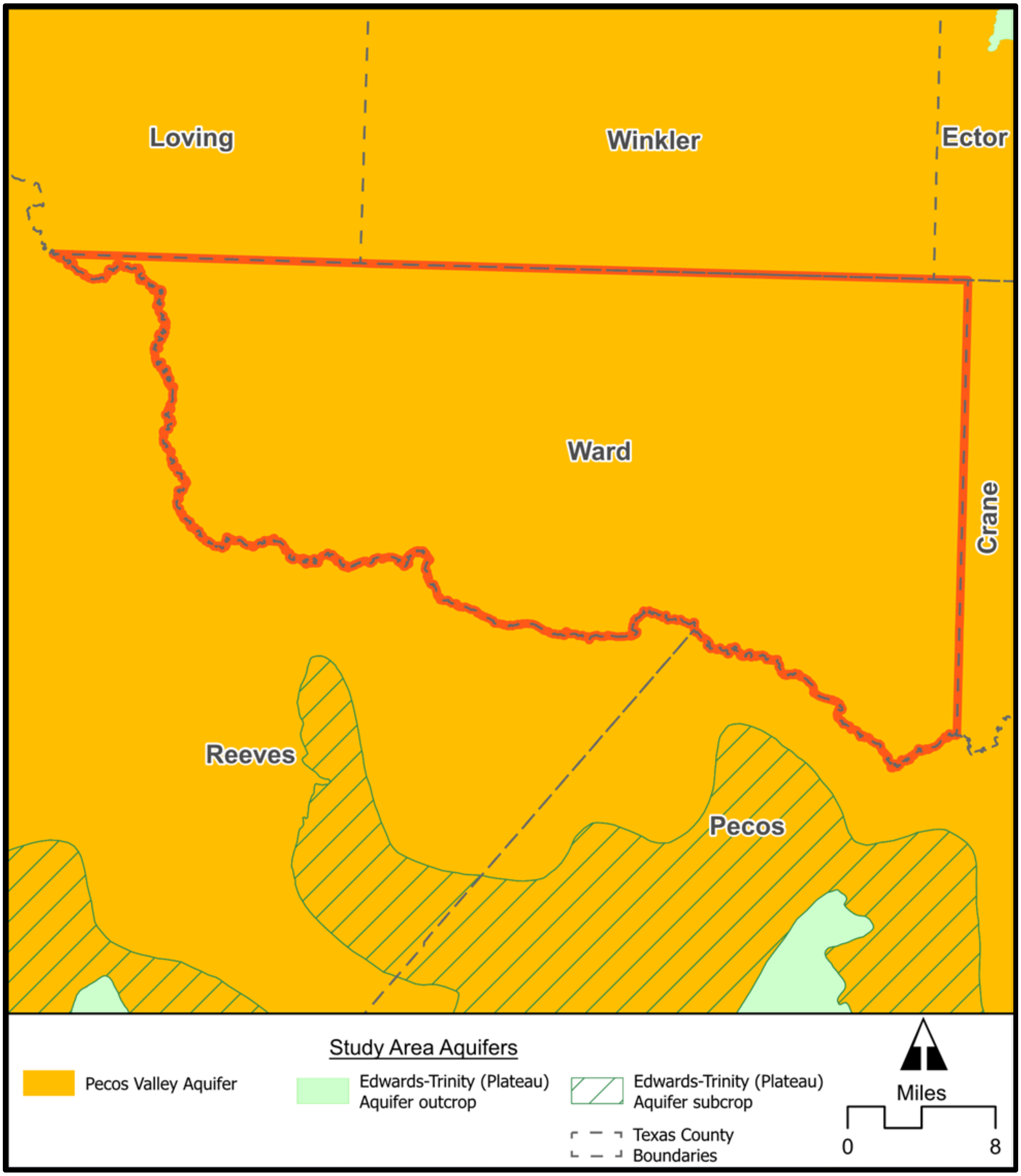


Figure 342. Ward County showing the extent of the Pecos Valley Aquifer.

We would also expect groundwater pumping for irrigation in Ward County to correlate positively to the area of potentially irrigated land overlying the aquifer. Figure 349 indicates that as the area of potentially irrigated land overlying the Pecos Valley Aquifer increased in the county, particularly since 2000, the reported pumpage for irrigation also increased. Figure 350 indicates a linear correlation value of 0.54 between potentially irrigated land area and groundwater pumpage for irrigation use. This moderate positive correlation suggests that pumpage for irrigation in Ward County matches the temporal trend in potentially irrigated land. We will revise this correlation during subsequent tasks of this project, including after researching and potentially revising anomalous irrigation pumping data identified for Ward County.

Table 58 provides the years identified as having anomalous pumping amounts for Ward County based on our manual review, year-to-year change (Figure 344), and standard deviation (Figure 345) analyses.

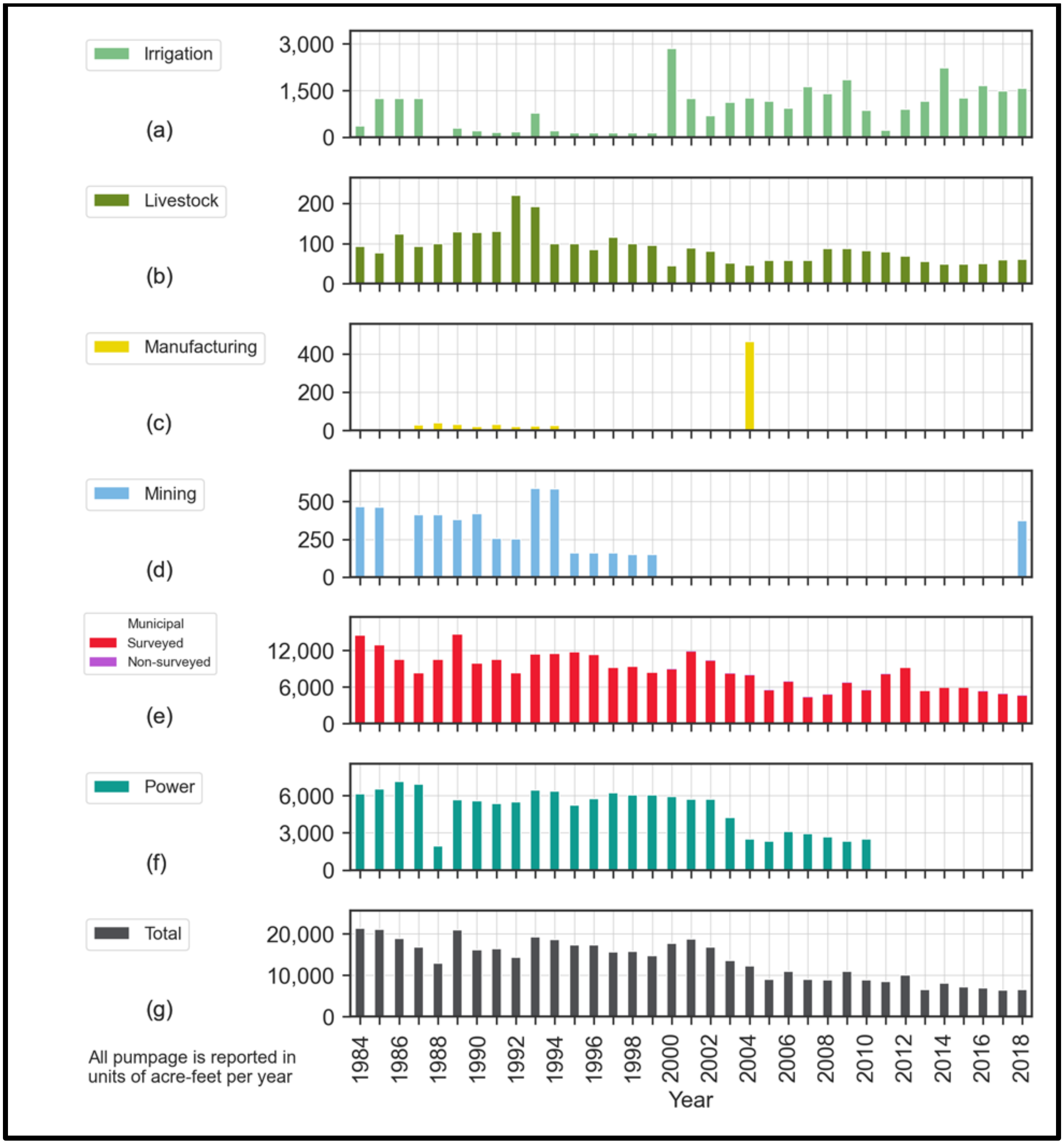


Figure 343. Ward County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

Figure 344. Ward County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

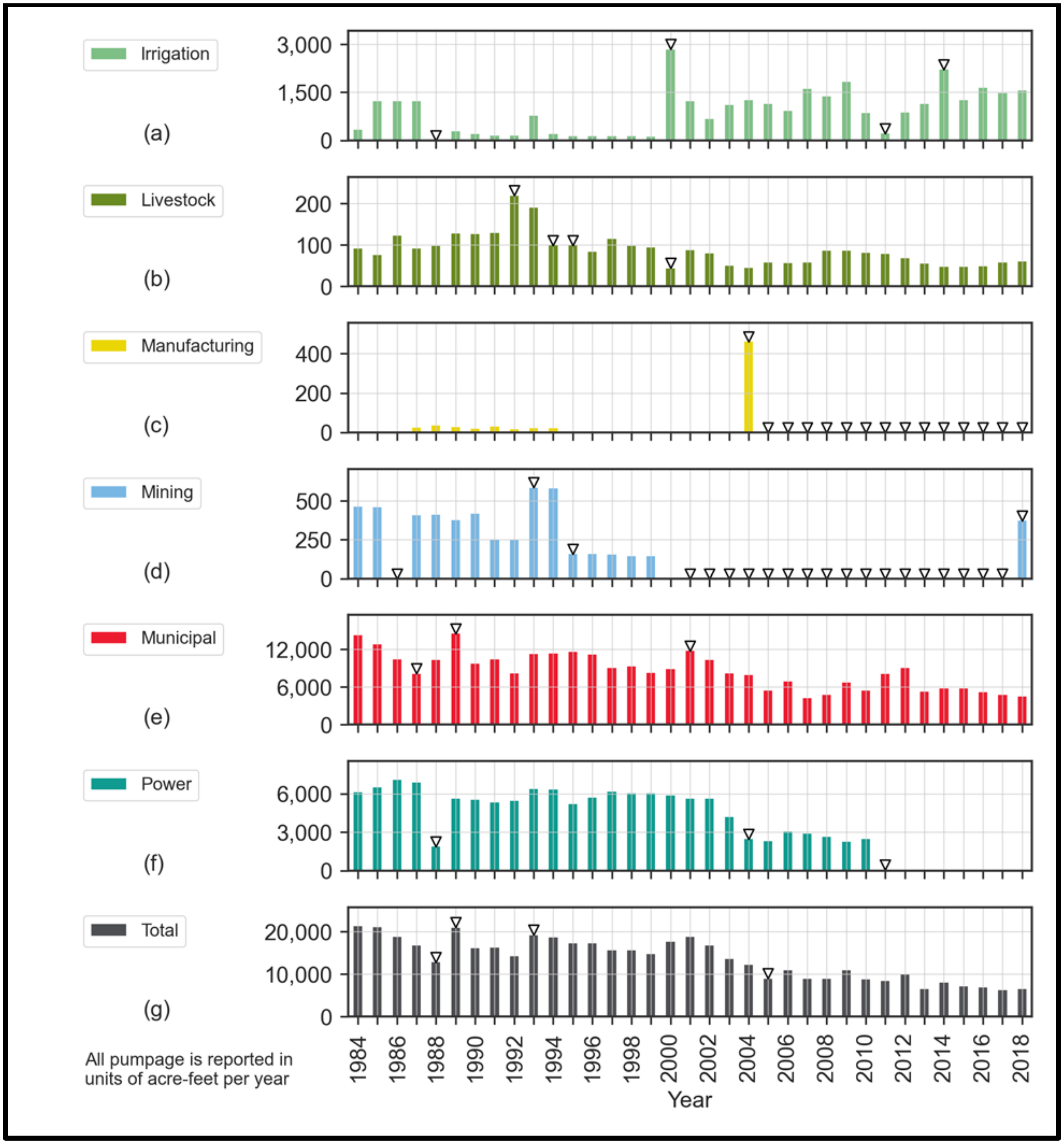


Figure 345. Ward County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

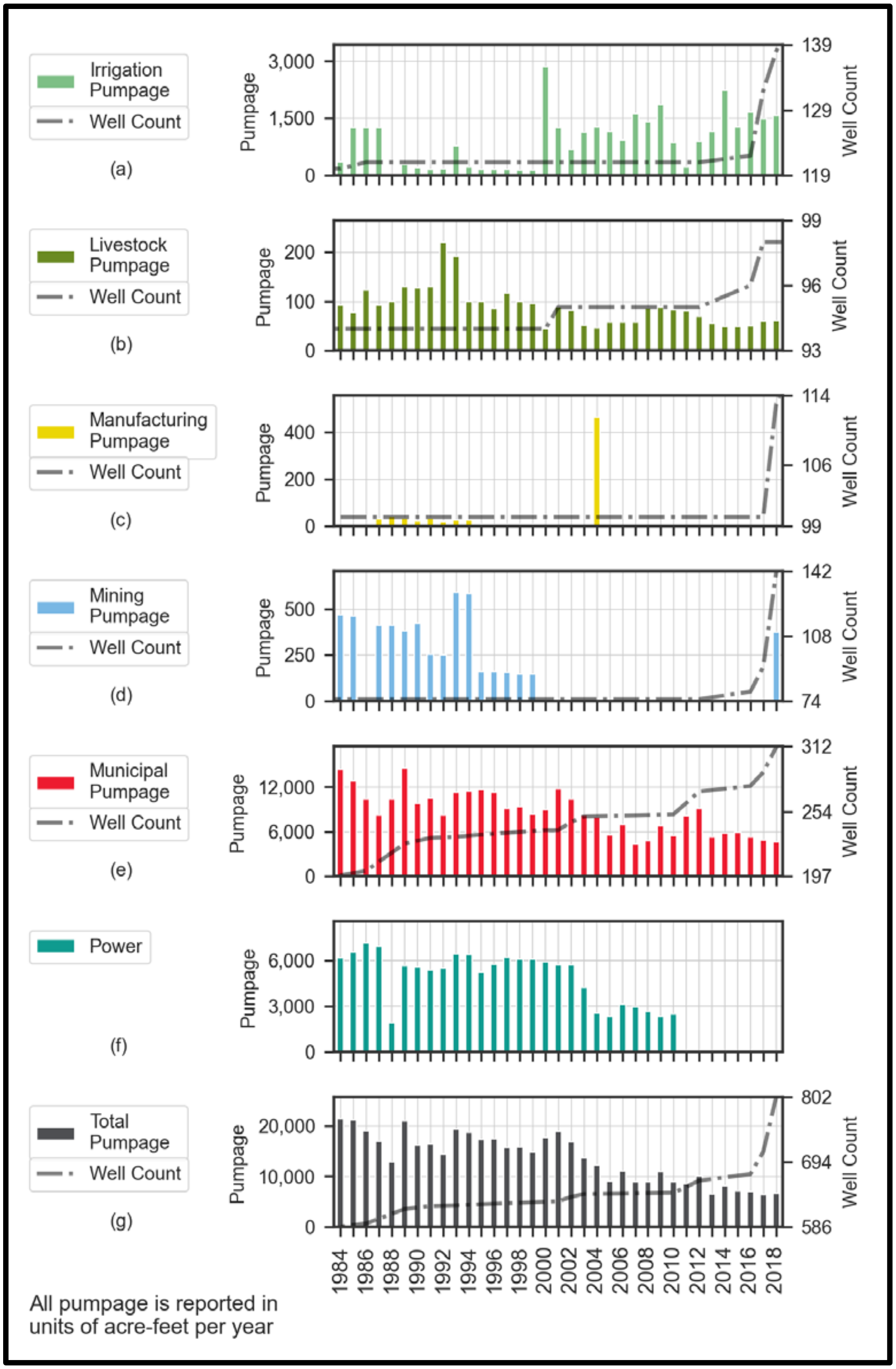


Figure 346. Ward County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer as recorded in publicly available databases.

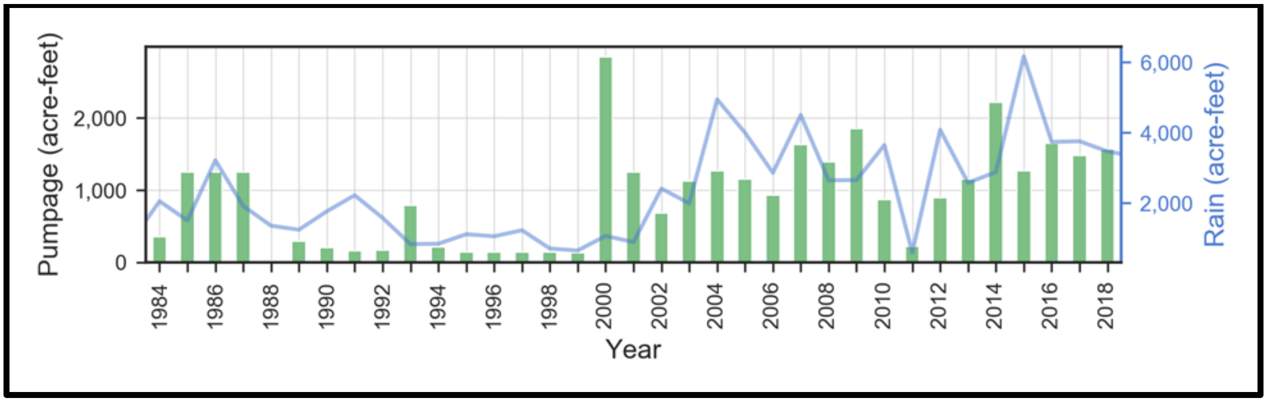


Figure 347. Ward County Pecos Valley Aquifer groundwater pumping, in acre-feet per year, as reported in the TWDB Water Use Survey data and total precipitation, in acre-feet per year, that occurred on potentially irrigated land (according to land use data) within the county over the aquifer.

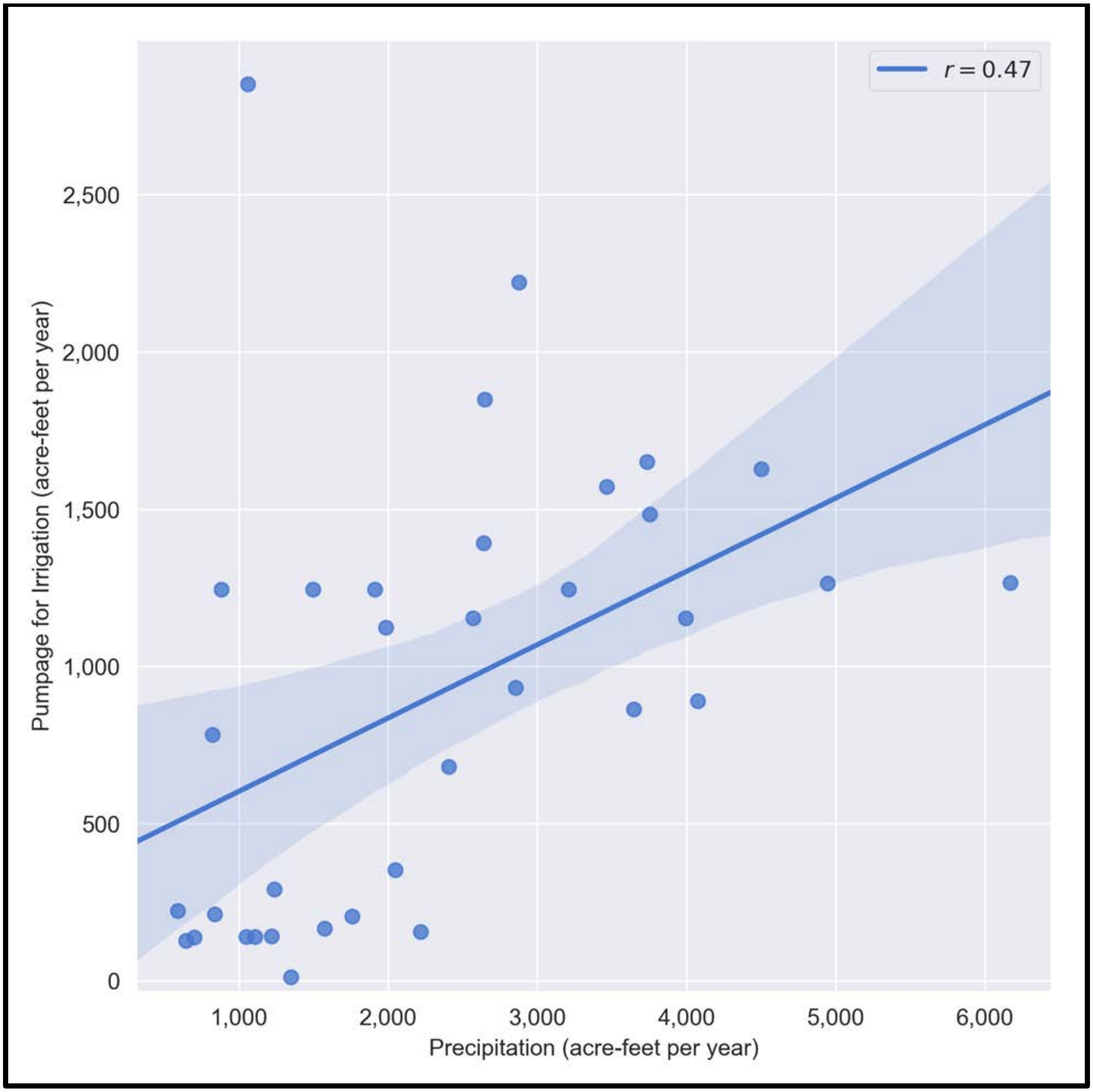


Figure 348. Ward County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data versus total precipitation that occurred on potentially irrigated land (according to land use data) within the county over the study area aquifers in acre-feet per year. Blue shaded area represents the 95 percent confidence interval based on the linear regression.

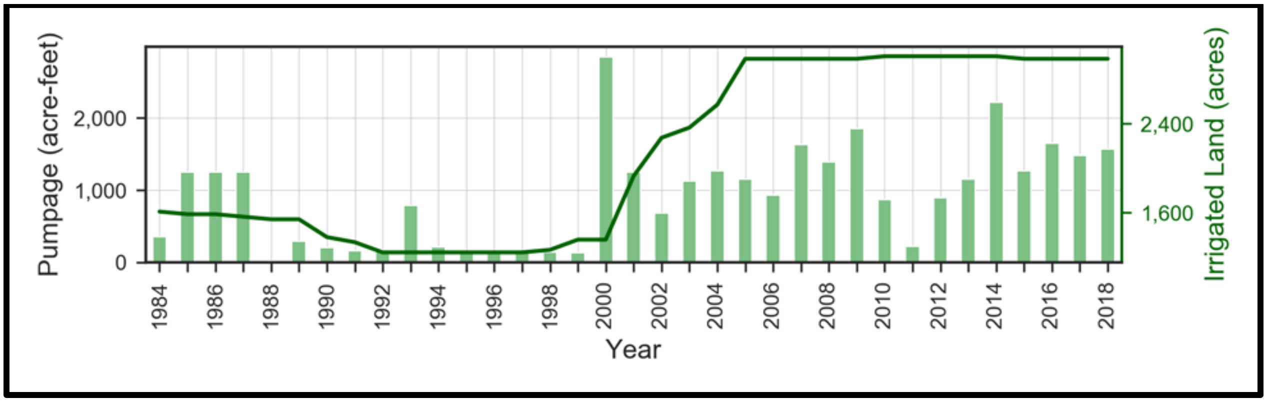


Figure 349. Ward County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

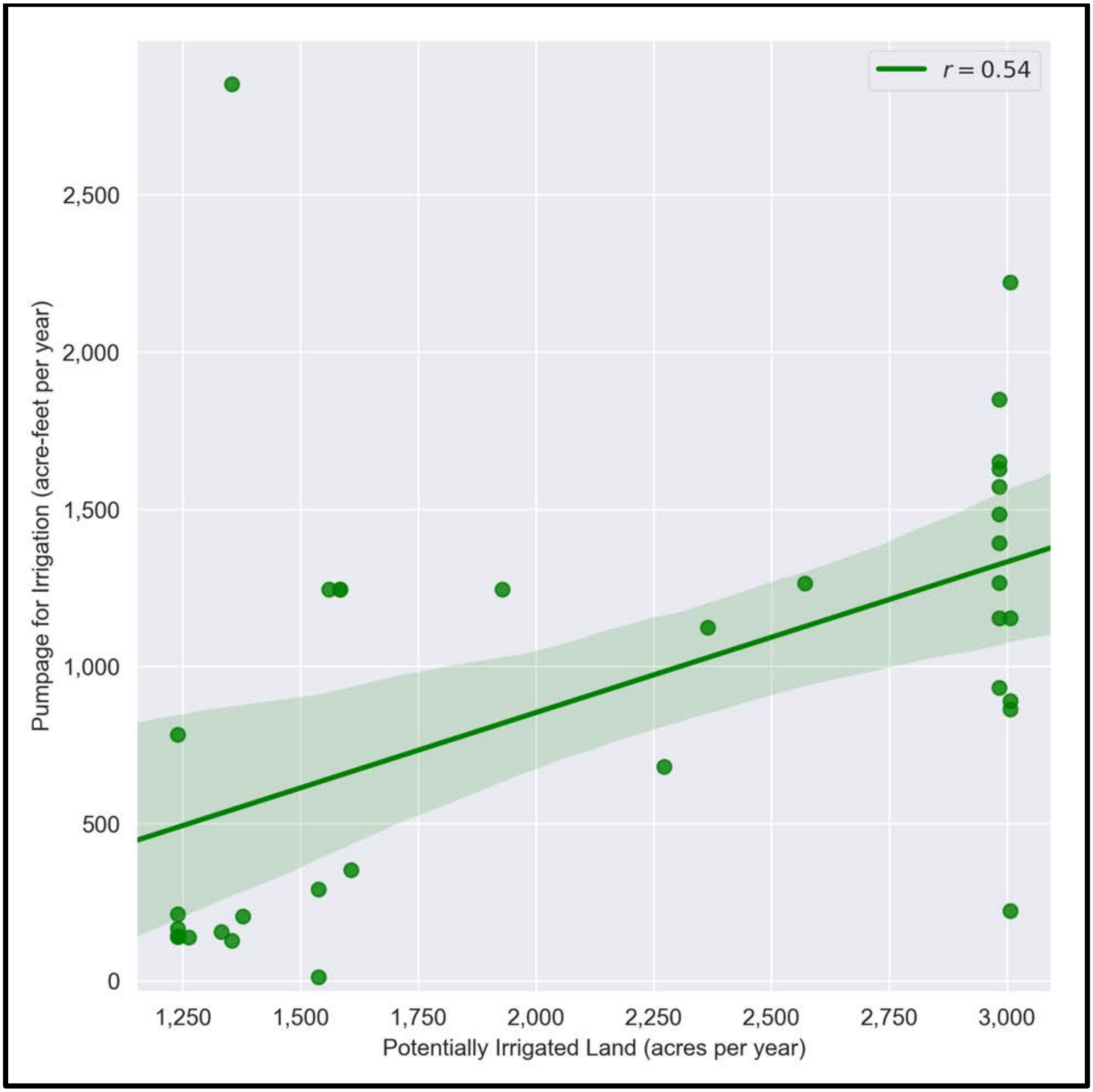


Figure 350. Ward County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 58. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Ward County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Pecos Valley	Irrigation	1985, 1988, 1993, 2000, 2001, 2004, 2011, 2014	1984, 1985, 1988, 1993, 2000, 2001, 2003, 2009-2012, 2014	1993, 2000, 2003, 2004, 2009, 2011, 2014
	Livestock	1993, 1994, 2000	2000, 2001, 2005, 2008, 2010, 2012	2008, 2009, 2011
	Manufacturing	2004	1984, 1985, 1987, 1992, 1993, 1995, 1996, 1998, 1999	1987, 1992, 1993, 1995, 1998-2000
	Mining	1986, 1993, 1995, 2000-2017, 2018	1984-1990, 2000-2018	1984-1991, 2000-2018
	Municipal	1989, 2011, 2012	1988, 1990-1992, 1997, 2000	1988, 1992
	Power	1988, 2004, 2011-2018	1989, 1998, 1999, 2004-2018	1989, 1998, 2004-2018

3.3.52 Winkler County

The Pecos Valley Aquifer covers almost the entire area of Winkler County with a small portion in the northeastern corner underlain by the Edwards-Trinity (Plateau) Aquifer (see Figure 351). As shown on Figure 352, total groundwater pumping from the Pecos Valley Aquifer generally increased over time and reached approximately 12,500 acre-feet in 2018. The TWDB Water Use Survey also indicates less than four acre-feet per year of pumping from the Edwards-Trinity (Plateau) Aquifer in Winkler County for livestock use during all but one year of the study period (see Figure 353). During subsequent evaluations we will assess the potential production from the Edwards-Trinity (Plateau) Aquifer in Winkler County but will not further consider anomalies in the data in this section.

With respect to the Pecos Valley Aquifer within Winkler County, for much of the study period irrigation was the primary groundwater use. However, from 2014 through 2018 municipal use exceeded irrigation use. Municipal use increased from low levels in 2013 to over 8,000 acre-feet in 2018. Pumping for irrigation after 2000 typically ranged between 2,000 and 4,000 acre-feet per year. Prior to 2000, withdrawals were significantly lower and were unreported for some years (1989, 1990, and 1993 through 1999). Pumping for livestock use was generally constant at 100 acre-feet per year except for a single year usage spike of 300 acre-feet in 2007. Pumping for manufacturing was essentially nonexistent after 1994 yet approached 50 acre-feet per year from 1985 through 1987. Pumpage for mining was generally low or unreported after a peak usage of about 1,200 acre-feet in 1991. Figure 354 (year-to-year change analysis) and Figure 355 (standard deviation analysis) identify these and other anomalous pumping amounts in the TWDB Water Use Survey data for the Pecos Valley Aquifer in Winkler County.

Figure 356 shows approximately 99 new wells completed in the Pecos Valley Aquifer since 2016 with a proposed manufacturing use and 30 new wells completed since 2016 for mining use. However, groundwater pumpage for manufacturing and mining use since 2016 is significantly lower than the previous years. The addition of wells with a decrease in pumping suggests a potential anomaly in the data that may warrant additional investigation. An alternative explanation for these observations is that newly installed wells are replacing older wells that are under performing or not in service. We will investigate the relationship between well completions and pumpage during subsequent project phases.

The area of potentially irrigated land overlying the Pecos Valley Aquifer in Winkler County correlates linearly to groundwater pumpage from the Pecos Valley Aquifer for irrigation use. Figure 357 indicates that as the area of potentially irrigated land increased in the county, the reported pumpage for irrigation also increased. Figure 358 indicates a linear correlation value of 0.65 between potentially irrigated land area and groundwater pumpage for irrigation use. This strong positive correlation suggests that pumpage for irrigation in Winkler County matches the trend in potentially irrigated land. We will revise this correlation during subsequent project phases, including after researching and potentially revising anomalous irrigation pumping data identified for Winkler County.

Table 59 provides the years identified as having potentially anomalous pumping amounts for the Pecos Valley Aquifer within Winkler County based on our manual review, year-to-year change (Figure 354), and standard deviation (Figure 355) analyses.

Figure 351. Winkler County showing the extent of the Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer.

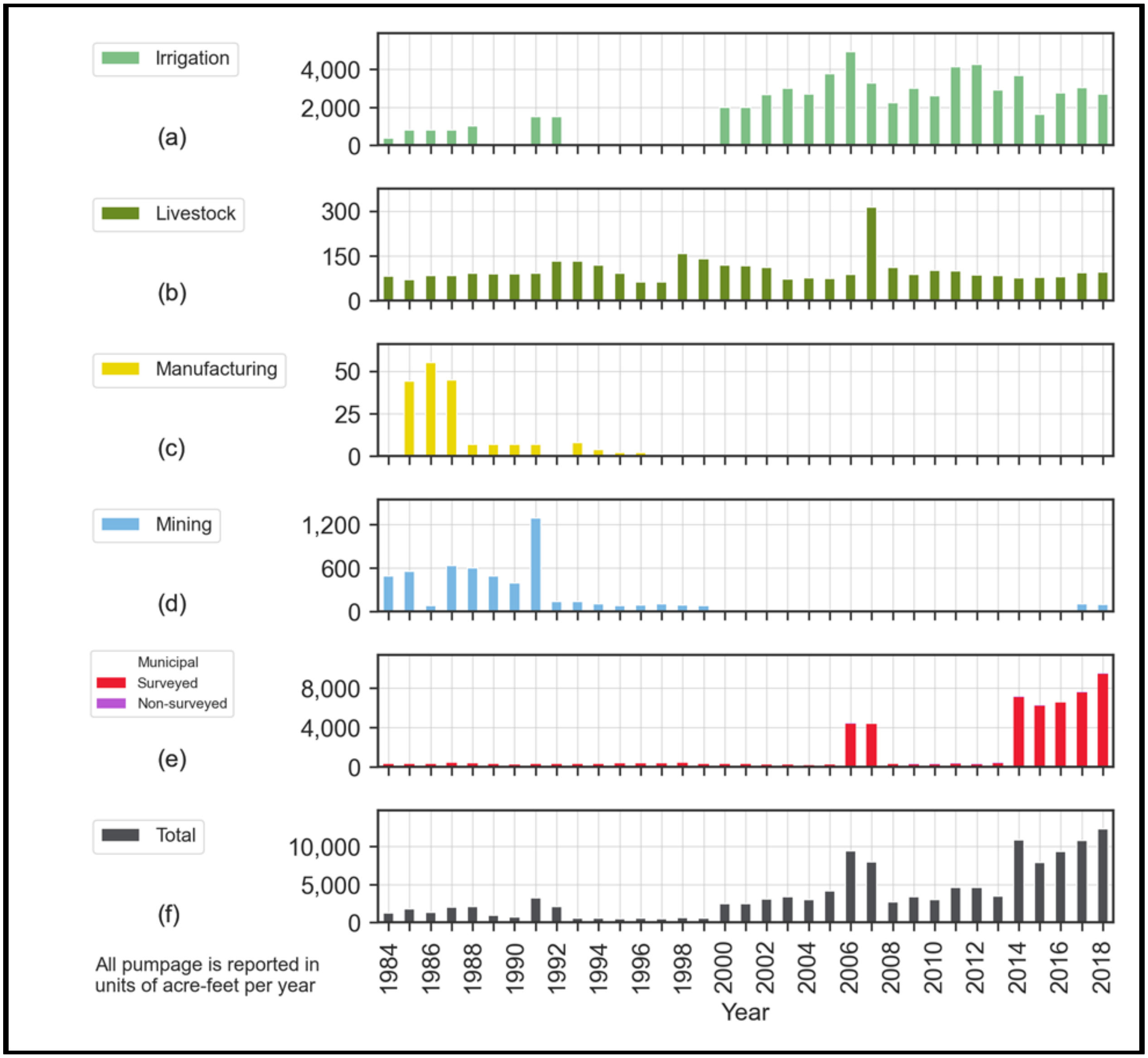


Figure 352. Winkler County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

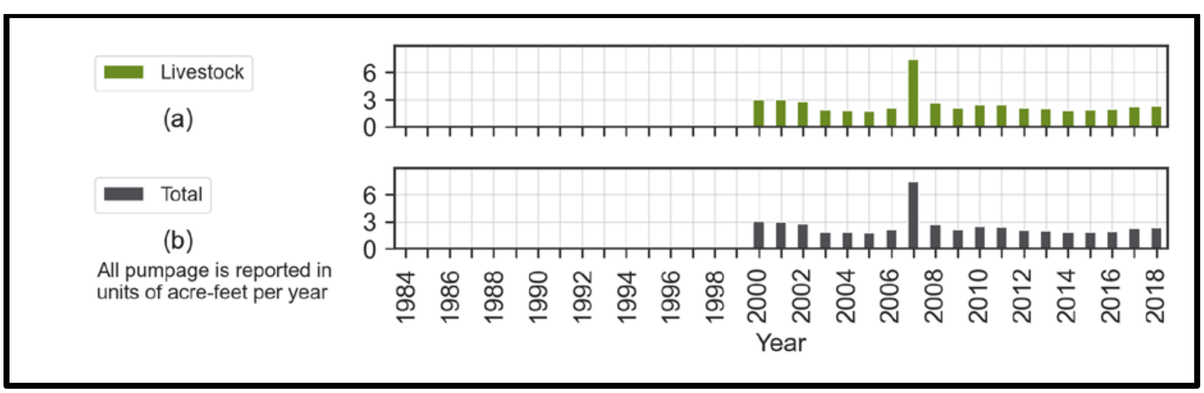


Figure 353. Winkler County Edwards-Trinity (Plateau) Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data.

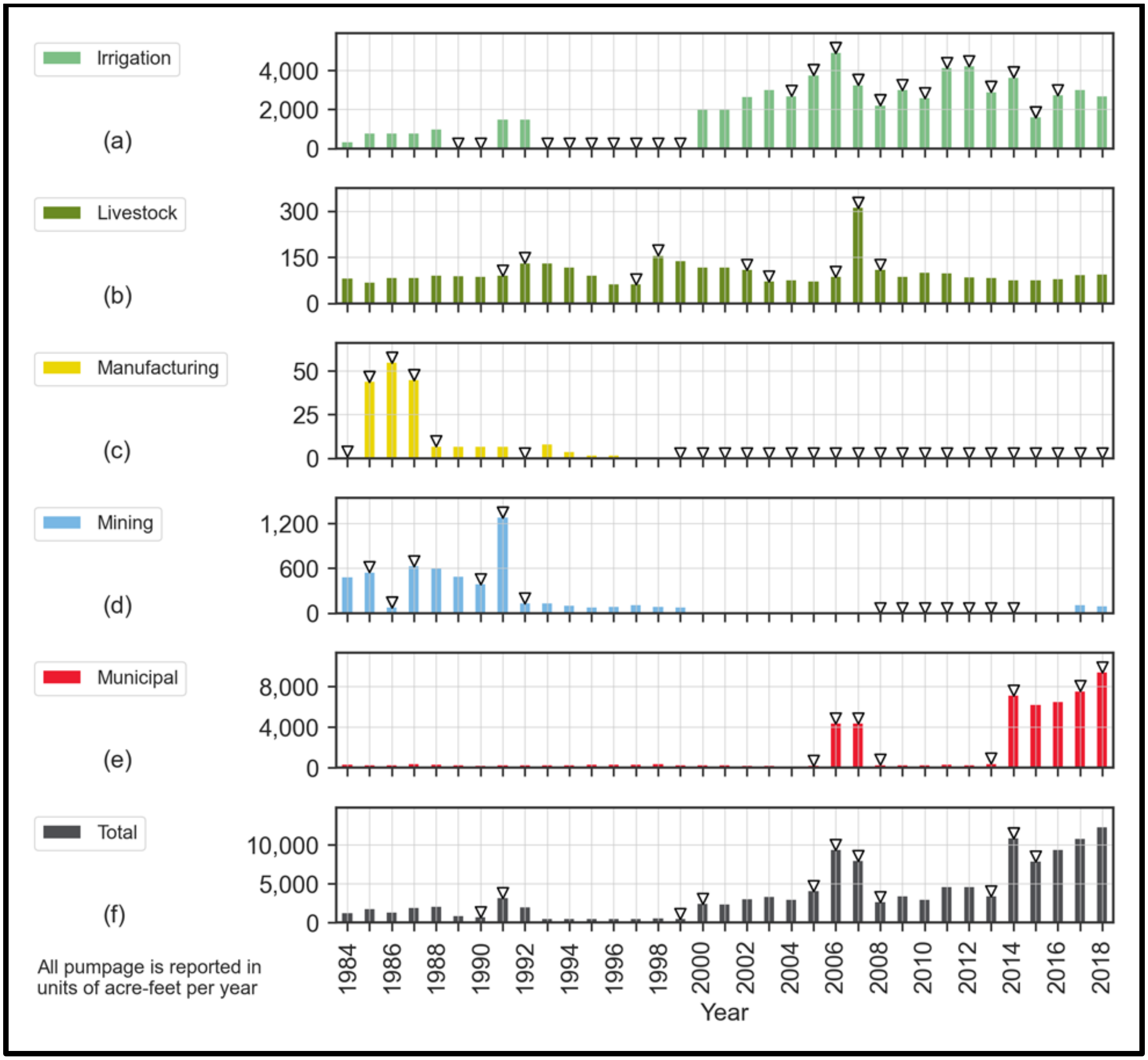


Figure 354. Winkler County Pecos Valley Aquifer apparent anomalies based on the year-to-year change in groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

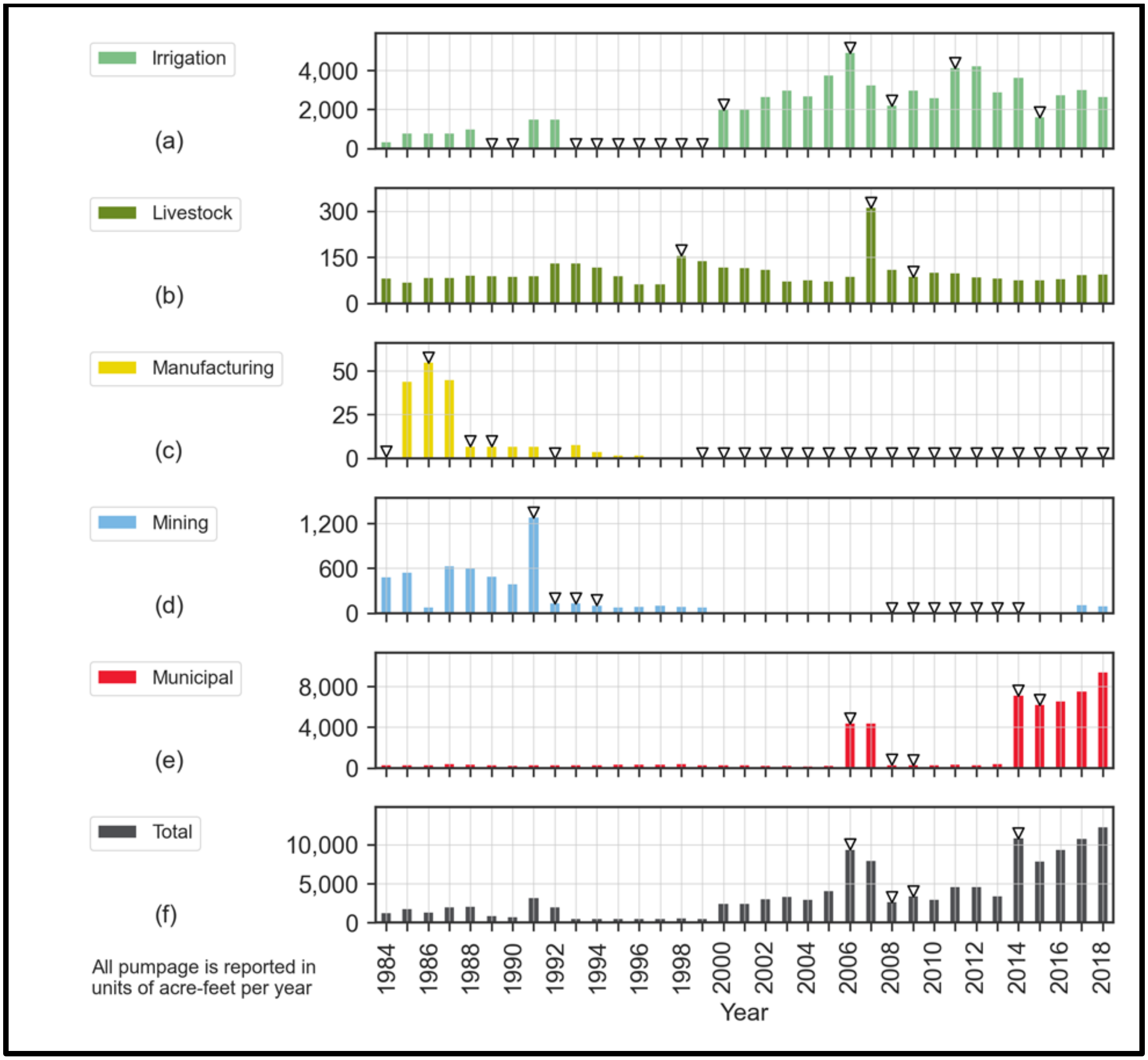


Figure 355. Winkler County Pecos Valley Aquifer apparent anomalies based on the criterion of 1.5 standard deviations from the 3-year average of groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data. Triangles mark years where the data appears anomalous.

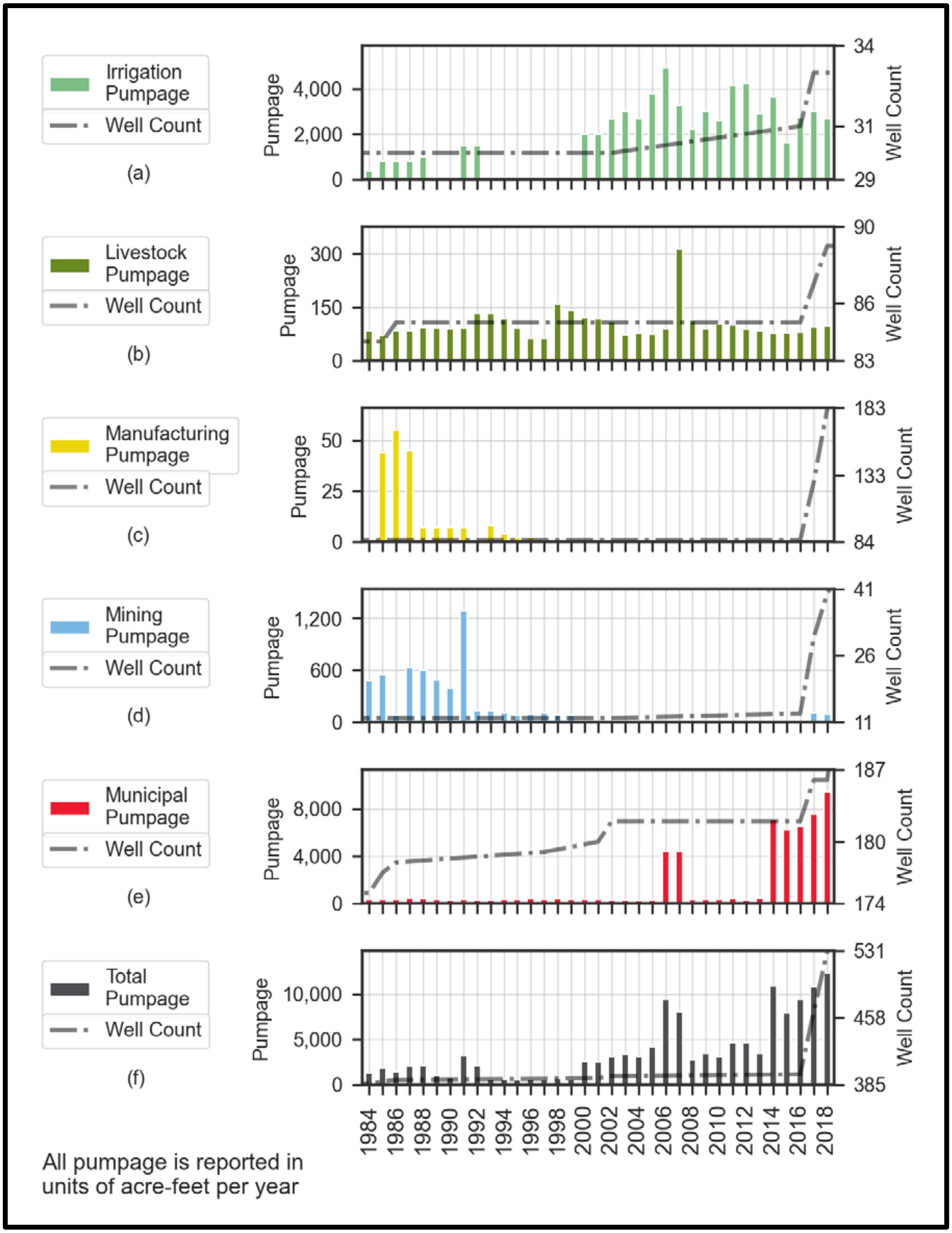


Figure 356. **Winkler County Pecos Valley Aquifer groundwater pumping in acre-feet per year as reported in the TWDB Water Use Survey data and the total number of wells completed in the aquifer as recorded in publicly available databases.**

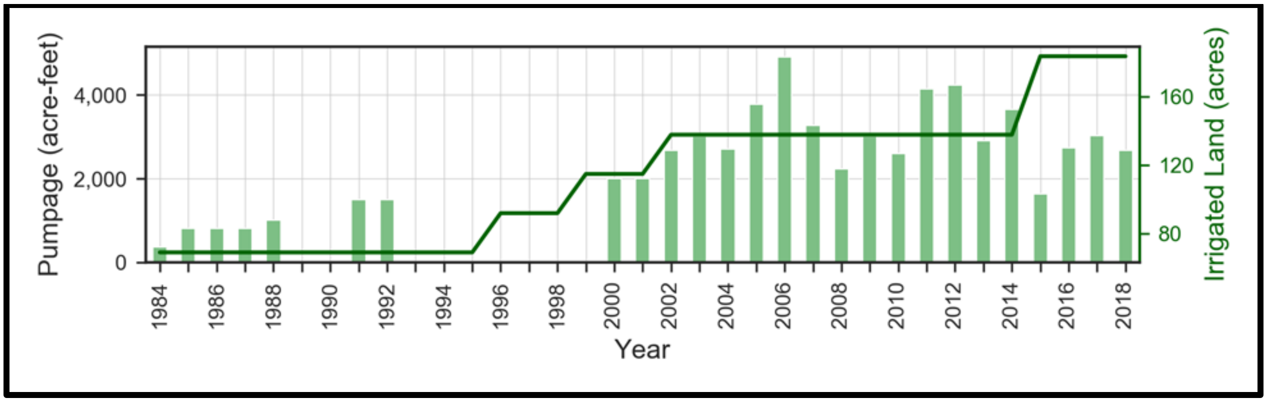


Figure 357. Winkler County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, as reported in the TWDB Water Use Survey data and potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer.

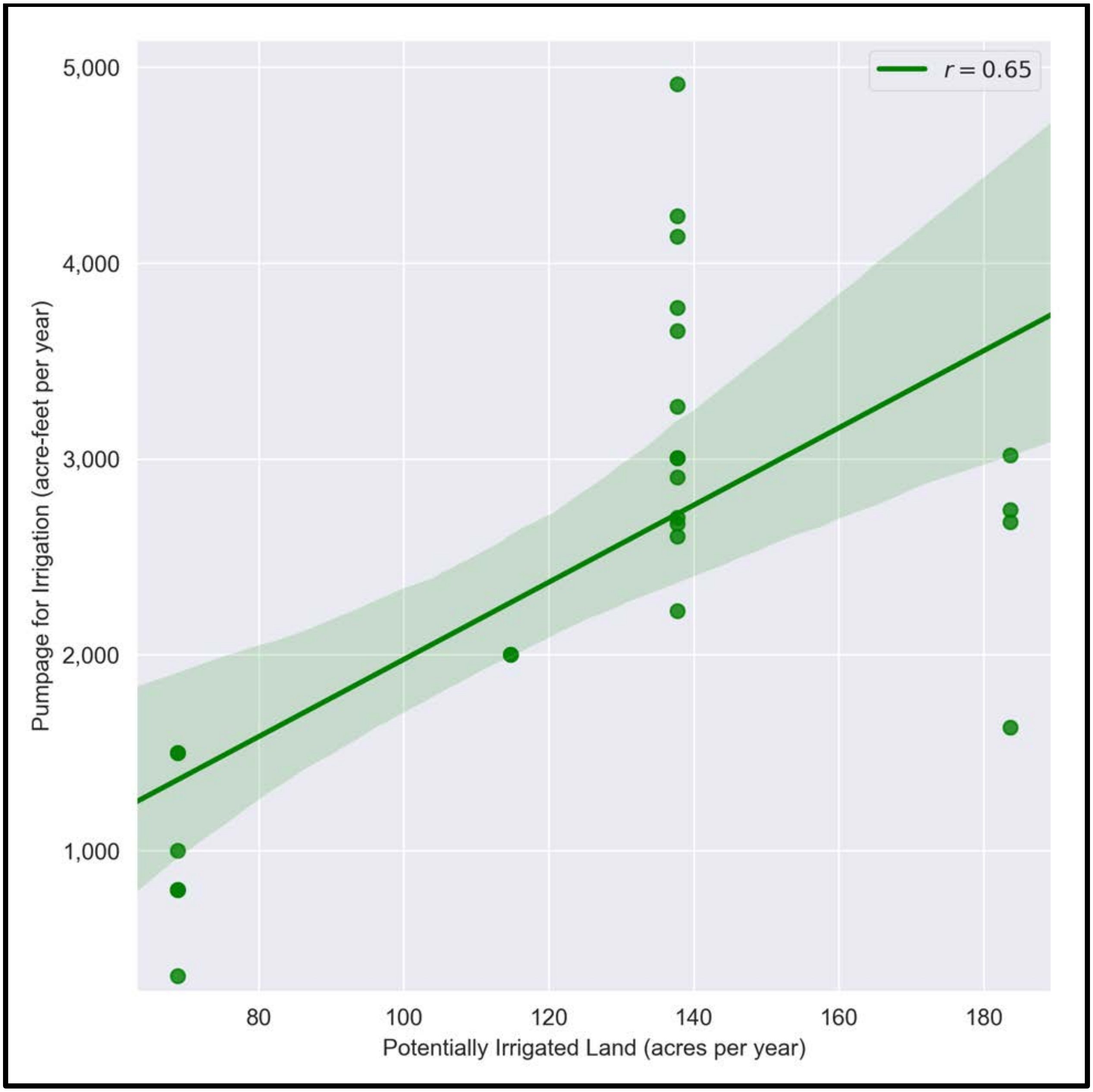


Figure 358. Winkler County Pecos Valley Aquifer groundwater pumping for irrigation, in acre-feet per year, correlated with potentially irrigated land area (according to land use data), in acres per year, overlying the aquifer. Green shaded area represents the 95 percent confidence interval based on the linear regression.

Table 59. Years identified in the TWDB Water Use Survey data as containing anomalous groundwater pumping amounts for Winkler County.

Aquifer	Use	Manual Review	Year-to-Year Change	Standard Deviation
Pecos Valley	Irrigation	1989, 1990, 1993, 1999, 2000, 2006, 2008, 2011, 2015	1989-1991, 1993-2000, 2005-2009, 2011, 2013-2016	1989, 1990, 1993-2000, 2006, 2008, 2011, 2015
	Livestock	1998, 2007	1992, 1998, 2003, 2007, 2008	1998, 2007, 2009
	Manufacturing	1984, 1986, 19882000-2018 Increase in well county by 99 wells since 2016	1984-1988, 1992, 1999-2018	2000, 2001, 2007, 2008, 2011
	Mining	1986, 1991, 1992 Increase in well county by 30 wells since 2016	1986, 1987, 1991, 1992, 2008-2014	1991-1994, 2008-2014
	Municipal	2006, 2007, 2014-2018	2006, 2008, 2014, 2018	2006, 2008, 2009, 2014, 2015

3.4 Counties with No Pumping in the Study Area and Aquifers

The TWDB Water Use Survey dataset does not contain pumpage data for study area aquifers within Bastrop County, Frio County, Zavala, and Mitchell County. Each of these counties have a relatively small subcrop extent of a study area aquifer present within the county boundaries (see Figure 359, Figure 360, and Figure 361). While we do not anticipate production from the study aquifers within these counties, during subsequent evaluations we will assess the potential production from the study area aquifers in each county.

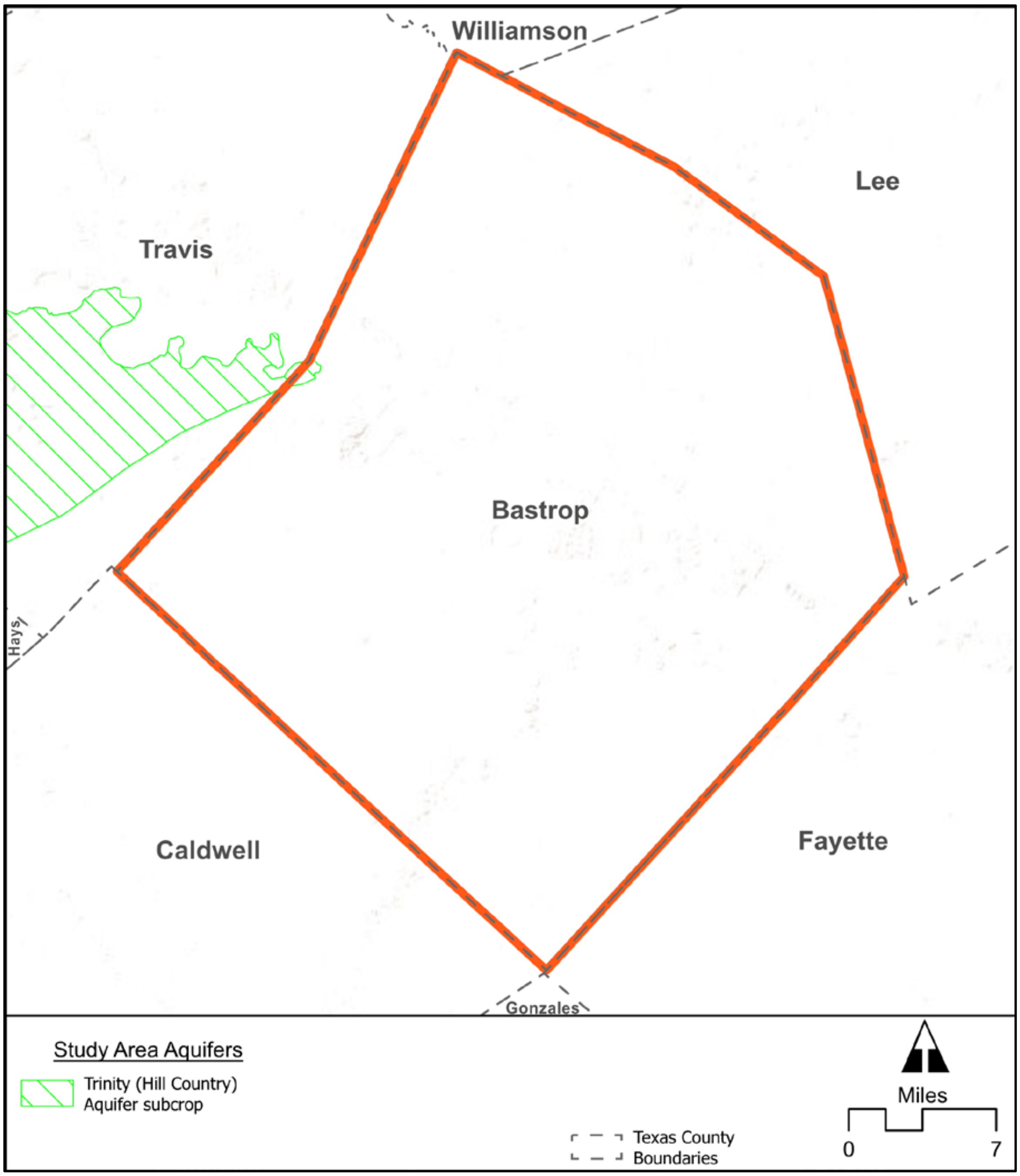


Figure 359. Bastrop County showing the extent of the Trinity (Hill Country) Aquifer.

Figure 360. Frio County showing the extent of the Edwards (Balcones Fault Zone) Aquifer.

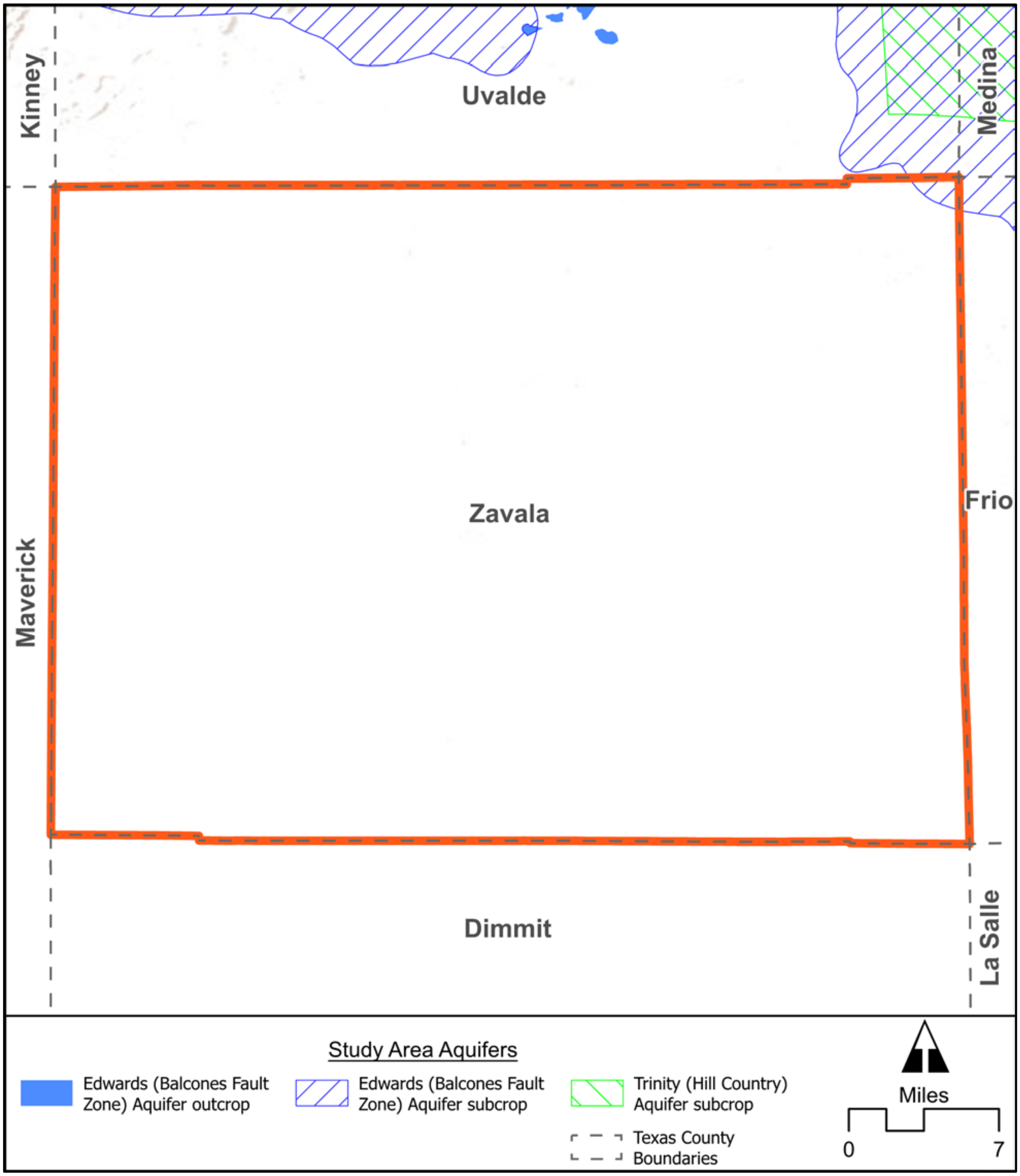


Figure 361. Zavala County showing the extent of the Edwards (Balcones Fault Zone) Aquifer

The TWDB Water Use Survey data reports less than two acre-feet per year of pumping from the Pecos Valley Aquifer in Mitchell County. However, as shown on Figure 362, while there is a very small portion of the Edwards-Trinity (Plateau) Aquifer present within Mitchell County, the TWDB defined footprint for the Pecos Valley Aquifer does not extend into Mitchell County. Therefore, we consider the identified Pecos Valley Aquifer pumpage for Mitchell County to be in error. While we do not anticipate much production from the study aquifers within Mitchell County, during subsequent evaluations we will assess the potential production from the Edwards-Trinity (Plateau) Aquifer.

Figure 362. Mitchell County showing the extent of the Edwards-Trinity (Plateau) Aquifer.

4 Addressing Water Use Survey Data Anomalies

Our plan for addressing anomalies was different for each water use category. For all uses we begin with the assumption that the Water Use Survey data are correct unless there is evidence to the contrary. TWDB staff have devoted many years of effort to developing estimates of water use and the groundwater production associated with that use. We are not proposing to change the Water Use Survey data but are focused on developing a pumping dataset that is as accurate as possible for the study area for groundwater modeling purposes.

Like the TWDB's estimates of historical groundwater pumpage (TWDB, 2020c), our approach is focused on the location where groundwater is pumped. As such, like the TWDB, our estimates of groundwater production location may differ from the location of use. The following report sections discuss how we approached addressing the Water Use Survey anomalies discussed in Section 3 within each Water Use Survey use category (see Table 3).

4.1 Municipal Use

Surveyed municipal use includes all water usage by active community public water systems as defined by the Texas Commission on Environmental Quality (TWDB, 2020a). It includes city-owned utilities, districts, water supply corporations, or private utilities supplying residential, commercial (non-goods-producing businesses), and institutional (schools, governmental operations) entities (TWDB, 2020a). These entities are required to report water usage data to TWDB on an annual basis, and this reported data is included within the TWDB Water Use Survey databases. Non-surveyed municipal water use consists of all other municipal water use not included in the surveyed municipal category and not reported to TWDB as part of the annual Water Use Survey program. These non-surveyed water volume estimates primarily reflect rural domestic use, but may also include estimated use for entities that did not respond to the Water Use Survey.

4.1.1 Surveyed Municipal

Each year, approximately 4,500 municipal active community public water suppliers provide data for the Water Use Survey which represents a response rate of 70 to 80 percent. In regard to groundwater information, the surveys require the water user to indicate the aquifer and county where water was pumped, annual and monthly intake volumes, total population directly served, and the name of the water provider if water was purchased (Billingsley, 2019).

Methodology to Address Water Use Survey Surveyed Municipal Pumping Anomalies

We evaluated anomalies identified in the surveyed municipal groundwater pumping database by first reviewing the values reported by each entity in a county. We used the historical Water Use Survey data compiled during our work to facilitate this review. By reviewing each entity, we were able to identify issues that may have been the cause of the Water Use Survey anomaly in the county-wide dataset.

For example, if an entity did not report pumping for some years, we sought to determine if the entity existed during those years. If the entity did exist, we then investigated if they should have reported pumping. If the entity should have reported, we began by investigating if the pumping was reported elsewhere (including incorrect reporting for a different county, aquifer, or use category) or, as the final option, we estimated the pumping for the missing year(s) based on an interpolation between the last year of reported pumping before the gap and the first year of reported pumping after the gap.

Once we addressed the anomalies in the pumping data, we assigned the location of the pumping based on the location of the pumping entity's well location(s) or service area, as reported from the TWDB Water Service Boundary Viewer, if there is insufficient well data. If pumpage for a certain entity is known to have occurred within a different county from the entity, then the pumpage is assigned to the location of source well, rather than to the location of the entity. For example, the Cities of Odessa and Midland utilize groundwater pumped from the Pecos Valley Aquifer in Ward and Winkler counties. Pumpage for these entities is recorded in Ward and Winkler County, rather than in Ector County (for Odessa) or Midland County (for Midland). The vertical distribution of pumping (that is, from which aquifer the groundwater is withdrawn) corresponded to the well's open interval depths (if known) or the well depth. Figure 363 illustrates our approach for addressing anomalies in the Water Use Survey data and for developing a groundwater pumping dataset for surveyed municipal pumping.

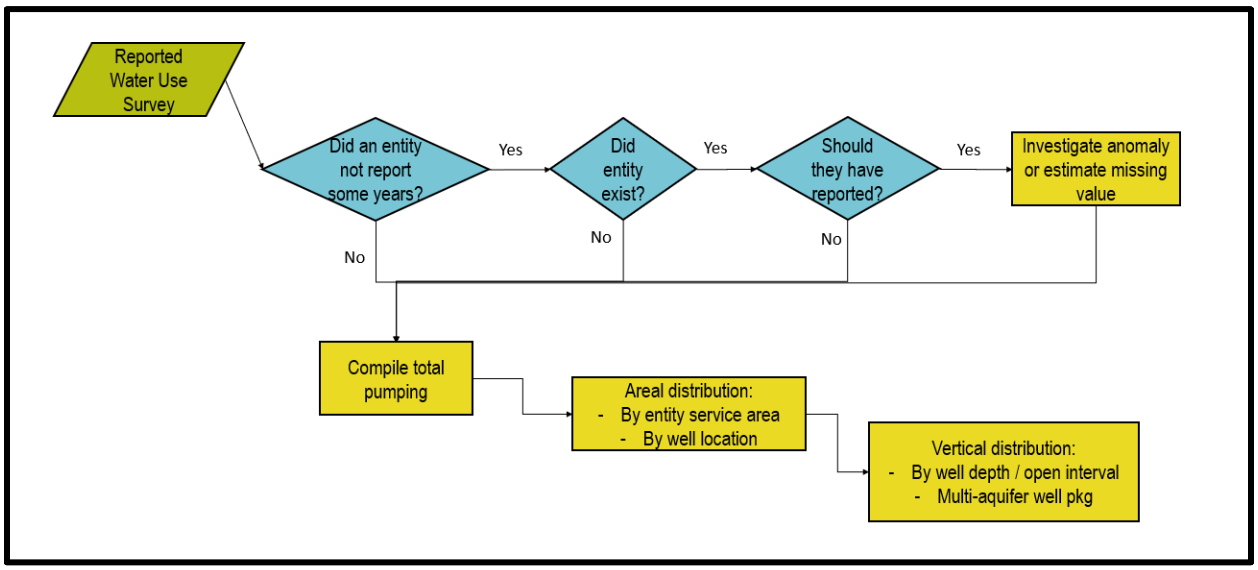


Figure 363. Schematic diagram illustrating the plan for addressing anomalies in the surveyed municipal pumping Water Use Survey data and for preparing a pumping dataset.

Surveyed Municipal Methodology Test Case

As a test case for the plan, we reviewed municipal surveyed pumping from the Edwards-Trinity (Plateau) Aquifer in Val Verde County. As reported in Section 3.3.50, most of the groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Val Verde County is for municipal use. As discussed in Section 3.3.50, we found several anomalies in the data based on manual review, a year-to-year change analysis, and a standard deviation analysis (see Figure 364).

Upon review of the reported Edwards-Trinity (Plateau) Aquifer pumping for surveyed municipal use per entity in Val Verde County, the main source of the anomalies is evident. Figure 365 shows the reported surveyed municipal groundwater pumping for each entity in Val Verde County. Review of Figure 365 indicates that most of the reported pumping is by the entity with a survey number of “221200” which corresponds to the City of Del Rio. The white space on Figure 365 for the City of Del Rio, between 2007 and 2009, is where there is no reported pumping by the city. However, upon additional review of the Water Use Survey data, we found that reported use by the City of Del Rio for those three years was assigned to surface water suggesting the anomaly identified during this 2007-2009 period may simply be an error in source assignment.

To further investigate the anomalous data, we also reviewed a hydrogeologic study for the City of Del Rio (EcoKai, 2014). This report included several years of City of Del Rio annual pumping. Figure 366 provides a comparison of the pumping amounts in the Water Use Survey and by EcoKai (2014) for the City of Del Rio. Review of the data illustrated on Figure 366 suggests the values presented by EcoKai (2014) provide a reasonable correction for many of the anomalies identified in the Water Use Survey data for municipal surveyed Edwards-Trinity (Plateau) Aquifer pumping in Val Verde County.

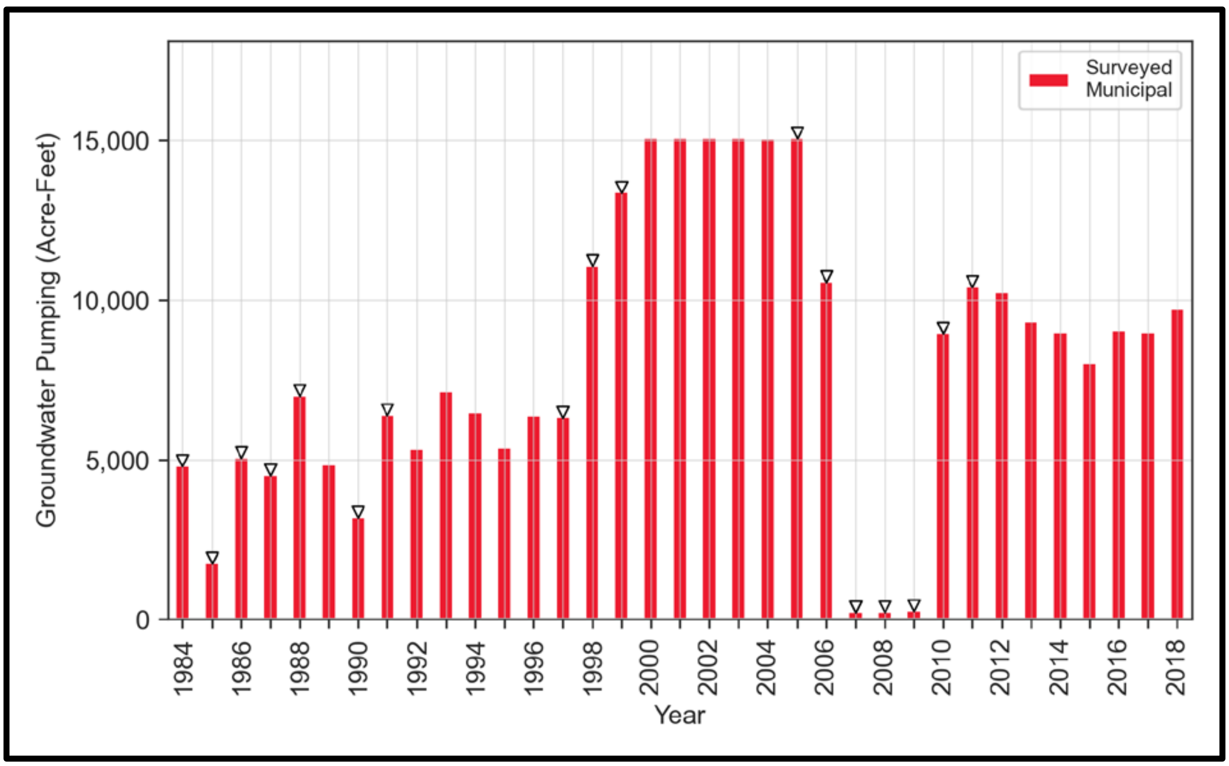


Figure 364. Val Verde County Edwards-Trinity (Plateau) Aquifer groundwater pumping for surveyed municipal use as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

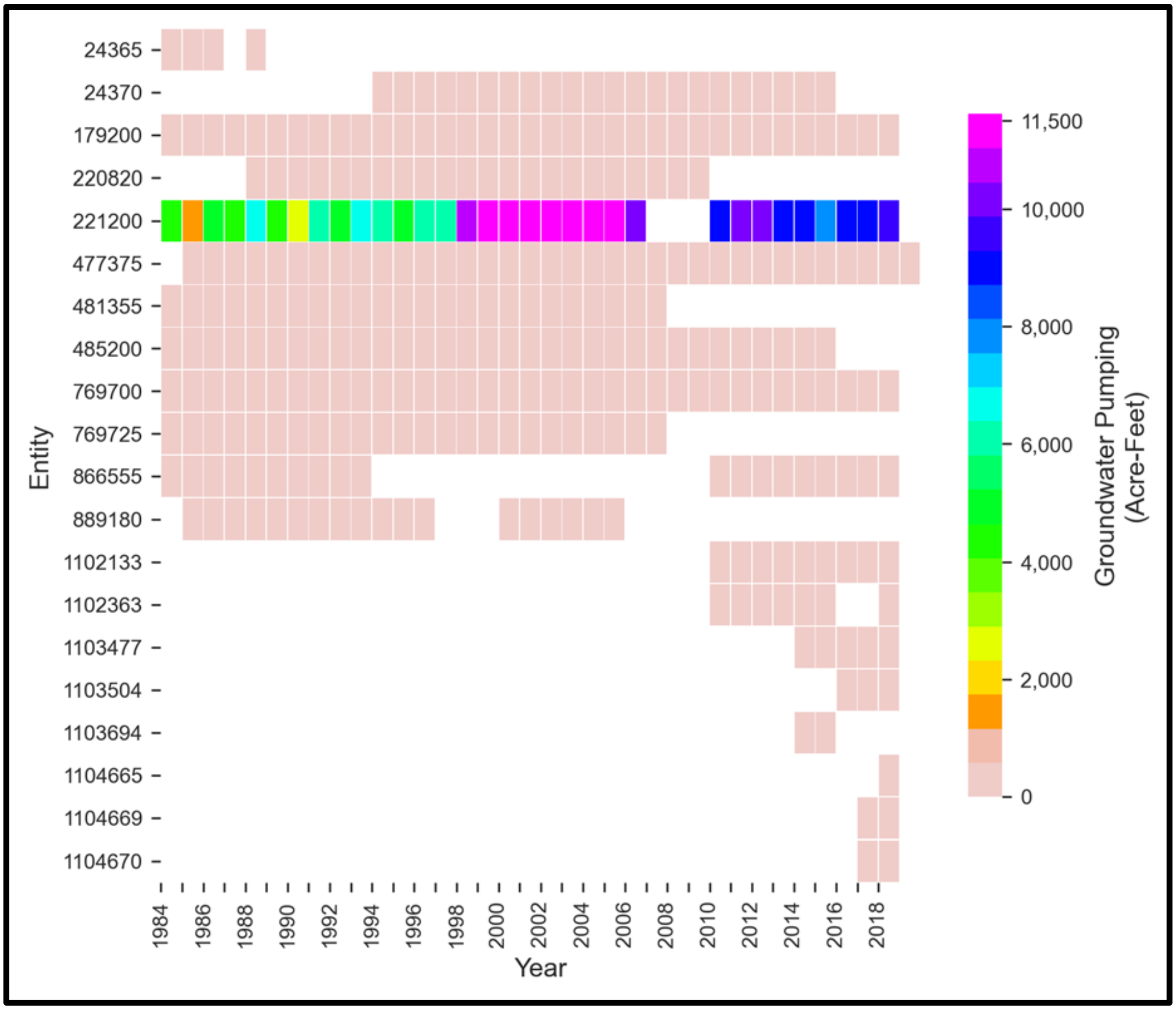


Figure 365. Reported groundwater pumping for surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Val Verde County by reporting entity.

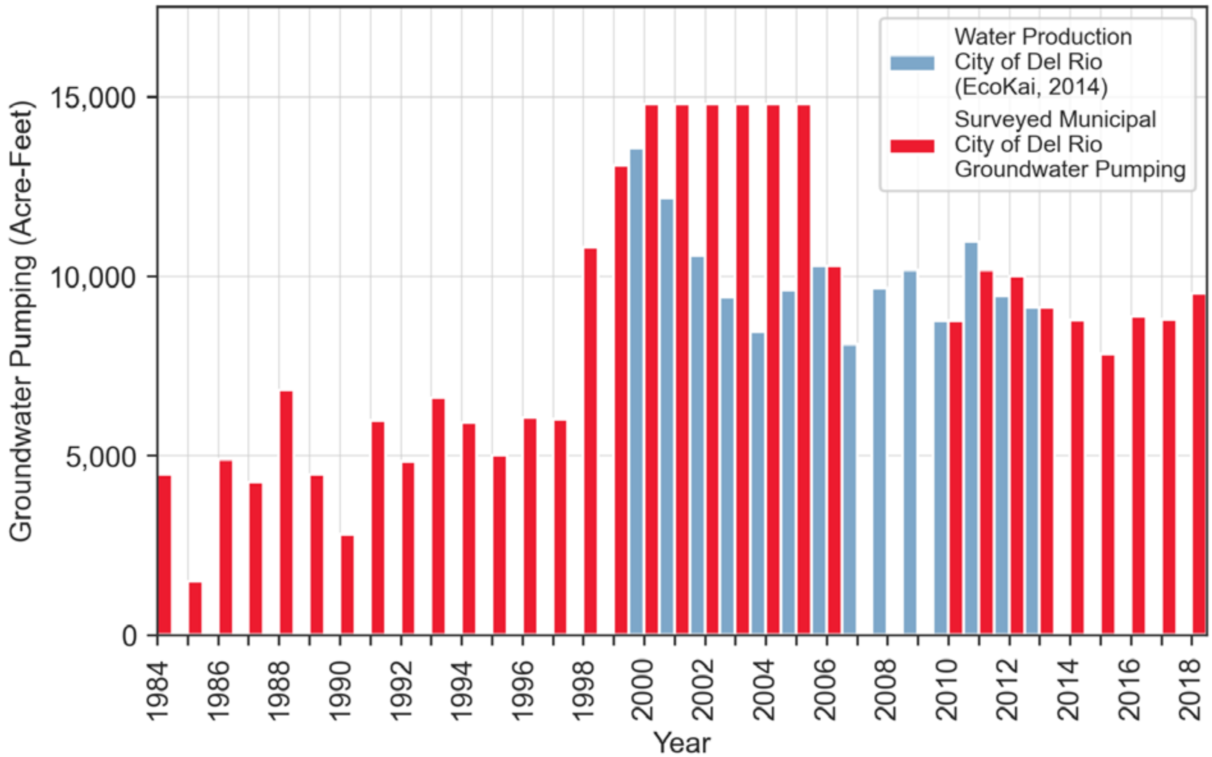


Figure 366. Comparison of groundwater pumping reported in the Water Use Survey and water production reported by EcoKai (2014) for the City of Del Rio.

Similarly, Weinberg and others (2018) investigated water supplies and demands in Val Verde County as part of an assessment for potentially designating Val Verde County as a Priority Groundwater Management Area. Weinberg and others (2018) noted the same types of anomalies and discrepancies regarding reporting of groundwater pumping for municipal usage (as well as other uses). They utilized the EcoKai (2014) report and other sources to revise estimates of pumping amounts for the period from 2000 to 2015. Figure 367 illustrates the revised estimates by Weinberg and others (2018) and highlights the differences between the surveyed municipal pumping in the Water Use Survey database and pumping estimates by Weinberg and others (2018) which were based on the premise that the City of Del Rio's use of water captured at the San Felipe Springs discharge should not be classified as groundwater pumping.

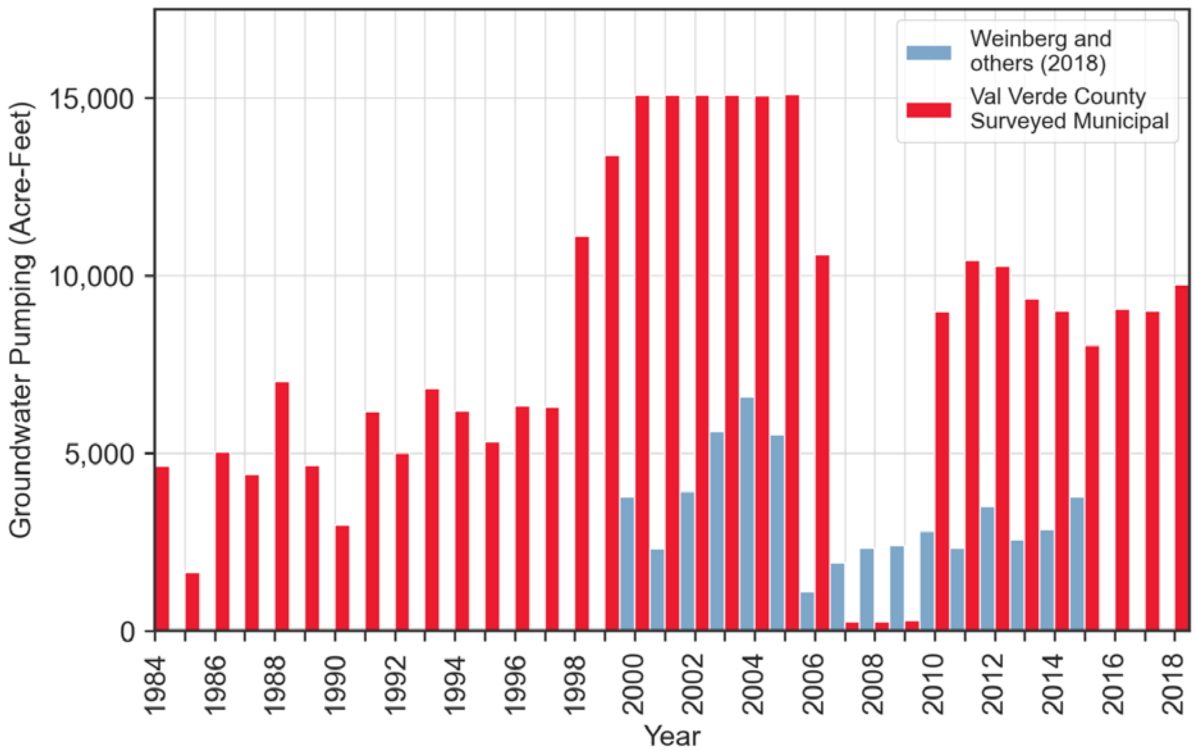


Figure 367. Comparison of surveyed municipal pumping reported in the Water Use Survey and revised estimates reported by Weinberg and others (2018) for Val Verde County.

Review of the Texas Commission on Environmental Quality Public Water Supply well database (TCEQ, 2020) indicates there are three active wells associated with the City of Del Rio (see Figure 368). However, review of the Texas Drinking Water Watch data system (TCEQ, 2021) for the City of Del Rio (Water System Number TX2330001) indicates the City actually has a total of five wells with the three wells in the Public Water Supply well database (TCEQ, 2020) reported to be inactive. The remaining two wells identified in the Texas Drinking Water Watch data are active, but they are associated with San Felipe Springs. In this case, our investigation of the anomalous data revealed that though the water used should continue to be reported as groundwater, for modeling purposes we agree with EcoKai (2014) and Weinberg and others (2018) that it is likely more accurate to include the reported City of Del Rio pumping as part of the San Felipe Springs outflow rather than as groundwater production. We will continue to investigate this test case as we develop the pumping dataset during that next project phase.

Figure 368. City of Del Rio and other nearby public water supply wells per TCEQ (2020) records.

4.1.2 Non-Surveyed Municipal

Municipal water use is directly taken from the responses to the municipal surveys. Families and small businesses that primarily use water from private wells for residential or small-scale commercial purposes are considered in the municipal water use category by developing estimates of the county's population not served by a water system, and of the rural gallons per capita daily value (Billingsley, 2019).

Methodology to Address Water Use Survey Non-Surveyed Municipal Pumping Anomalies

The TWDB began incorporating non-surveyed municipal water use estimates into their Water Use Survey database in the year 2000. To estimate non-surveyed municipal water use, they estimated the population not served by a water system (the "non-system population") and multiplied that population estimate by the average rural statewide per person water use. The TWDB uses the statewide per capita water use for Water Supply Corporations and Investor-Owned Utilities as a representative value for what rural households may use (Billingsley, 2019). In 2010, the non-system population was estimated using the 2010 Census block shapefile and the Statewide Water System Map to delineate the areas not served by community water systems. After 2010, the non-system population growth was estimated by comparing the growth in the number of total connections reported in the Water Use Survey to the county population growth estimated by the Texas State Data Center. Using the non-system population estimates and the per capita use estimate, TWDB staff developed estimates of the non-surveyed municipal use for each county.

There are two types of municipal use that appear to be captured in the non-surveyed amount. First, there is a rural population served by their own private water wells. Second, there are public water systems that may not have responded to the survey. While there are likely differences in the per capita use, both water-use types can be estimated using the same methodology.

To address anomalies and develop estimates of non-surveyed municipal use for our full period of interest from 1984 through 2018, we utilized water use data from the U.S. Geological Survey. The U.S. Geological Survey has developed water use estimates in the United States at a county level every five years since 1985 (USGS, 2018). The U.S. Geological Survey estimates of water use are available for public supply, irrigation, livestock, aquaculture, industrial, mining, thermoelectric power, and domestic. Their approach for estimating domestic use is very similar to the approach used by the TWDB.

The U.S. Geological Survey defines domestic water use as water used for indoor and outdoor household purposes such as drinking, cooking, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens (USGS, 2021). In developing the estimates of use, the U.S. Geological Survey only considers self-supplied water withdrawals for which the main source is generally a groundwater well. All self-supplied domestic groundwater withdrawals are considered freshwater and the self-supplied domestic population is defined as the difference between the total population, as determined by the U.S. Census Bureau, and the population served by public suppliers, as provided by a State agency or other source. The U.S. Geological Survey estimates the domestic total water use using the self-supplied population and rural per capita use coefficients which vary spatially and are derived using public supply delivery data for domestic use (Hutson and others, 2004). Historically, U.S. Geological Survey staff contacts the state representatives to obtain this information. The withdrawal data provided to the U.S. Geological Survey includes the reported municipal un-surveyed seller volumes and the estimated non-surveyed municipal volumes (Billingsley, 2019).

Non-Surveyed Municipal Methodology Test Case

To demonstrate the similarity in the approaches to estimating non-surveyed municipal use by the TWDB and estimation of self-supplied domestic use by the U.S. Geological Survey, we reviewed and compared data for Val Verde County. One limitation of the U.S. Geological Survey data is that it is only available for every five years since 1985 up to 2015. Figure 369 illustrates a comparison between the TWDB Water Use Survey non-surveyed municipal pumping estimates and the U.S. Geological Survey self-supplied domestic pumping estimates for the Edwards-Trinity (Plateau) Aquifer in Val Verde County. For purposes of addressing Water Use Survey anomalies using the U.S. Geological Survey data, we can assume 1984 pumping is equal to 1985 values, pumping changes linearly between years with data, and for the year 2016 and following the Water Use Survey non-surveyed municipal estimates are most reasonable.

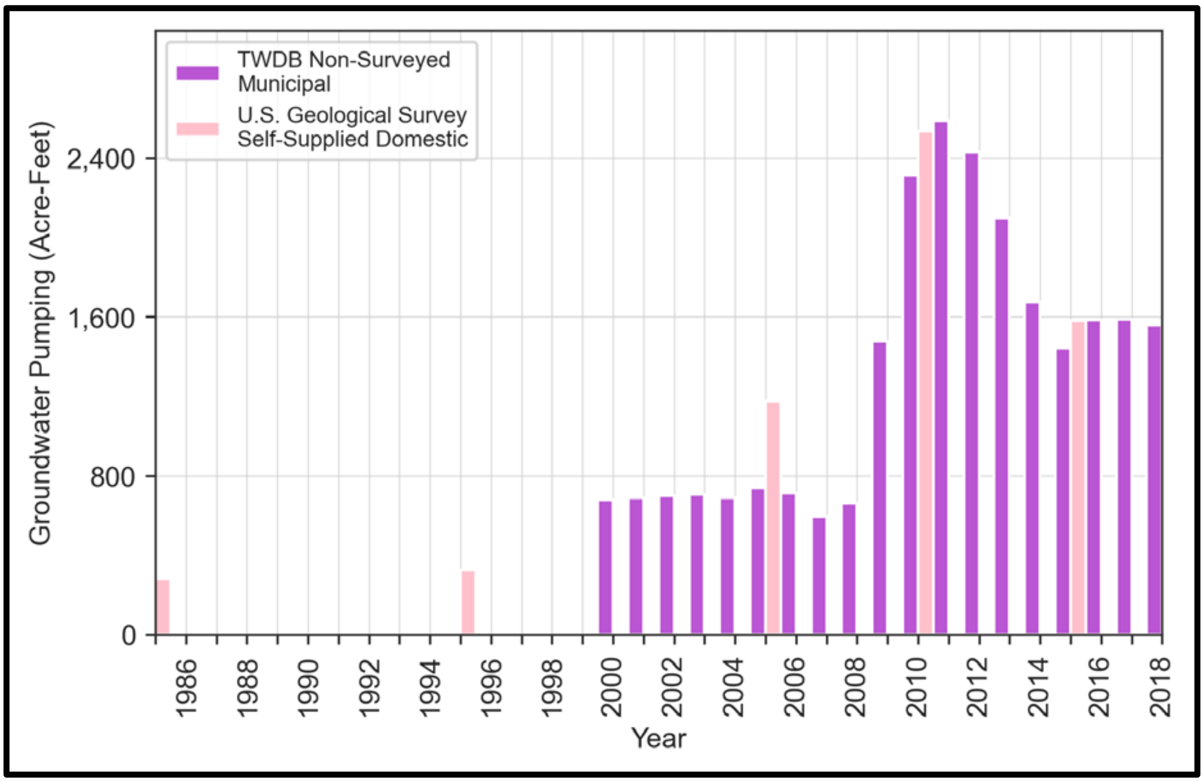


Figure 369. Val Verde County Edwards-Trinity (Plateau) Aquifer TWDB Water Use Survey estimated non-surveyed municipal pumping and U.S. Geological Survey estimated self-supplied domestic pumping.

The estimates from the TWDB and the U.S. Geological Survey agree reasonably well. One notable difference is the increase from 2008 to 2010 in the TWDB data. However, the increases in pumping shown on Figure 369 are reasonable and may be reflected in observed water level changes in the area that also correlate with drought that began in 2011 (Weinberg and others, 2018). The differences in the datasets are not significant and comparison of the datasets shows how utilization of the U.S. Geological Survey data will aid in developing a more complete dataset.

To determine the spatial location of non-surveyed municipal pumping, we used well location data to guide the placement of the production. For Val Verde County, Figure 370 illustrates the reported location of domestic use wells completed in the Edwards-Trinity (Plateau) Aquifer. While Figure 370 does not depict locations of all domestic wells in the county, the shown locations provide guidance on the general locations for assigning pumping and where we should concentrate non-surveyed municipal pumping amounts in the spatial dataset. When possible, we excluded areas serviced by public water supplies (and therefore reported within the Municipal Surveyed category). When the dataset includes the year a well was drilled, we did not assign pumping to that well prior to that year; however, for wells without a completion date we assigned pumping starting in 1984.

For Val Verde County, well information was sufficient to aid in assigning pumping locations to non-surveyed municipal estimates. Should sufficient data not be available for such analyses, we would assume a uniform pumpage distribution across portions of the county-aquifer footprint that are not serviced by an entity reporting municipal surveyed usage.

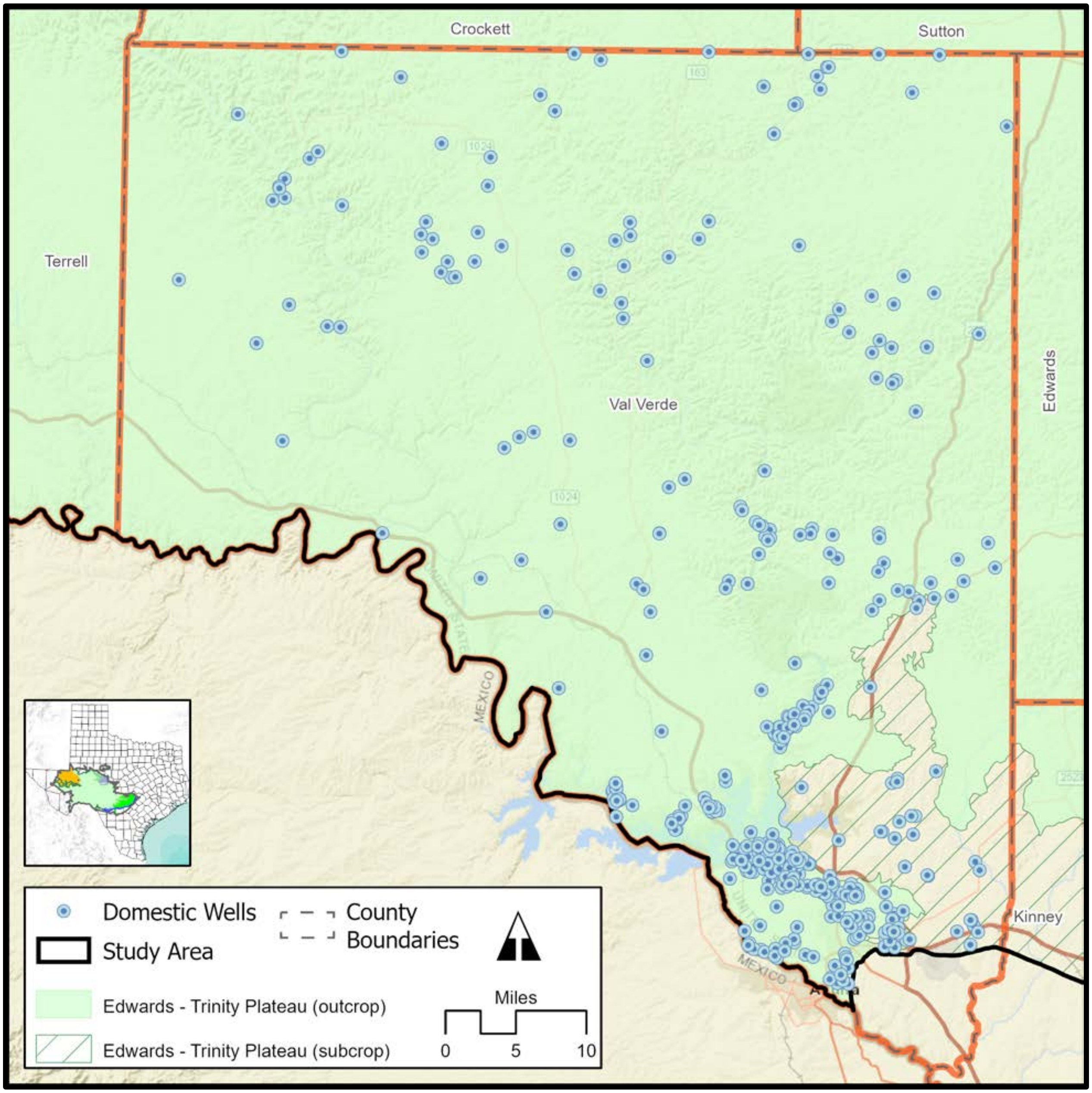


Figure 370. Location of domestic wells completed in the Edwards-Trinity (Plateau) Aquifer in Val Verde County per TWDB Groundwater Database (TWDB, 2020b) and Submitted Drillers Report Database (TWDB, 2020e).

4.2 Irrigation

Texas ranks first in the nation for total number of farms, accounting for 127 million acres of agricultural land which represents 74 percent of the state's land and a $25 billion contribution to the economy (USDA, 2019). However, the TWDB does not have the authority to require agricultural producers to report actual irrigation water use volumes and must thus aggregate information from various sources to develop irrigation water use estimates (TWDB, 2020d). Since 1985, the TWDB has annually estimated water use for irrigation, and the methods for estimating irrigation use and groundwater production associated with irrigation have changed and improved over time (TWDB, 2020e; Turner, 2020) .

Delgado (2018) summarizes the evolution of the TWDB methodology for estimating irrigation water use. Recent methods include utilizing geographic information systems to leverage gridded climatological and crop datasets. Delgado (2018) emphasizes the importance of input from local experts in determining the acres of crops and amount of water used for irrigation of those crops.

Methodology to Address Water Use Survey Irrigation Pumping Anomalies

Our plan for addressing anomalies in the Water Use Survey data involved applying some of the current TWDB methods described by Delgado (2018). We leveraged the available gridded climatological, crop, and land use datasets along with the TWDB crop acreages to refine the pumping amounts where needed and guide the spatial distribution of irrigation pumping. Figure 371 illustrates our plan for addressing anomalies in the Water Use Survey data and for developing a groundwater pumping dataset for irrigation pumping.

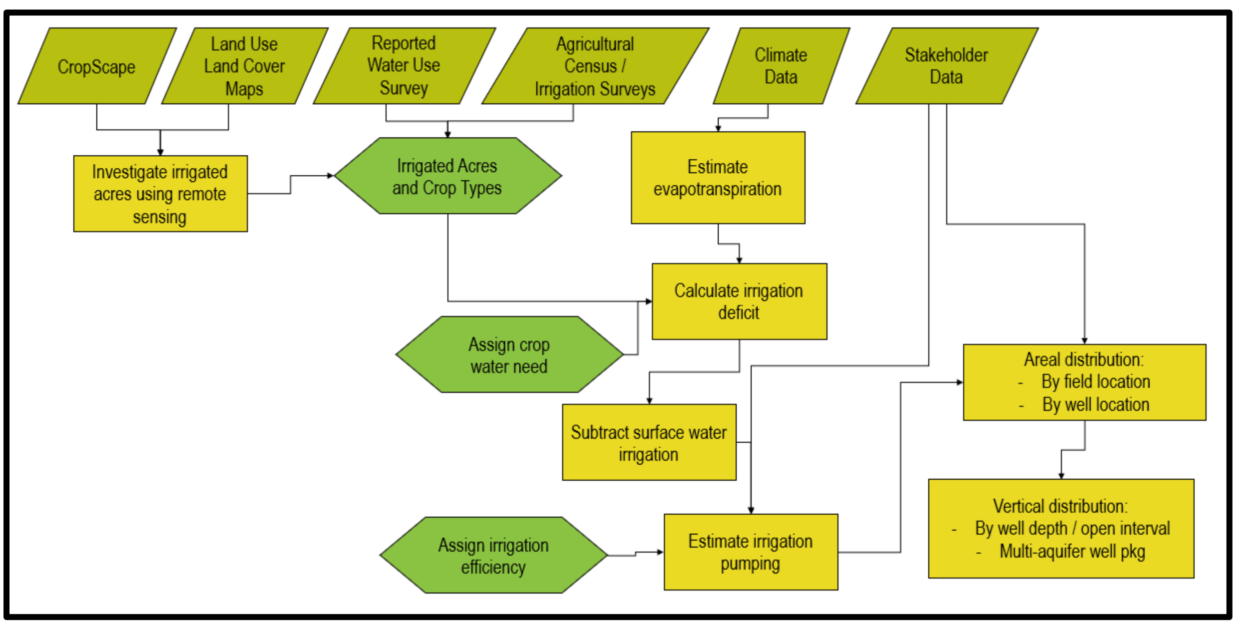


Figure 371. Schematic diagram illustrating the plan for addressing anomalies in the irrigation pumping Water Use Survey data and for preparing a pumping dataset.

While we identified anomalies in the irrigation pumping estimates, our analysis suggested that though the pumping amounts needed to be addressed, the TWDB estimates of the number of acres irrigated are reliable values upon which to build. For quantifying the number of acres per crop in each county, we used the same data sources as TWDB staff but were not able to reach out to local experts for revision as TWDB staff have already done in past years. As such, we used the number acres per crop per county provided by the TWDB and developed refinements to the irrigation rates (for example acre-feet of water applied per acre planted) for those crops as needed. As the annual estimates of crop acreage began in 1985, for year 1984 estimates we used the total irrigated acreage for the county (TWDB, 2001) and the average percent of the area for each crop from the annual estimates. We also acknowledge that TWDB irrigation estimates are based on crop acreage, and following TWDB procedures a 100-acre field with two crops in a year would be calculated as 200 acres. We utilized this same methodology.

Building upon our evaluation of gridded land use data from Sohl and others (2014; 2016), we developed refined estimates of where crops are planted within the study area. We also investigated using a technique developed by Deines and others (2019) where they leveraged Google Earth Engine to map annual irrigation across the Ogallala Aquifer. However, we found the technique to be labor intensive and did not provide significantly different results than could be obtained using other publicly available datasets to estimate crop areas and likely irrigation.

To improve our estimates of irrigation areas and the crops within those areas, we used the gridded Crop Data Layer for the years 2008 through 2019 developed by the U.S. Department of Agriculture National Agricultural Statistics Service (USDA-NASS, 2008-2019). The Crop Data Layer (also known as CropScape) provides a reasonable estimate of crop areas based on remote sensing methods. However, the data layers, with 30-meter by 30-meter pixels, do not provide an exact representation of the acreage each year and tend to show non-crop pixels within an irrigation area (for example, a shrubland pixel surrounded by alfalfa pixels representing a center pivot irrigation area). For the years from 1984-2008, we assumed the relative spatial distribution of crops across a county was identical to that identified in the Crop Data Layer for 2008.

To use the Crop Data Layer grids for our study area, rather than using the grid for each year to define the crops, we calculated the mode (that is, the value that occurs most often) at each pixel location from the twelve-year period available. By calculating the mode for each pixel location, we are essentially determining the most common crop or other land type at that location over the last twelve years based on remote sensing analysis. Using the number of pixels for a particular crop type in the county, we can determine the percent of the crop area each pixel represents. Using these percentages, we are then able to estimate back to the start of the study period (that is, 1984) the type and location of the specific crops tracked by the TWDB for developing irrigation water use estimates. For example, if we find there are 10,000 pixels representing alfalfa in a given county, we then assume each pixel represent 0.01 percent of the TWDB's acreage value for alfalfa in that county for each year. Using this method, provides an approximation of the spatial location of the crop acreage in the county back to 1984. If the TWDB dataset reports that 200 acres of alfalfa were grown within the county in a given year (for example), this 200 acres of alfalfa would be evenly distributed across the county based on the locations of pixels identified as alfalfa within the Crop Data Layer.

Our next step involved developing estimates of irrigation water need from available gridded climatological data (PRISM, 2020) obtained for the study area. To estimate evapotranspiration, we used a modified version of the Hargreaves-Samani equation (Equation 1) with coefficients that vary monthly (Awal and others, 2020). Awal and others (2020) calibrated the coefficients of the Hargreaves-Samani equation to reference evapotranspiration calculated using the Food and Agriculture Organization Penman-Monteith equation at climate station locations. Table 60 provides the monthly coefficients used in the equation. Using the modified Hargreaves-Samani equation, we can use the readily available gridded minimum, maximum, and average temperature, along with the latitude of each pixel to estimate extraterrestrial radiation (Jain, 1984), to rapidly calculate daily reference evapotranspiration across the study area.

$$ET_0 = a \times 0.408R_a \times \left(T_{avg} + b\right) \times (T_{max} - T_{min})^c \quad (1)$$

Where

$ET_0 = reference\ evapotranspiration, millimeters\ (divide\ by\ 25.4\ for\ inches)$

R_a
$= extraterrestrial\ radiation, megajoules\ (0.408\ converts\ to\ millimeters\ per\ day)$

$T_{avg} = average\ air\ temperature, °C$

$T_{max} = maximum\ air\ temperature, °C$

$T_{min} = minimum\ air\ temperature, °C$

$a, b, \&\ c = empirical\ coefficients$

Table 60. Monthly empirical coefficients used in the Hargreaves-Samani equation for calculating reference evapotranspiration within the study area.

Month	Coefficient "*a*"	Coefficient "*b*"	Coefficient "*c*"
January	0.00511	10.26	0.507
February	0.00446	11.36	0.493
March	0.00339	12.05	0.533
April	0.00378	9.23	0.516
May	0.00340	2.96	0.591
June	0.00690	-7.60	0.473
July	0.00578	-6.31	0.472
August	0.00606	-5.50	0.438
September	0.00298	3.16	0.594
October	0.00375	8.63	0.491
November	0.00470	13.87	0.413
December	0.00355	11.51	0.596

For the study area, we assumed a crop growing season from March 15 through October 15 each year. The method could be modified to include alternative growing seasons, including winter seasons, with separate seasons used in different portions of the study area. Such modifications were not incorporated into the revised pumpage dataset documented herein. Using the gridded crop data, we applied the applicable crop coefficient (Allen and others, 1998) to the calculated reference evapotranspiration to estimate potential crop water demand. We then subtracted the gridded precipitation data (PRISM, 2020) to estimate the water deficit as the irrigation demand. While the method does not explicitly account for soil moisture available to crops or runoff during high precipitation events, our analysis does yield insight on year-to-year trends in likely irrigation need. From the estimated irrigation need, we subtract any known surface water amounts diverted for irrigation to estimate the irrigation need to be met with groundwater. Assuming most irrigation is performed using sprinkler or other more efficient systems, we divide the estimated groundwater irrigation need by 0.75 to account for the field application efficiency (Brouwer, 1989).

Surface water diversions for irrigation were obtained from the Water Use Survey database by county and year. We estimated where diversions would occur within a given county based upon the locations of significant rivers or waterbodies within the county, and based on these locations we approximated how much surface water would have been used to supplement groundwater usage from given underlying aquifers. We then assumed a delivery efficiency for surface water identical to that of groundwater irrigation by sprinkler, thereby reducing the surface water applied to crops based on the efficiency. For example, if 100 acre-feet of surface water were diverted for irrigation use, we assumed only 75 acre-feet of that diversion would reach the crops to be irrigated (as 100 acre-feet x 75% efficiency = 75 acre-feet). Continuing this example, if we computed that a county needed 125 acre-feet for irrigation in a given year, and 75 acre-feet was available from surface water sources, then the remaining 50 acre-feet of demand was to have been meet by groundwater pumpage. This pumpage would have been 66.66 acre-feet, however, in order to account for the sprinkler irrigation efficiency (as 66.66 acre-feet x 75% efficiency = 50 acre-feet).

One limitation of the approach as applied for this project is that it uses a defined irrigation season that may not account for winter or year-round crops. However, the approach allows for the use of multiple grids defining the crop types for estimating irrigation water needs and could be applied to develop revised evapotranspiration estimates which inform the groundwater production estimates. In addition, the approach as applied for this project assumes irrigation need will be met with either surface water or groundwater. That is, dry land farming is not excluded from the estimation of water need. As such, estimated pumping may be too high if there is significant dry land farming occurring. Nonetheless, the approach provides reasonable estimates of groundwater production and we do not believe they invalidate the approach.

A second potential limitation of this approach to irrigation needs estimation is the method's ignoring of runoff and soil moisture availability. Specifically, runoff water generated from overland flow could become water used to support crops in adjacent regions. We minimize this possibility as most runoff would become channelized in streams or creeks, and would not therefore be available to cover large areas of irrigated crops. Soil moisture availability may allow for less irrigation water usage, as the crops could draw from the soil moisture in dry periods, and therefore utilize less irrigation water. We also ignored this possibility, favoring a more conservative estimate of irrigation demands.

Our evaluation of potential groundwater irrigation needs informed our investigation of Water Use Survey anomalies for irrigation pumping. In cases where stakeholders provided data, we prioritized its use above estimates obtained from other methods. The location of known irrigation wells and crop areas guided the spatial distribution of the irrigation pumping. The vertical distribution of pumping (that is, from which aquifer the groundwater is withdrawn) will correspond to the well's open interval depths (if known) or the well depth. Our proposed methodology also does not exclude dryland farming areas from the estimation of irrigation demand. This may be important for this study area, which does include a significant amount of dryland production.

Irrigation Methodology Test Case

As a test case, we reviewed the irrigation pumping Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer in Pecos County. Farmers in Pecos County have used abundant water supplies for about 150 years to irrigate crops downstream from Leon Springs (in the Leon-Belding Irrigation Area) and from Comanche Springs near the City of Fort Stockton. Comanche Creek and irrigation canals were historically used to distribute water to members of the Pecos County Water Control and Improvement District No. 1. TWDB has noted that:

> "Pecos County is not a fair sample of the study area to test this methodology. It is a best-case scenario because agricultural fields are accurately identified remotely in this arid county and there is a smaller percentage of dryland production." (See TWDB Comment #49 in Appendix).

From the 1940s numerous large capacity water wells were drilled in other parts of Pecos County and six additional irrigation areas were developed. Some of the irrigation areas relied primarily on wells completed in the Pecos Valley Aquifer (formerly called the Cenozoic Pecos Alluvium Aquifer) and some areas relied predominantly on wells completed into the Edwards-Trinity (Plateau) Aquifer. Maximum acreages irrigated and accompanying pumping rates occurred in the 1960s with the highest TWDB reported estimate of approximately 339,000 acre-feet per year in 1964. During the maximum irrigation period of the 1960s, estimates of groundwater production from the Leon-Belding Area (primarily the Edwards-Trinity (Plateau) Aquifer) are up to 120,000 acre-feet per year (Thornhill and others, 2008; Harden and others, 2011; Mace and others, 2020), and more than 177,000 acre-feet per year were pumped from the Coyanosa area which mainly tapped the Pecos Valley Aquifer (Thornhill and others, 2008).

By 1969 irrigation had reportedly decreased to about 180,000 acre-feet per year in the county. Since the mid-1970s, water usage from aquifers in the Trans-Pecos Region has declined substantially, primarily due to economic considerations associated with the oil embargo and other factors, and partly due to increased farming efficiencies. Total pumping for Pecos County from 1985 to 2005 generally remained between 50,000 and 80,000 acre-feet per year. Assessing the distribution of pumping between the Edwards-Trinity (Plateau) Aquifer and the Pecos Valley Aquifer requires an understanding of the historical locations of pumping.

Maintaining historical pumping rights was a primary consideration for the formation of the Middle Pecos Groundwater Conservation District. The establishment of Historic and Existing Use permits provided the primary regulatory framework for the District. Based on a historic period from September 20, 1989 through September 20, 2004, unless an applicant could prove a continuous historical pumping period prior to that period, the District reviewed applications and granted Historic and Existing Use permits. For a few years, the only permits granted by the

District were Historic and Existing Use permits. The District granted these permits with total allocations of 230,813 acre-feet per year which included all the historical irrigation areas. The District granted 117,489.3 acre-feet per year for the Edwards-Trinity (Plateau) Aquifer and 94,759.8 acre-feet per year for the Pecos Valley Aquifer (Thornhill and others, 2008).

The District has since permitted approximately an additional 8,400 acre-feet per year for two non-exempt production permits, although that water was known to have been produced during the Historic and Existing Use production period. Based on the geologic structure of the Edwards-Trinity (Plateau) Aquifer and its relationship to the Pecos Valley Aquifer, it is likely that some of the permits were originally assigned to an incorrect aquifer. The District may have corrected those aquifer assignments based on their three-dimensional modeling efforts.

As reported in Section 3.3.36 and illustrated on Figure 372, since 1984 the reported pumping from the Edwards-Trinity (Plateau) Aquifer for irrigation ranged between 20,000 and 100,000 acre-feet per year. We found several anomalies in the data based on manual review, a year-to-year change analysis, and a standard deviation analysis (see Figure 372).

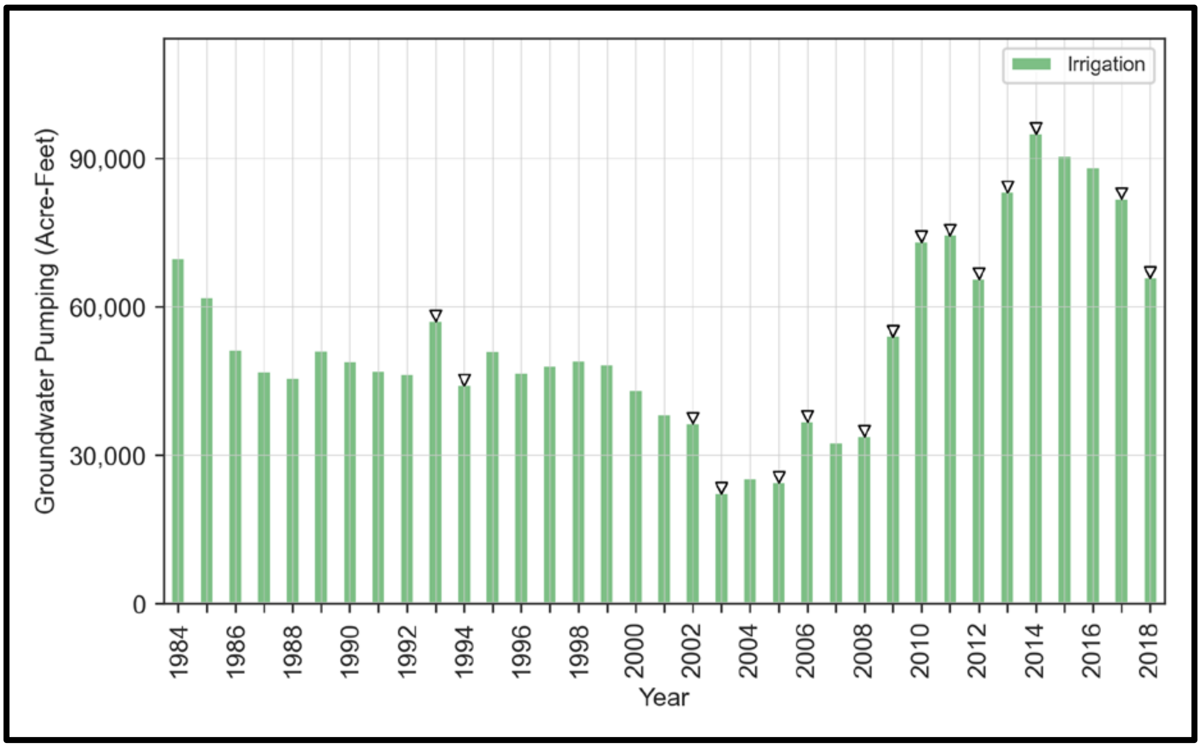


Figure 372. Pecos County Edwards-Trinity (Plateau) Aquifer groundwater pumping for irrigation use as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Figure 373 illustrates the irrigated crop areas within Pecos County based on the CropScape data analysis that identified the most frequently occurring crop type. The TWDB estimates of the number of acres associated with the crops are available for the entire county (see Figure 374). To determine the irrigated acres associated with each aquifer in Pecos County, we used the delineations of each study area aquifer as shown on Figure 373. Much of the irrigated acreage in

Pecos County is located atop and near the Edwards-Trinity (Plateau) Aquifer outcrop area. As an initial estimate of the irrigated acres associated with the Edwards-Trinity (Plateau) Aquifer, we summarized the acreage values for pixels located in both the Edwards-Trinity (Plateau) Aquifer outcrop and subcrop areas. Figure 375 illustrates the estimated crop acres associated with the Edwards-Trinity (Plateau) Aquifer in Pecos County.

The calculated irrigation water need based on the reference evapotranspiration values, without application of crop coefficients or irrigation efficiency, for the Edwards-Trinity (Plateau) Aquifer outcrop and subcrop areas in Pecos County typically varies between 40,000 and 50,000 acre-feet per year. Figure 376 illustrates the estimated irrigation need and its relative stability. The estimates are informative of the expected trends in irrigation pumping and were later refined to include applicable crop coefficients and irrigation efficiency.

Figure 377 illustrates the difference between Water Use Survey reported irrigation pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County (Figure 372) and estimated irrigation water need (Figure 376). Since 2009, the difference between the Water Use Survey reported value and the estimated need value is positive indicating irrigation is more than the estimated irrigation need. As our initial estimates shown in Figure 376 do not include the crop coefficients or irrigation efficiency, we expect that they would underestimate the actual need.

Prior to 2010, many of the differences are negative or near zero. With our expectation that the irrigation need for this test case is underestimated, we expect that many of the Water Use Survey reported irrigation values prior to 2010 are low. While many of the identified anomalies in the Water Use Survey data were for more recent years (see Figure 372), it appears earlier years are likely to have underestimated amounts of pumping with the more recent years being more accurate.

For the six highest acreage crops in Pecos County, Figure 378 illustrates the annual irrigation rate TWDB staff applied to irrigated acres to estimate total irrigation use. Since 2010, the irrigation rate for each crop is generally higher than the 1984 through 2009 rate. This increase in the acre-feet of water per acre of crop results in the overall higher estimated irrigation pumping in recent years and further reflects the importance of input from local experts and stakeholders. Note that in granting Historic and Existing Use permits, the district provided crop allocation guidance to permit applicants with the allotments shown in Table 61. The District allocations were based on input from farmers and locally accepted practices and correspond well to the recent allocations presented in Figure 378.

Using the more recent application rates based on stakeholder input with our estimates of crop acreage, we updated the pumping estimates for previous years. Using the average irrigation rate for the last five years of data (2013 through 2018) for each crop and the estimated crop area associated with the Edwards-Trinity (Plateau) Aquifer in Pecos County, we updated the estimates of groundwater production from the Edwards-Trinity (Plateau) Aquifer in Pecos County from 1984 through 2009. For the years 2010 and following, we used the Water Use Survey pumping estimates. Figure 379 illustrates the revised estimates of annual groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County for irrigation use.

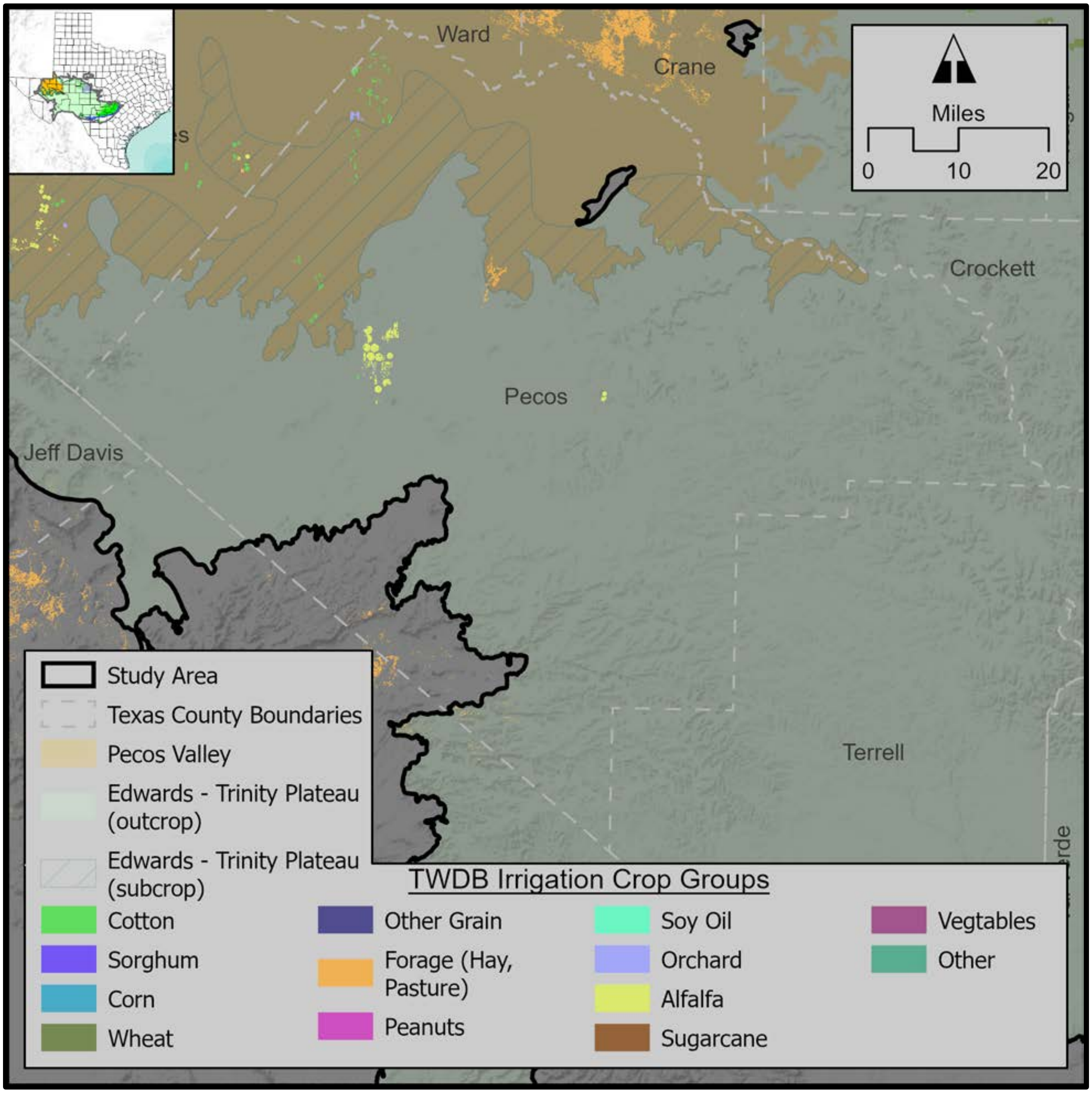


Figure 373. Pecos County irrigated crop areas based on most frequently occurring crop in the gridded crop data (USDA-NASS, 2008-2019). Non-crop areas not shown.

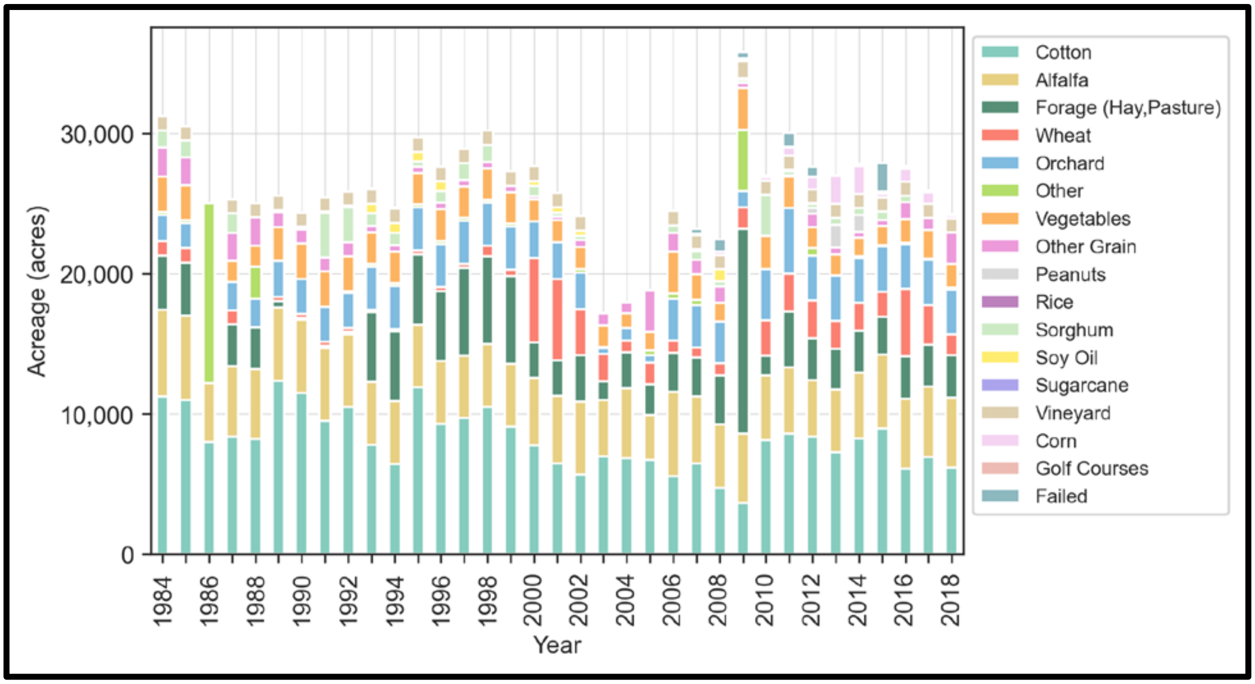


Figure 374. TWDB crop area estimates.

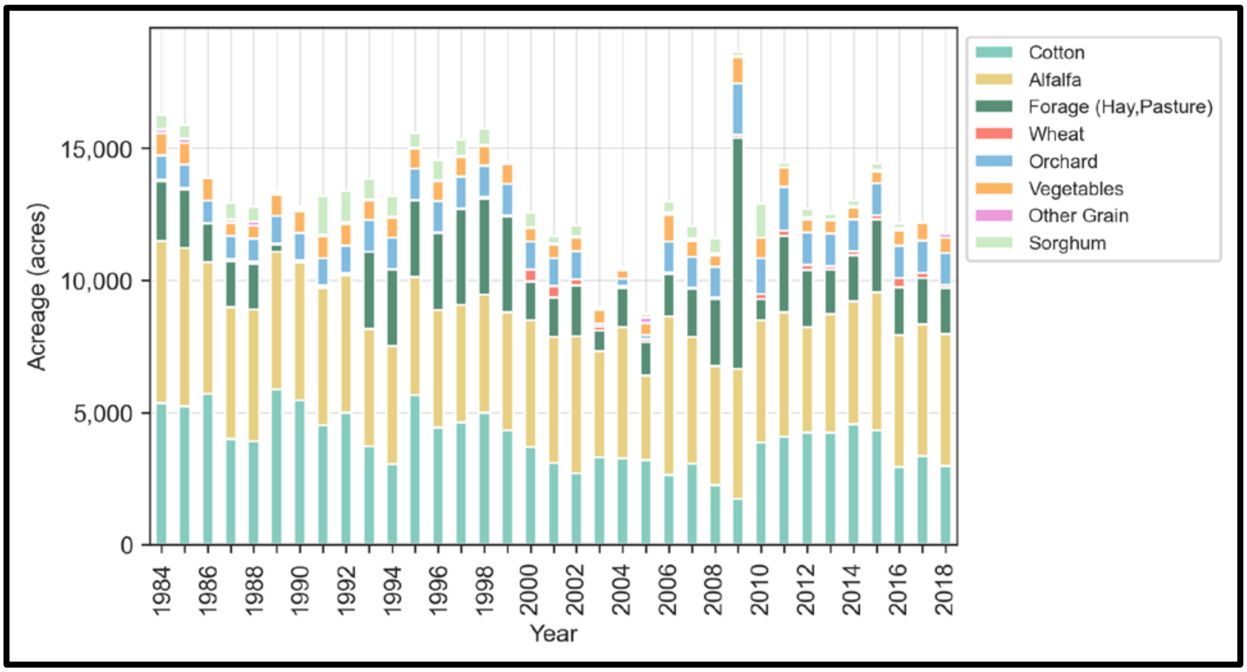


Figure 375. Estimated crop area associated with the Edwards-Trinity (Plateau) Aquifer in Pecos County.

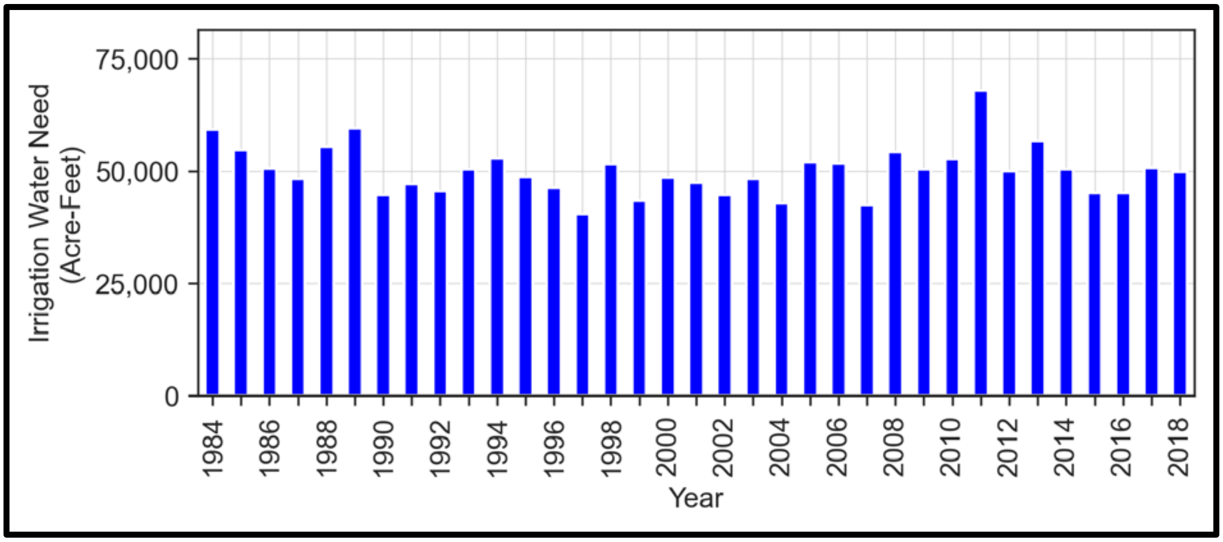


Figure 376. Estimated irrigation water need based on evapotranspiration estimates, without application of crop coefficients, for Edwards-Trinity (Plateau) Aquifer outcrop and subcrop areas in Pecos County.

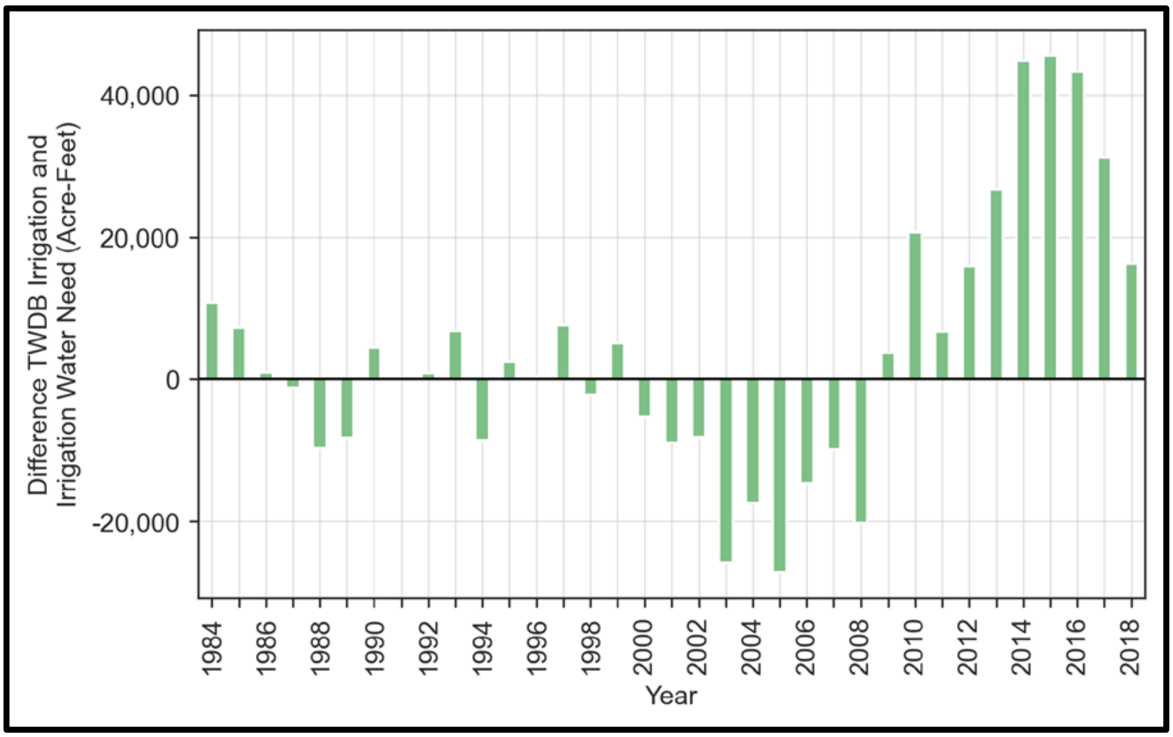


Figure 377. Difference between the Pecos County Edwards-Trinity (Plateau) Aquifer groundwater pumping, as reported in the TWDB Water Use Survey data, and the estimated irrigation water need based on evapotranspiration estimates, without application of crop coefficients, for Edwards-Trinity (Plateau) Aquifer outcrop and subcrop areas in Pecos County.

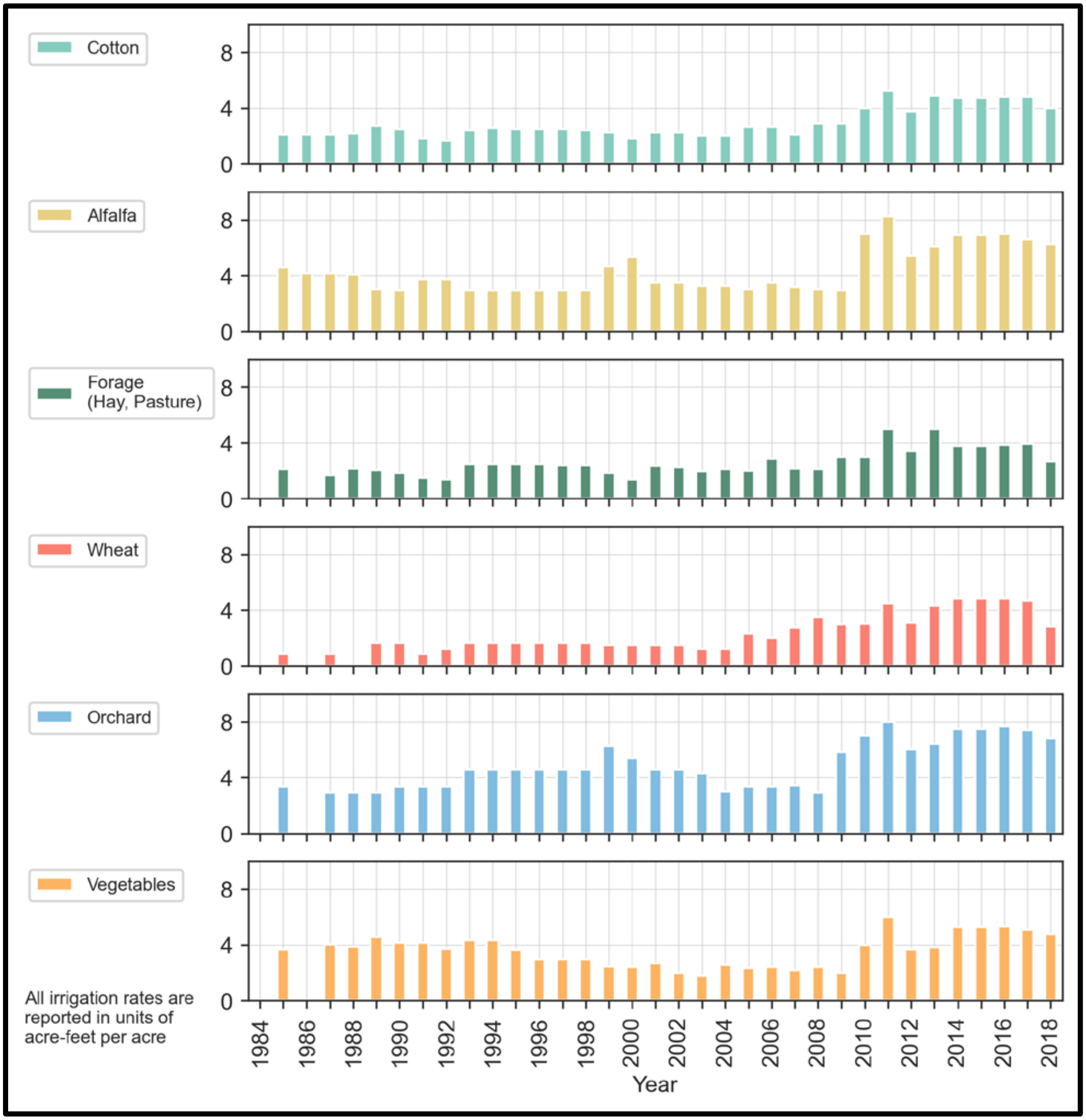


Figure 378. TWDB applied irrigation rates per year for the six highest estimated water use crops in Pecos County.

Table 61. Middle Pecos Groundwater Conservation District crop water use allocations.

Crop	Acre-Feet per Acre Allocation
Cotton	4
Alfalfa	7
Forage	4
Wheat	4
Pecans	7
Vegetables	4 to 7

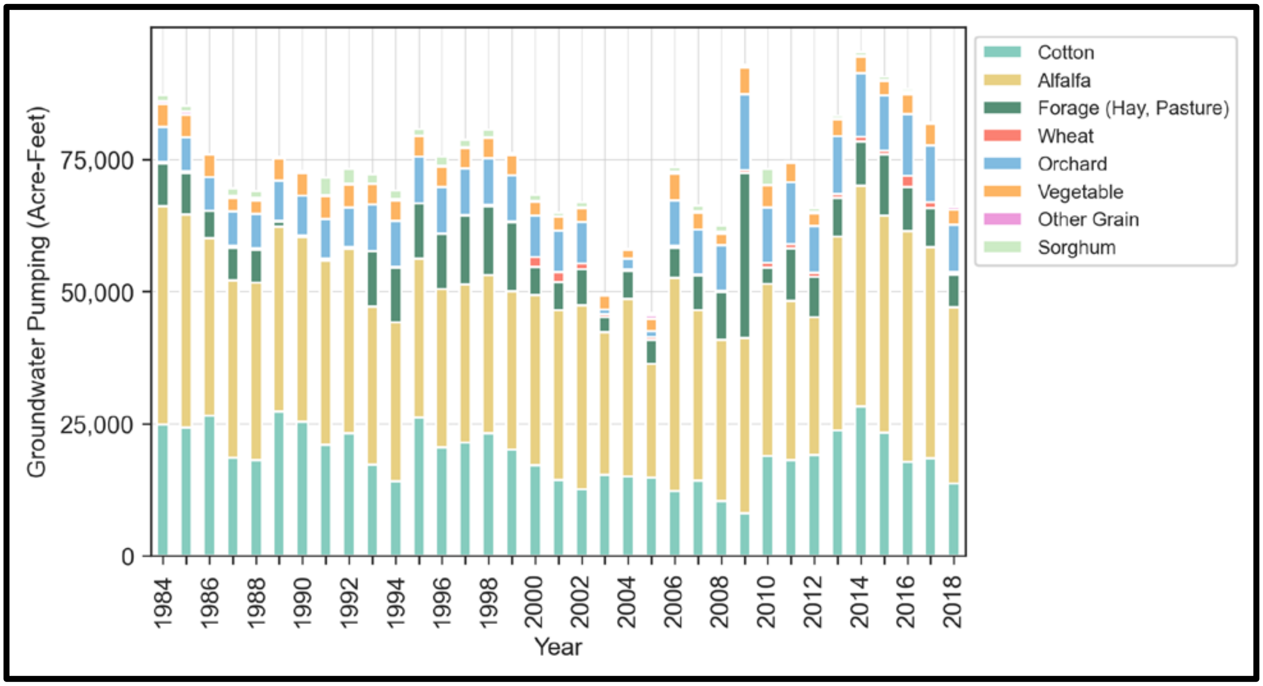


Figure 379. Estimated groundwater pumping for crop areas associated with the Edwards-Trinity (Plateau) Aquifer in Pecos County.

The Middle Pecos Groundwater Conservation District has required annual pumping reports from non-exempt and Historic and Existing Use permit holders for more than ten years. While most permit holders do not meter pumping, some of the larger irrigation operations meter and/or tally their pumping on a daily basis. Other permit holders simply report pumping in accordance with their Historic and Existing Use allocations. Therefore, reported pumping is not necessarily accurate. Additionally, the District continuously monitors water levels in numerous wells across its jurisdiction, including in areas where the highest concentration of pumping occurs. Continuing to compare pumping estimates derived from methodologies developed for this study to reported pumping and aquifer responses will allow for refinement. Finally, for Pecos County the Middle Pecos Groundwater Conservation District has developed a three-dimensional geologic model that may be useful in discerning and refining the vertical distribution of pumping within the aquifers.

4.3 Power

The Water Use Survey groundwater pumping volumes for power use are primarily based on the responses to the annual survey sent to power generating entities, excluding any co-generation facilities (as these are included in the manufacturing water use). All electric power generating plants that sell power on the open market are surveyed regardless of volume pumped (TWDB, 2020a).

Methodology to Address Water Use Survey Power Pumping Anomalies

We investigated anomalies identified in the power groundwater pumping by first reviewing the values reported by each entity in each county. We used the historical Water Use Survey data to facilitate this review. By reviewing each entity, we were able to identify issues that may have been the cause of the Water Use Survey anomaly in the county-wide datasets.

For example, if an entity did not report pumping for some years, we sought to determine if the entity existed during those years. If the entity did exist, we then investigated if they should have reported pumping. If the entity should have reported, we began investigating if the pumping was reported elsewhere or if we could estimate the pumping for the missing year(s).

To estimate pumping, we began with data available from the Energy Information Administration, in particular forms EIA 860 (EIA, 2020a) and EIA 923 (EIA, 2020b), to determine the power plant type, fuel type, cooling system type and the annual net generation for each power plant configuration. We used net generation instead of gross generation to estimate groundwater pumpage because it was available for the entire study period from 1984 to 2018 whereas gross generation values are only available from 2011 onwards. We then converted the net power generation values to volumes of water used following the methods described by Sledge and others (2003) to estimate water use for years with anomalous data to update the Water Use Survey pumping dataset. In all instances, our computed net generation values were positive.

Sledge and others (2003) conclude that it is possible to estimate water usage from power generation values based on the type of generation, fuel type, type of cooling system, and electric production of the plant. The main data source for the detailed power generation information is the United States Energy Information Administration. This organization was established in 1977 by the Department of Energy Organization Act to become the single Federal Government authority for energy information. Soon after establishment, the Energy Information Administration began gathering detailed data on energy industry finances, energy consumption, and greenhouse gas emissions, among others. Using data from forms EIA 860 (EIA, 2020a) and EIA 923 (EIA, 2020b), we were able to apply the method of Sledge and others (2003) to estimate water use for power generation. This method is schematically illustrated in Figure 380.

Once we addressed the anomalies in the pumping data, we assigned the location of the pumping from the entity corresponding to the entity's well location(s). The vertical distribution of pumping (that is, from which aquifer the groundwater is withdrawn) corresponds to the well's open interval depths (if known) or the well depth. Figure 381 illustrates our plan for addressing anomalies in the Water Use Survey data and for developing a groundwater pumping dataset for pumping associated with power use.

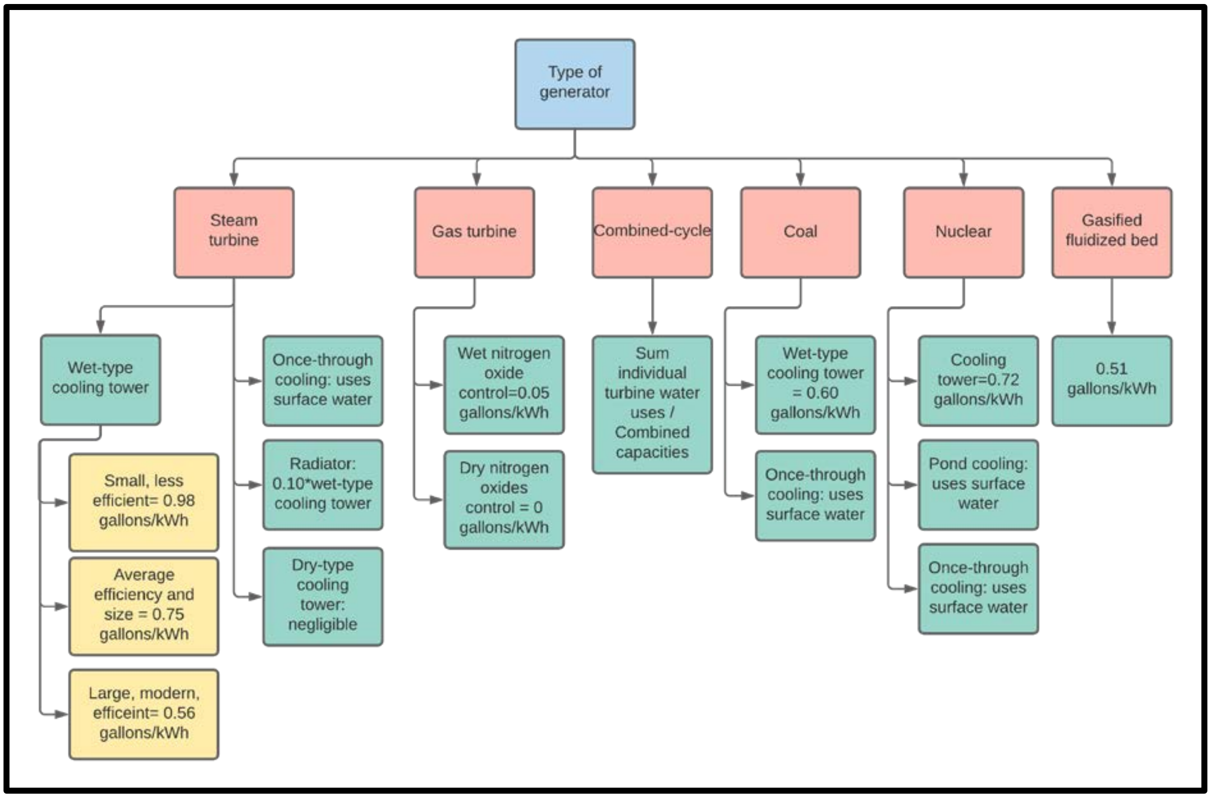


Figure 380. Methodology to estimate water use for power generation based on the type of generation.

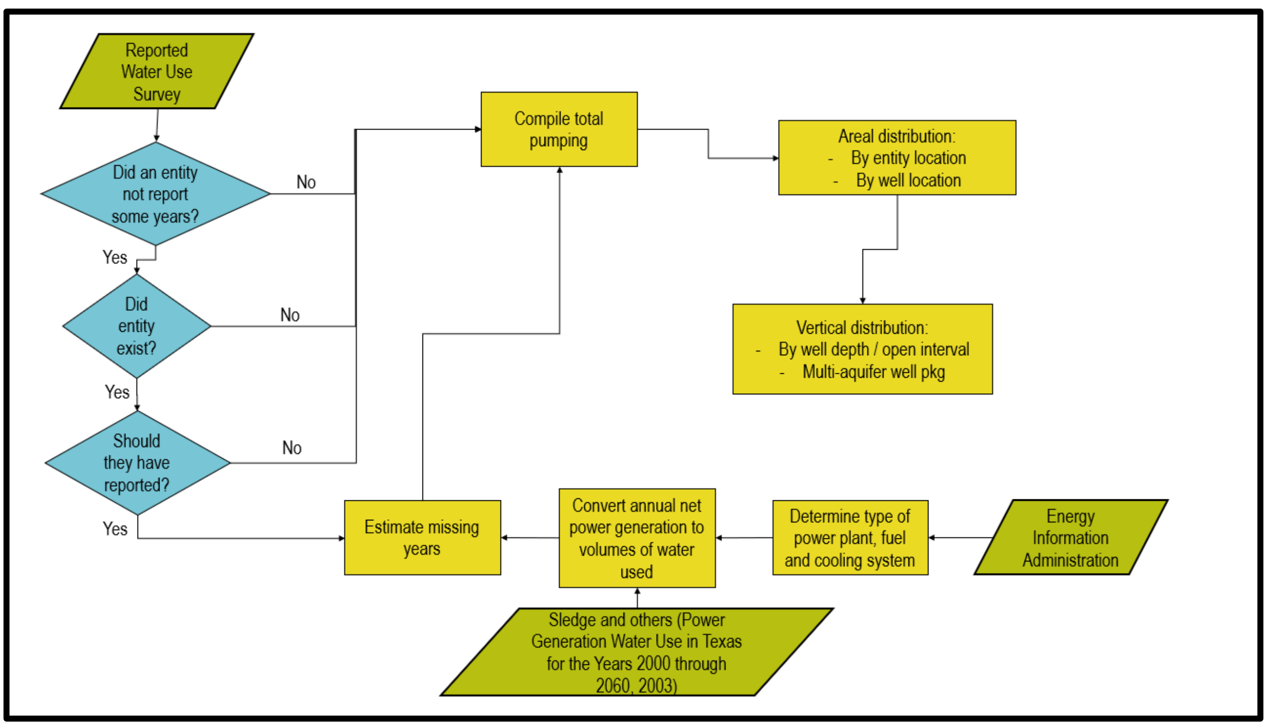


Figure 381. Schematic diagram illustrating the plan to address anomalies in the power pumping Water Use Survey data and for preparing a pumping dataset.

Power Methodology Test Case

As a test case for estimating pumping for power generation use, we applied our methodology to data for Ward County. As reported in Section 3.3.51 and illustrated on Figure 382, pumping from the Pecos Valley Aquifer in Ward County for power use generally ranged between 4,000 and 6,000 acre-feet between 1984 and 2003 except for 1988 when pumping decreased abruptly to less than 2,000 acre-feet. From 2003 through 2012, pumping for power use decreased gradually. After 2012, the Water Use Survey dataset does not contain data for power use. We found several anomalies in the data based on manual review, a year-to-year change analysis, and a standard deviation analysis (see Figure 382).

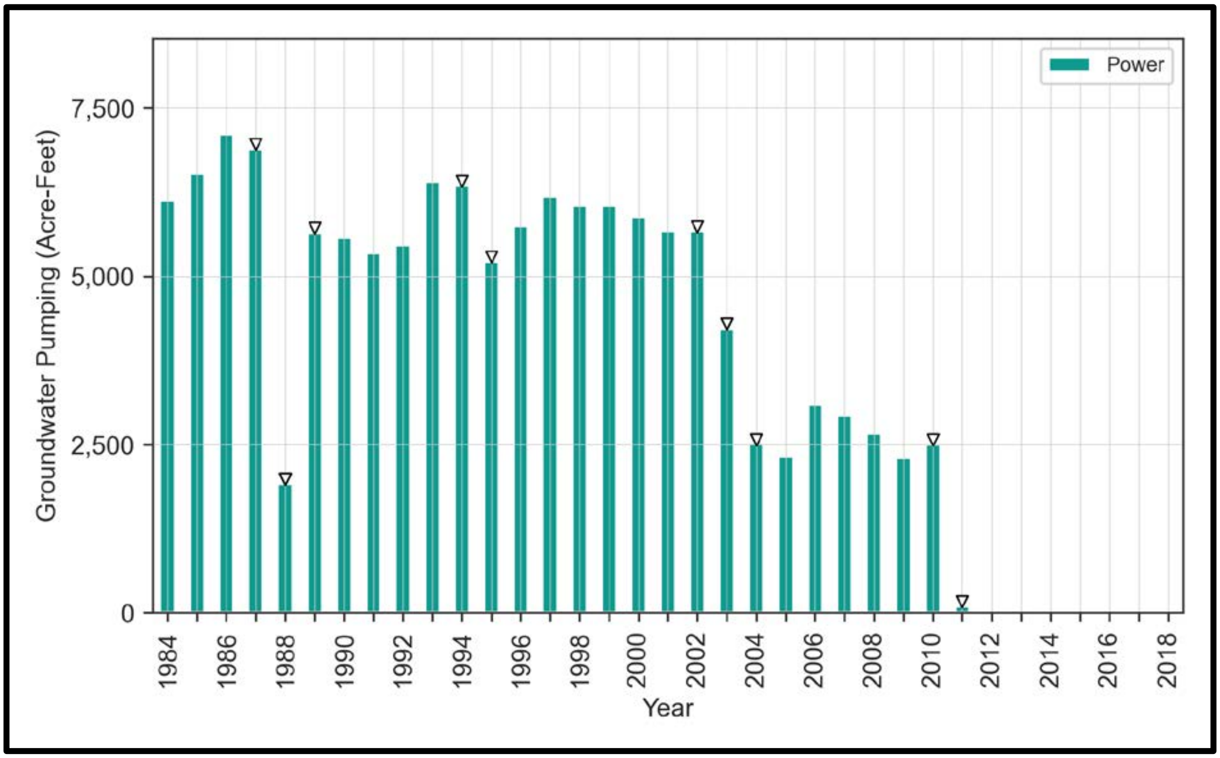


Figure 382. Ward County Pecos Valley Aquifer groundwater pumping for power use as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Pecos Valley Aquifer pumping for power use per entity in Ward County, we determined there was only one surveyed entity reporting groundwater production. The sole reporting entity was Luminant Generation Company LLC - Permian Basin Steam Electric Station (hereafter referred to as "Luminant Power Plant"). The location of the Luminant Power Plant is shown in Figure 383.

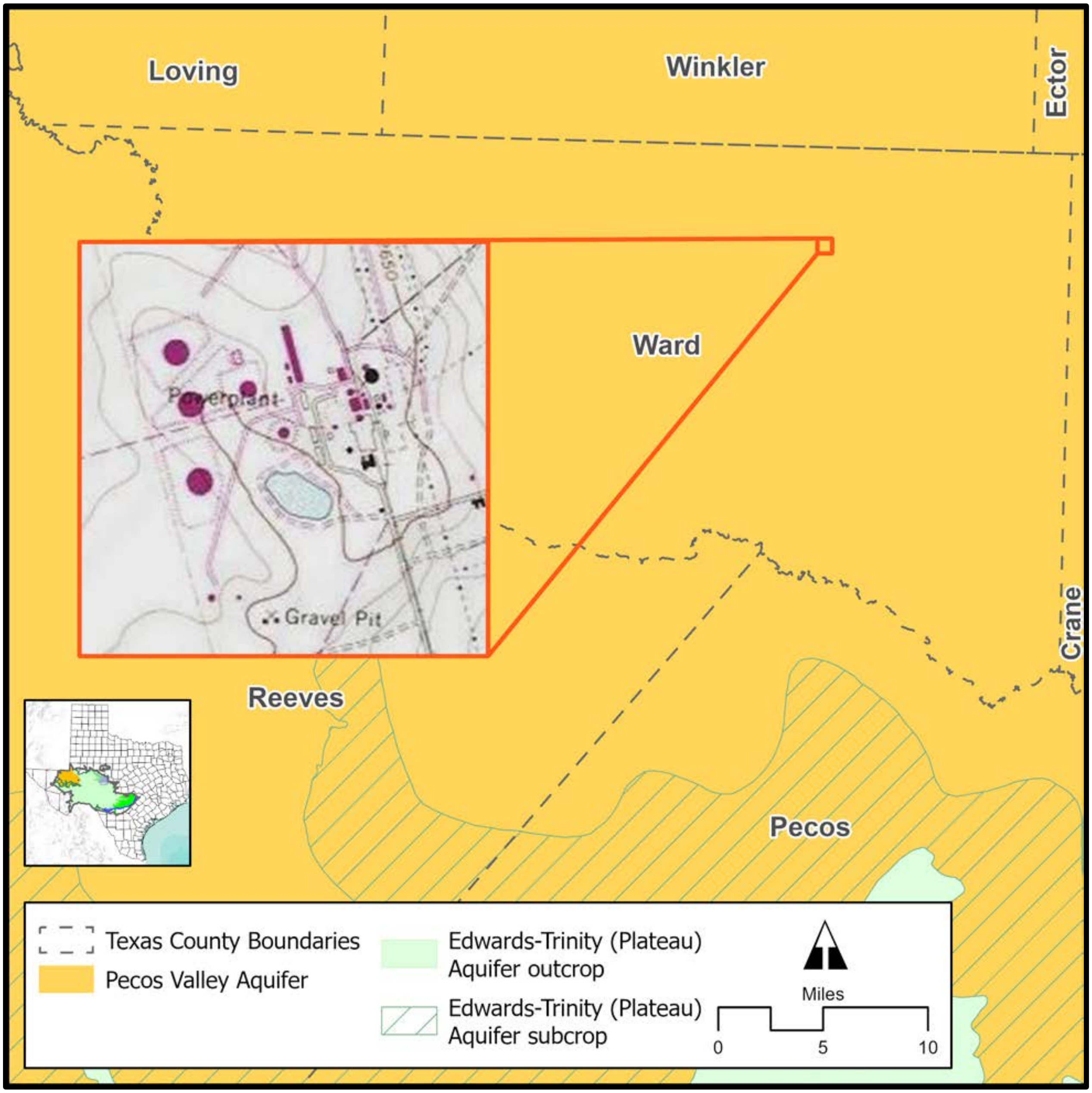


Figure 383. Location of the Luminant Power Plant in Ward County.

The Luminant Power Plant has a 325-megawatt operating capacity. It is a gas-fired facility with five combustion turbines, one mothballed steam unit, and one retired steam unit (Luminant, 2015). To investigate the anomalies in the Water Use Survey data, we reviewed the two applicable forms from the Energy Information Administration. Form EIA-860 (EIA, 2020a) has information regarding the type of power generation turbine used, the cooling tower type, fuel type, and whether the turbine was operating or out of service. Form EIA-923 (EIA, 2020b) has annual net power generation data for each power generating unit. Table 62 presents the timeline of operation events as provided on form EIA-860.

Table 62. Luminant Power Plant timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type
1958	ST 5	Began operation	Steam Turbine	Fossil fuels	Mechanical draft, wet process
1973	ST 6	Began operation	Steam Turbine	Fossil fuels	Mechanical draft, wet process
1988	CTs 1, 2, 3	Began operation	Gas Turbine	Fossil fuels	Not Applicable
1990	CTs 4, 5	Began operation	Gas Turbine	Fossil fuels	Not Applicable
2011-2015	ST 5	Out of Service	Steam Turbine	Fossil fuels	Mechanical draft, wet process
2012	ST 6	Out of Service	Steam Turbine	Fossil fuels	Mechanical draft, wet process
2012-2015	ST 6	Standby	Steam Turbine	Fossil fuels	Mechanical draft, wet process
2016	STs 5, 6	Retired	Steam Turbine	Fossil fuels	Mechanical draft, wet process

According to Sledge and others (2003), most of the water for a power plant is utilized in the cooling process. However, the amount of use is largely dependent on the type of device used to power the electric generator. Also, there are additional amounts of water for purposes other than cooling in some generation processes.

Steam turbines and boilers, such as Luminant Power Plant units ST 5 and ST 6, heat water and subsequently condense the steam. These types of turbines have cooling requirements much greater than combustion or gas turbines. Using information gathered from EIA-860 (Table 62), we know that the Luminant Power Plant steam turbines use a wet-type cooling tower. The Luminant Power Plant would fall under the classification of a large power plant but given that the power plant began operation in 1958 we can assume that it is not as efficient as a modern power plant. We therefore assigned it an average water use value of 0.75 gallons per kilowatt-hour (see Figure 380).

Gas turbines have relatively small cooling systems in comparison to steam turbines since water is used only to control emissions of nitrogen oxides (Sledge and others, 2003). Form EIA-860 did not specify if the gas turbine used a wet or dry nitrogen oxide control. Given that the gas turbines started operating in 1988 (EIA, 2020a), we can assume that the turbines used wet nitrogen oxides control. Based on our assumption, we assigned the years with gas turbine operation a water use value of 0.05 gallons per kilowatt-hour.

Using the net power generation values from form EIA-923 (EIA, 2020b), we were then able to address the identified anomalies in the Water Use Survey data. Ideally, we would prefer to use the gross power generation values, as these include generation used on site by the facility rather than just the amount sold, for estimating the water use for the facility. However, only net power generation values are publicly available from the Energy Information Administration.

Figure 384 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Luminant Power Plant. Figure 384e illustrates the complete estimated pumping dataset incorporating the Water Use Survey data with the pumping estimates based on the turbine type. We applied these revised estimates of pumping for power use from the Pecos Valley Aquifer in Ward County based on the location of the power plant (Figure 383) and any associated wells.

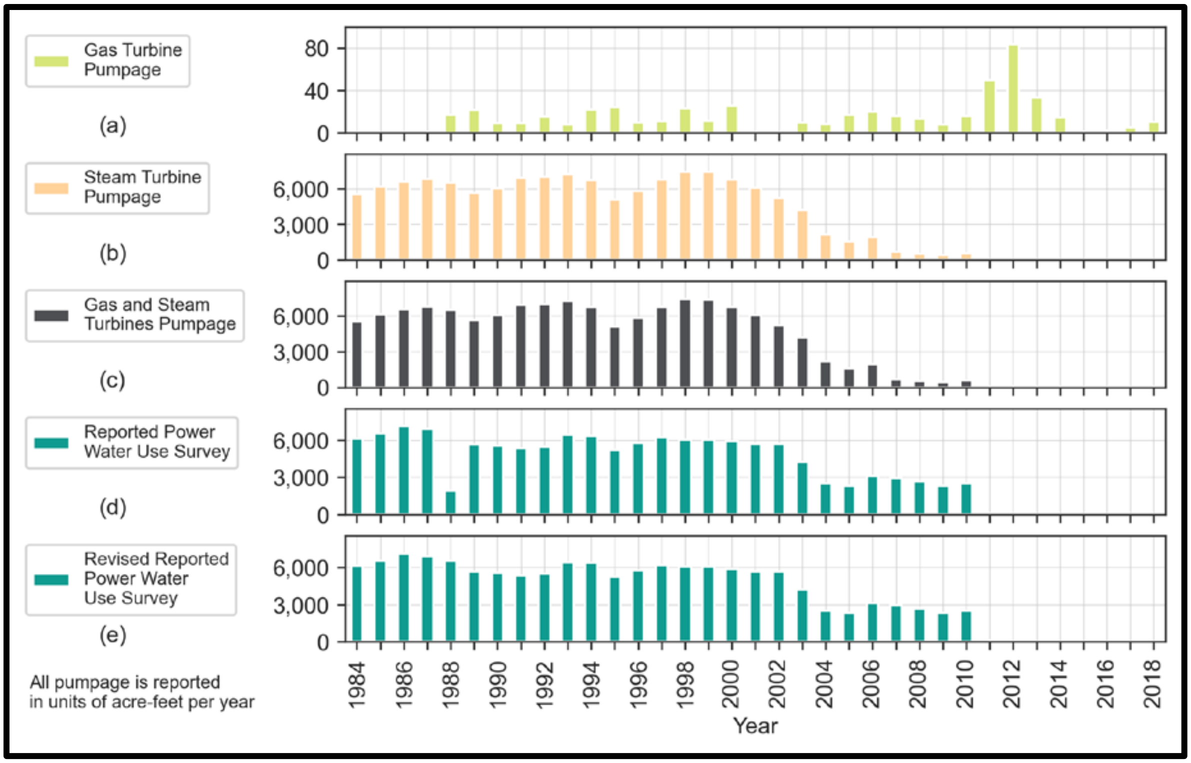


Figure 384. Luminant Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated groundwater pumping associated with steam turbine power generation, (c) Estimated combined groundwater pumping by both steam and gas turbines (d), Reported groundwater pumping by the Water Use Survey, and (e) Revised groundwater pumping.

4.4 Mining

The TWDB aggregates the water used in the extraction of minerals or materials, including oil, natural gas, sand, gravel, aggregates, coal, uranium, and other materials in the mining water use category. The water use volume is composed of both the annual net use of survey facilities (such as coal, sand and gravel, and aggregate facilities) and the estimated (non-surveyed) water use of the hydraulic fracturing and drilling activities occurring in each county (Billingsley, 2019).

Methodology to Address Water Use Survey Mining Pumping Anomalies

Surveyed water use for mining is reported annually by large groundwater users (primarily quarries and lignite mines). Non-surveyed mining pumping estimates included within the TWDB Water Use Survey database represent water volumes from smaller users (primarily oil and gas); these estimates have been prepared since 2008. These estimates typically have an “Unknown” aquifer designation, due to oil and gas operators often choosing to use brackish or saline groundwater sources. TWDB staff have historically calculated total non-surveyed oil and gas water use estimates based on FracFocus data, and applied estimated water source split percentages (groundwater/surface water and brackish/fresh) from Nicot and others (2012).

We reviewed various estimates of water usage for oil and gas production from the U.S. Geological Survey (Lovelace, 2009b), the FracFocus database (FracFocus, 2021), the Bureau of Economic Geology (Nicot and others, 2011; Nicot and others, 2012), and the TWDB Water Use Survey database. We also prepared estimates for freshwater usage associated with oil and gas production using a modification of the method by Nicot and others (2012). We derived the estimates of non-surveyed groundwater use for mining through application of three methodologies. Our plan for estimating non-surveyed mining (that is, oil and gas) groundwater pumping is shown in Figure 385 with the three methodologies described below.

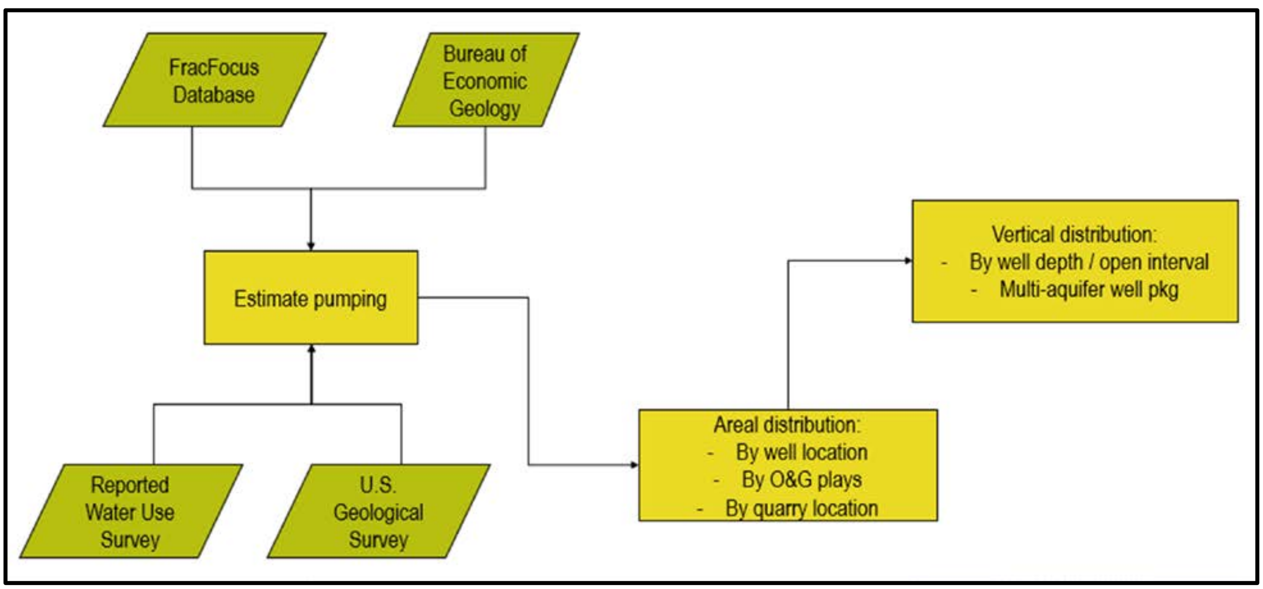


Figure 385. Schematic diagram illustrating the plan to prepare a non-surveyed mining pumping estimate.

Method #1 – U.S. Geological Survey – Groundwater Fresh

The U.S. Geological Survey maintains the national databases of water-use information. The data is collected and compiled every five years for each state. County-level data is available from 1985 to 2015. The mining water use data is classified into three categories – "Groundwater Fresh," "Groundwater Saline," and "Groundwater Total." We used only the freshwater estimates. Per Lovelace (2009b), water use estimates from the U.S. Geological Survey "Groundwater Fresh" data were derived in part through the following assumptions:

- Well counts are based on the number of secondary waterflood recovery wells;
- All of the water injected into oil and gas wells for production enhancement purposes was pumped groundwater, without any reuse;
- All wells required an equal volume of water, as calculated by dividing the total amount of water requested in permit applications by the total number of wells requested on the permit application; and,
- In cases where a combination of fresh and saline water was indicated, it was assumed that half of the water used was fresh water.

Since the data are available at five-year intervals, we used linear interpolation to estimate water use data on an annual basis for the years 1985 through 2015.

Method #2 – Data Extraction from the FracFocus Databases

Data from databases maintained by FracFocus is available from 2012 to 2019 (FracFocus, 2021). The data is available for an entire country and the total volume of water used from hydraulic fracturing is provided. We performed data analysis by extracting the FracFocus data, consolidating to yearly totals, and calculating the total volume of water use from the extracted sites, taking into account the locations of wells and the aquifer footprints within each county. Importantly, this data only pertains to total water used in hydraulic fracturing operations. Because reuse of water is common in hydraulic fracturing operations, it is not expected that fresh groundwater would make up a large percentage of the total use.

Method #3 –Bureau of Economic Geology Estimates

The report "Oil & Gas Water Use in Texas: Update to the 2011 Mining Water Use" (Nicot and others, 2012) documents future and projected water use in all segments of the Texas oil and gas industry. The report contains a detailed analysis and accounting of water usage within three main categories in the upstream segment of the oil and gas industry: 1) drilling, 2) waterflooding and enhanced oil recovery, and 3) hydraulic fracturing. Water usage is estimated by multiplying the number of active oil and gas wells by the average water usage by each well according to the following steps:

1. Estimate Water Use Percentages for Reuse, Brackish and Freshwater
2. Estimate the Groundwater split
3. Distinguish between water usage for horizontal and vertical wells

Based on our review of the available information, we used Method #3 (Nicot and others, 2012) for estimating groundwater pumping associated with oil and gas activities.

Once we have prepared the non-surveyed pumping data, we will assign the location of the pumping based on known well locations corresponding to the reporting entity. The vertical distribution of pumping (that is, from which aquifer the groundwater is withdrawn) will be determined based on the well's open interval depths (if known) or the well depth.

Mining Methodology Test Case

As a test case for the plan, we focused on the non-surveyed estimate for Reeves County. Figure 386 illustrates the TWDB Water Use Survey mining use pumping values for the Pecos Valley aquifer in Reeves County. However, as mentioned above, there are estimates of water use for mining beginning in 2008 with an "Unknown" aquifer designation.

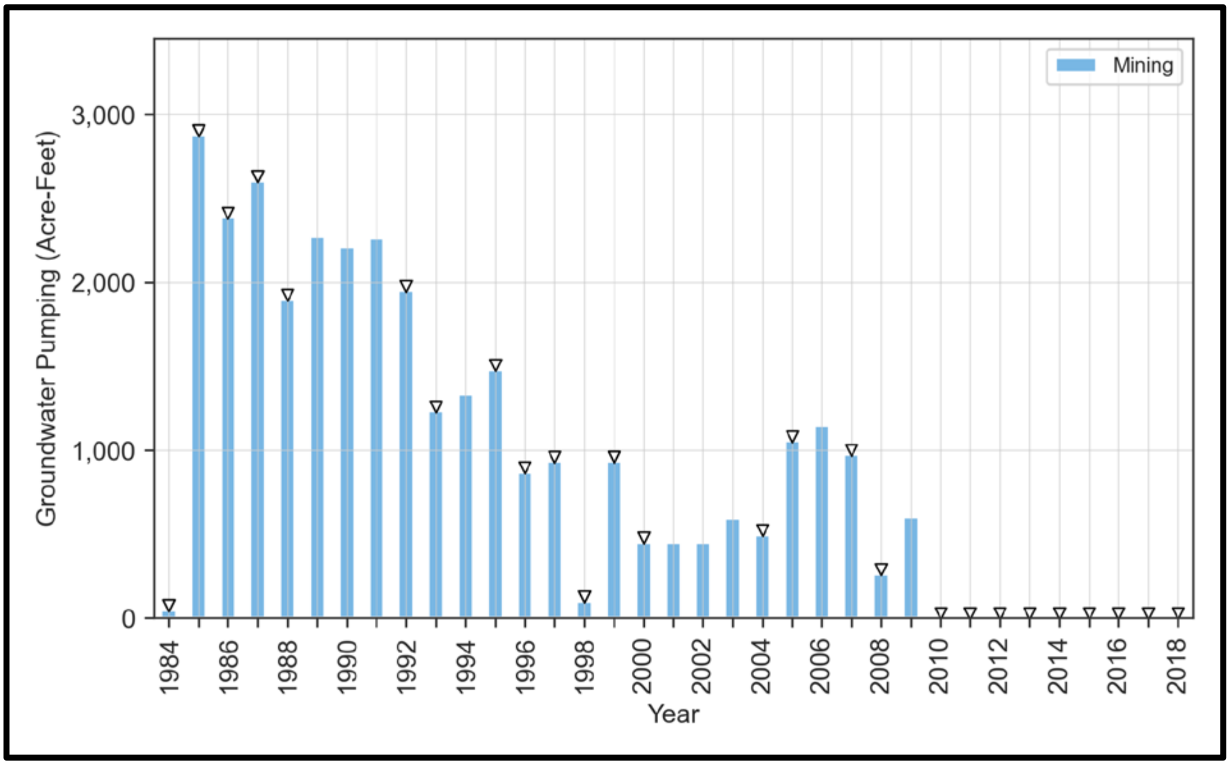


Figure 386. Reeves County Pecos Valley Aquifer groundwater pumping for mining use as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

For our test case, we reviewed the estimates for water usage to support oil and gas operations, calculated on a freshwater basis using U.S. Geological Survey (Lovelace, 2009b) and the modified Bureau of Economic Geology methodology. These are shown below along with the FracFocus total water usage for hydraulic fracturing and the TWDB Water Use Survey non-surveyed mining estimate in Table 63.

Table 63: Estimates of Non-Surveyed Oil and Gas Groundwater Use for Reeves County

Year	U.S. Geological Survey (Groundwater-Fresh)	FracFocus (Total Water Use in acre-feet)	TWDB Water Use Survey Non-Surveyed Estimate	Modified Bureau of Economic Geology Water Use*
1984				53
1985	45			63
1986				68
1987				68
1988				69
1989				71
1990	672			72
1991				72
1992				72
1993				72
1994				73
1995	1,423			75
1996				75
1997				75
1998				71
1999				83
2000	213			83
2001				83
2002				83
2003				83
2004				83
2005	103			78
2006				91
2007				106
2008			121	131
2009			275	158
2010	1,031		429	86
2011			193	225
2012		1,407	43	247
2013		1,595	401	246
2014		6,289	1,065	246
2015	1,367	8,851	1,371	235
2016		14,668	1,558	235
2017		18,213	5,648	235
2018		18,309	8,000	235

*Uses Railroad Commission Enhanced Recovery well count and Bureau of Economic Geology estimates of water use per horizontal/vertical well on a county level basis over the Pecos-Valley aquifer. Per-well water use estimate values extended to the years (1984-2003, 2013-2018) not covered by the Bureau of Economic Geology report (Nicot and others, 2012).

Method 1 (U.S. Geological Survey) is the simplest approach for estimating groundwater pumping associated with oil and gas. Method 2 is also simply reporting the values from FracFocus. As stated previously, our approach focused on applying Method 3. Using Method 3, based on the literature review and data analysis, the average water use per well in Reeves County may be obtained by implementing the procedural steps listed below:

1. Estimate Water Use Percentages for Reuse, Brackish and Freshwater: As Reeves County falls in Permian Far West region, the estimated percentages of recycling/ reused, brackish, and freshwater used in mining wells is shown in Table 7 of Nicot and others (2012).
2. Estimate the groundwater split: Based on Table 8 of Nicot and others (2012), estimated groundwater split for Permian Far West region is 100 percent.
3. Distinguish between water usage for horizontal and vertical wells: Use Nicot and others (2012, p. 37) to compile different water use estimates for horizontal and vertical wells. From Figure 25 of Nicot and others (2012), the ratio of horizontal to vertical wells in Reeves County is 3.5 (that is, for every horizontal well there are 3.5 vertical wells). We applied this ratio to the number of active enhanced oil recovery wells in each year.

We obtained the average per-well water use estimates for each year from 2004 to 2012 from Nicot and others (2012, pp. 30-31) for horizontal and vertical wells, respectively. We based the average per-well water use estimates for other years (1984-2003, 2013-2018) on the 2004-2012 estimates. The total water use in each year was calculated by combining water use from both horizontal and vertical wells. The number of active Class II enhanced oil recovery injection wells in each year in Reeves County were determined by analyzing the Texas Railroad Commission Underground Injection Control Database as well as the Oil and Gas Well Data Full Wellbore Database (RRC, 2021a).

A list of all Class II Injection wells within Reeves County from 1980 through 2020 was generated by importing the underground injection control wells into the ESRI ArcGIS software and clipping the dataset to Reeves County. The list of Class II Injection wells within Reeves County was exported to MS Access, where fields from the Full Wellbore Database were appended for respective API Numbers, including “WB_ORIG_COMPL_YY”, which is the date reported on the W-2 or G-1 forms when the well was originally completed, and “WB_SHUT_IN_YEAR”, which is the date that all wells in a wellbore have been inactive. The list was then exported to Excel, and a matrix of wells active in each year was generated using various logic statements with the determined range of years extracted from the Full Wellbore Database fields (“WB_ORIG_COMPL_YY” and “WB_SHUT_IN_YEAR”). As a final step, the matrix was filtered to include only enhanced oil recovery wells. Historical enhanced oil recovery wells compiled as described above are shown in Figure 387, Figure 388, and Figure 389 for selected years 1990, 2010, and 2018 respectively.

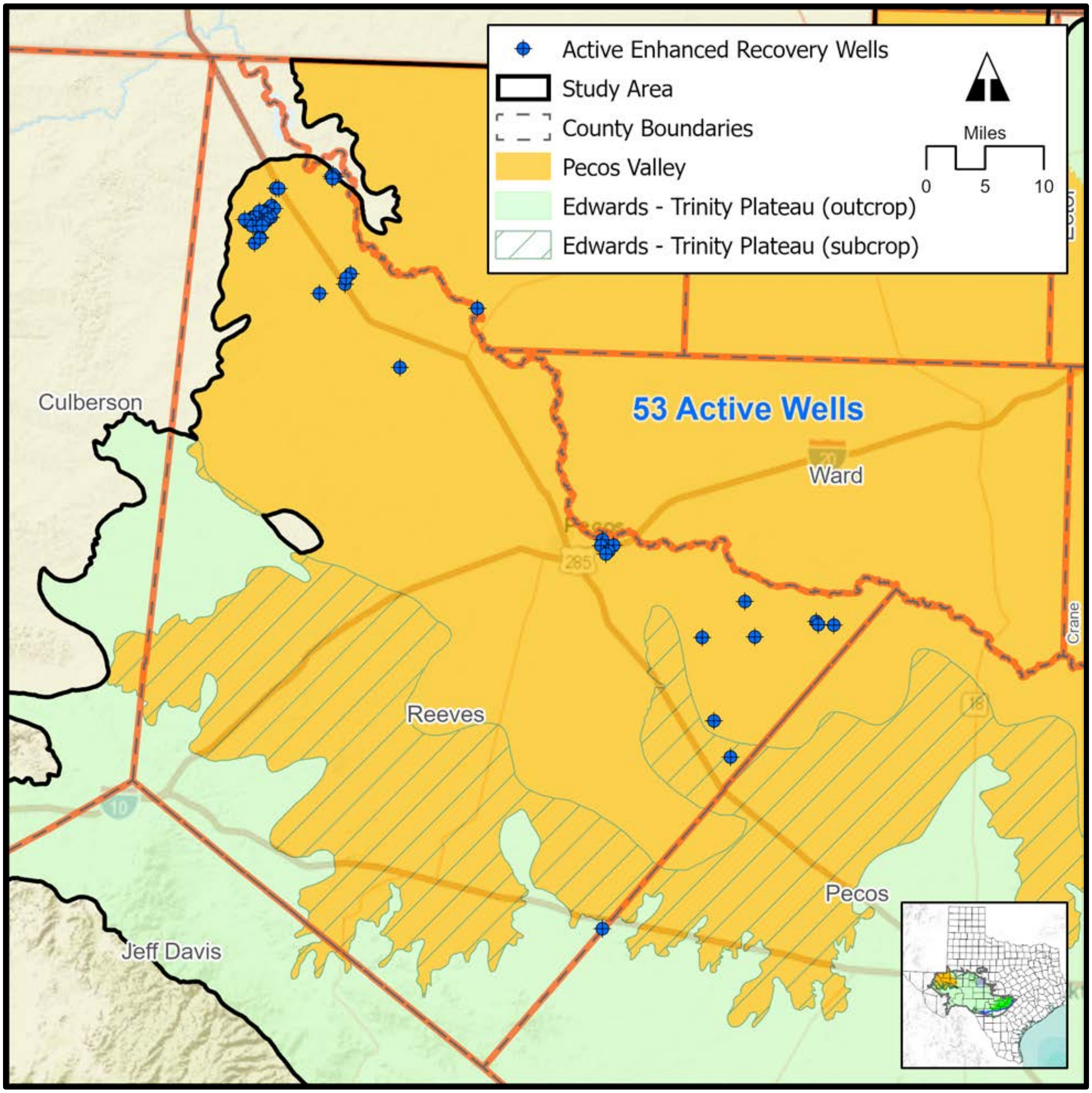


Figure 387. **Active enhanced recovery wells in Reeves County in 1990.**

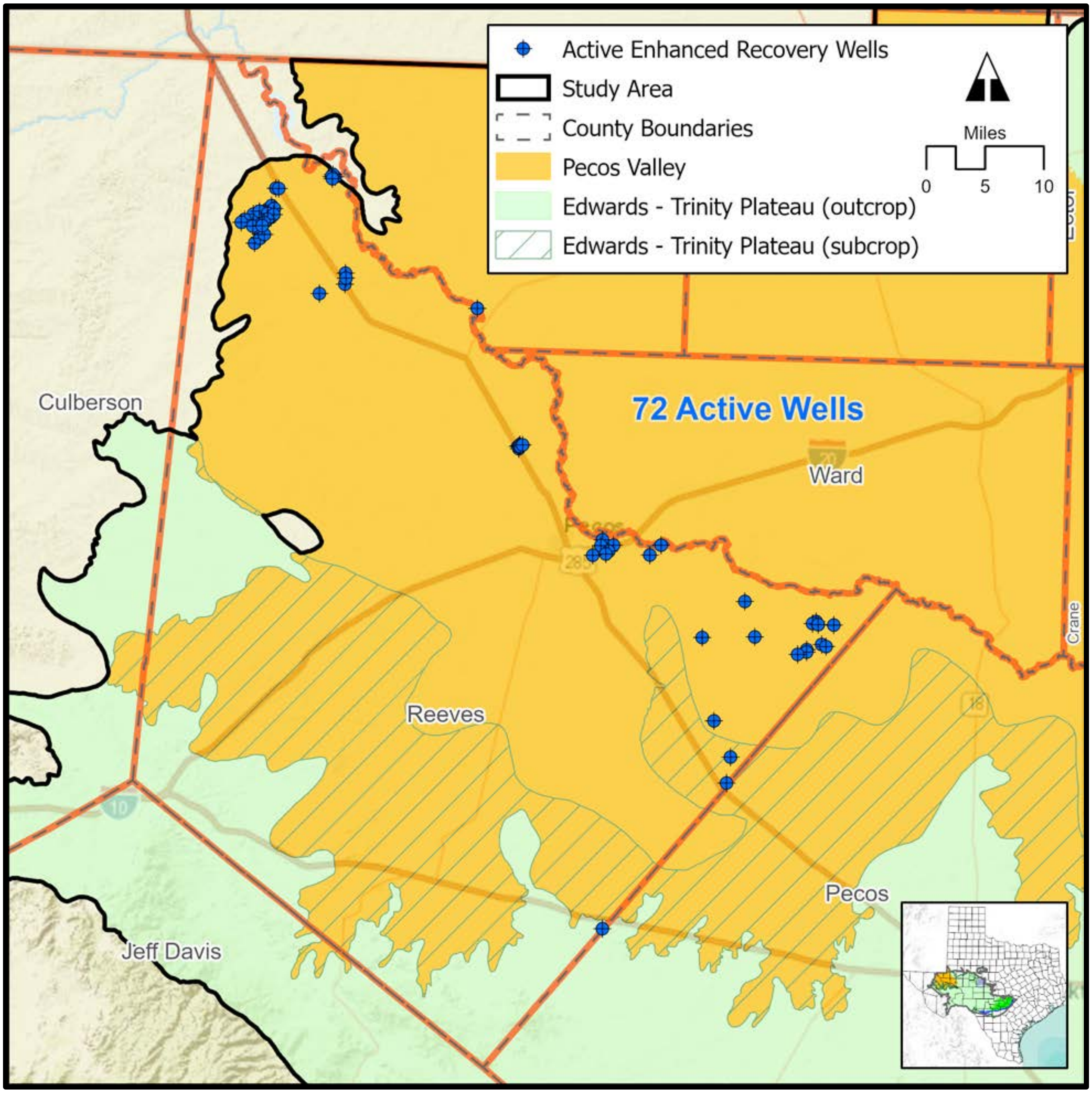


Figure 388. Active enhanced recovery wells in Reeves County in 2010.

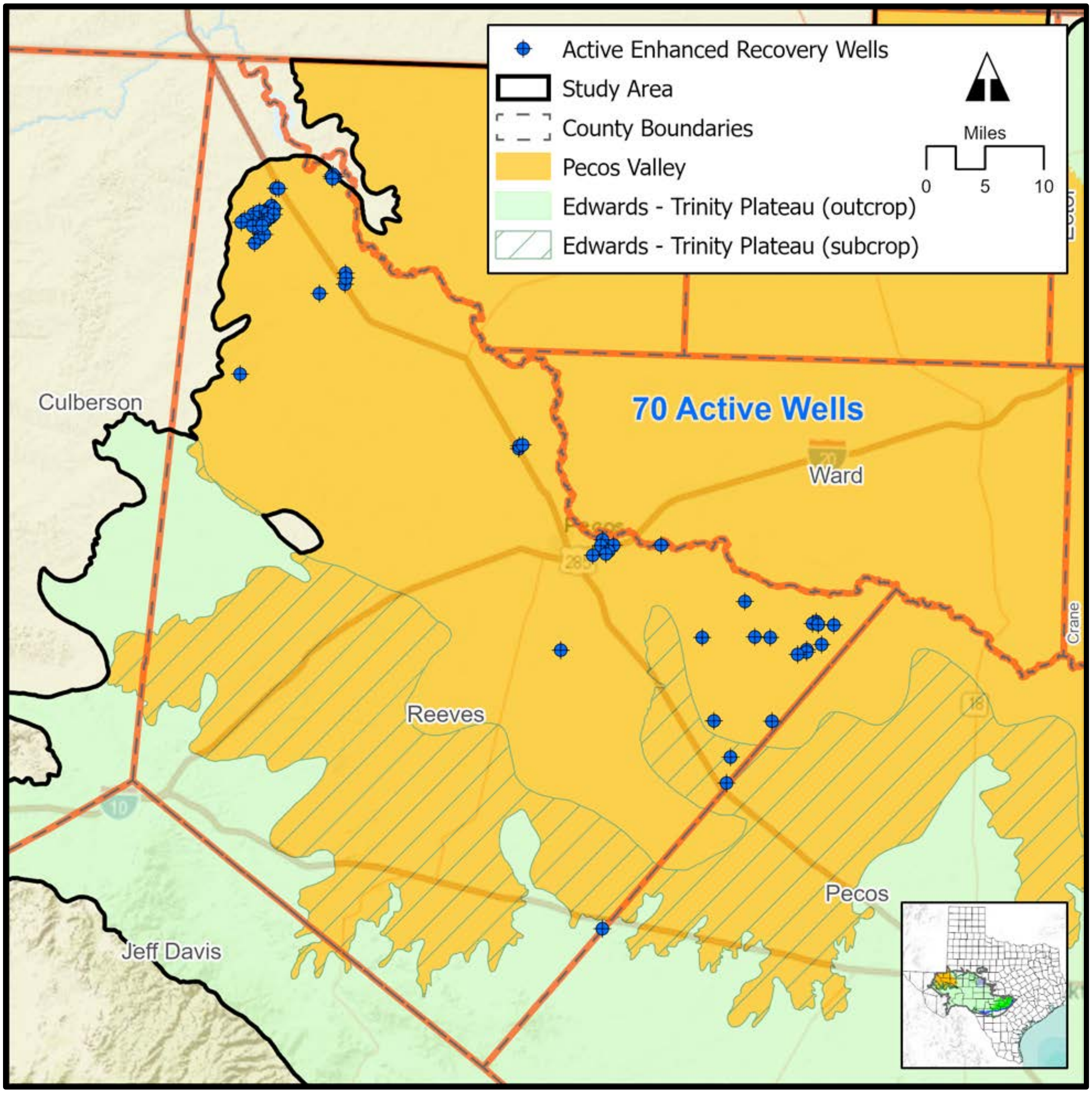


Figure 389. Active enhanced recovery wells in Reeves County in 2018.

Figure 390 illustrates the non-surveyed mining pumping estimate for Reeves County based on Method #3. We applied these revised estimates of pumping for mining use based on the location of the historical enhanced oil recovery wells and assigned the pumping to the Pecos Valley Aquifer.

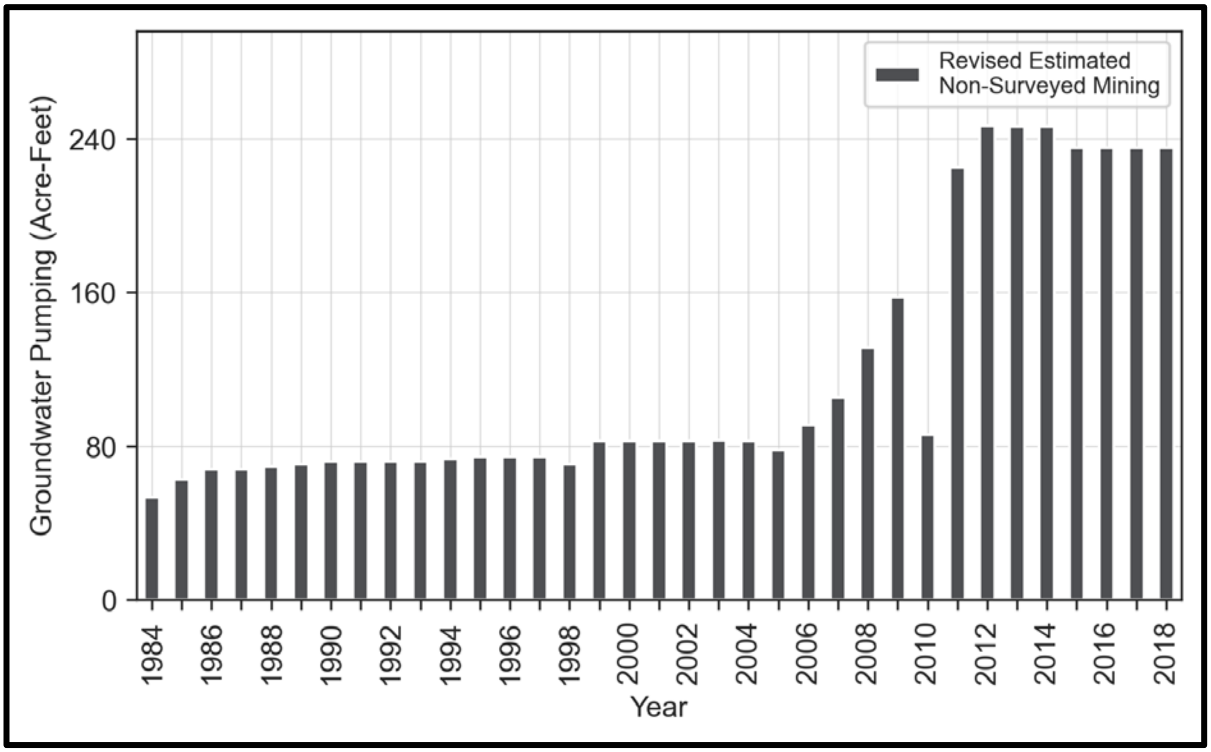


Figure 390. Revised estimates of non-surveyed mining use groundwater pumping from the Pecos Valley Aquifer in Reeves County from 1984 through 2018.

4.5 Manufacturing

Manufacturing water use is based on the responses to the annual industrial Water Use Survey. The groundwater pumping for manufacturing use includes the surveyed self-supplied groundwater volumes used by manufacturing facilities and the purchased groundwater volumes for manufacturing from non-surveyed sellers sourced to a county and aquifer. (Billingsley, 2019)

Methodology to Address Water Use Survey Manufacturing Pumping Anomalies

Water use estimates for manufacturing are based on annual survey reports of pumped groundwater submitted by large manufacturers. We evaluated anomalies identified in the manufacturing groundwater pumping by first reviewing the values reported by each entity in a county. For example, if an entity did not report pumping for some years, we sought to determine if the entity existed during those years. If the entity did exist, we then investigated if they should have reported pumping. If the entity should have reported, we began by investigating if the pumping was reported in a different use category, under a different entity name, or as being from a different aquifer or county. Figure 391 illustrates our plan for addressing identified manufacturing water use anomalies.

For anomalous pumping values where the entity and aquifer were correct, we updated the pumping value to be consistent with other pumping data reported by the entity. For example, if the entity went out of business, its pumping would be set to zero but if the entity was missing a year, we deemed it reasonable to interpolate the missing value.

Figure 391 illustrates our plan for addressing identified manufacturing water use anomalies.

Once we have addressed the anomalies in the pumping data, we will assign the location of the pumping based on the known well locations, facility locations, or service area pertaining to each entity. To create a pumping distribution file, we researched the latitude and longitude coordinates for each entity. In cases where the entities and their associated wells were listed in the TWDB Groundwater Database (TWDB, 2020b), we used the reported well coordinates. We also checked the Submitted Driller's Reports database (TWDB, 2020f) to locate additional wells.

If no well location could be found in either database, we assumed that each entity pumps water from a well near their respective facility and will use the facility address as an approximate location for pumping. We verified the address of each entity using Google Earth. In instances where an address could not be verified, perhaps because the entity was no longer in business, the nearest city was used as a surrogate for location. When the entity's address or city could not be confirmed, we used the coordinates for the center of the county.

The vertical distribution of pumping (that is, from which aquifer the groundwater is withdrawn) will correspond to the well's open interval depths (if known) or the well depth. For wells in all use categories with reported completion interval data, we will set up the MODFLOW package creation tools to allow users of the tools the option for writing the applicable multi-aquifer well package (such as, MNW2 for MODFLOW-NWT or MAW for MODFLOW 6).

Manufacturing Methodology Test Case

As a test case for the plan, we reviewed the Comal County Water Use Survey pumping data for manufacturing use. As illustrated on Figure 392, estimated and reported pumping for manufacturing use ranged between 400 and 9,200 acre-feet for the years 1984 through 2003. As can be seen in Figure 392, many of the reported estimates are anomalous with respect to both pumping volume and the designated aquifer. Most reported manufacturing pumping occurs in the Edwards (Balcones Fault Zone) Aquifer, however there are anomalous years in 2012, 2014, and 2015 where manufacturing pumping in the county has significantly increased and been designated as occurring in the Trinity (Hill Country) Aquifer.

Examination of the surveyed manufacturing pumping entities revealed that almost all are engaged in quarrying to produce aggregate and/or cement. Quarrying falls under the TWDB Water Use Survey mining use classification, whereas groundwater pumped for cement manufacturing would be classified as manufacturing use. It is possible that variations in the Water Use Survey data for manufacturing use are due to the hybrid nature of many quarries in Comal County and changing of respondent’s staff performing the reporting resulted in varying designations for use (and aquifer) in Comal County. Figure 393 illustrates reported groundwater pumping associated with mining use in Comal County. As shown on Figure 393, like reported groundwater pumping for manufacturing use, the reported pumping for mining use also has large variations in the annual volumes.

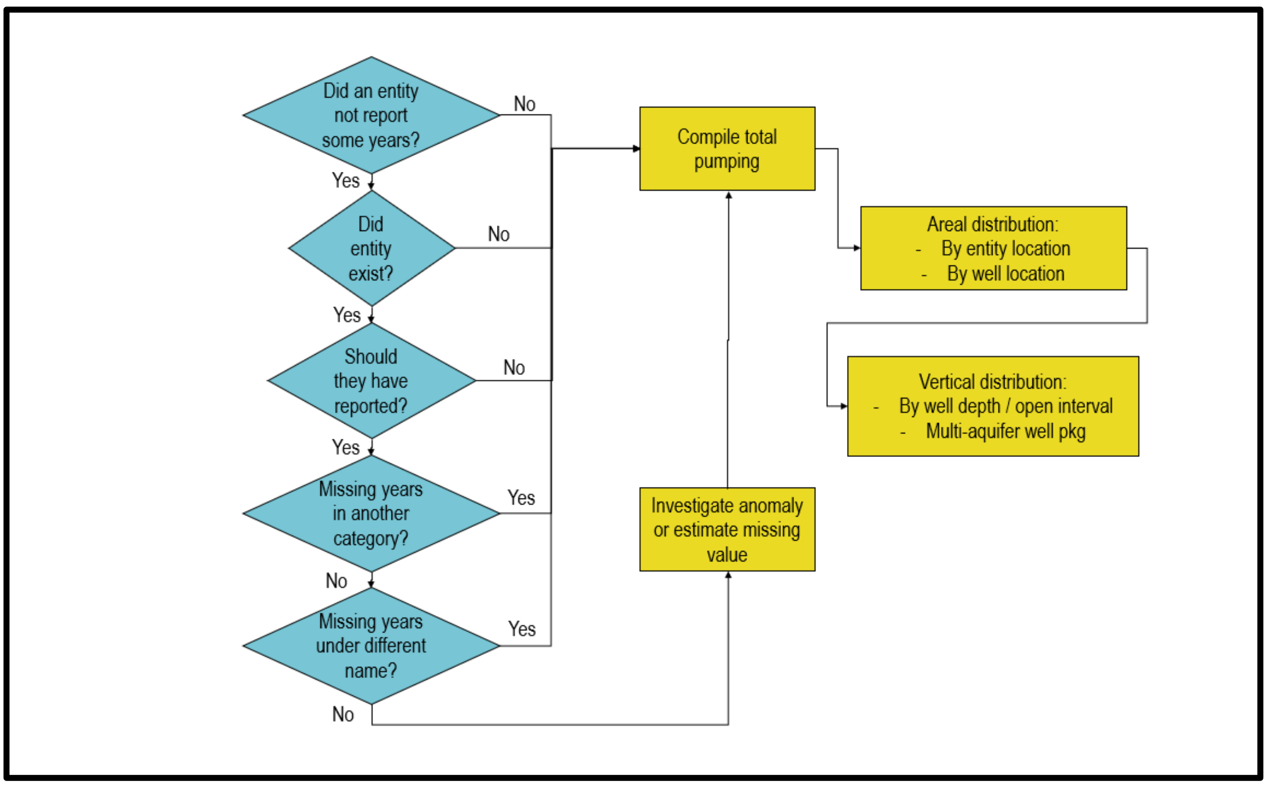


Figure 391. Schematic diagram illustrating the plan to address anomalies in the surveyed manufacturing pumping Water Use Survey data and for preparing a pumping dataset.

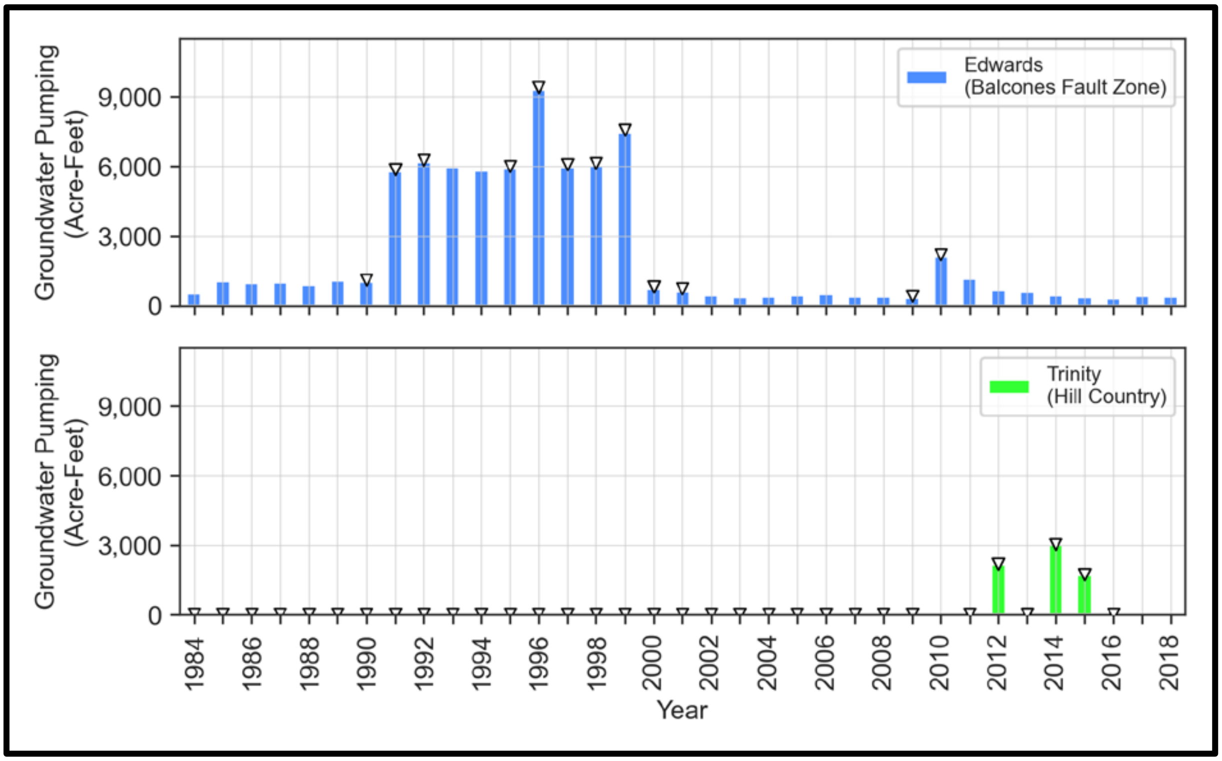


Figure 392. TWDB Water Use Survey reported pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer associated with manufacturing use in Comal County. Triangles mark years identified as having anomalous data.

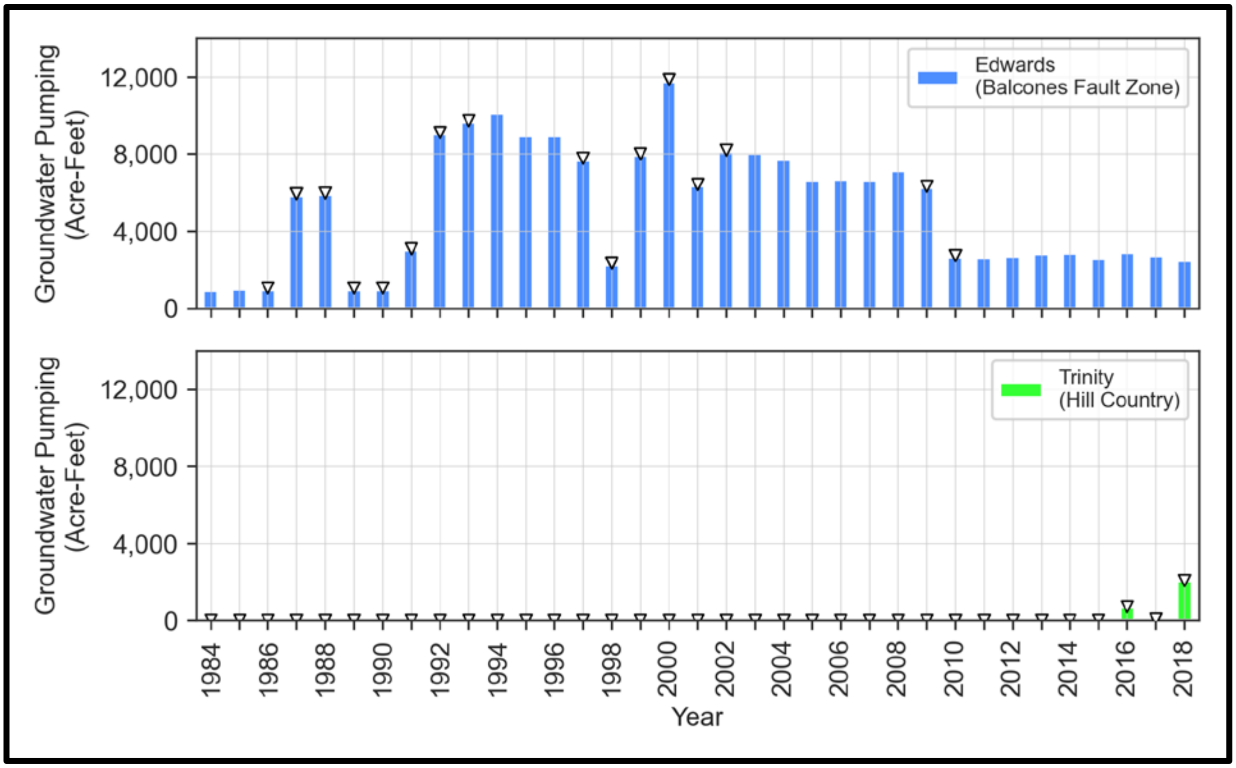


Figure 393. TWDB Water Use Survey reported pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer associated with mining use in Comal County.

The combined groundwater pumping associated with mining use and manufacturing use in Comal County from both the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer is shown in Figure 394. There is less year-to-year variation in this combined pumping. Careful examination of the TWDB Water Use Survey data mining and manufacturing records for Comal County reveals that several entities have switched between reporting groundwater pumping as being for manufacturing use and as being for mining use over the period of record.

A further complication is that some entities report under different names for the same facility in different years. Also, over the period of record some entities change ownership resulting in a change in the name associated with the survey. We anticipate only being able to resolve these complications through investigation of each case. In addition, in certain cases aquifer designation may need to be updated based on examination of wells along with the aquifer designation in years prior and subsequent to the designation for a year in question.

To standardize the pumping estimates for Comal County, we reassigned facility respondents primarily involved in quarrying, but self-labeled as manufacturing in a given year, as mining for that year. Similarly, we reassigned facilities primarily involved in cement manufacture, but self-labeled as mining, as manufacturing for that year. We also standardized historical names to current names for surveyed entities. A summary of the standardized names and uses, along with alternate names, uses, and aquifer designations are in Table 64.

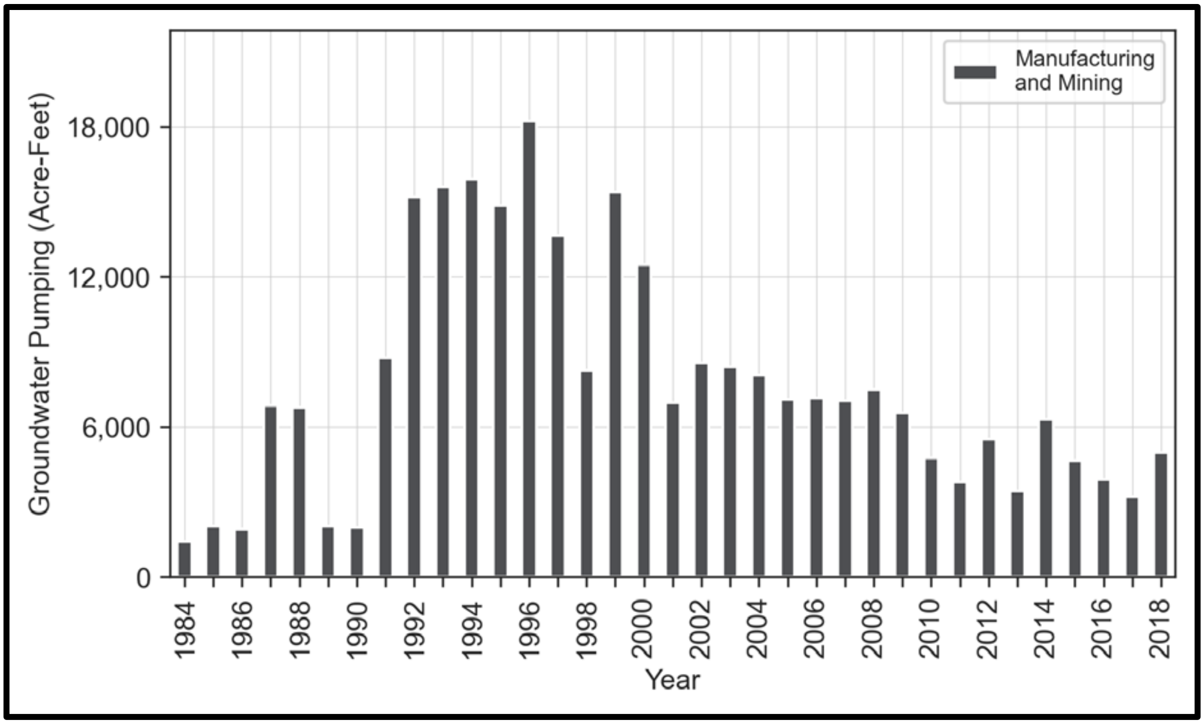


Figure 394. Total reported groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer in Comal County associated with mining and manufacturing use.

Table 64. Summary of Standardization for WUS Names and Uses for Manufacturing in Comal County

Standardized Name	Standardized Use	Alternate Water Use Survey Names	Water Use Survey Uses	Water Use Survey Aquifer	Notes
Cemex Balcones Plant	Manufacturing	Cemex Construction Materials South LLC - Balcones Plant	Mining (2000-2001, 2016-2018), Manufacturing (2011-2018)	Edwards (Balcones Fault Zone)	Cement plant pumping was included in the Cemex Quarry data from 2002-2010.
Cemex Balcones Quarry	Mining	Cemex Construction Materials LLC - Wald Road Plant Cemex Construction Materials South LLC - Balcones Quarry	Mining (2000-2009, 2016-2018) Manufacturing (2010-2015)	Edwards (Balcones Fault Zone) (2000-2011) Trinity (Hill Country) (2012-2018)	Deep Trinity well in 2004. Water reuse system implemented in 2016.
Brauntex Materials, Inc.	Manufacturing	None	Mining (2000-2009), Manufacturing (2010-2018)	Edwards (Balcones Fault Zone)	
Lhoist North America Inc. - New Braunfels Plant	Manufacturing	Chemical Lime Company - New Braunfels Plant	Manufacturing (2000-2009), Mining (2010-2018)	Edwards (Balcones Fault Zone)	Ownership change.
TXI Cement-Hunter Road Cement Plant	Manufacturing	None	Manufacturing	Edwards (Balcones Fault Zone) (2000-2009) Edwards (Balcones Fault Zone) and Trinity (Hill Country) (2010-2018)	Martin Marietta on driller's reports. Has some deep Trinity wells
Evian	Manufacturing	None	Manufacturing (2000-2010)	Edwards (Balcones Fault Zone)	Stopped reporting in 2010, no current permits.
Capitol Aggregates Inc. - Solms Quarry	Mining	None	Manufacturing	Trinity (Hill Country)	Wrong use category.
DOT Metal Products	Manufacturing	None	Manufacturing	Edwards (Balcones Fault Zone)	Very low pumpage.

After standardization of entity names, uses, and aquifers, we calculated revised estimates of the groundwater pumping in Comal County associated with manufacturing use (Figure 395). The revised pumping estimates are much more consistent. The estimates of groundwater pumping for manufacturing use from 1991 through 1999 are questionable, but we do not have reason to remove them from the estimates as being inaccurate. While the water use classification may be incorrect, without evidence to the contrary we will leave these pumping estimates in the dataset for Comal County. We will apply these revised estimates of pumping for manufacturing use based on the location of manufacturing plants and/or associated quarries focusing the spatial distribution around any known wells operated by the manufacturing entities.

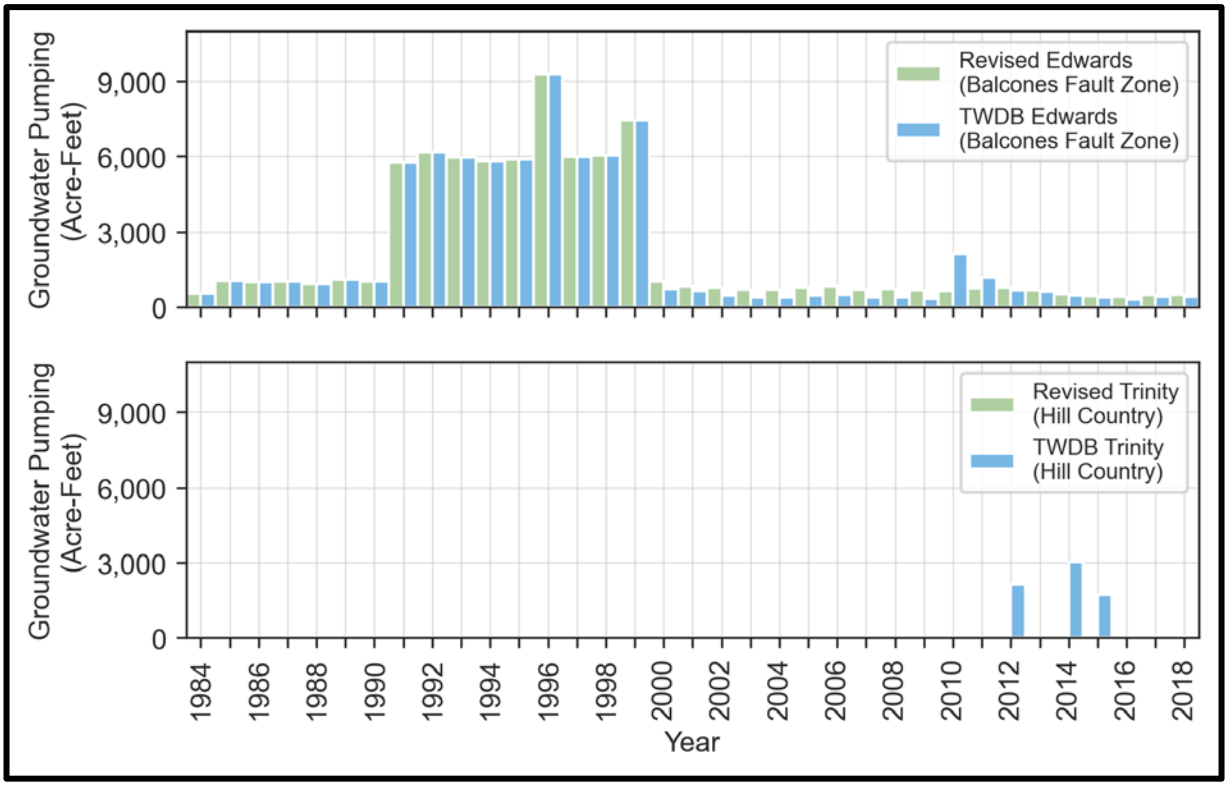


Figure 395. Revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer in Comal County associated with manufacturing use.

4.6 Livestock

Livestock water use is estimated on an annual basis and represents net water use of select livestock-related facilities, such as fish hatcheries and farms, and the estimated (non-surveyed) water used to raise livestock (Billingsley, 2019).

Methodology to Address Water Use Survey Livestock Pumping Anomalies

Water use for livestock is calculated annually from USDA-NASS and is specified by animal class. Data is typically compiled by the TWDB Projections and Socioeconomic Analysis department. The data is calculated by multiplying estimates of animal populations by an average water usage rate per animal. The TWDB Projections and Socioeconomic Analysis department has been updating per-animal water use over time as better data become available. For example, water use for chickens has been adjusted due to more cooling systems used in facilities. Additionally, TWDB staff estimate water use for beef cattle and dairy cattle separately using different water use units.

We evaluated anomalies identified in the livestock groundwater pumping using census data for county-level animal counts (USDA, 2019) and estimated water use per animal (Lovelace, 2009a). The census data from the USDA (2019) are only available in five-year increments and the intervening years must be interpolated from the census years. Table 65 provides the median per-animal water use (Lovelace, 2009a). By multiplying the estimated number of animals by the per-animal water use we determined the estimate of total livestock water use in a given county. We then subtracted estimates of surface water used for livestock from the total to develop an estimate of the amount of groundwater pumped for livestock use.

Table 65. Median per-animal water use (Lovelace, 2009a).

Animal	Median Water Use (gallons per animal per day)
Cattle	12
Chickens	0.06
Hogs	3.5
Sheep	2.0

Once we addressed the anomalies in the pumping data, we distributed the pumping evenly across the aquifer outcrop within the county. The vertical distribution of pumping was the most likely aquifer (based on hydrogeology and water quality) from which livestock pumping would occur. Figure 396 illustrates our plan for addressing identified livestock water use anomalies and developing a pumping dataset for livestock use.

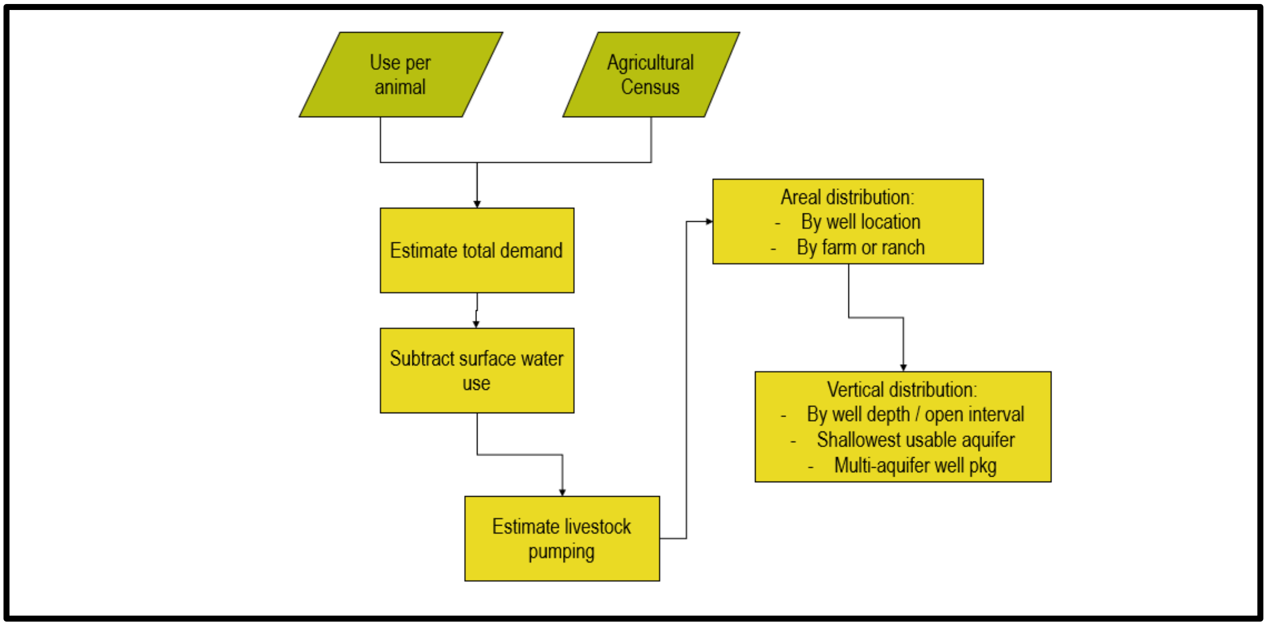


Figure 396. Schematic diagram illustrating the plan to address anomalies in the estimated Water Use Survey pumping data for livestock use and for preparing a pumping dataset.

Livestock Methodology Test Case

As a test case, we reviewed the livestock water usage data for Bandera County. As illustrated on Figure 397, estimated pumping for livestock use was between 100 and 300 acre-feet per year from 1984 through 2003. Livestock pumping in Bandera County occurs from both the Trinity (Hill Country) Aquifer and Edwards-Trinity (Plateau) Aquifer. As shown on Figure 397, there is an anomalous period of low pumping from 2001 through 2004. It is also noted that pumping from the Trinity (Hill Country) Aquifer decreases after 2000, whereas pumping from the Edwards-Trinity (Plateau) Aquifer increases during this time.

The Census of Agriculture (USDA, 2019) contains county-level livestock counts at five-year intervals. Between Census years, U.S. Department of Agriculture – National Agricultural Statistics Service (USDA-NASS) conducts an annual survey that is used by TWDB to estimate livestock inventory. For our evaluations we used data beginning in 1982 and ending in 2017. We estimated the annual livestock counts for non-census years using linear interpolation of the five-year data. We estimated livestock counts for 2018 using linear extrapolation. The estimated annual counts are shown by animal in Figure 398.

We multiplied the animal counts by the median per-animal water use values in Table 65 and summed the results to obtain estimates of total livestock water demand in Bandera County (see Figure 399). To reflect the possibility that some water demand for livestock was satisfied by surface water usage, we estimated the amount of surface water usage based on the ratio of the reported county usage of groundwater and surface water for livestock, within the original TWDB dataset. We then assumed this ratio would apply to the demand calculated using our revised methodology, computed the amount of surface water used to meet demands, and subtracted that quantity from the total livestock water demand. The remaining value became the estimated groundwater pumpage for livestock. Such groundwater amounts for Bandera County are shown in Figure 400, where the anomalous low groundwater pumping amounts from 2001 through 2004 appear to be a result of the TWDB Water Use Survey surface water livestock use estimate. During these years, reported surface water use exceeded reported groundwater use for livestock. We investigated the surface water estimate for this period, yet could not determine the accuracy of these estimates. To spatially distribute the groundwater pumpage, we assumed equal pumpage across all portions of each aquifer footprint within the county.

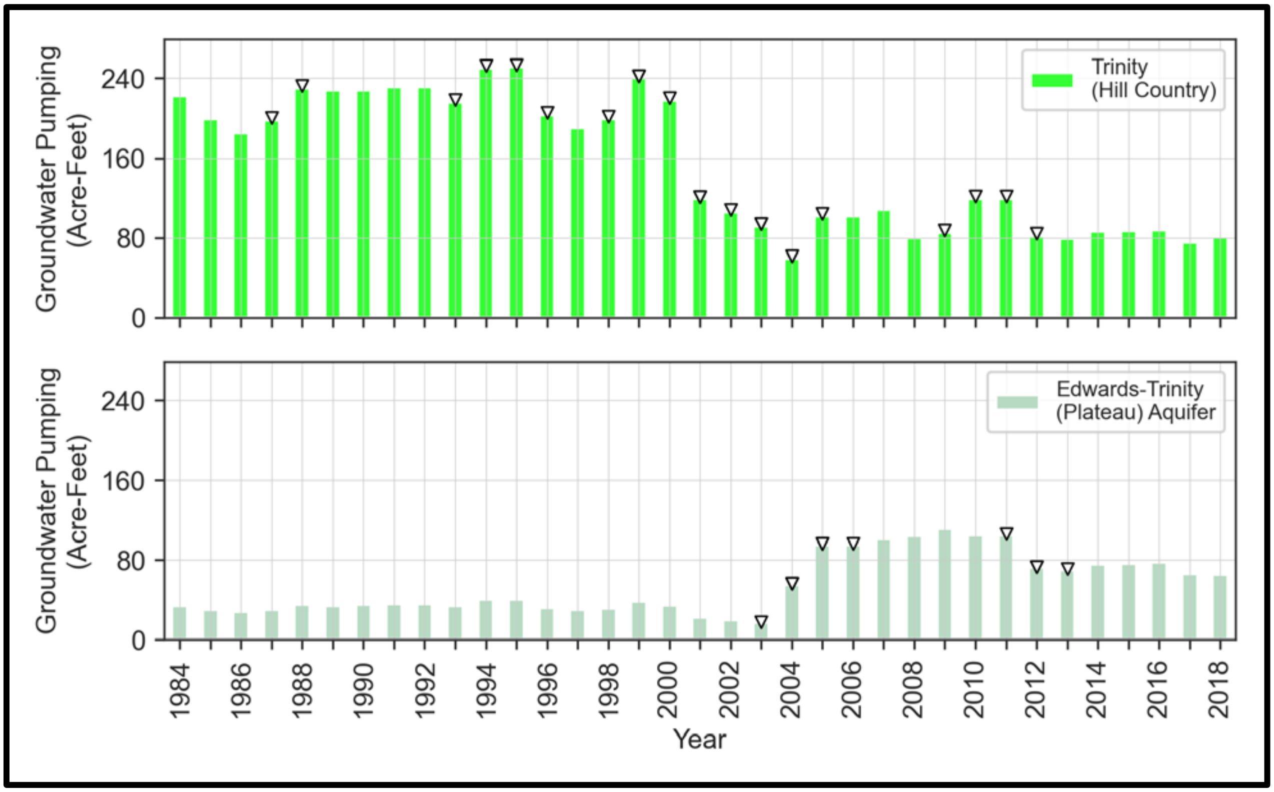


Figure 397. Bandera County Edwards-Trinity (Plateau) Aquifer and Trinity (Hill Country) Aquifer groundwater pumping for livestock use as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

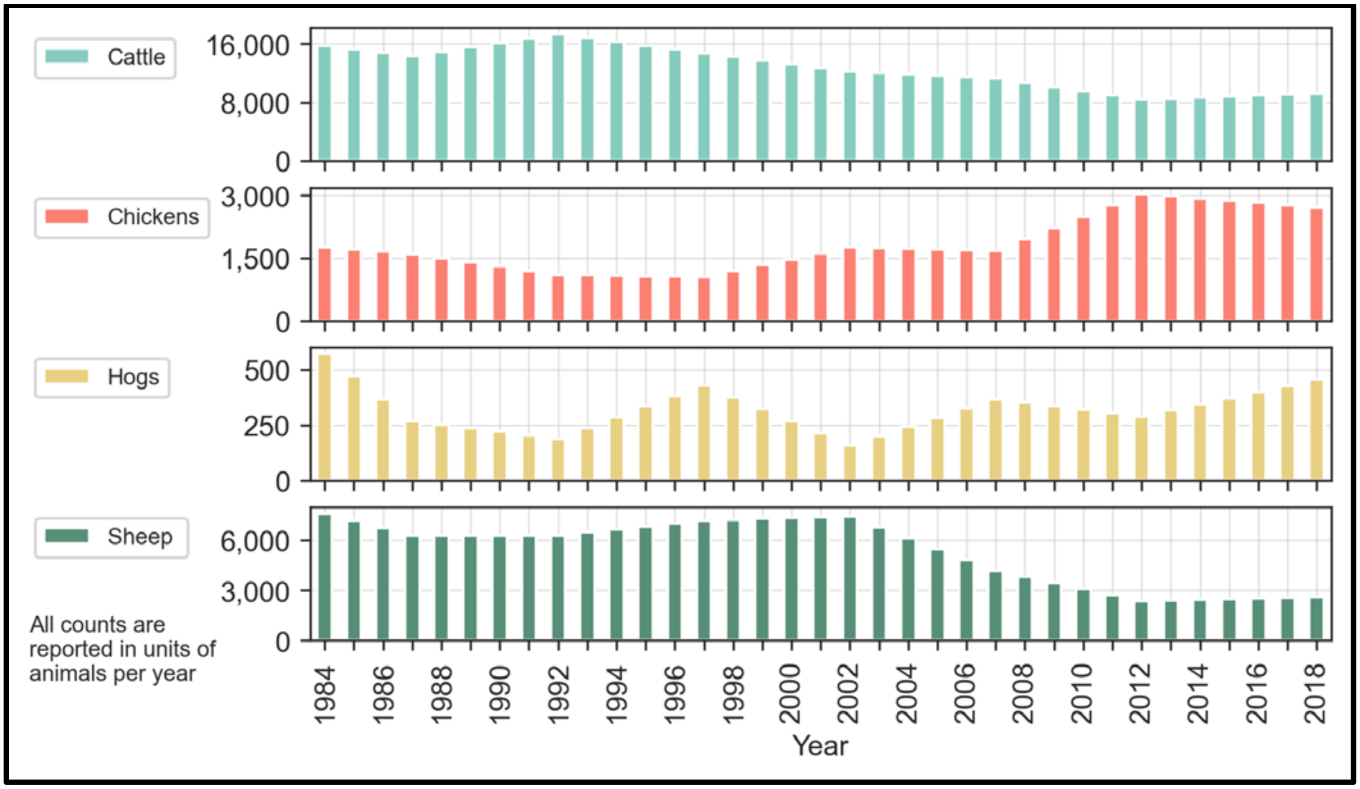


Figure 398. Estimated livestock counts for Bandera County from 1984 through 2018 as derived from the Census of Agriculture data (USDA, 2019).

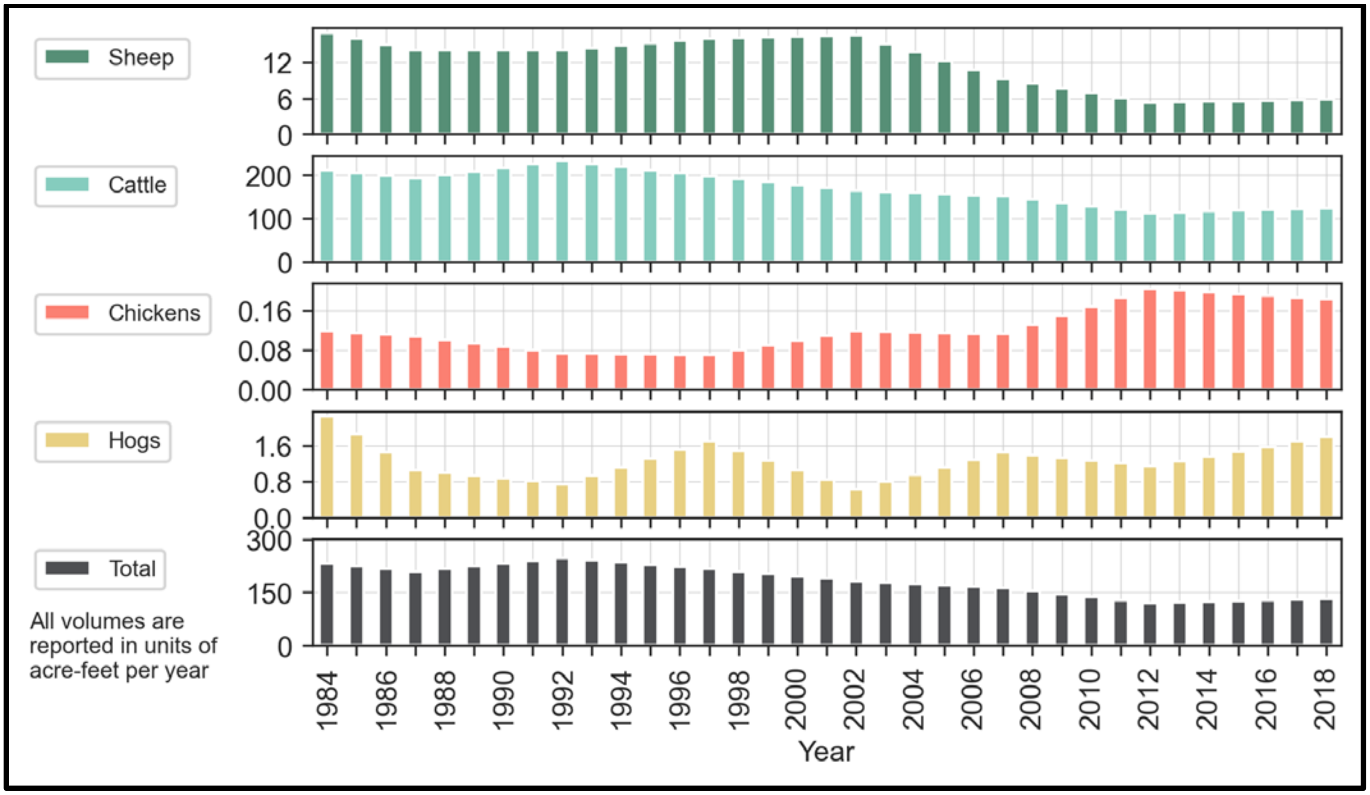


Figure 399. **Estimated water demand for livestock in Bandera County from 1984 through 2018.**

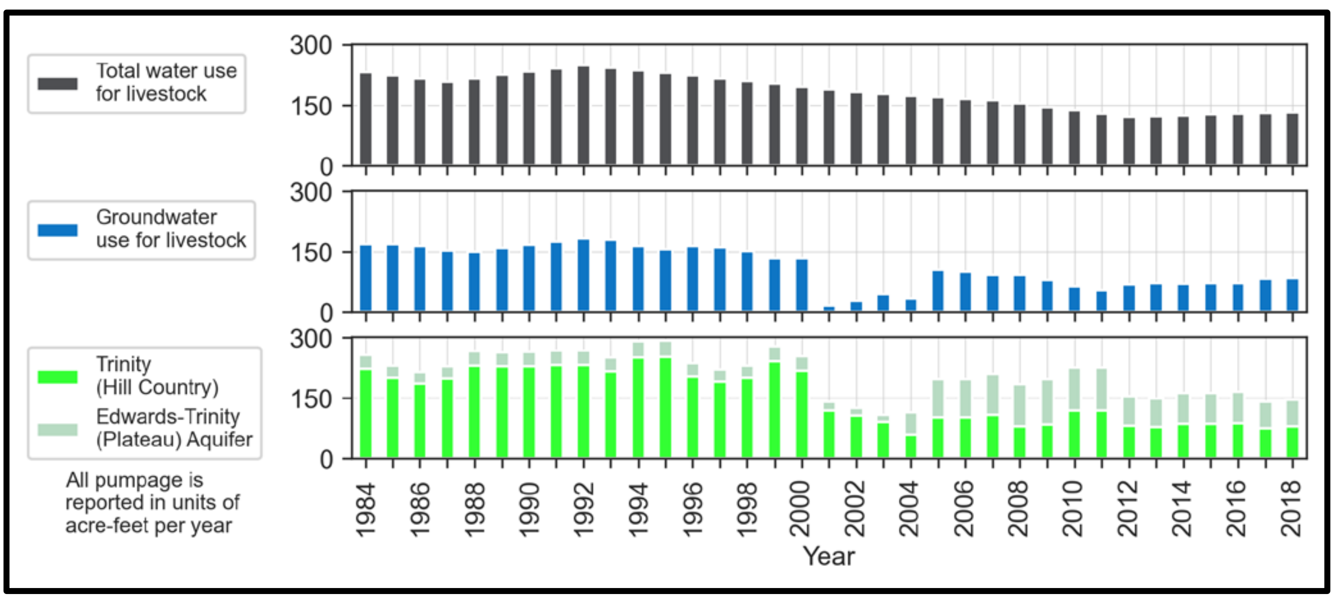


Figure 400. **Revised eestimates of groundwater pumping for livestock use in Bandera County from 1984 through 2018.**

4.7 Other Anomalies

Some anomalies do not fall specifically under one of the Water Use Survey types. For example, as discussed in Section 3.3.15, the Water Use Survey data has pumping beginning in 2007 for municipal and manufacturing use assigned to the Trinity (Hill Country) Aquifer in Ector County. However, the assignment appears to be anomalous as the TWDB delineation of the footprint of the Trinity (Hill Country) Aquifer does not extend to Ector County and the pumping assigned to this aquifer is more likely coming from the Edwards-Trinity (Plateau) Aquifer. In developing the pumping dataset for the study area, we revised pumping estimates to be more consistent with the aquifer from which the pumping is likely occurring.

We also documented any other anomalies discovered as we worked with the available data. We investigated these identified anomalies and revised pumping estimates as needed. Aquifer, use, and county assignment of the production were based on the results of each specific anomaly investigation.

5 Updated Groundwater Pumping Estimates

Through implementation of our approach to address anomalies in the Water Use Survey data we developed revised estimates of groundwater pumping for the study area aquifers. The following sections discuss the revisions to the groundwater pumping estimates for each water use category within each aquifer. Within each section we highlight the changes resulting from the review of existing data and new methodologies developed to address anomalies. Where necessary, we have detailed changes to the methodologies presented in Section 4 and we provide explanations for any methodology changes that resulted through our review of pertinent data. We then provide the revised pumping estimates for each county with county-specific discussions.

5.1 Application of Anomaly Analysis

Through application of our plan to address anomalies in the groundwater pumping estimates in the Water Use Survey dataset, we identified refinements to the process which informed our final estimates of groundwater pumping. The following provides a brief discussion of our approach for estimating groundwater pumping implemented for each use category.

5.1.1 Surveyed Municipal

Our methodology for assessing groundwater pumping associate with surveyed municipal use is detailed within Section 4.1.1. Our proposed process was to review the reported annual pumpage by each entity, county, and aquifer as included within the original TWDB Water Use Survey dataset, and then to adjust datasets as necessary. Common adjustments included:

- Interpolation of missing data;
- Re-assignment of reported pumpage to a different aquifer; and,
- Re-assignment of reported pumpage to a different county.

Our methodology assumes that the pumpage numbers reported by the specified entities accurately reflect the actual pumpage that physically occurred; we did not investigate the accuracy of the reported pumpage values. However, we did note anomalous reported values for specific entities, and we discuss these anomalies on a county-by-county basis. We also assumed that entities would report usage during their first and last years of operation, yet may have inadvertently neglected to report usage for one or multiple years in-between. With this assumption we are regarding the timing of pumpage reporting by an entity as an accurate reflection of when that entity was operating and actively withdrawing groundwater. We assumed pumping was occurring for all years in between the first and last years for which an entity reported pumpage within the water use survey dataset.

We used linear interpolation to fill-in any gaps in reported data from a given entity. For example, if an entity reported pumpage of 100 acre-feet in 2001, and then next reported 200 acre-feet of pumpage in 2003, we interpolated pumpage of 150 acre-feet for 2002. We did utilize reported data from outside of the study period (1984 through 2018) when performing data interpolations. As such, if an entity reported 200 acre-feet of pumping in 2016 and then next reported 500 acre-feet of pumping in 2019 (one year outside of the study period), we interpolated pumpage of 300 acre-feet in 2017 and 400 acre-feet in 2018. We did not extrapolate data outside of the time periods for which an entity reported data; only data interpolations were performed.

Occasionally we determined that the original TWDB Water Use Survey data included improper allocations of pumpage to counties and/or aquifers. Most often, this involved reporting pumpage from an aquifer that does not physically exist within a given county. In such instances, we researched the physical location of the entity doing the reporting and used that location to re-assign the pumpage to an appropriate aquifer. If the entity location was determined to be outside of the reported county, we removed that pumpage from the county totals, and added it to the totals of the appropriate county (assuming the county was within the study area). Occasionally individual entities would report pumpage from one aquifer for many years, and then would report pumpage from a different aquifer for subsequent years. In these instances, we attempted to identify the well from which pumping was being reported, and assess the appropriate aquifer based on the well's screened interval. If such well data were unavailable, we assigned the pumpage to the most-likely aquifer based on the aquifer footprint and our estimate of the location of the entity.

In many instances, an entity would report pumpage from an "Other Aquifer." We attempted to determine the specific aquifer through researching the likely entity location, and by reviewing pumping and water planning information from TWDB regional water plans. In many cases, pumpage from the Lipan Aquifer was originally classified as being from an "Other Aquifer," typically at earlier years within the study period before the Lipan Aquifer was officially designated by TWDB. In other instances, however, we believe the reporting entity was simply unsure of from which aquifer it was withdrawing water. For instances where we could ascertain the source aquifer with a high degree of certainty (in our professional judgement) we re-classified pumpage as being from "Other Aquifer" to a specific aquifer within our study area.

Specific explanations of revisions we made to the original TWDB Water Use Survey datasets are provided below on a county-by-county basis. We provide explanations only if the revisions yielded significant changes from the original TWDB Water Use Survey dataset.

5.1.2 Non-Surveyed Municipal

Our methodology for assessing groundwater pumping associated with non-surveyed municipal use is detailed within Section 4.1.2. Through application of our approach, a few changes were necessary for developing the final pumping dataset. We did identify some gaps in the U. S. Geological Survey data we used for our analysis. Since the U.S. Geological Survey data are only available at five-year intervals, we developed an approach for estimating the missing years.

We found that if domestic self-supplied withdrawal was missing, then typically the domestic self-supplied population data was also missing. We began to address the missing data by assessing the ratio of total county population to domestic population for each of the data points available for the county. We then estimated the missing domestic self-supplied population and self-supplied per capita usage based on the adjacent five-year data through either interpolation or extrapolation. Finally, we estimated the missing five-year interval by calculating a per capita water use and multiplying it by the estimated domestic self-supplied population.

Using the five-year interval groundwater use estimates, we distributed the pumping by aquifer based on the number of domestic wells completed in that aquifer relative to the total number of domestic wells in the county. For the annual estimates, we limited our calculation of the number of wells per aquifer and county based on the year the well was reportedly drilled. For example, if a well was drilled in 1996, we did not include the well in the allocation of pumping until year 1996 and following. If a well did not have a completion date, we assumed the well existed prior to 1984.

5.1.3 Irrigation

As detailed within Section 4.2, we developed a detailed methodology for assessing groundwater pumpage needs for irrigation across each county within the study area. Upon implementing this process for all regions of the study area, we identified process adjustments and simplifications needed to improve the process and streamline the production of revised pumpage estimates.

The first process modification implemented in estimating irrigation pumpage involved linking TWDB records of historical crop acreage to geographic locations identified by the CropScape grids. TWDB records are provided as total acreage (of a specific crop) planted and cultivated within a county over the given year. We used the CropScape data (USDA-NASS, 2008-2019) to determine the location within the county of the given agricultural operation. While CropScape provides the crop type and acreage, we found that these results were often inconsistent with TWDB estimates. This CropScape limitation was discussed in Section 4.2. To account for the discrepancies between the two datasets, we developed a normalized method for approximating countywide irrigation operations at specific CropScape-identified locations within the county. This process allows us to geographically link the TWDB reported crop production to areas within the county and to generally tie the crop production to a specific underlying aquifer. Essentially, we are eliminating crop segregation within counties and modeling water demands as if all crops grown in the county are grown in each identified agricultural region in the county, on an area-normalized basis.

The second process modification involves the application of crop-coefficients to identified crop areas which was necessitated by the averaging process developed through the first modification. Our basic methodology involves computing a reference evapotranspiration rate for each location within our study area for each day of the growing season. Crop coefficients are then used to adjust the reference evapotranspiration rate based on the typical water needs of a given crop, with water needs varying both by crop and by the growth cycle of the crop over the growing season. Our procedure involved implementing daily crop coefficients for each of the TWDB crop classifications (for example, cotton, sorghum, corn, rice, etc.) based on the number of days past since planting. However rather than doing so for a given crop at a given location, we determined county-wide weighted crop coefficients, based on the TWDB reported crop production acreages. On a given day within the growing season, cotton and rice would each require a different amount of water, as determined by the different crop coefficient curves for each plant. Our methodology was to determine the crop coefficient for each crop grown within the county, and then compute a normalized crop coefficient for use countywide based on the number of acres cultivated. For example, consider a county which produced 600 acres of cotton and 400 acres of rice. On a given day within the growing season, the crop coefficient (“CC_{cotton}”) for cotton is determined to be

1.08, and that for rice (“CC_{rice}”) would be 1.2. The county-wide weighted crop coefficient (“CC_w”) for that given day would then be calculated as:

$$CC_w = \frac{CC_{cotton} \cdot A_{cotton} + CC_{rice} \cdot A_{rice}}{A_{cotton} + A_{rice}} = \frac{1.08 \cdot 600\ acres + 1.2 \cdot 400\ acres}{600\ acres + 400\ acres} = 1.128$$

With “A_x” signifying the total area of crop “X” cultivation within the county. This weighted crop coefficient would then be multiplied by the reference evapotranspiration value calculated for the specific location within the county in order to estimate the daily water needs. Irrigation needs would then be determined for the given day by subtracting daily precipitation values for the given location from the computed daily water need, and any positive results would be recorded for that location as an irrigation water need.

The last process modification developed to estimate irrigation pumpage needs involved the use of surface water. The TWDB water use survey dataset presents county-wide surface water and groundwater usage estimates for irrigation purposes. We assumed the surface water usage estimates were accurate and we allocated the reported per-county surface water usage to individual aquifers within the county based upon the relative footprints of the aquifers within the county and our professional judgement. We also assumed that 12 percent of surface water diverted for irrigation purposes was lost (due to leakage, evaporation, or other causes) as this water was transferred from its source location to the irrigated fields. This 12 percent loss is in addition to a 75 percent efficiency rating assigned to the generalized field irrigation system. Thus, for every one acre-foot of surface water actually used in on-field irrigation, 1.52 acre-feet of surface water must have been diverted. Groundwater demands for irrigation were calculated as the difference between the computed localized water demand for irrigation and the available quantity of surface water within the county. Localized irrigation demands were allocated quantities of available surface water based on the ratio of the localized demand relative to the total computed demand from the aquifer footprint within the county. For example, if the total county demand for irrigation were 10 acre-feet, and a location within the county had a demand for 5 acre-feet, then that location would have 50 percent of the total county demand and would therefore receive up to 50 percent of the available surface water used by the county in meeting irrigation demands. If the available surface water exceeds irrigation demands (for the county or an individual location), then the groundwater pumpage is set to zero.

The discussion in Section 5.2 details the revised groundwater pumpage for irrigation by county within the study area. Within the short descriptions provided for our assessments for each county, we often reference reviewing well locations from two sources. The first of these sources is the groundwater well geodatabase we compiled in 2018 while performing a statewide subsidence risk feasibility study for TWDB (Furnans and others, 2018). This dataset was processed from TWDB well databases available at that time and each identified well was attributed with the name of the aquifer within which the well was estimated to be completed. We used this dataset for this pumping assessment project because it contains as complete a record as possible of all wells within the study area counties through 2018.

The second source of groundwater well information consulted within this analysis was the groundwater data viewer maintained by TWDB and available (as of October 21, 2021) at https://www3.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer. From this website we accessed information for various wells of interest throughout the study area and reviewed general trends in well information within specific regions of the study area. Assessments based on review of data from the groundwater data viewer are generally subjective and were based on our best professional judgement of the provided information.

5.1.4 Power

Our methodology for assessing groundwater pumping associated with power use is detailed within Section 4.3. Through application of our approach, no changes were necessary for developing the final pumping dataset.

5.1.5 Mining

WSP, Inc. staff were primarily responsible for assessing pumpage to support mining activities. Their team developed expertise in assessing mining water usage through a project for the TWDB Innovative Water Technology Division involving Class II injection wells. WSP, Inc developed and implemented the methodology documented herein for estimating mining pumpage within the project study area. This methodology evolved from that presented in Section 4.4 to be more applicable to all counties within the study area.

Fresh groundwater pumping estimates for mining use are associated with oil and gas activities along with surface mining activities. The updated approach expanded on methodology #3 (the modified Bureau of Economic Geology method) based on the work by Nicot and others (2012) as discussed in Section 4.4. Through this effort, WSP ascertained that the original TWDB Water Use Survey estimates for mining use did not include groundwater pumping related to enhanced oil and gas recovery wells, and were therefore under-estimates of true pumpage for mining use. WSP made a "First Estimate" of mining pumpage by adding water needs for the enhanced oil and gas recovery wells to the original TWDB Water Use Survey estimates on a county and aquifer basis. They then made a "Second Estimate" of mining pumpage for each county and aquifer using the U.S. Geological Survey – Groundwater Fresh dataset, described as method #1 within Section 4.4. Under this method #1, county-wide mining pumpage estimates published by the U.S. Geological Survey are converted to county-aquifer estimates based on the relative area of the aquifer footprint within the county boundary. The final step is to compare the pumping totals from the "First Estimate" and "Second Estimate," with the revised pumpage for mining becoming the larger of the two pumping estimates.

This method of pumpage estimation makes the following assumptions regarding data accuracy:

- Assumption #1 – the data within the original TWDB Water Use Survey database is accurate.
- Assumption #2
    - The data published by the U.S. Geological Survey is accurate; and,
    - The aquifer area reasonably represents the distribution of pumping.

As discussed in Section 3.3, there are anomalies in the groundwater pumping estimates in Water Use Survey data. As such, questions remain regarding the validity of Assumption #1.

Assumption #2 relies on the accuracy of the external data source and that the aquifer area is a reasonable surrogate for the portion of pumping in a county. While these assumptions raise questions about the revisions, they do have the advantage of not relying on a single source. As such, if evidence was not available to contradict a pumping estimate based on the two sources, we accepted it as plausible and added the estimated pumping associated with the enhanced oil recovery wells.

We obtained updated data on oil and gas wells from the Railroad Commission of Texas (RRC, 2021a). Being the entity with regulatory jurisdiction over surface mining as well as oil and gas activities in Texas, the Railroad Commission of Texas has the most updated publicly available data on these activities. Figure 401 shows the enhanced oil and gas recovery wells used to estimate groundwater pumping for mining. While other types of oil and gas wells also use some water during drilling or other operational processes, enhanced oil and gas recovery wells use larger amounts of water during their operational process. As such, we limited our analysis to only consider water usage needs for enhanced oil and gas recovery wells.

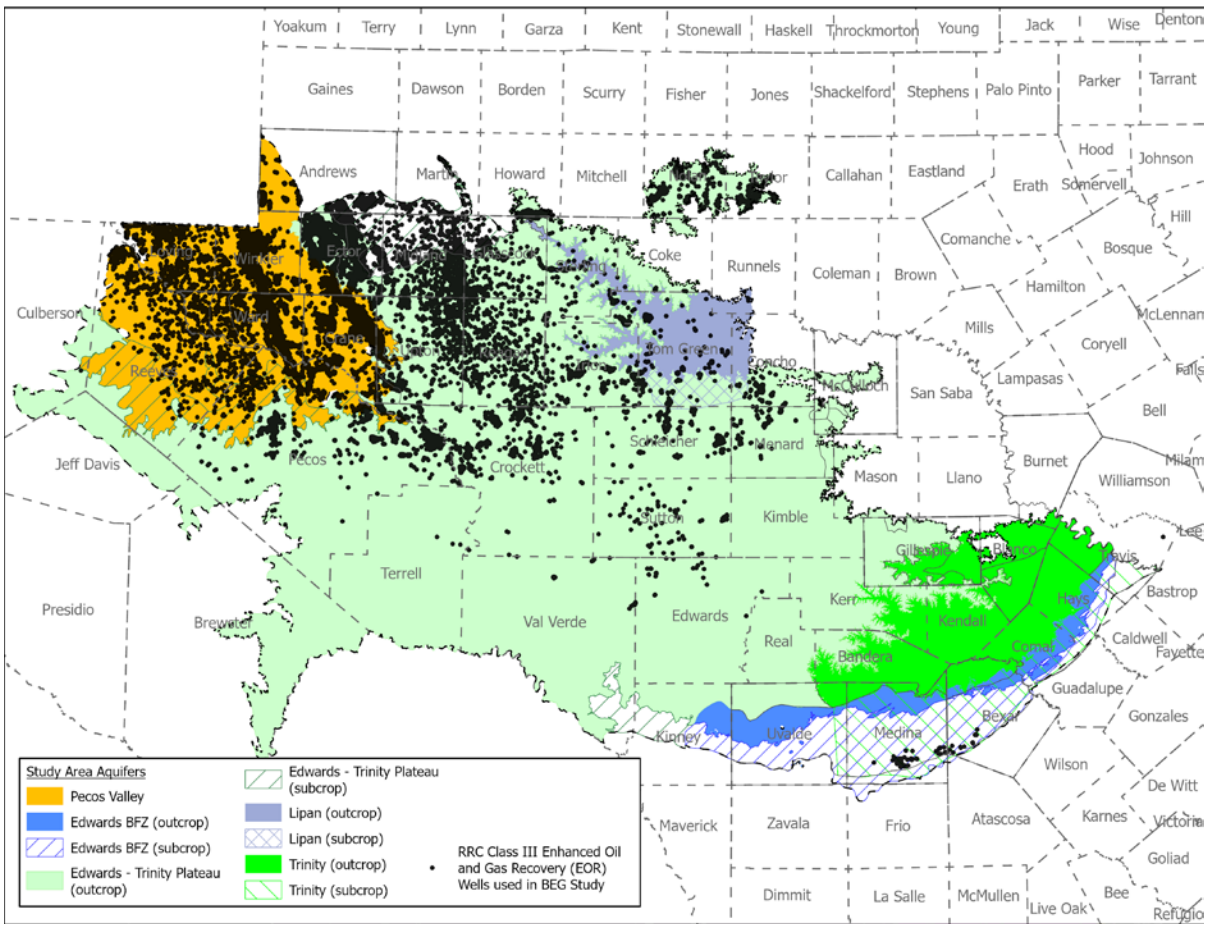


Figure 401. Enhanced oil and gas recovery wells used in the Bureau of Economic Geology (BEG) mining water use estimate. The Railroad Commission of Texas is abbreviated as, "RRC".

We estimated surface water mining use using the information available from the surface mining and reclamation division of the Railroad Commission of Texas (RRC, 2021b). The major surface mines (RRC, 2021c) in Texas are surface coal mines (RRC, 2021d) and Uranium explorations. Some coal mines were identified within the project study area, but no Uranium mine permits were found (RRC, 2021e). More details on pumping estimates for mining use are provided in detail in the next sections.

Pumping Estimation for Oil and Gas Usage

In Section 4.4, we analyzed multiple possible mining use estimation methodologies and recommended the modified Bureau of Economic Geology methodology. For the county-by-county analysis, we expanded on the modified Bureau of Economic Geology methodology. The first difference was estimation of the distribution of vertical and horizontal oil and gas wells within the counties. We used this well distribution analysis to apportion the number of vertical wells and horizontal wells among the identified active wells in each county.

We estimated the water use rates for the vertical and horizontal wells using the values reported by Nicot and others (2011; 2012) as described in Section 4.4. We calculated pumpage estimates for all active wells during the study period by multiplying the water use value per well type (horizontal or vertical) by the number of those type of well. We compiled these estimates per county and they are reported in acre-feet per year.

Note that there are a few counties with zero pumping estimates for oil and gas usage which could be due to one of the following factors:

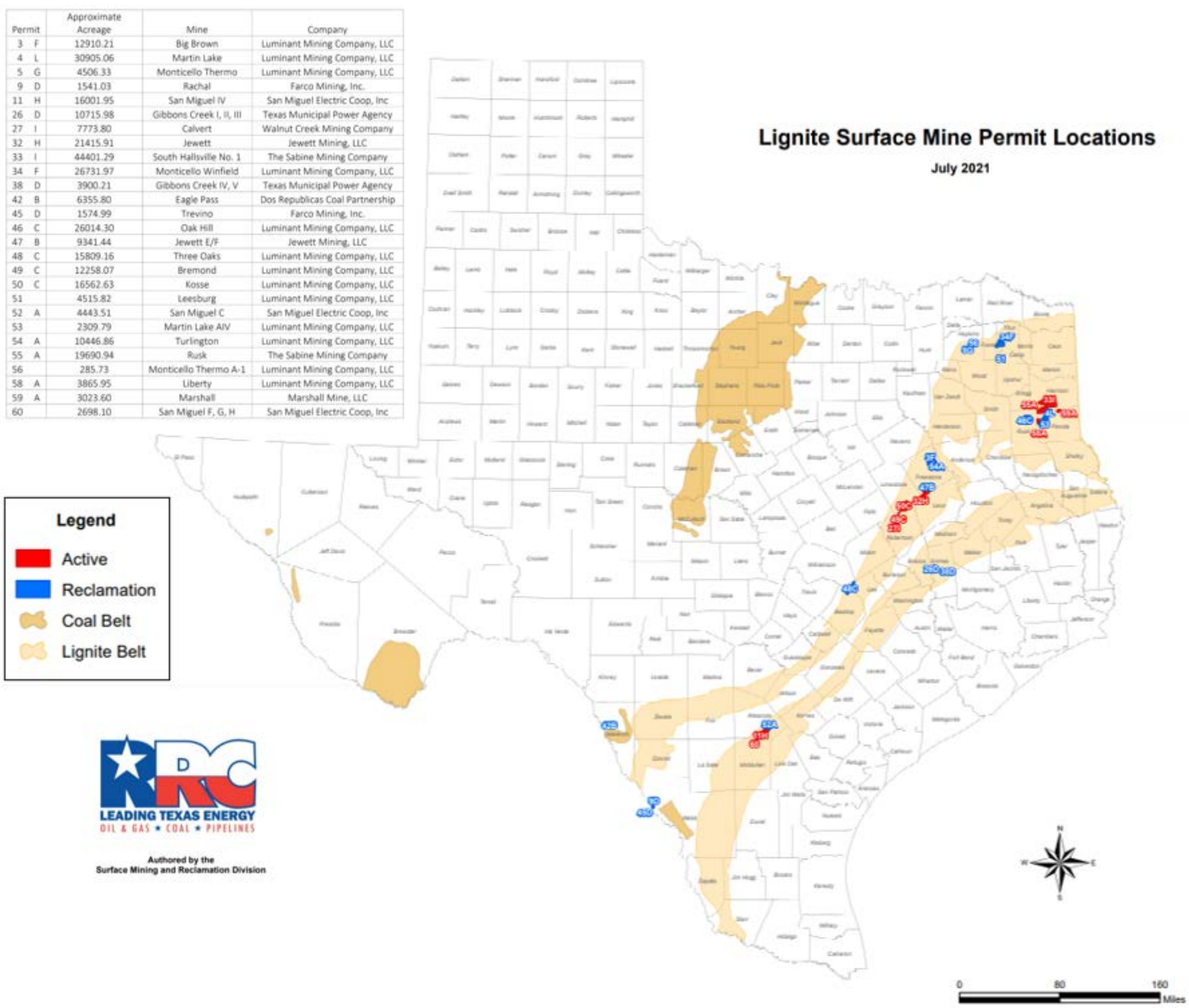
- There may be no active enhanced oil and gas recovery wells in that county; and/or
- The active enhanced oil and gas recovery wells in that county might not have been reported or inaccurately reported in the Railroad Commission of Texas database.

Pumping Estimation for Surface Water Mining Usage

We used data available from the surface mining and reclamation division of the Railroad Commission of Texas to estimate fresh groundwater use by surface mines. The major surface mines in Texas are coal mines and Uranium explorations. After researching records within the database, we were unable to locate any exploration permits for Uranium mines within the study area.

The Railroad Commission of Texas provides information on mining activity within the state. For coal mines, water is used to extract, wash, and sometimes transport the coal. Figure 402 presents the lignite surface coal mine permit locations per the Railroad Commission of Texas (RRC, 2021d). We found only one active mine in the study area, the San Miguel coal mine. Coal mines use water to extract and process the raw materials and it is difficult to ascertain the source of the water used. Therefore, additional information was needed, and some assumptions had to be made. The San Miguel mine overlies two counties within the study area: Atascosa and McCulloch. Using the location of the San Miguel mines, we checked the TWDB groundwater database (TWDB, 2020b) for any water wells located in that area associated with mining water use. We also reached out to the staff at San Miguel mines to determine their daily water usage for managing and operating the surface mines. The staff informed us that there is minimal groundwater pumping for surface water mines in these two counties but did not provide any raw pumping data information. San Miguel mines staff also mentioned that most of the water used for coal mine purposes is recycled.

The project team also checked for Uranium exploration permits but none were found within the study area (RRC, 2021e).



Permit		Approximate Acreage	Mine	Company
3	F	12910.21	Big Brown	Luminant Mining Company, LLC
4	L	30905.06	Martin Lake	Luminant Mining Company, LLC
5	G	4506.33	Monticello Thermo	Luminant Mining Company, LLC
9	D	1541.03	Rachal	Farco Mining, Inc.
11	H	16001.95	San Miguel IV	San Miguel Electric Coop, Inc
26	D	10715.98	Gibbons Creek I, II, III	Texas Municipal Power Agency
27	I	7773.80	Calvert	Walnut Creek Mining Company
32	H	21415.91	Jewett	Jewett Mining, LLC
33	I	44401.29	South Hallsville No. 1	The Sabine Mining Company
34	F	26731.97	Monticello Winfield	Luminant Mining Company, LLC
38	D	3900.21	Gibbons Creek IV, V	Texas Municipal Power Agency
42	B	6355.80	Eagle Pass	Dos Republicas Coal Partnership
45	D	1574.99	Trevino	Farco Mining, Inc.
46	C	26014.30	Oak Hill	Luminant Mining Company, LLC
47	B	9341.44	Jewett E/F	Jewett Mining, LLC
48	C	15809.16	Three Oaks	Luminant Mining Company, LLC
49	C	12258.07	Bremond	Luminant Mining Company, LLC
50	C	16562.63	Kosse	Luminant Mining Company, LLC
51		4515.82	Leesburg	Luminant Mining Company, LLC
52	A	4443.51	San Miguel C	San Miguel Electric Coop, Inc
53		2309.79	Martin Lake AIV	Luminant Mining Company, LLC
54	A	10446.86	Turlington	Luminant Mining Company, LLC
55	A	19690.94	Rusk	The Sabine Mining Company
56		285.73	Monticello Thermo A-1	Luminant Mining Company, LLC
58	A	3865.95	Liberty	Luminant Mining Company, LLC
59	A	3023.60	Marshall	Marshall Mine, LLC
60		2698.10	San Miguel F, G, H	San Miguel Electric Coop, Inc

Figure 402. Permitted coal mines locations adapted from (RRC, 2021d).

Filling the Data Gaps in Pumping Estimates for Mining Use

To identify and fill in the data gaps for the counties in the study area, we looked at various data sources and decided to use the U.S. Geological Survey's Groundwater Fresh database (U.S. Geological Survey, 2018). The U.S. Geological Survey maintains the national database on water-use information. Since 1980, they have collected and compiled county level water use data every five years for each state. We used linear interpolation to populate values for the intervening years. We extracted mining water use for counties with missing data from the U.S. Geological Survey database and analyzed to determine the aquifer source for the well. Since the U.S.

Geological Survey reports data on a county level, respective aquifer and partial county usage was apportioned using a simple areal coverage method. In case of overlaps, the usage was apportioned using the well details from the Railroad Commission of Texas underground injection control database and the TWDB groundwater well databases. The result of the analysis was an independent mining water use reference for the subject study area over the study period that can be used to identify data gaps.

To identify the data gaps, we assumed that the Water Use Survey does not consider estimates of fresh groundwater pumping due to oil and gas usage whereas the U.S. Geological Survey database accounts for all the mining usage estimate including oil and gas. Therefore, pumpage estimates for each aquifer in each county obtained from the modified Bureau of Economic Geology methodology and the Water Use Survey were summed up and compared to the estimates reported by the U.S. Geological Survey database. During review of the comparison, data gaps were identified and filled.

Upon review by TWDB, it was noted that TWDB staff previously estimated total fracking water use and applied the water source split ratios from Nicot and others (2012). Thus the original TWDB water use survey data would have included pumpage estimates due to oil and gas usage, in contrast to the assumption used in developing this methodology.

The data gaps were filled by assigning that the greater of the comparative mining use estimate values as the revised mining use estimate. Therefore, if the pumping estimate using the U.S. Geological Survey data is greater the sum of the values recorded in the modified Bureau of Economic Geology and the TWDB Water Use Survey data, then the pumping estimate from the U.S. Geological Survey is used and vice versa. Overall, we observed that the revised mining pumping estimates generally reveal a smooth pattern over time and most data gaps, if not all, were filled using our approach.

Geospatial Sourcing of the Pumping Use to Approximate Locations

Geospatial sourcing of the total groundwater pumping for mining use to approximate locations can be difficult, particularly when a significant number of wells used for mining use may be underreported (especially for oil and gas usage). Therefore, we made the following assumptions to assign the approximate locations for the mining use pumping for each county:

- if the county contained wells tagged with mining use within the groundwater databases available from TWDB, then allocate all mining use evenly between those wells;
- If the county contained municipal use wells from groundwater databases available from TWDB and enhanced oil recovery wells from the Railroad Commission of Texas database, then allocate all mining use evenly between those wells after removing any overlapping records from these databases;
- if the county contained no mining use wells but contained enhanced oil recovery wells for which we have locations, then allocate all mining use pumping between those enhanced oil recovery wells; and,
- If the county contains neither mining use wells nor enhanced oil recovery wells, then recommend that mining use pumping be diffused throughout the county.

5.1.6 Manufacturing

To address the Water Use Survey data anomalies associated with manufacturing use, we first reviewed the values reported by each entity in a county. In many cases, we found an entity listed under a different name in the same use category, presumably due to typographic errors or changes in entity ownership. In these cases, we did not modify the entity name but rather analyzed the data based on the TWDB Survey Number. After verifying the entity name and TWDB Survey Number, we reviewed the aquifer designations for each entity by reviewing the entity locations within the aquifer extent. Typically, the aquifer designations appeared correct though there were occasions where pumping appeared to be attributed to an incorrect aquifer (as discussed for the test case in Section 4.5). For anomalous pumping values where the entity and aquifer were correct, we updated the pumping value to be consistent with other pumping data reported by the entity. For example, if the entity went out of business, its pumping would be set to zero but if the entity was missing a year, we deemed it reasonable to interpolate the missing value.

After updating the manufacturing use pumping data, we assigned the location of the pumping based on the known well or facility locations. To create a pumping distribution file, we researched the latitude and longitude coordinates for each entity. In cases where the entities and their associated wells were listed in the TWDB Groundwater Database (TWDB, 2020b), we used the reported well coordinates. We also checked the Submitted Driller's Reports database (TWDB, 2020f) to locate additional wells. If there had been a change in entity ownership, the wells were typically listed in the databases under another owner's name with the same TWDB survey number. In this way, we were able to track well locations in the TWDB databases even though there had been changes in ownership over time.

If no well location could be found in either database, we assumed that each entity pumps water from a well near their respective facility and used the facility address as an approximate location for pumping. We verified the address of each entity using Google Earth. In instances where an address could not be verified, perhaps because the entity was no longer in business, the nearest city was used as a surrogate for location. When the entity's address or city could not be confirmed, we used the coordinates for the center of the county.

5.1.7 Livestock

Our methodology for assessing groundwater pumping associated with livestock use is detailed within Section 4.6. Through application of our approach, no changes were necessary for developing the final pumping dataset.

5.2 County Revisions

The following sections provide a brief discussion of the results of our evaluations and revisions to the TWDB Water Use Survey data for the purpose of developing groundwater pumping estimates.

5.2.1 Andrews County

Figure 403 and Figure 404 illustrate our revisions to the estimated groundwater pumping from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Andrews County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

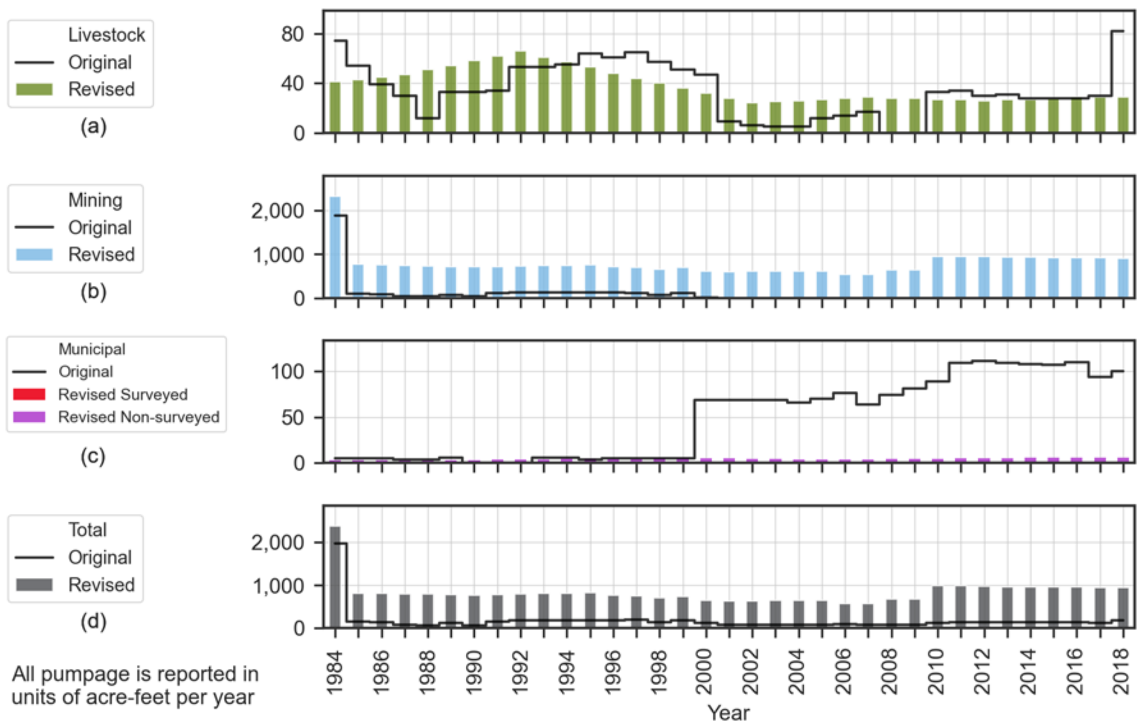


Figure 403. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Andrews County from 1984 through 2018.

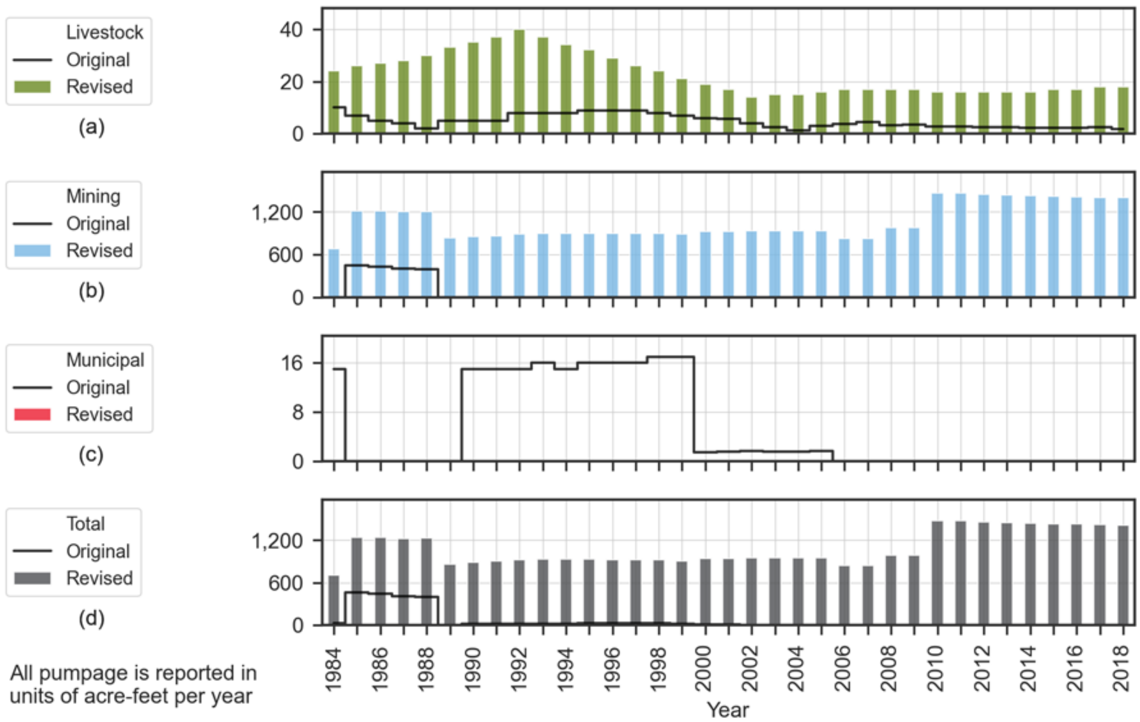


Figure 404. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Andrews County from 1984 through 2018.

Surveyed Municipal

Figure 403c illustrates the changes in groundwater pumping associated with surveyed municipal use from the Pecos Valley Aquifer in Andrews County during the study period. Figure 404c illustrates the changes in groundwater pumping associated with surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Andrews County during the study period. Our review of the available data indicated that no pumping for this use occurs from the Pecos Valley Aquifer or Edwards-Trinity (Plateau) Aquifer. All pumpage previously attributed to these aquifers was re-allocated to be from the Ogallala Aquifer, based upon the screened intervals of available wells.

Non-Surveyed Municipal

Figure 405 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer in Andrews County during the study period. Our estimates are several times less than the TWDB Water Use Survey data. Our review of the available data suggested the pumping for this use is less than previous estimates suggest. This reduction in revised pumping is not reflective of the revision of the aquifer footprints of the Pecos Valley Aquifer and Ogallala Aquifer over this study period, as suggested by TWDB (See comment #72 in Appendix).

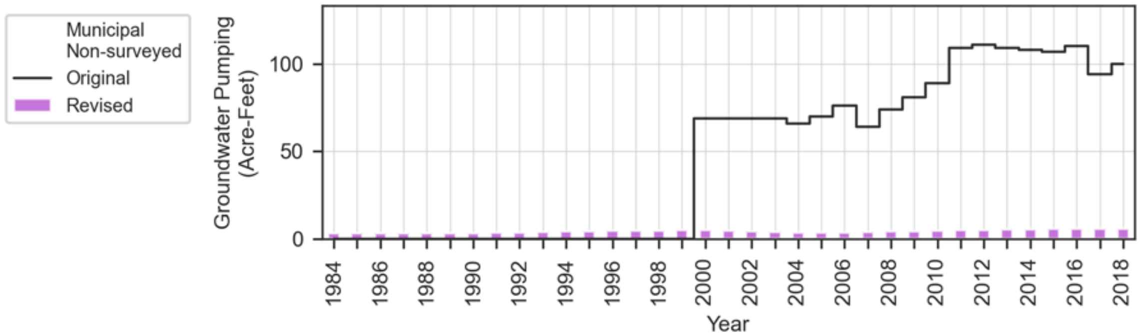


Figure 405. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Andrews County from 1984 through 2018.

Irrigation

The Pecos Valley Aquifer spans most of the southwest corner of Andrews County (Figure 406). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation water need for land above the footprint of the Pecos Valley Aquifer ranged from 1,600 acre-feet per year to over 8,500 acre-feet per year. However, all the identified groundwater wells located within the Pecos Valley Aquifer footprint appear to be screened to withdraw water from the Dockum Aquifer. As such, our analysis confirms that groundwater from the Pecos Valley Aquifer is not used for irrigation purposes within Andrews County.

The Edwards-Trinity (Plateau) Aquifer is located along the southeastern portion of Andrews County (Figure 406). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation water need for land above the footprint of the Edwards-Trinity (Plateau) Aquifer ranged from just under 400 acre-feet per year to over 1,800 acre-feet per year. However, all the identified groundwater wells located within the Edwards-Trinity (Plateau) Aquifer footprint appear to be screened to withdraw water from the Ogallala Aquifer which overlies the Edwards-Trinity (Plateau) Aquifer in this area. As such, this analysis confirms that groundwater from the Edwards-Trinity (Plateau) Aquifer is not used for irrigation purposes within Andrews County.

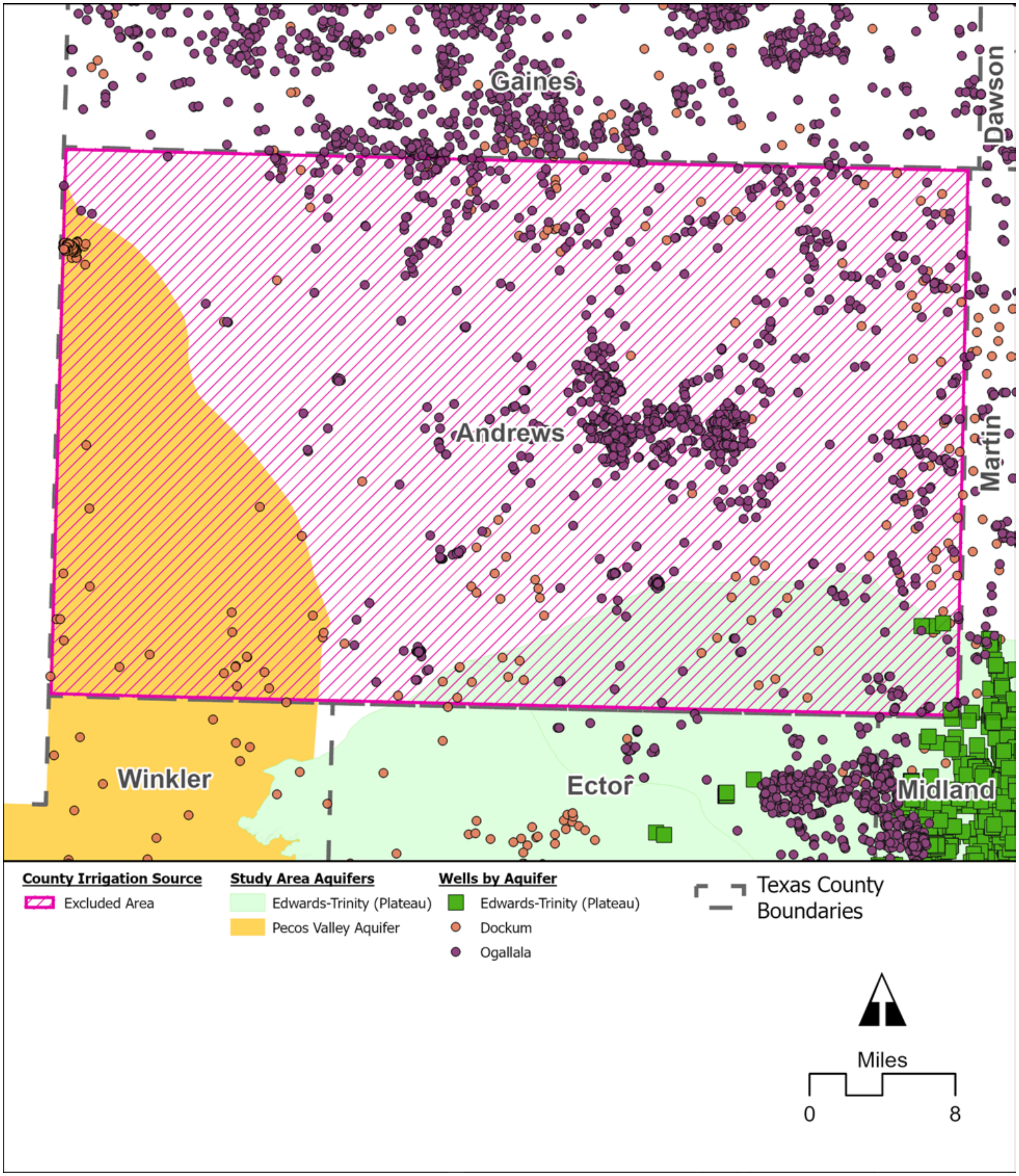


Figure 406. Andrews County map showing aquifers and wells used in assessing irrigation pumpage.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Andrews County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Andrews County.

Mining

Figure 403b and Figure 404b illustrate the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Andrews County during the study period. According to the Railroad Commission of Texas database, the number of active enhanced oil recovery wells in Andrews County was about 540 in 1980 and has increased to 850 wells in 2020. Since there are a significant number of Class II injection wells in Andrews County, we can infer that there is significant pumping related to oil and gas activities. It is observed that in Andrews County, 57 percent of water for mining use is pumped from the Edwards-Trinity (Plateau) and 43 percent from the Pecos Valley Aquifer.

There was only one mining use pumping record for this county in the Water Use Survey data. The TWDB Water Use Survey data indicated the groundwater was pumped from the Pecos Valley Aquifer by the Union Oil Company of California-Dollar hide Unit for mining in the year 2000. We included this record in our final county estimate for the Pecos Valley Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Andrews County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Andrews County.

Livestock

Figure 403a and Figure 404a illustrate the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Andrews County during the study period. Estimated pumping for livestock use is similar in magnitude to the Water Use Survey estimates for the Pecos Valley Aquifer. However, our estimated pumping from the Edwards-Trinity (Plateau) Aquifer is several times higher given the number of cattle, chicken, and sheep reported in the agriculture census dataset utilized to determine the pumpage for livestock.

5.2.2 Atascosa County

Figure 407 illustrates our revisions to the estimated groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Atascosa County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

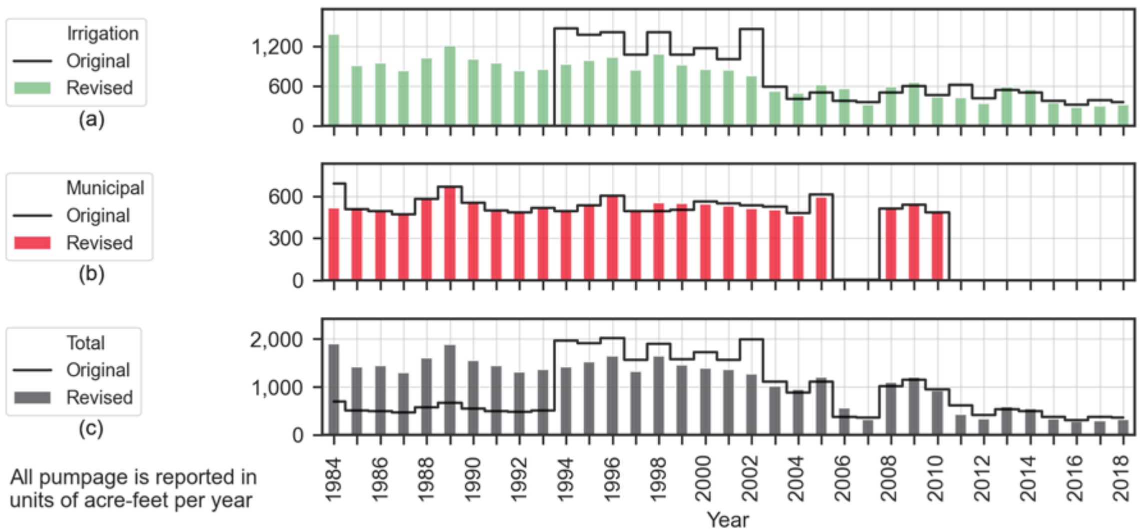


Figure 407. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Atascosa County from 1984 through 2018.

Surveyed Municipal

Figure 407b illustrates the changes in groundwater pumping associated with surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer in Atascosa County during the study period. Our review of the available data indicated that only the City of Lytle pumps groundwater for this use from the Edwards (Balcones Fault Zone) Aquifer. It is likely that the low pumpage values reported for the City of Lytle in 2006-2007 are incorrect.

Non-Surveyed Municipal

The TWDB Water Use Survey data includes up to about 21 acre-feet of pumping 2005. However, only a small portion of the Edwards (Balcones Fault Zone) Aquifer is present in the county and is below the Carrizo-Wilcox Aquifer. Based on the location of the aquifer, our estimates do not include any non-surveyed municipal use pumping in Atascosa County.

Irrigation

Only the north-west corner of Atascosa County overlies portions of the Trinity (Hill Country) Aquifer and the Edwards (Balcones Fault Zone) Aquifer. Original Water Use Survey data for irrigation indicated that up to 1,500 acre-feet per year had been used in this region for irrigation between 1994 and 2002, with around 500 acre-feet per year used from 2003 to 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation water need for land above the footprint of the Edwards (Balcones Fault Zone) Aquifer ranged from 1,400 acre-feet per year in 1984 to approximately 900 acre-feet per year in 2002, with pumpage fluctuating between 700 acre-feet per year and 400 acre-feet per year from 2003 to 2018 (Figure 408). Fluctuations over this time were due to the varying rainfall patterns that occurred. The general decrease in pumpage that occurred around the 2002 to 2003 timeframe is attributed to a change in the overall distribution of crops and crop types grown within the county before and after this period.

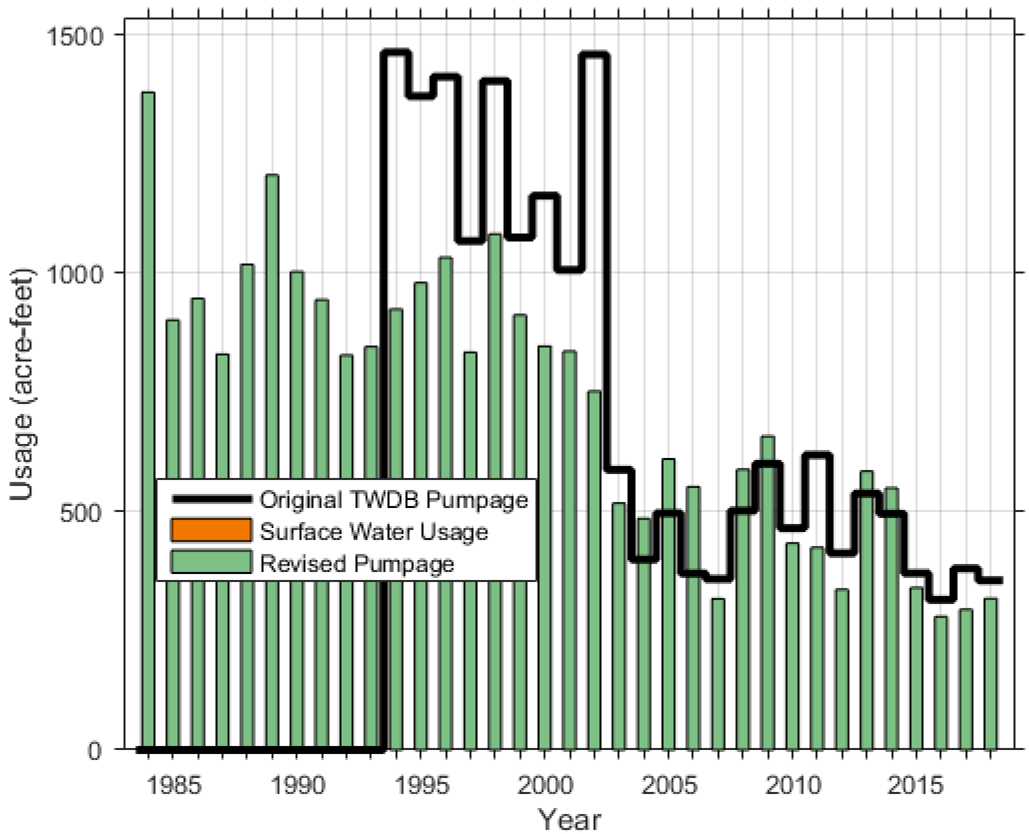


Figure 408. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Atascosa County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Atascosa County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Atascosa County.

Mining

The TWDB Water Use Survey dataset does not contain any records of groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer in Atascosa County during the study period. No enhanced oil recovery wells are reported within the county. However, San Miguel surface mines do overlap Atascosa County. Based on the areal coverage of the San Miguel mines, groundwater well databases were analyzed for any mining water wells located in the area. The U.S. Geological Survey database was also accessed to estimate groundwater pumping for mining use. Based on our analysis, there is no indication unreported groundwater pumping for mining use from one of study area aquifers is occurring.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Atascosa County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Atascosa County.

Livestock

For the study period and the study area aquifers, there is no groundwater pumping associated with livestock use in Atascosa County. Also, there is no indication unreported groundwater pumping associated with livestock use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for livestock use in Atascosa County.

5.2.3 Bandera County

Figure 409 and Figure 410 illustrates our revisions to the estimated groundwater pumping from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Bandera County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

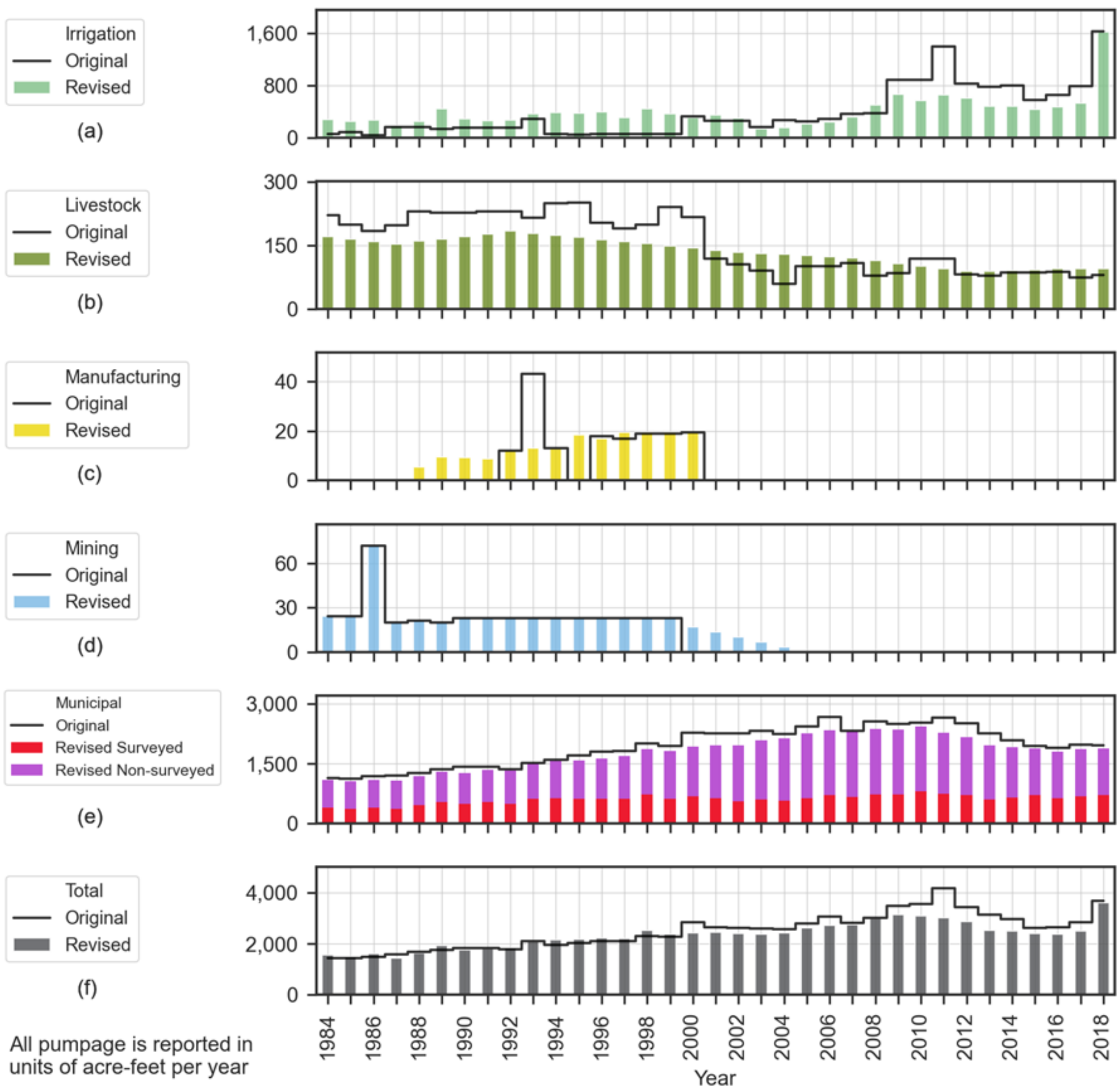


Figure 409. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Bandera County from 1984 through 2018.

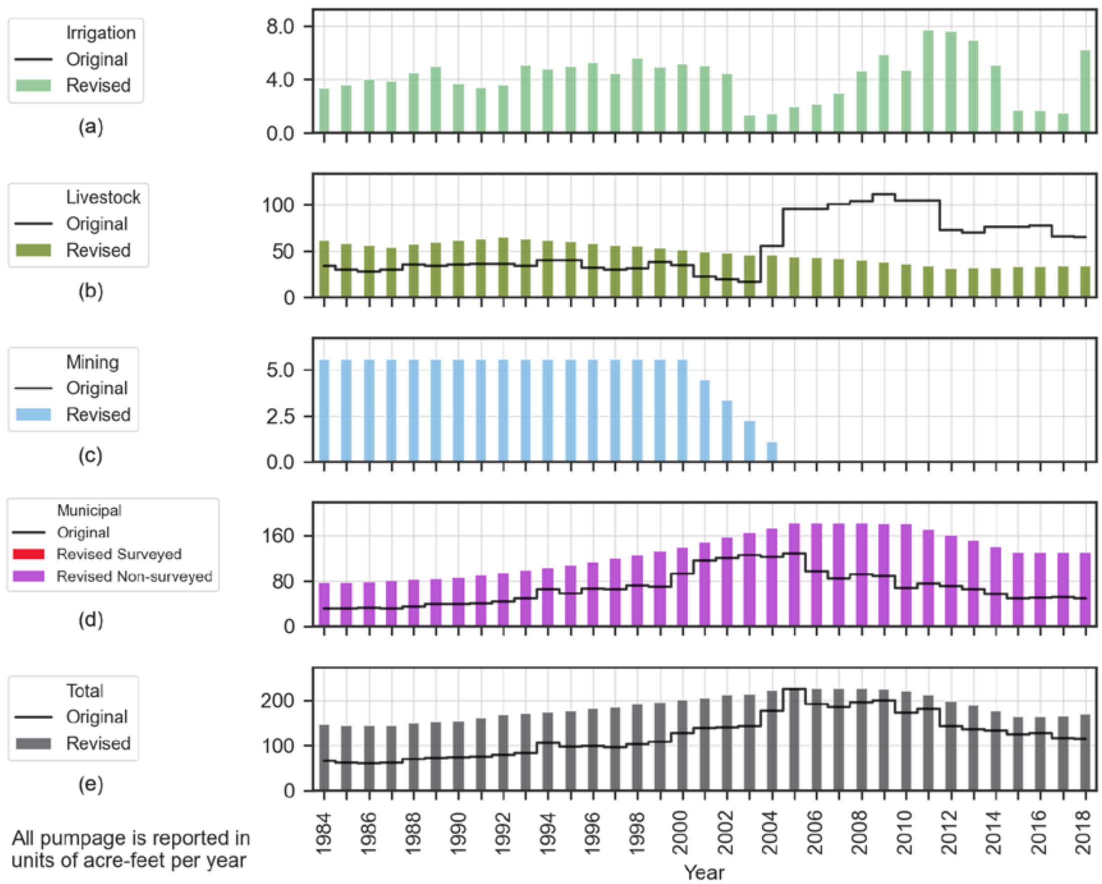


Figure 410. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Bandera County from 1984 through 2018.

Surveyed Municipal

Figure 409e and Figure 410d illustrate the changes in groundwater pumping associated with surveyed municipal use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Bandera County. The groundwater pumpage for two locations (Ranch Hills WSC and Hill Country Utilities – Comanche Cliffs) were originally assigned to the Edwards-Trinity (Plateau) Aquifer, but were reassigned to the Trinity (Hill Country) Aquifer based on their locations and the aquifer footprints within Bandera County. This adjustment removed all municipal-surveyed pumpage from the Edwards Trinity (Plateau) Aquifer within the county.

Non-Surveyed Municipal

Figure 411 and Figure 412 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Bandera County during the study period. Our estimates for the Trinity (Hill Country) Aquifer are generally consistent with the TWDB Water Use Survey data. However, for the Edwards-Trinity (Plateau) our review of the available data suggested the pumping for this use is about double the TWDB Water Use Survey data after 2005.

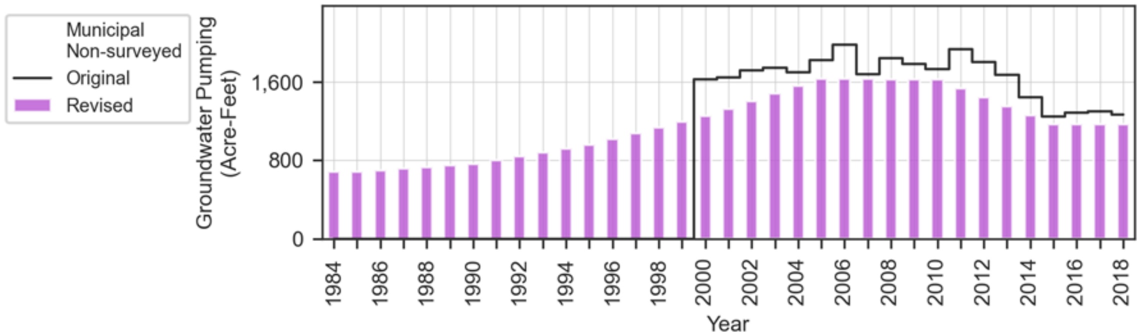


Figure 411. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Bandera County from 1984 through 2018.

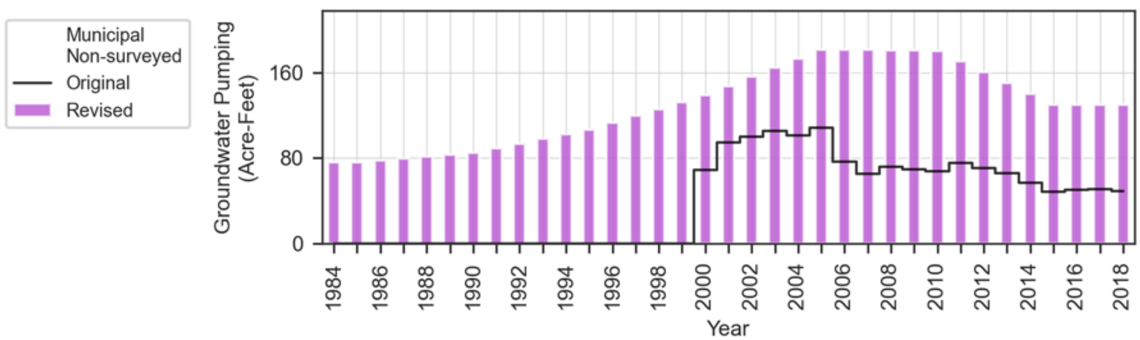


Figure 412. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Bandera County from 1984 through 2018.

Irrigation

The eastern and southern portions of Bandera County overly portions of the Trinity (Hill Country) Aquifer, whereas the northern and western corners of the county overly the Edwards-Trinity (Plateau) Aquifer. Original TWDB Water Use Survey data suggested that irrigation pumpage only occurs from the Trinity (Hill Country) Aquifer. Original Water Use Survey data estimates ranged from less than 300 acre-feet per year to approximately 1,600 acre-feet per year, with a notable increase after 2009 (Figure 413). Revised pumpage estimates suggest greater pumpage from 1984 to 2002, nearly equal pumpage from 2003 to 2008, and then less annual pumpage from 2009 to 2017. Original and revised pumpage is nearly identical for 2018, which is the year of maximum original pumpage as reported in the TWDB Water Use Survey. The revised pumpage also accounts for surface water usage to support irrigation operations in Bandera County, with this usage occurring mostly prior to 2003 with lower usage occurring from 2013 to 2017.

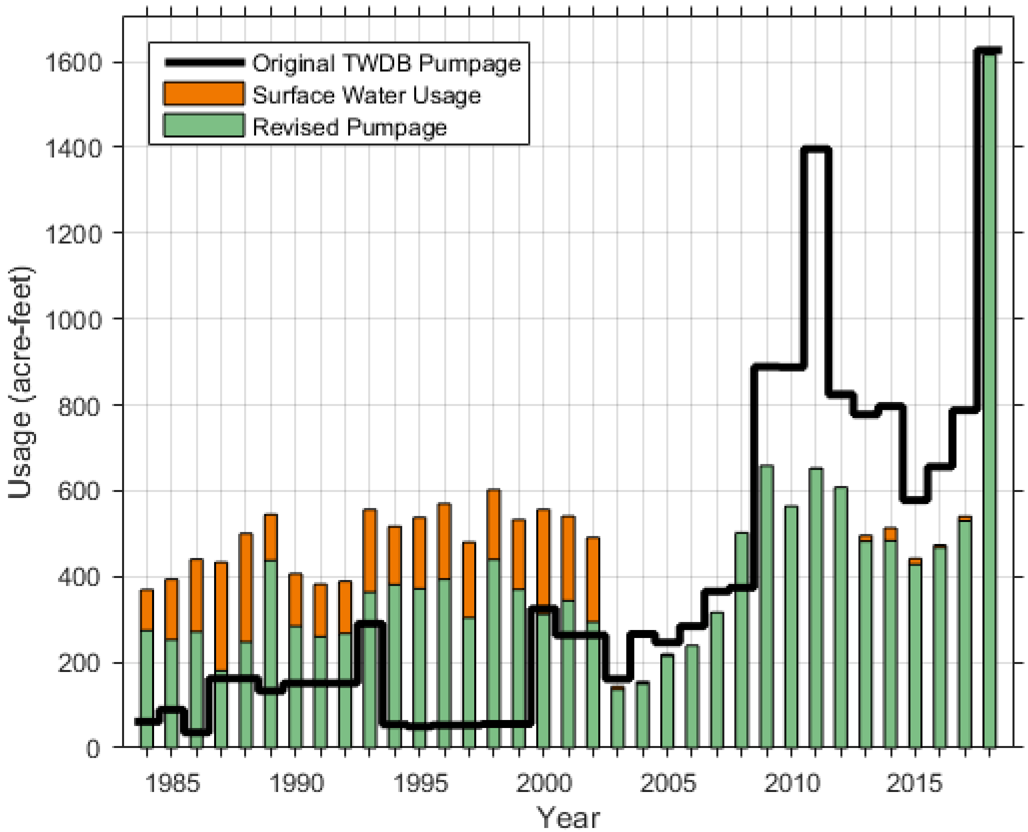


Figure 413. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Bandera County.

Of the 1,616 wells located within Bandera County, 1,507 are identified as being screened within the Trinity (Hill Country) Aquifer, mostly located within the eastern portion of the county. There were 109 wells are located within the Edwards-Trinity (Plateau) Aquifer footprint, the majority of which are listed as supporting domestic or livestock usage. Some wells are listed as supporting irrigation efforts, however. The revised pumpage analysis indicates that between one and eight acre-feet per year would be needed to support irrigation operations over the Edwards-Trinity (Plateau) Aquifer within Bandera County (Figure 414). Original TWDB Water Use Survey data did not indicate any irrigation pumpage from the Edwards-Trinity (Plateau) Aquifer within Bandera County.

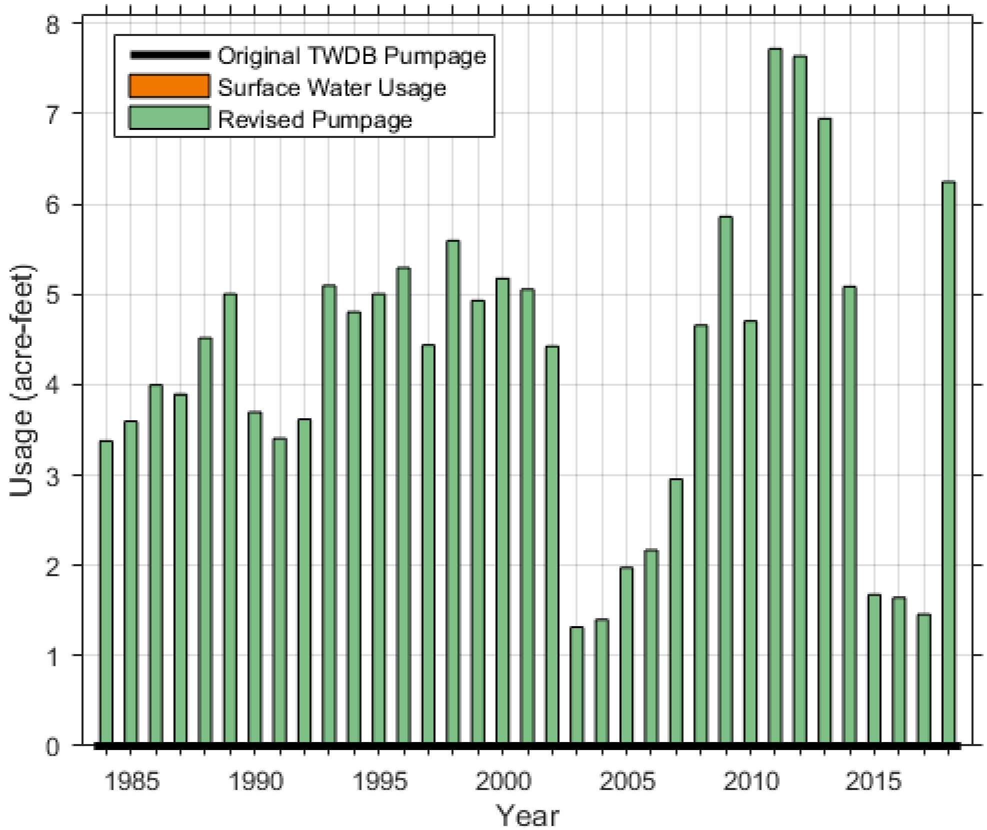


Figure 414. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Bandera County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Bandera County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Bandera County.

Mining

Figure 409d illustrates the changes in groundwater pumping associated with mining use from the Trinity (Hill Country) Aquifer, in Bandera County during the study period. There were no reported enhanced oil recovery wells within Bandera County. The groundwater pumping estimates for mining use obtained from U. S. Geological Survey database were used along with the reported source aquifers. Approximately, 75 percent of mining use water is extracted from the Trinity (Hill Country) and 25 percent is from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 409c illustrates the changes in groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Bandera County during the study period. These changes in pumping for manufacturing use are associated with a single entity that is no longer in business. The decrease in 1993 is to correct for apparent entry error that year and the increase for a missing value in 1995 is for consistency with the previous and subsequent years.

Livestock

Figure 409b and Figure 410b illustrate the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Bandera County during the study period. Estimated pumping for livestock use is similar to the Water Use Survey estimates for the Trinity (Hill Country) Aquifer. However, our estimated pumping from the Edwards-Trinity (Plateau) Aquifer is higher from 1984 through 2003 after which our estimates are lower than the TWDB Water Use Survey data. Our estimates indicate a more gradual change in the number of cattle, chicken, and sheep reported in the agriculture census dataset compared to the TWDB Water Use Survey data's sudden increase in livestock pumpage in 2004.

5.2.4 Bexar County

Figure 415 and Figure 416 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Bexar County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

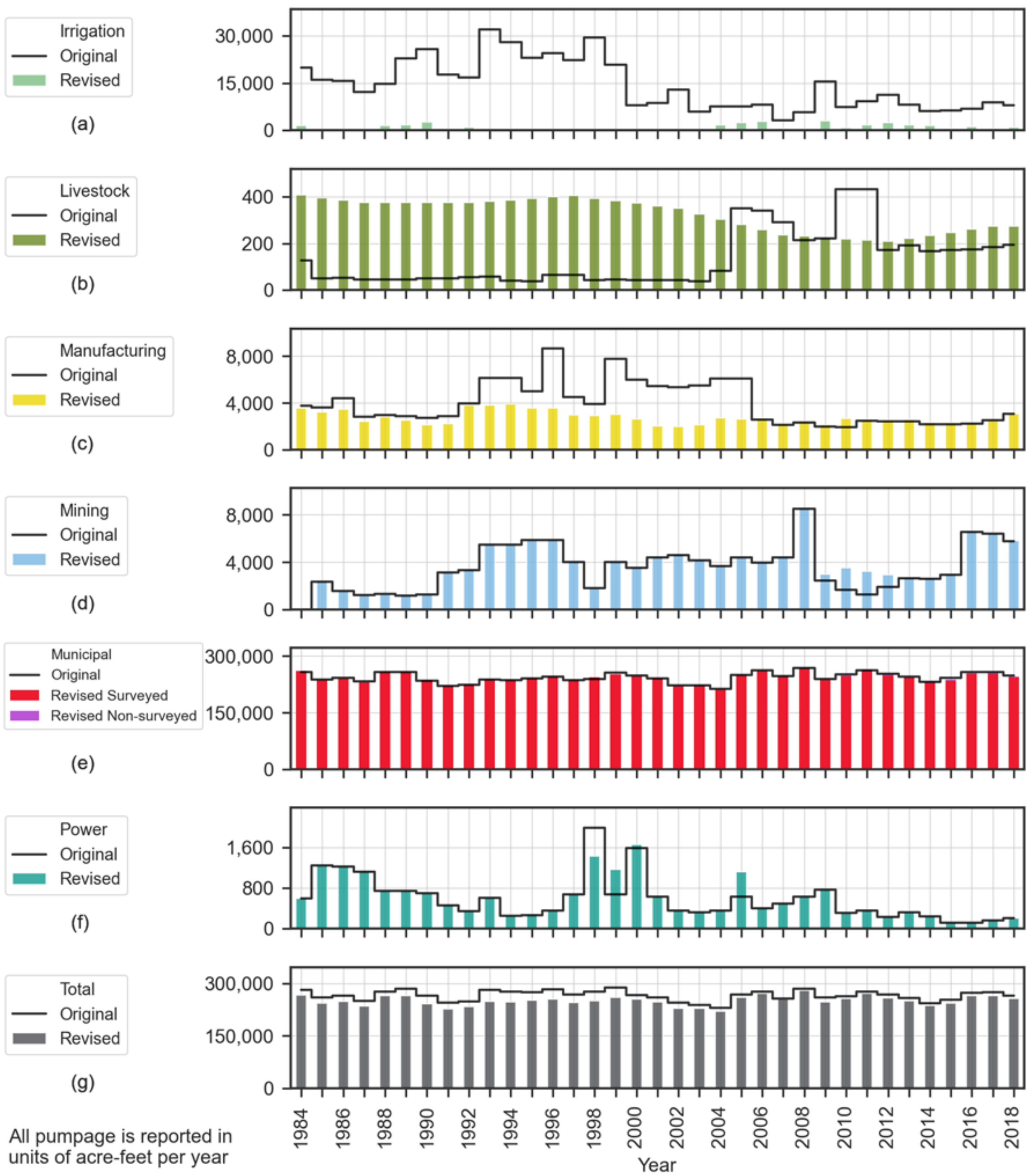


Figure 415. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Bexar County from 1984 through 2018.

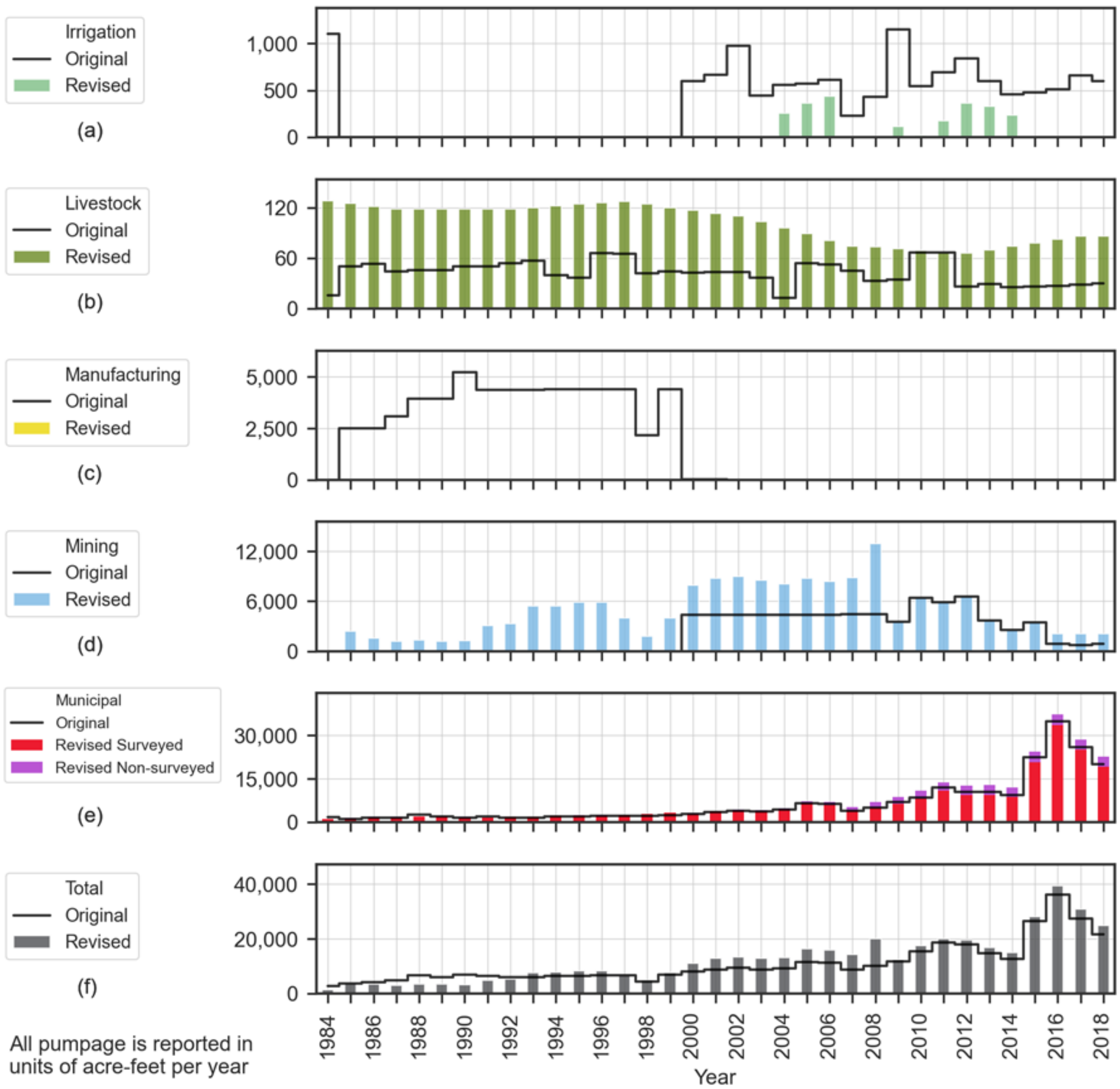


Figure 416. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Bexar County from 1984 through 2018.

Surveyed Municipal

Minimal changes resulted from the revision of groundwater pumping associated with surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Bexar County during the study period. Our revised estimates include some years of interpolated data that were not reported within the original TWDB Water Use Survey data. The majority of pumping is attributed to the San Antonio Water System, which was one of the few entities for which pumping was reported in all study years. Within the TWDB Water Use Survey database, 141 uniquely named entities submitted at least one annual pumpage report during the study period, reporting pumpage from the Edwards (Balcones Fault Zone) Aquifer. For the Trinity (Hill Country) Aquifer, 51 separate entities provided reports, and the number of different entities reporting in any given year ranged from 13 in 2018 to 23 in 2004.

Related to pumping in the Edwards (Balcones Fault Zone) Aquifer, many entities stopped reporting in 2015, while numerous entities under the "Bexar MWD" title all stopped reporting in 2011. Further research was performed to verify that these entities were absorbed into the San Antonio Water System in/after 2011, and water usage by these entities was consequently properly reported under the San Antonio Water System name in 2012-2018. Tracking the operational history of each of these entities could yield additional insight into the accuracy of the reported surveyed municipal pumpage, and was investigated for Bexar County through approximately 20 hours of internet-based search efforts. The objective was to determine the operational timeline of the largest municipal water users within Bexar County, and to determine if this operational timeline included years within which a given entity did not report municipal water usage. In such instances, we interpolated or extrapolated usage data based on the overall trends in the data reported by the entity. For entities for which we were unable to define operational timelines, we assumed the entity was operational for the entire study period, and we extrapolated and interpolated entity pumping data accordingly. The resulting dataset, referred to as the "Potential Pumpage" dataset, effectively constitutes a reasonable "error-range" to be expected within the municipal data. For Bexar County, this Potential Pumpage dataset typically differed from the revised pumping dataset by a median value of 12,065 acre-feet per year for the Edwards (Balcones Fault Zone) Aquifer. This is a median percentage increase of 5% of the revised annual pumpage estimates. From this effort, we concluded that our revised pumpage estimates must be within 5% of the actual unknown municipal pumpage estimate. Further effort researching pumping reported by entities, above the 20 hours of effort, yielded diminishing returns in terms of improved information regarding the various entities. We do not recommend significant effort be expended to research reported pumping anomalies from individual entities unless those entities report over 1,000 acre-feet per year water usage. We also favor the revised pumpage dataset over the "Potential Pumpage" dataset, as we feel it is more likely to accurately represent historical pumpage.

Non-Surveyed Municipal

Figure 417 and Figure 418 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Bexar County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data. While our estimates are lower than the Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer, they are higher for the Trinity (Hill Country) Aquifer.

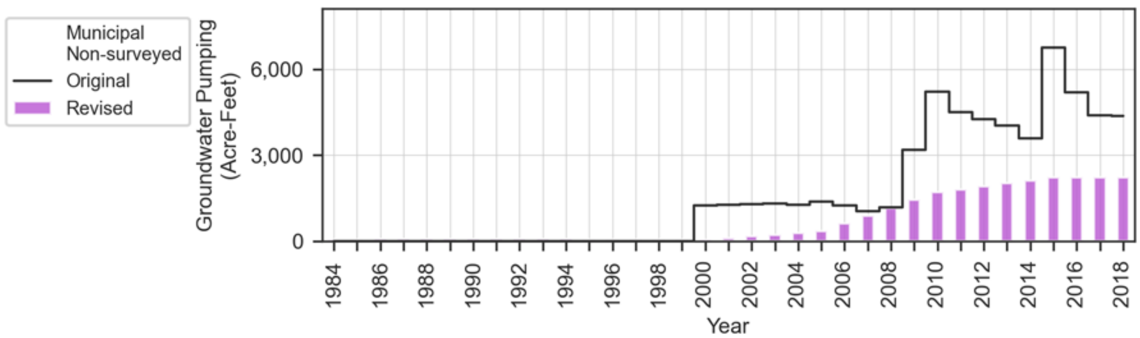


Figure 417. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Bexar County from 1984 through 2018.

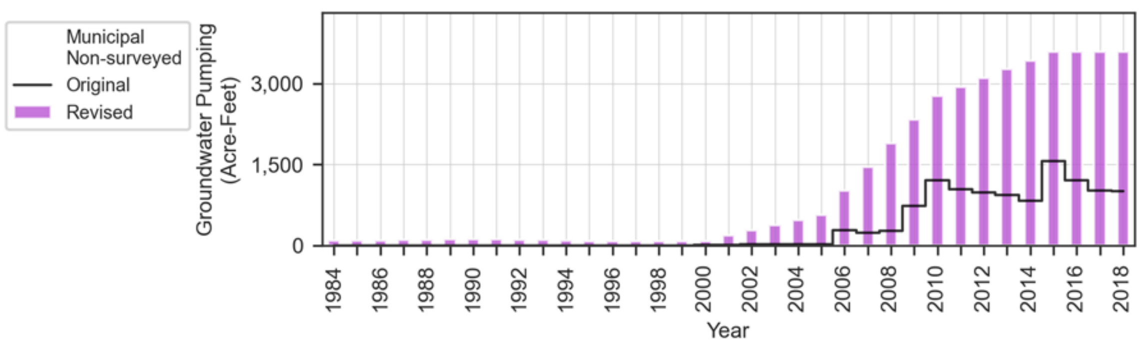


Figure 418. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Bexar County from 1984 through 2018.

Irrigation

Bexar County is underlain by the Trinity (Hill Country) Aquifer, the Edwards (Balcones Fault Zone) Aquifer, and the Carrizo Aquifer (Figure 417). The Carrizo Aquifer, which is not a part of this study, underlies the southeastern portion of the county. Wells within Bexar County are geographically consistent such that those screened in the Trinity (Hill Country) Aquifer are located to the north of the county and all wells screened in the Edwards (Balcones Fault Zone) Aquifer are located generally within the middle of the county. Revised irrigation water needs estimates were determined based on the geographic distribution of wells screened in the Trinity (Hill Country) Aquifer and those screened in the Edwards (Balcones Fault Zone) Aquifer, rather than based on the overlapping aquifer footprints.

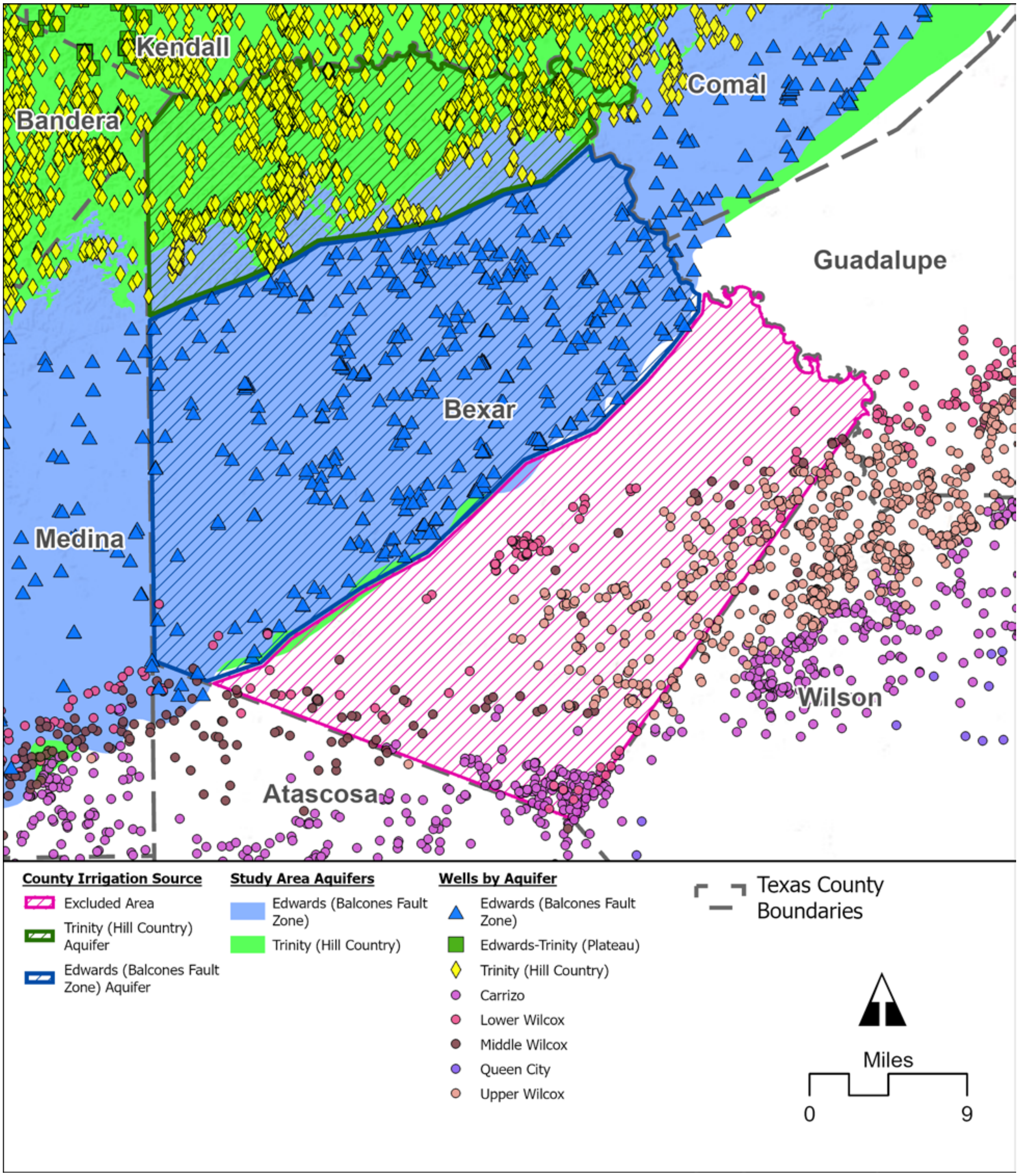


Figure 419. **Bexar County map showing aquifers and wells used in assessing irrigation pumpage.**

TWDB Water Use Survey data also indicate that surface water was routinely used for irrigation within Bexar County, often in quantities of the same order of magnitude as reported for groundwater usage. To distribute the surface water usage across Bexar County, 37 percent was provided for use over the Carrizo Aquifer footprint, 15 percent was provided for use over the

Trinity (Hill Country) Aquifer footprint, and 48 percent was provided for use over the Edwards (Balcones Fault Zone) Aquifer footprint. These percentages were based on the average annual irrigation demand for the entire county relative to the reported aquifer demands included within the TWDB Water Use Survey dataset.

Revised pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Bexar County ranged from zero acre-feet per year to approximately 3,000 acre-feet per year (Figure 420). In many years, computed pumpage is reduced to zero as sufficient surface water supplies were available to meet the modeled water demand. Modeled irrigation demand from the Edwards (Balcones Fault Zone) Aquifer is generally much less than usage reported in the original TWDB Water Use Survey datasets.

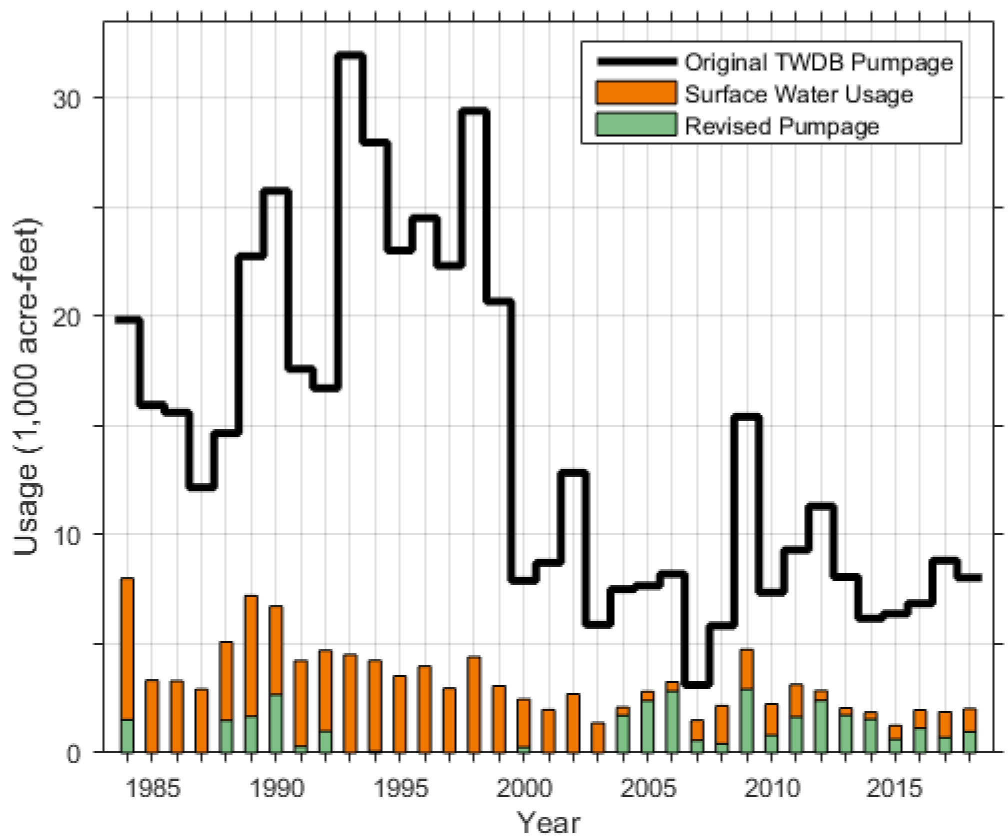


Figure 420. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Bexar County.

Revised pumpage for irrigation from the Trinity (Hill Country) Aquifer within Bexar County ranged from zero acre-feet per year to approximately 440 acre-feet per year (Figure 421). In many years, computed pumpage is reduced to zero as sufficient surface water supplies were available to meet the modeled water demand. Modeled irrigation demand from the Trinity (Hill Country) Aquifer is generally less than usage reported in the original TWDB Water Use Survey datasets. The original TWDB Water Use Survey dataset did not include pumpage for irrigation from the Trinity (Hill Country) Aquifer from 1985 to 1999. This analysis determined that between 1,000 and 2,000 acre-feet per year of irrigation water was needed during these years, but that this need was met through usage of surface water.

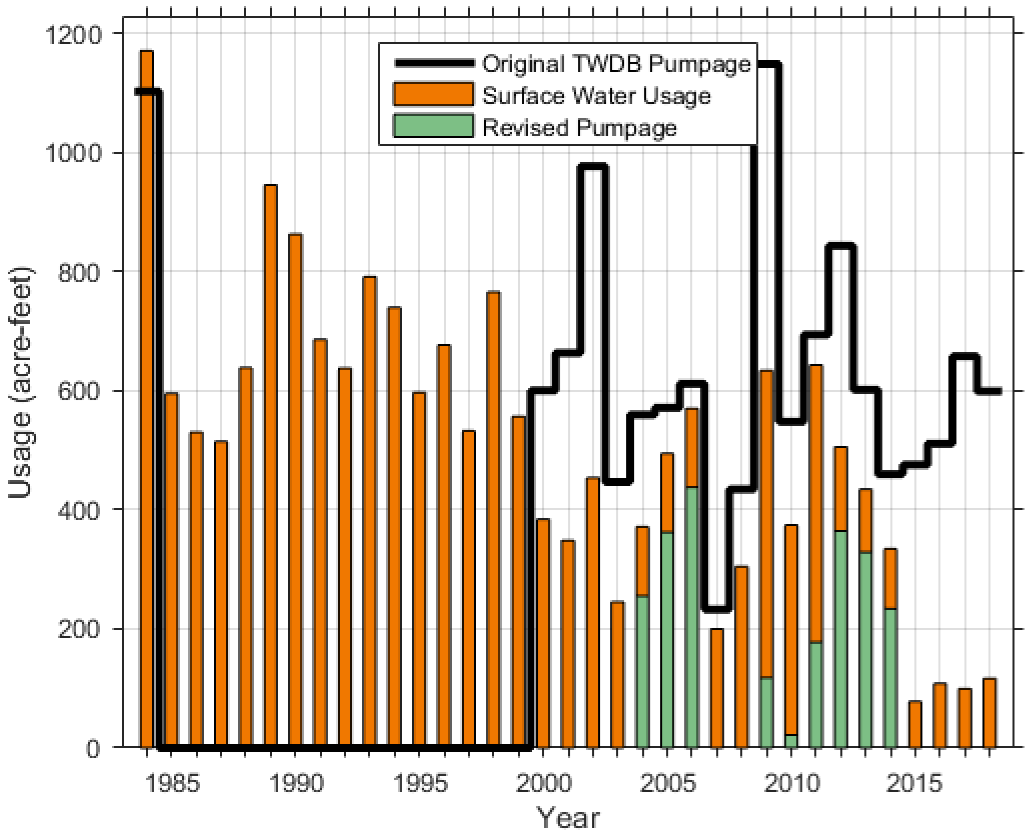


Figure 421. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Bexar County.

Power

As reported in Section 3.3.4 and illustrated on Figure 422, pumping from the Edwards (Balcones Fault Zone) Aquifer in Bexar County for power generation use ranged between 250 acre-feet and 750 acre-feet, except for during the 1985-1987 and 1998-2000 periods when pumpage surpassed 1,000 acre-feet. We found several anomalies in the data based on our manual review, a year-to-year change, and a standard deviation analyses.

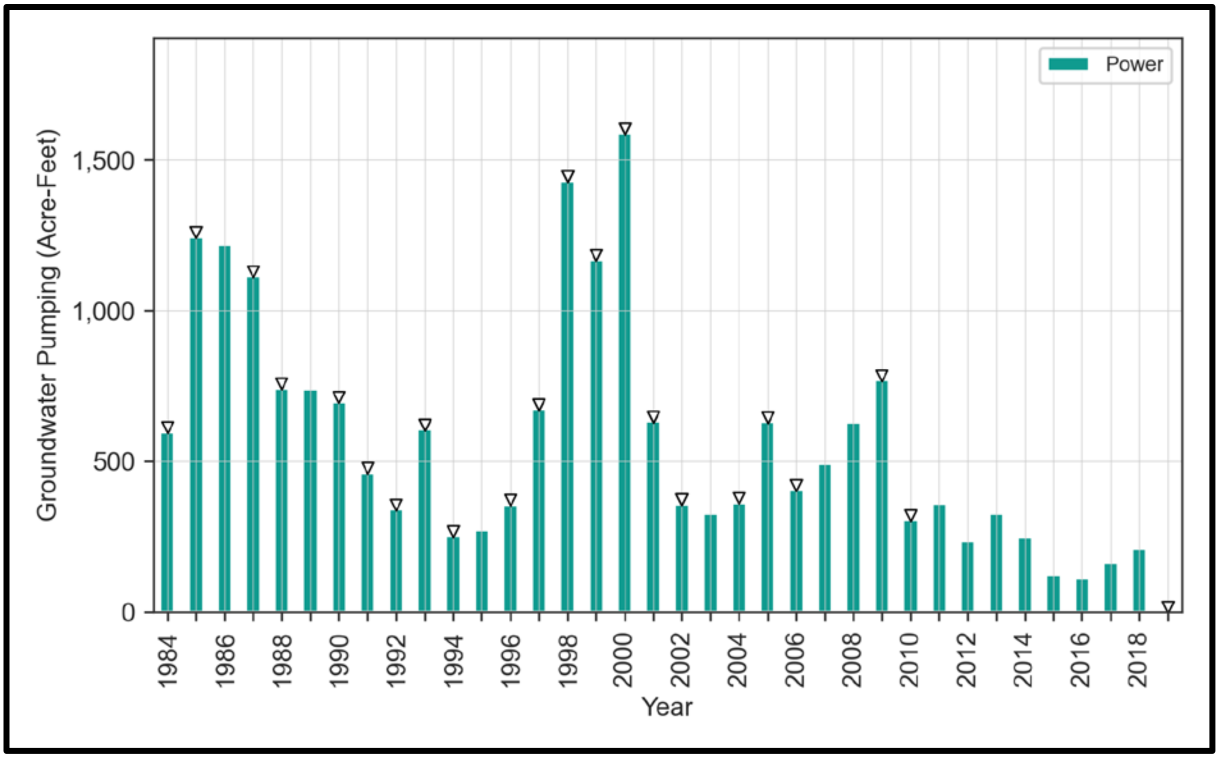


Figure 422. Edwards (Balcones Fault Zone) Aquifer groundwater pumping for power use in Bexar County as reported in the original TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Edwards (Balcones Fault Zone) Aquifer pumping for power use per entity in Bexar County, we determined there were several surveyed entities reporting groundwater production. The reporting entities were the following:

1. CPS Energy – Leon Creek Power Plant (hereafter referred to as "Leon Creek Power Plant"). The location of the Leon Creek Power Plant is shown in Figure 423.
2. CPS Energy – Mission Road Power Plant (hereafter referred to as "Mission Road Power Plant"). The location of the Mission Road Power Plant is shown in Figure 424.
3. CPS Energy – Tuttle Power Plant (hereafter referred to as "Tuttle Power Plant"). The location of the Tuttle Power Plant is shown in Figure 425.

Table 66, Table 67, and Table 68 present the timeline of operation events as provided on form EIA-860 for each power plant in Bexar County.

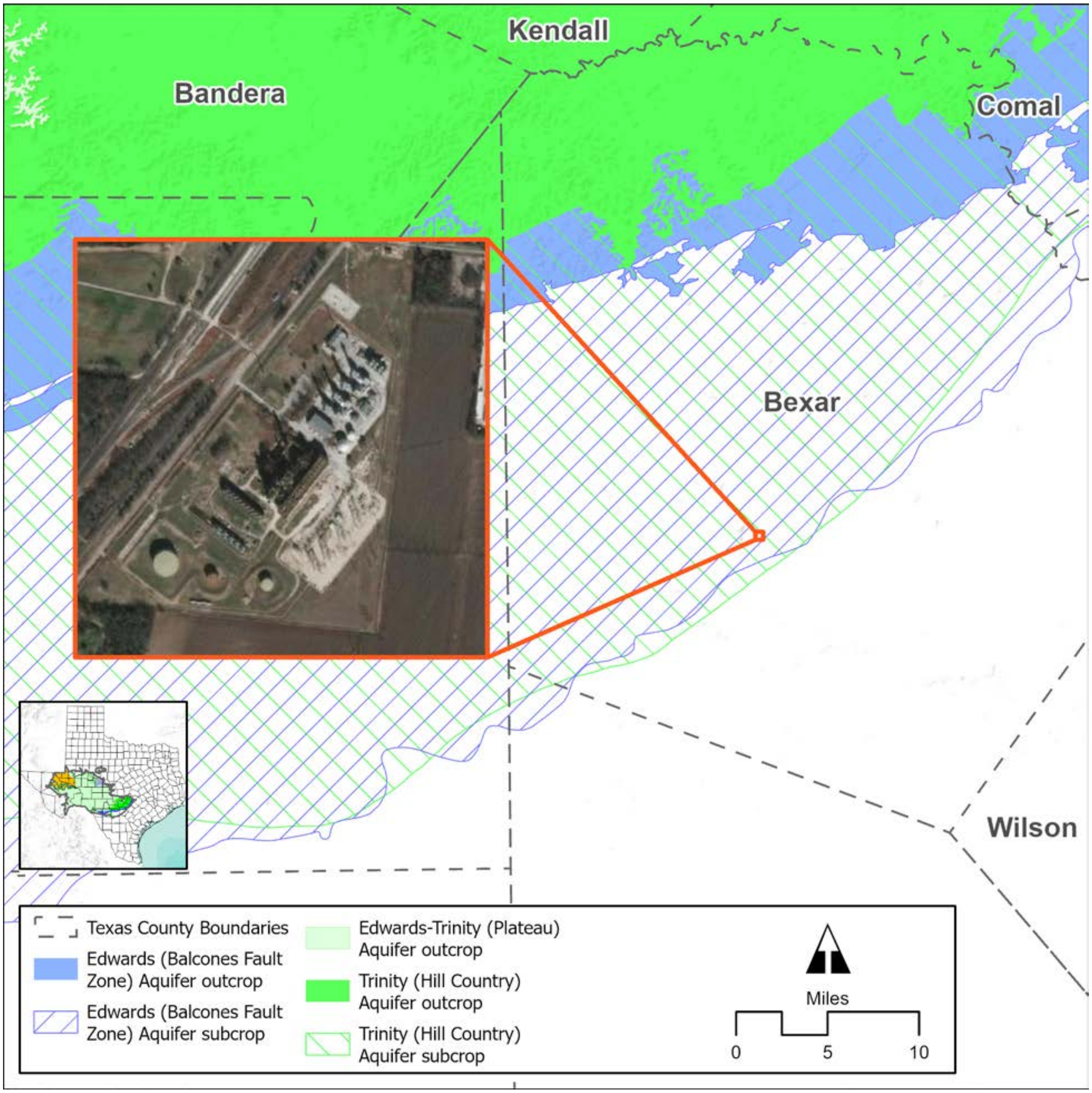


Figure 423. Location of the Leon Creek Power Plant in Bexar County.

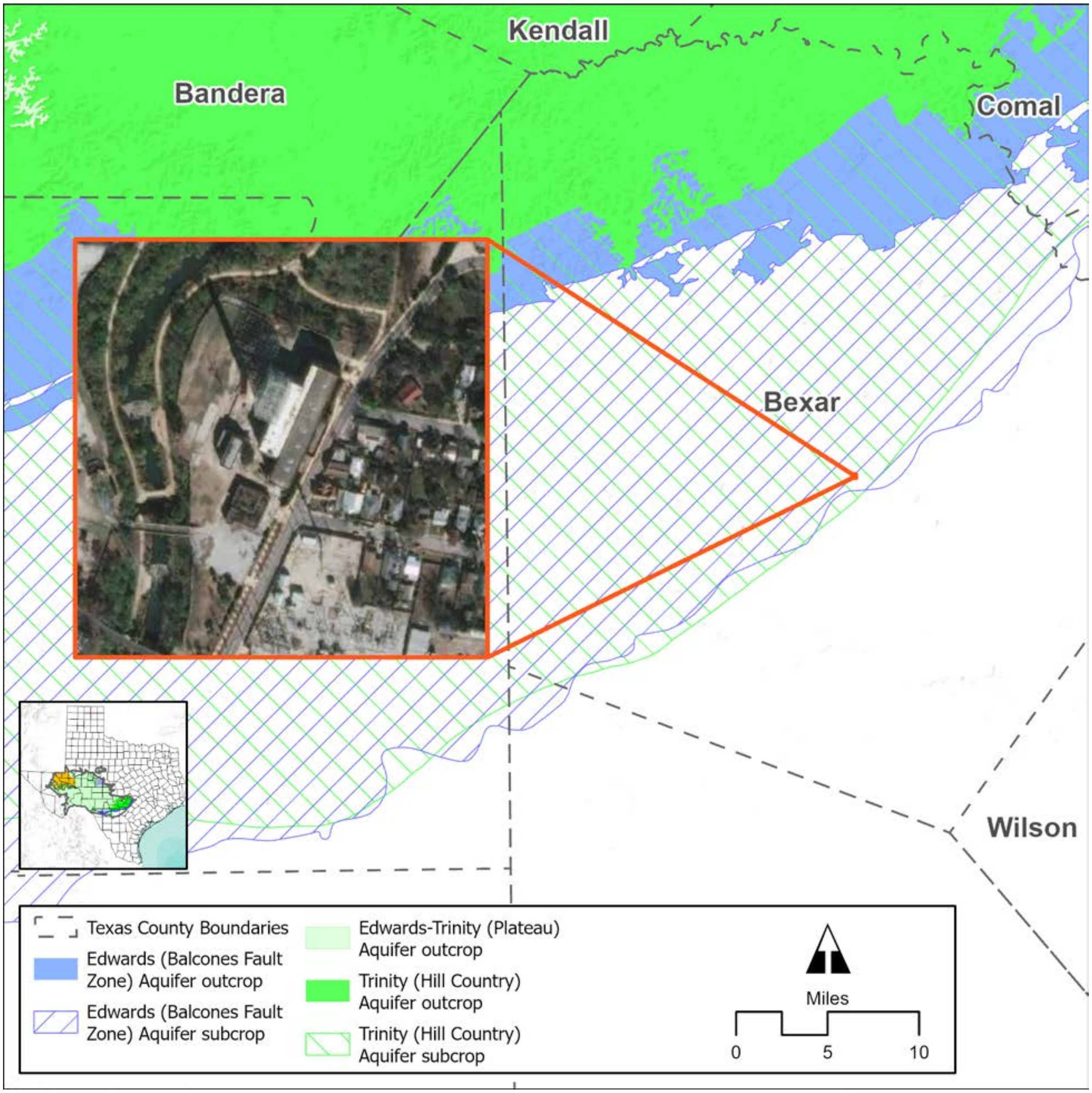


Figure 424. Location of the Mission Road Power Plant in Bexar County.

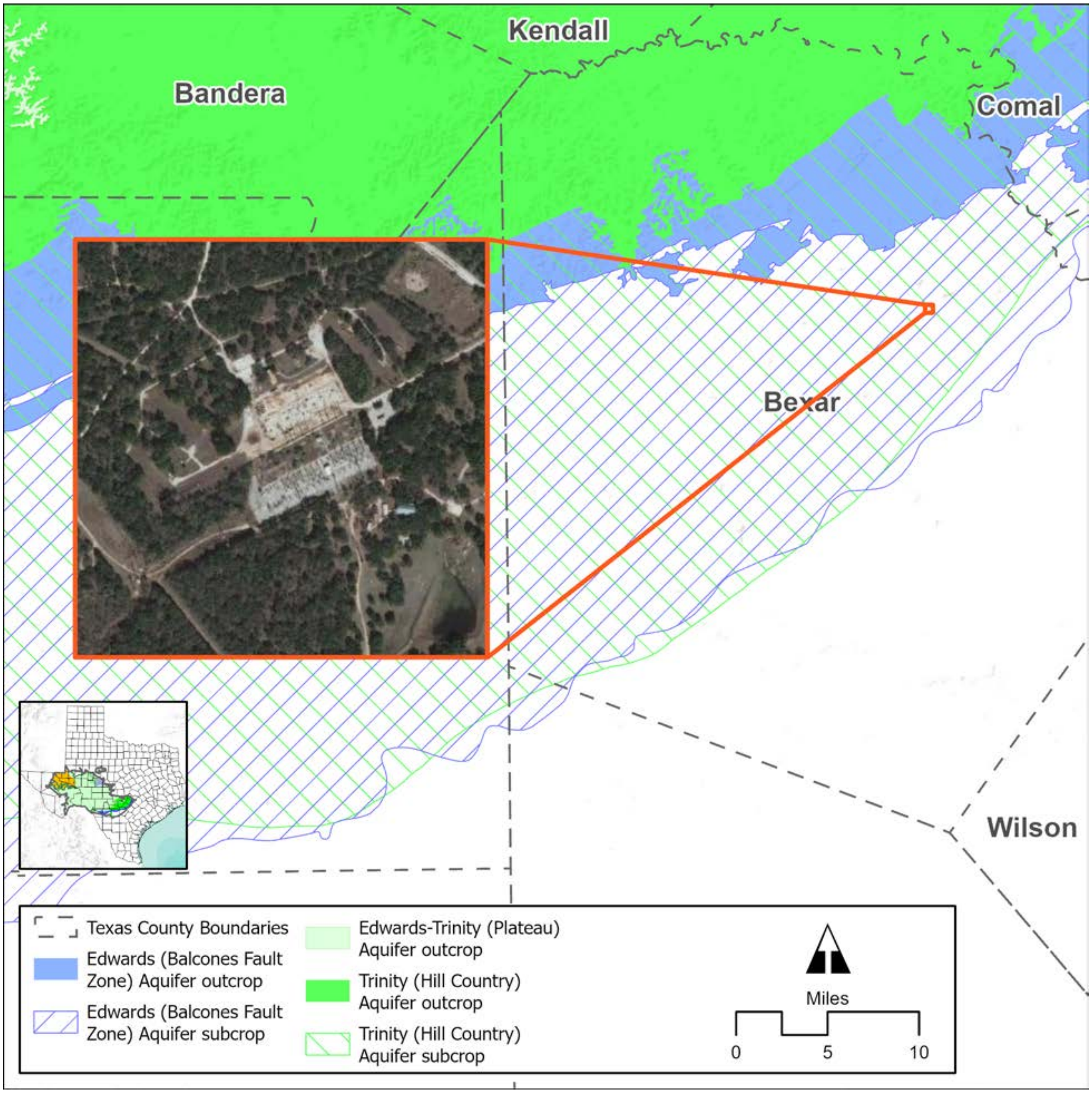


Figure 425. Location of the Tuttle Power Plant in Bexar County.

Table 66. Leon Creek Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
1959	ST 4	Began Operation	Steam Turbine	Fossil fuels	Mechanical draft, wet process	Recirculating with induced draft cooling tower(s)
1953	ST 3	Began Operation	Steam Turbine	Fossil Fuels	Mechanical draft, wet process	Recirculating with forced draft cooling tower(s)
2004	CGT1	Began Operation	Combustion Turbine	Fossil Fuels		
2004	CGT2	Began Operation	Combustion Turbine	Fossil Fuels		
2004	CGT3	Began Operation	Combustion Turbine	Fossil Fuels		
2004	CGT4	Began Operation	Combustion Turbine	Fossil Fuels		
2013	ST 3	Retired	Steam Turbine	Fossil Fuels	Mechanical draft, wet process	Recirculating with induced draft cooling tower(s)
2013	ST 4	Retired	Steam Turbine	Fossil Fuels	Mechanical draft, wet process	Recirculating with forced draft cooling tower(s)

Table 67. Mission Road Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
1958	ST	Began Operation	Steam Turbine	Fossil fuels		
2003	ST	Retired	Steam Turbine	Fossil fuels		

Table 68. Tuttle Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
1954	ST 1	Began Operation	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
1956	ST 2	Began Operation	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
1961	ST 3	Began Operation	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
1963	ST 4	Began Operation	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
2011	ST 1	Retired	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
2007	ST 2	Retired	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
2011	ST 3	Retired	Steam Turbine	Fossil fuels		Recirculating with Forced Draft
2011	ST 4	Retired	Steam Turbine	Fossil fuels		Recirculating with Forced Draft

Steam turbines and boilers (such as Leon Creek Power Plant units ST 3 and ST 4, Mission Road Power Plant unit ST, and Tuttle Power Plant units ST 1, ST 2, ST 3, and ST 4), heat water and subsequently condense the steam, and have larger cooling requirements than combustion turbines (such as Leon Creek Power Plant units CGT1, CGT2, CGT3, and CGT4).

Table 69 summarizes the water use values applied for each turbine for each power plant given the type of power generation turbine used, the cooling tower type, fuel type, and whether the turbine was operating or out of service.

Table 69. Bexar County Power Plant Water Use Values.

Power Plant	Size	Age	Steam Turbine (gallons per kilowatt-hour)	Gas Turbine (gallons per kilowatt-hour)
Leon Creek	Medium	Old	0.98	0.05
Mission Road	Small	Old	0.98	0.05
Tuttle	Medium	Old	0.80	0..05

Figure 426 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Leon Creek Power Plant. Figure 426d illustrates the pumpage based on the Water Use Survey and Figure 426e illustrates the revised pumpage based on the pumping estimates. The only year that was revised was 2005, where the pumping estimates indicated a peak in pumpage stemming from the steam turbines. We will apply these revised estimates of pumping for power use from the Edwards (Balcones Fault Zone) Aquifer in Bexar County based on the location of the power plant (Figure 423) and any associated wells.

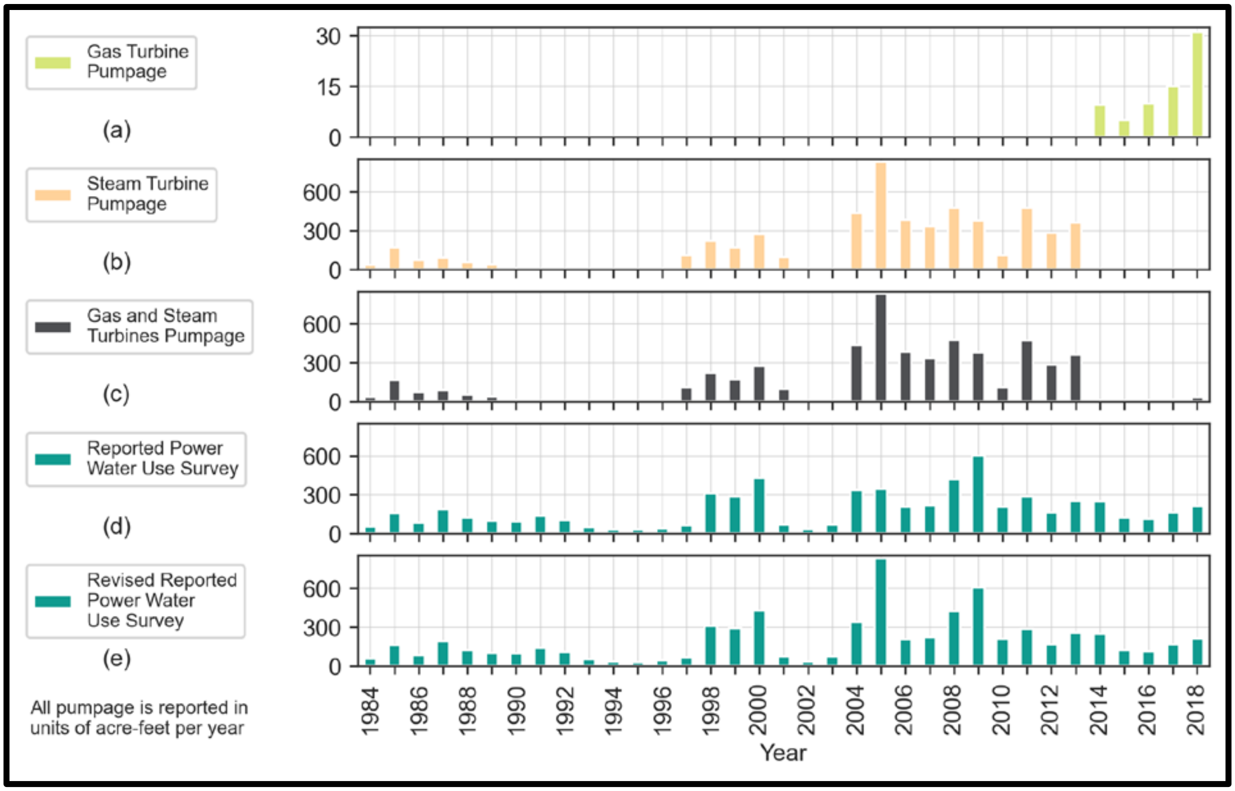


Figure 426. Leon Creek Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated groundwater pumping associated with steam turbine power generation, (c) Estimated combined groundwater pumping by both steam and gas turbines (d), Reported groundwater pumping by the Water Use Survey, and (e) Revised groundwater pumping.

Figure 427 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Mission Road Power Plant. Figure 427c illustrates the pumpage based on the Water Use Survey and Figure 427d illustrates the revised pumpage based on the pumping estimates. The only year that was revised was 2005, where the pumping estimates indicated an increased electricity generation from the steam turbines. We will apply these revised estimates of pumping for power use from the Edwards (Balcones Fault Zone) Aquifer in Bexar County based on the location of the power plant (Figure 424) and any associated wells.

Figure 428 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Tuttle Power Plant. Figure 428c illustrates the pumpage based on the Water Use Survey. The reported pumpage agreed with the reported pumpage from the original TWDB Water Use Survey dataset, and no further revisions were done at this power plant.

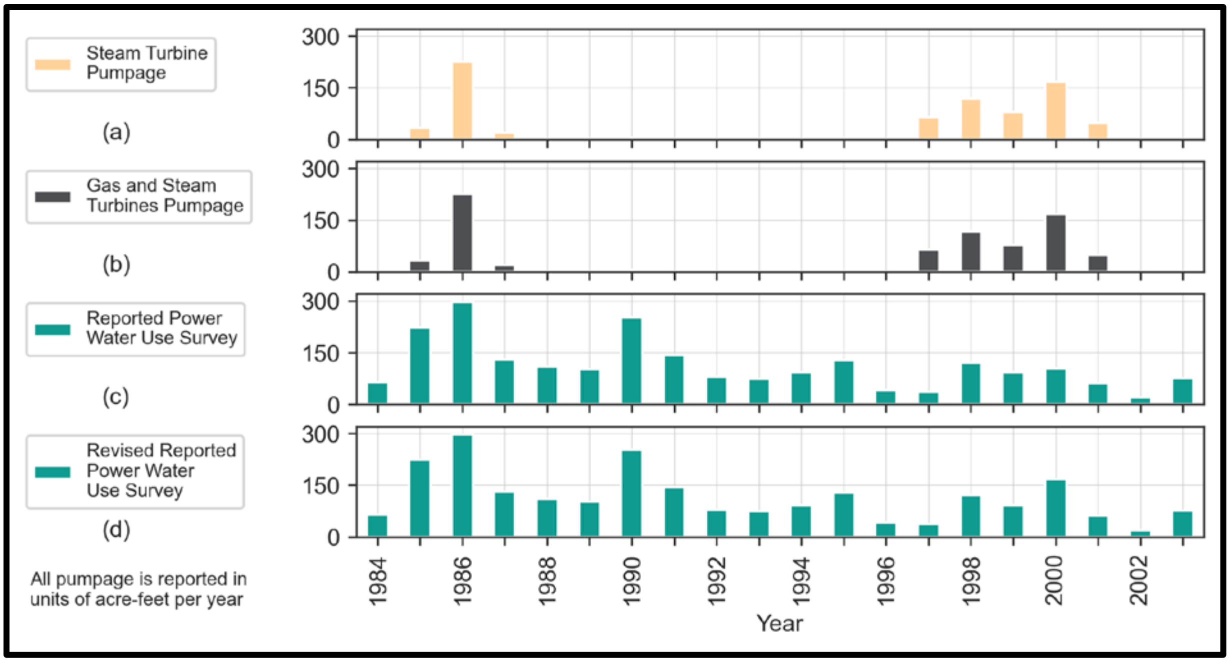


Figure 427. Mission Road Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated combined groundwater pumping by both steam and gas turbines (c), Reported groundwater pumping by the Water Use Survey, and (d) Revised groundwater pumping.

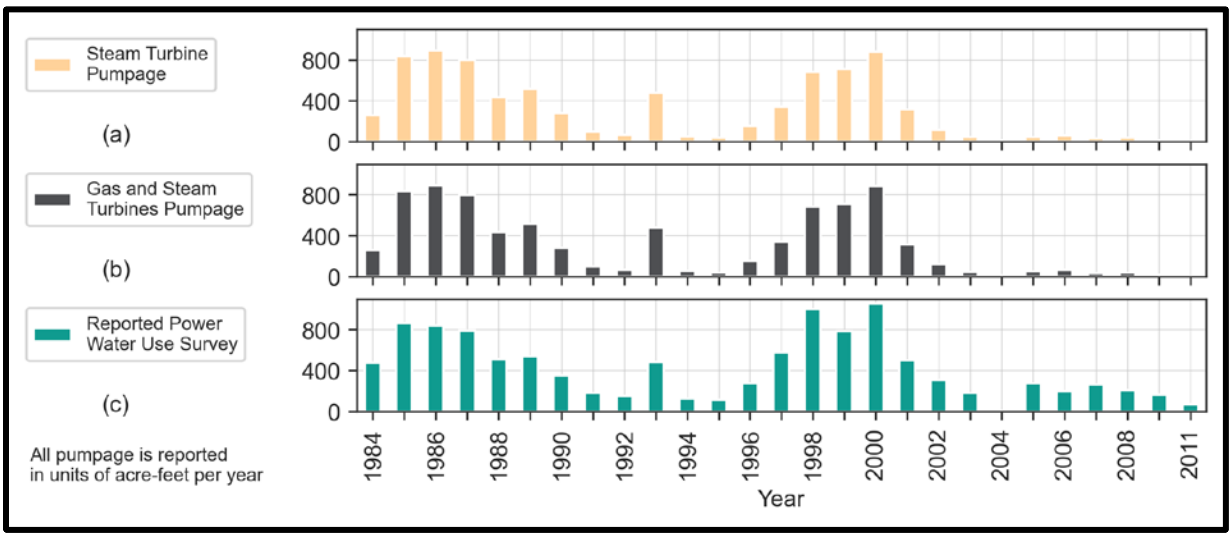


Figure 428. Tuttle Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated groundwater pumping associated with gas and steam turbine power generation, (c) Reported groundwater pumping by the Water Use Survey.

Mining

Figure 415d and Figure 416d illustrate the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer, respectively, in Bexar County during the study period. According to the Railroad Commission of Texas database, the number of active enhanced oil recovery wells in Bexar County was 17 in 2020. To estimate mining water use from these wells, we used the modified Bureau of Economic Geology and Water Use Survey data. Based on our analysis, 51 percent of groundwater for mining use is pumped from the Edwards (Balcones Fault Zone) Aquifer and 49 percent from the Trinity (Hill Country) Aquifer.

Review of Water Use Survey data indicated groundwater pumping for mining use from the Edwards (Balcones Fault Zone) Aquifer, Edwards-Trinity (Plateau) Aquifer, and Trinity (Hill Country) Aquifer. However, the extent of the Edwards-Trinity (Plateau) Aquifer does not overlap Bexar County. The groundwater pumping in the Water Use Survey reported as sourced from the Edwards-Trinity (Plateau) Aquifer by Alamo Concrete Products Ltd-Evans Road Plant is likely from the Edwards (Balcones Fault Zone) Aquifer as reported in previous years. In our revised pumping estimate, we included pumping for the Edwards (Balcones Fault Zone) Aquifer.

Manufacturing

Figure 415c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards (Balcones Fault Zone) Aquifer in Bexar County during the study period. The largest changes occur between 1993 and 2005 where the original estimates are more than double the revised estimates in several years. The reduction in estimated groundwater pumping during this period is primarily associated with a single entity (namely, Martin Marietta Materials – San Pedro Quarry Wells) that reported approximately 3,700 acre-feet per year for each year up to 2006. In 2006, the reported pumping for the entity decreased to about 225 acre-feet. We believe the values reported before 2006 may have been reported in error, mainly since the same large number was recorded every year from 2000-2005: 1,206,952,104 gallons (3,704 acre-feet). Martin Marietta Materials confirmed they do not keep water use records as far back as 2006 and are not aware of any significant operational changes at the San Pedro Quarry that would explain the reported water usage prior to 2006. We applied the lower value of 225 acre-feet to prior years for consistency.

Figure 416c illustrates the changes in groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Bexar County during the study period. We could not identify a source for the pumping estimates prior to 2000. The reduction in groundwater pumping estimates from the Trinity (Hill Country) Aquifer in Bexar County prior to 2000 are for consistency with the available data regarding entities that may have relied on the aquifer.

Livestock

Figure 415b and Figure 416b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer, respectively, in Bexar County during the study period. The largest difference in pumpage from the Edwards (Balcones Fault Zone) Aquifer is that our estimates indicate a gradual decrease in pumpage throughout the study period whereas the TWDB Water Use Survey dataset indicates a sudden increase in 2005. Estimated pumping for livestock use from the Trinity (Hill Country) Aquifer is almost twice the magnitude of the Water Use Survey estimates.

5.2.5 Blanco County

Figure 429 and Figure 430 illustrate our revisions to the estimated in groundwater pumping from the Trinity (Hill Country) Aquifer and the Edwards (Balcones Fault Zone) Aquifer, respectively, in Blanco County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

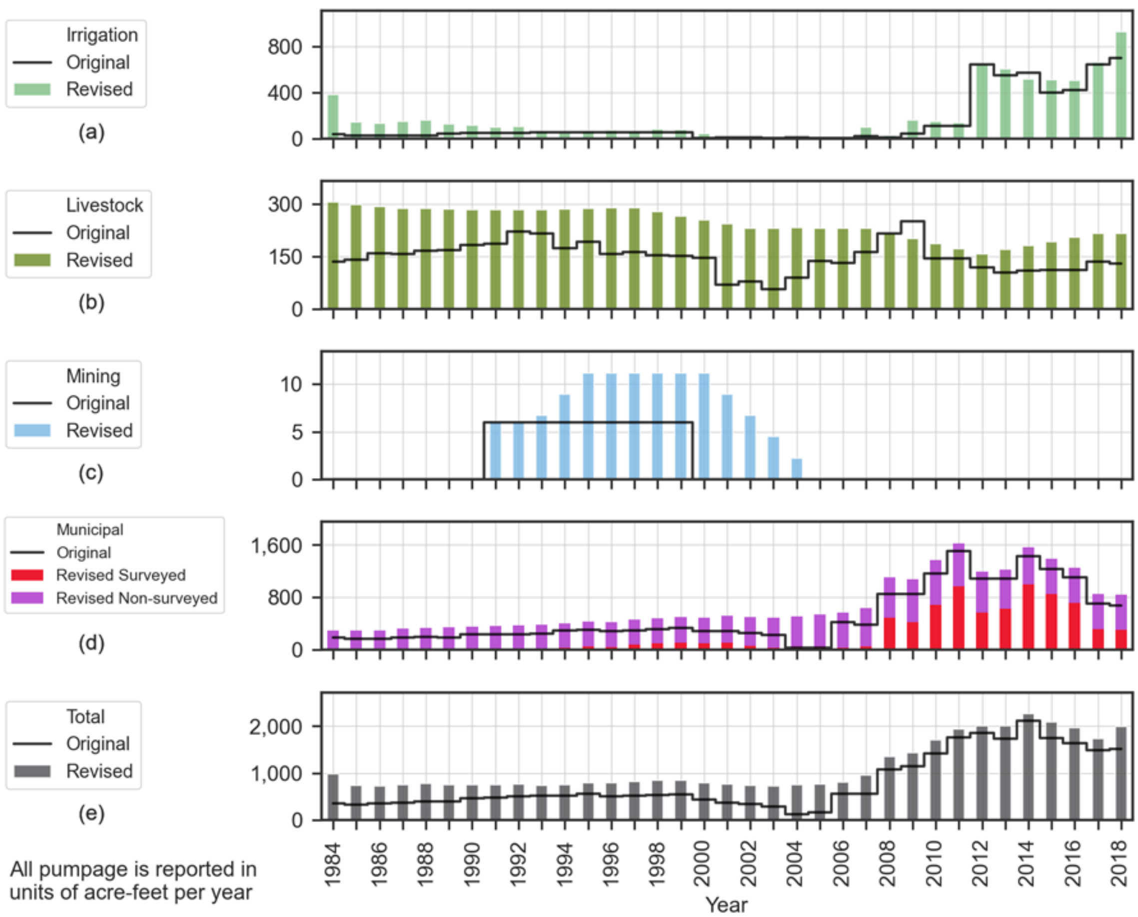


Figure 429. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Blanco County from 1984 through 2018.

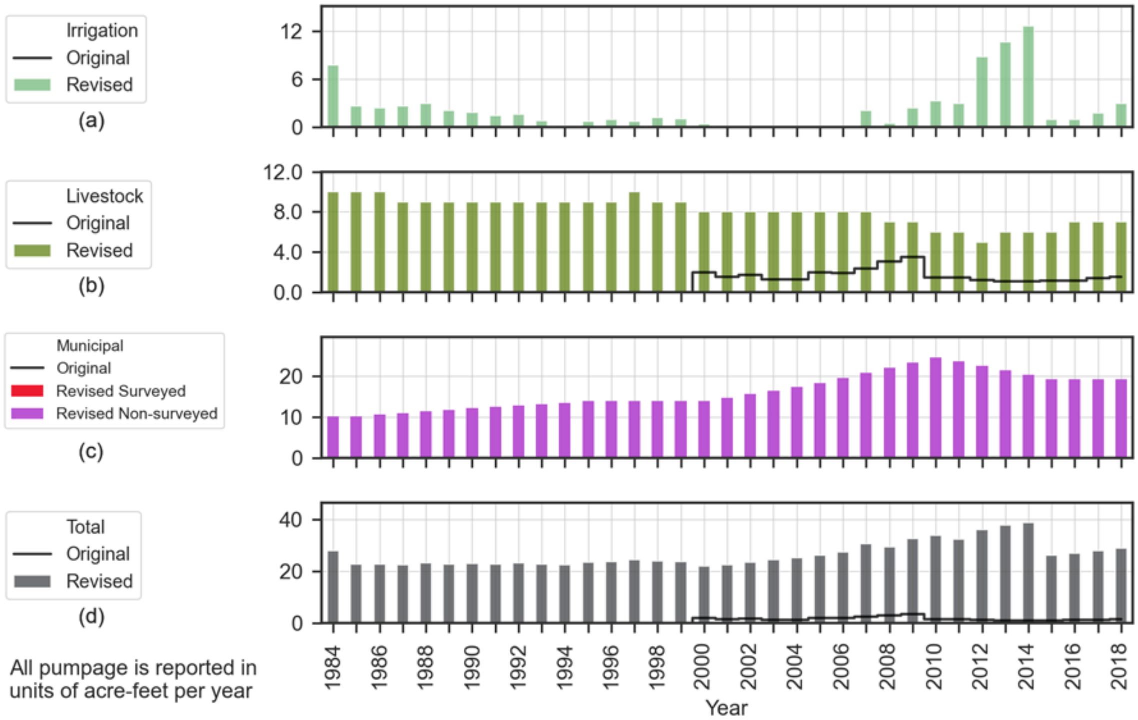


Figure 430. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Blanco County from 1984 through 2018.

Surveyed Municipal

Most of the surveyed municipal pumping within Blanco County was reported to be from the Ellenberger-San Saba Aquifer. Pumpage from the Trinity (Hill County) Aquifer increased after 2009, when the City of Johnson City began reporting pumpage from that aquifer rather than from the Ellenberger-San Saba Aquifer. Most wells drilled into the Ellenberger-San Saba Aquifer were drilled prior to 1975, whereas the wells completed within the Trinity (Hill Country) Aquifer are newer. This supports the hypothesis that the City of Johnson City has constructed newer wells within the Trinity (Hill Country) Aquifer and has switched its supply away from the Ellenberger-San Saba Aquifer. The revised surveyed municipal dataset does not include any data indication pumpage from the Edwards Trinity (Plateau) Aquifer within Blanco County.

Non-Surveyed Municipal

Figure 431 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Trinity (Hill Country) Aquifer in Blanco County during the study period. The TWDB Water Use Survey data is missing for 2004 and 2005. Our estimates of pumping peak in 2010 and subsequently follow a similar decline in estimated use as the Water Use Survey data. Our estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Blanco County non-surveyed municipal use are generally consistent with the TWDB Water Use Survey data.

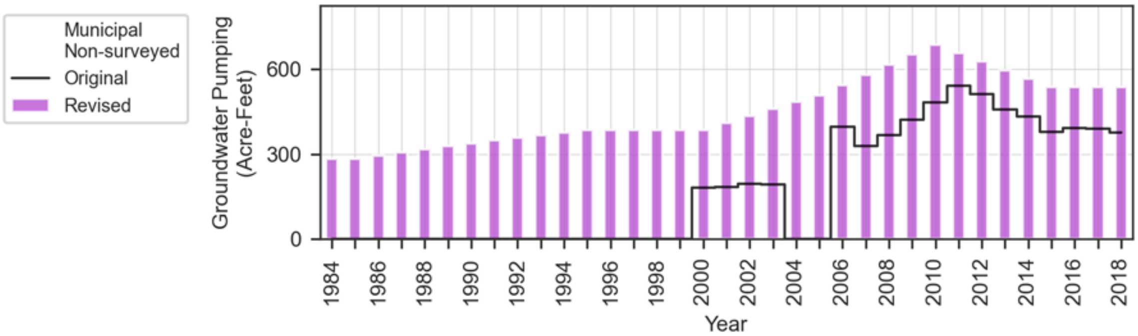


Figure 431. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Bexar County from 1984 through 2018.

Irrigation

Blanco County is underlain by the Trinity (Hill Country) Aquifer across most of the county, with a small portion of the county covered by the Edwards-Trinity (Plateau) Aquifer (Figure 432). Other aquifers present within the county, but not included in this study, are the Ellenburger-San Saba Aquifer and the Hickory Aquifer.

Wells located within Blanco County are geographically distinct in that wells in the Northern part of the county are generally screened in the Ellenburger-San Saba Aquifer or Hickory Aquifer, whereas those in the southern part of the county are screened in the Trinity (Hill Country) Aquifer. Wells located in footprint of the Edwards-Trinity (Plateau) Aquifer are also screened in that aquifer.

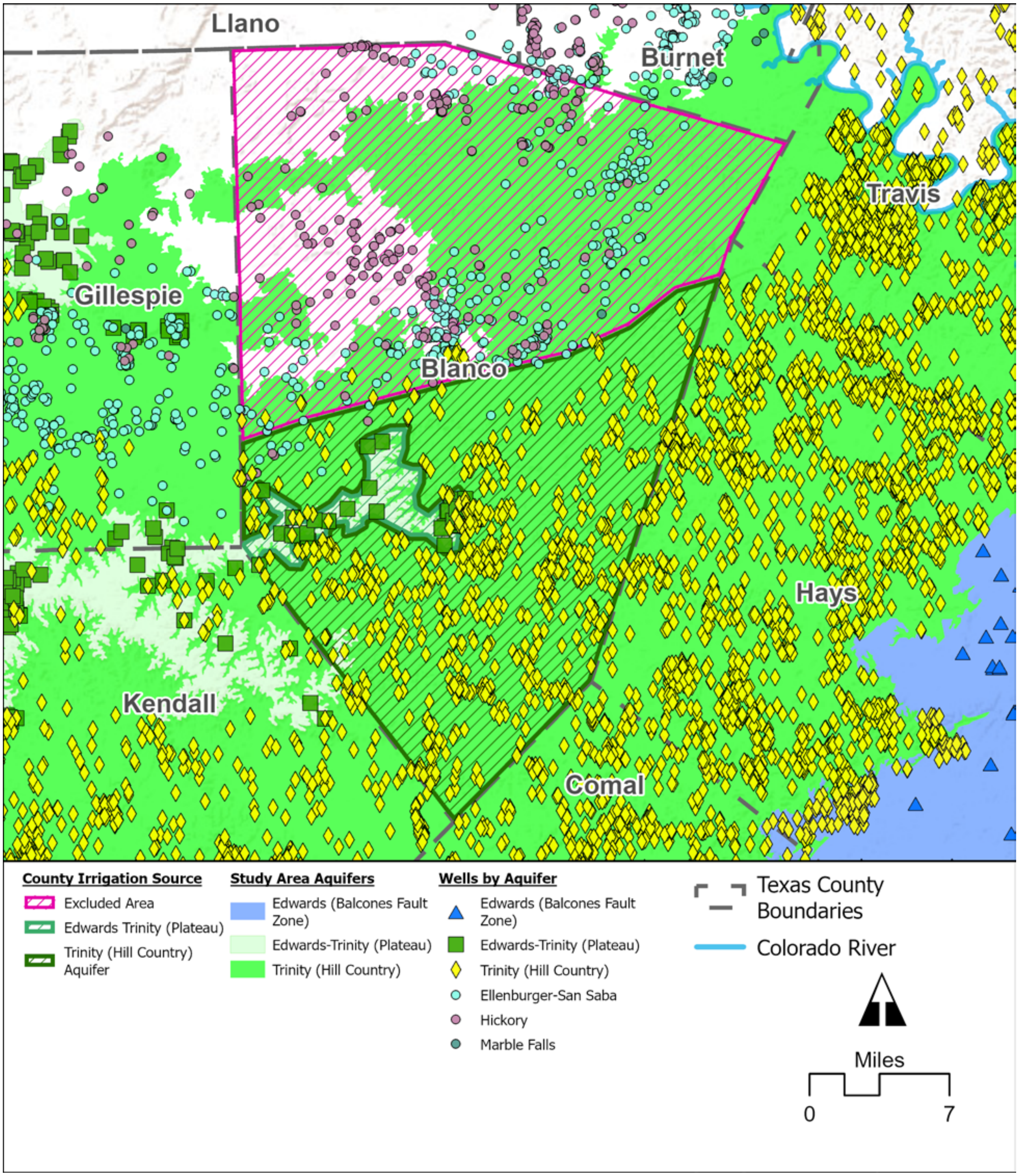


Figure 432. Blanco County map showing aquifers and wells used in assessing irrigation pumpage.

TWDB original Water Use Survey data for irrigation pumpage from the Trinity (Hill Country) Aquifer in Blanco County ranged from near zero acre-feet per year (from 2001 to 2006) to approximately 700 acre-feet per year in 2018 (Figure 433). Pumpage was fairly constant from 1984 to 1999 and increased by 400 to 500 percent from 2011 to 2012. These trends were also present within the revised pumpage dataset, although revised pumpage values were generally larger than those in the original dataset. Surface water usage for irrigation occurred from 1984 to 2006, and again in 2014. Within the revised pumpage dataset, surface water usage was sufficient to meet all irrigation water needs for the period from 2001 to 2006.

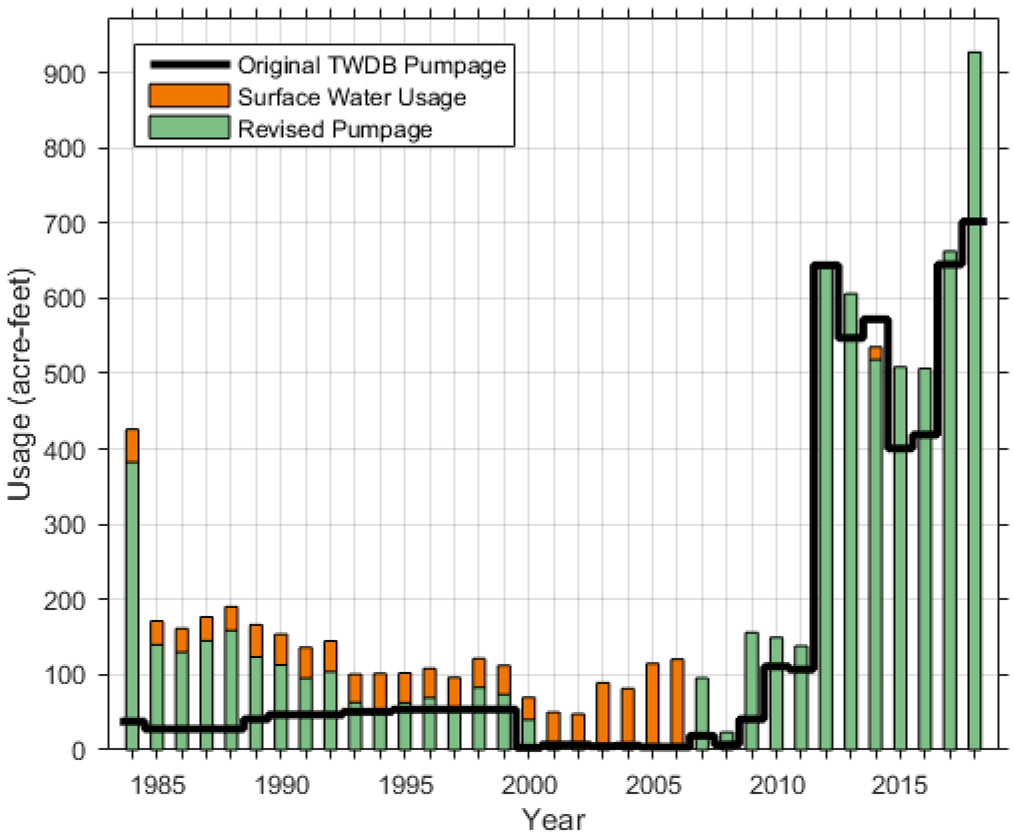


Figure 433. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Blanco County.

The TWDB original Water Use Survey data did not contain pumpage values for water withdrawals from the Edwards-Trinity (Plateau) Aquifer. Wells screened within the Edwards-Trinity (Plateau) Aquifer were identified within Blanco County. Based on crop spatial distribution data, rainfall patterns, computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Blanco County ranged zero acre-feet per year to approximately 12 acre-feet per year over this study period (Figure 434). Surface water usage was allocated to meet computed irrigation needs from 1984 to 2006 and in 2014, with sufficient surface water available in 2001 to 2006 such that groundwater pumpage was not necessary.

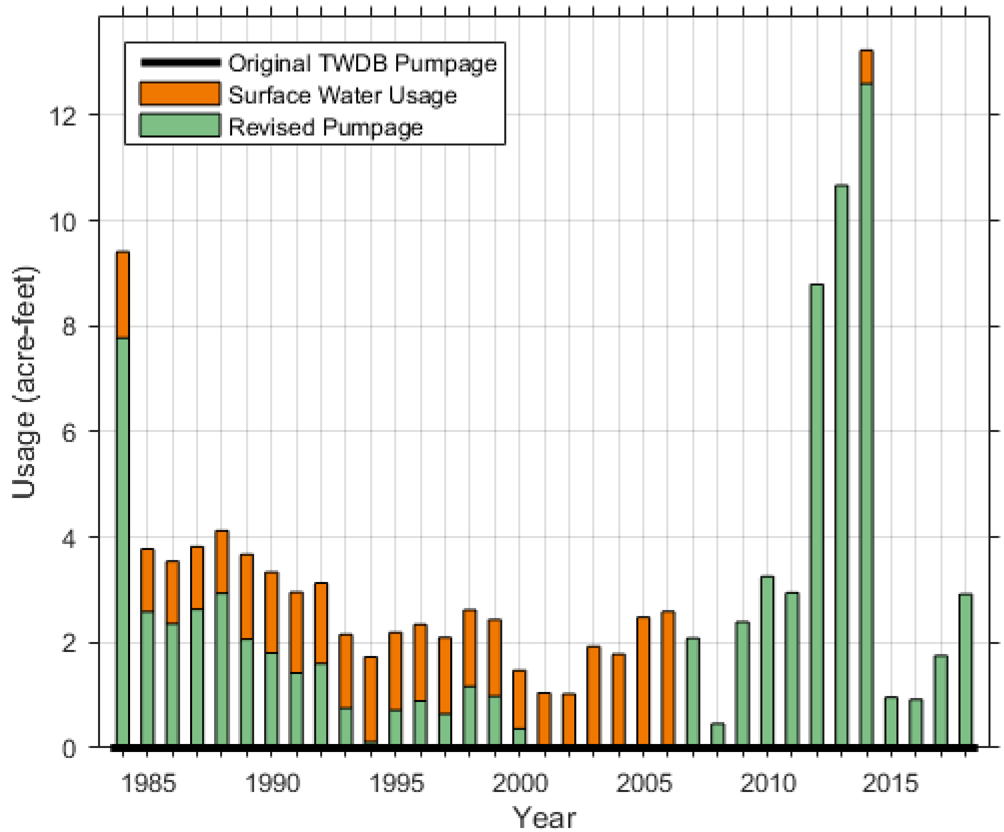


Figure 434. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Blanco County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Blanco County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Blanco County.

Mining

Figure 429c illustrates the changes in groundwater pumping associated with mining use from the Trinity (Hill Country) Aquifer in Blanco County during the study period. Since we did not find any enhanced oil recovery wells within Blanco County, we used the groundwater pumping estimates obtained from U.S. Geological Survey data. We estimate the entirety of groundwater pumping for mining use in our study area is pumped out from the Trinity (Hill Country) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Blanco County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Blanco County.

Livestock

Figure 429b and Figure 430b illustrate the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Blanco County during the study period. Based on livestock census data, our estimates of pumping for this use are higher in most years for both aquifers.

5.2.6 Brewster County

Figure 435 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Brewster County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

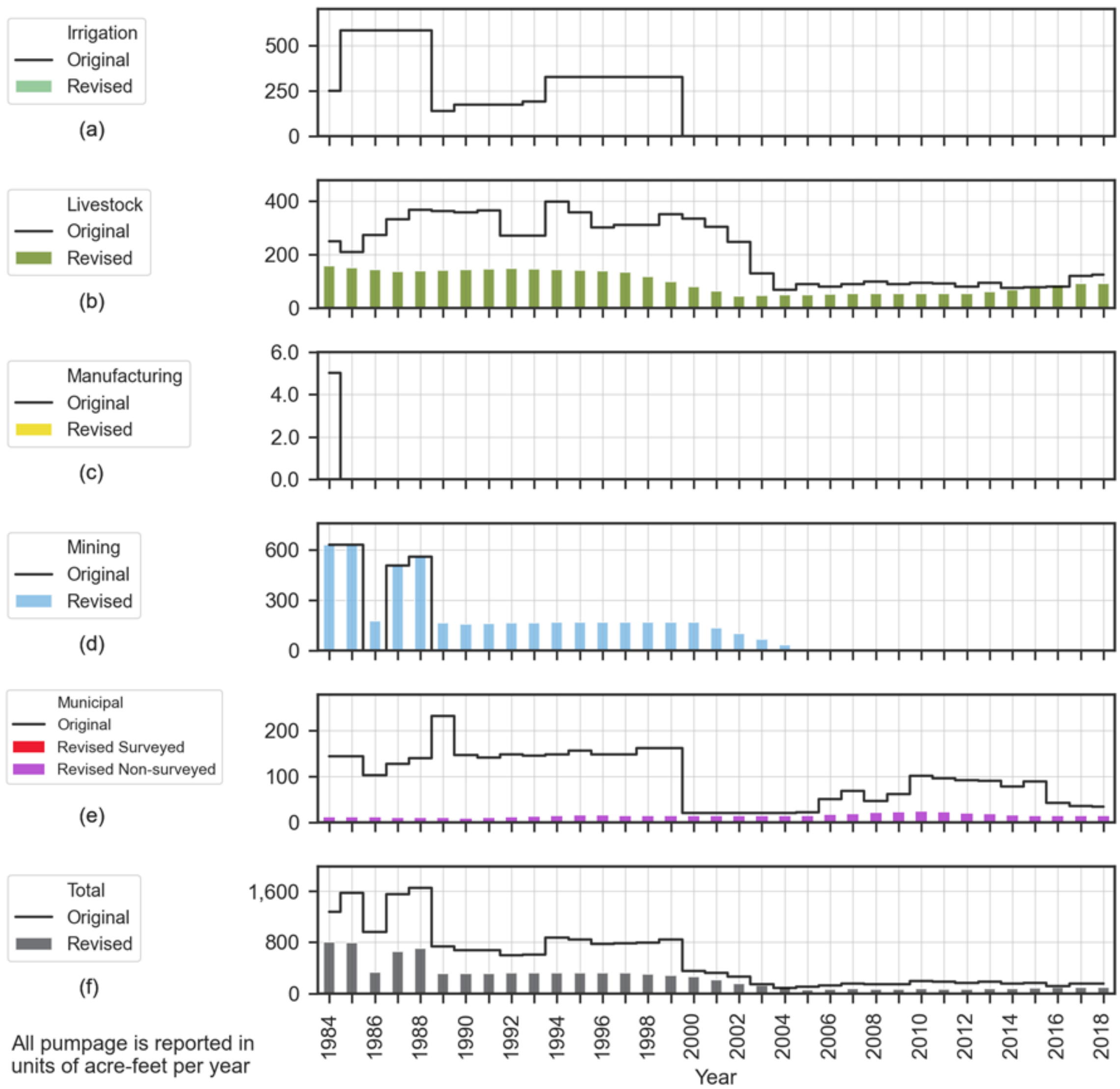


Figure 435. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Brewster County from 1984 through 2018.

Surveyed Municipal

Our review of the available data from the Edwards-Trinity (Plateau) Aquifer in Brewster County suggested municipal pumpage was originally mis-allocated to this aquifer. All entities reported as pumping from the Edwards-Trinity (Plateau) Aquifer were located within Terlingua and around Big Bend National Park, far from the aquifer footprint within Brewster County. We concluded that the Edwards-Trinity (Plateau) Aquifer has not been used of municipal supply to entities who would report usage to the TWDB.

Non-Surveyed Municipal

Figure 436 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Brewster County during the study period. Our estimates are several times less than the TWDB Water Use Survey data. Our review of the available data suggested the pumping for this use is less than previous estimates suggest although the pumpage trend is in general agreement.

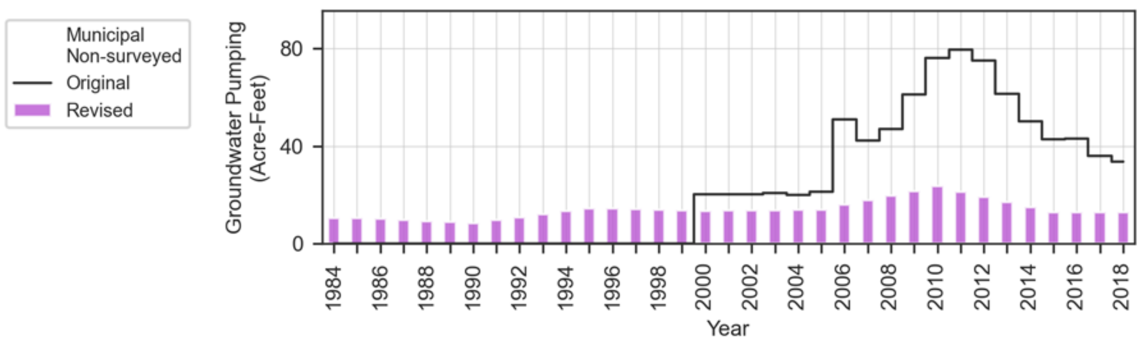


Figure 436. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Brewster County from 1984 through 2018.

Irrigation

Brewster County is partially underlain by the Edwards-Trinity (Plateau) Aquifer. Pumpage estimates from the original TWDB Water Use Survey dataset suggested groundwater usage for irrigation between 250 acre-feet per year and 600 acre-feet per year prior to the year 2000 (Figure 437). For the year 2000 and beyond, estimates were not provided within the TWDB Water Use Survey dataset. Figure 437A shows the entire 0-600 acre-feet range of the original TWDB pumpage dataset. Figure 437B limits the vertical range of the graphic to 100 acre-feet, so that the revised pumpage values become visible.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Brewster County ranged from zero acre-feet per year to approximately nine acre-feet per year.

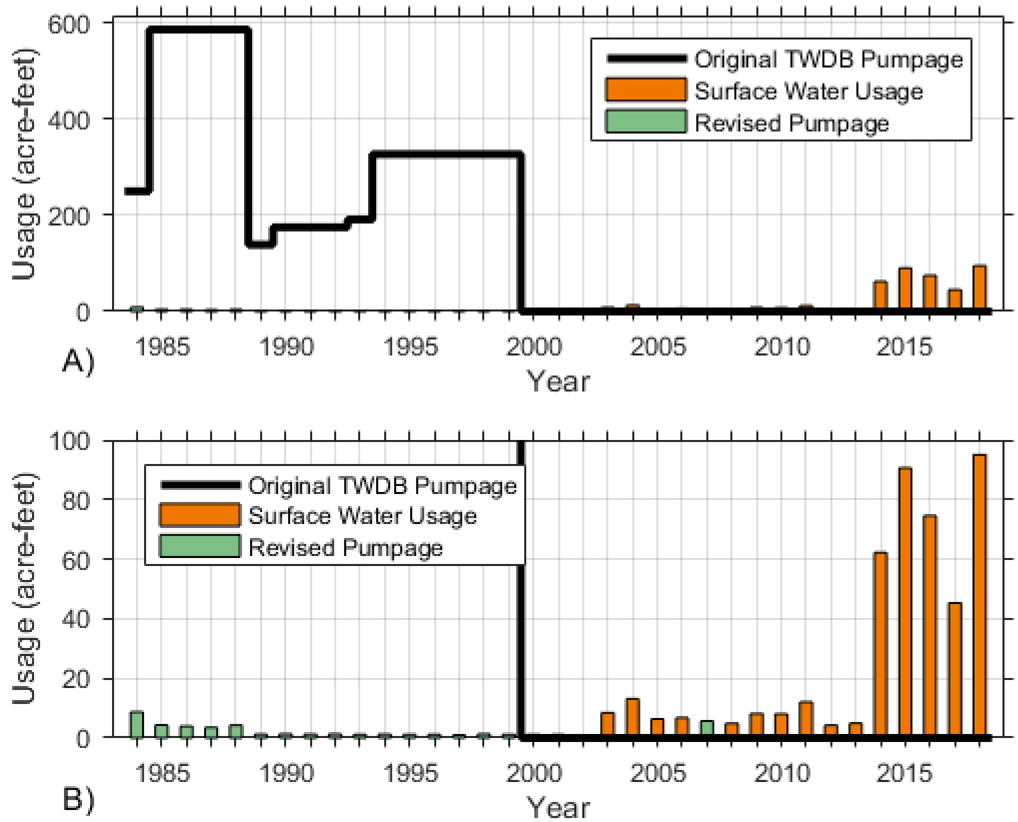


Figure 437. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Brewster County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Brewster County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Brewster County.

Mining

Figure 435d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Brewster County during the study period. No enhanced oil recovery wells were reported within Brewster County and therefore the U.S. Geological Survey mining-use estimates were used. We estimate that all groundwater pumping for mining use in Brewster County is pumped out from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Brewster County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Brewster County.

Livestock

Figure 435b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Brewster County during the study period. Our estimates are consistently lower than the TWDB Water Use Survey until 2003. After 2003, our estimates of groundwater pumping for livestock use are similar to the TWDB Water Use Survey data.

5.2.7 Burnet County

Figure 438 illustrates our revisions to the estimated in groundwater pumping from the Trinity (Hill Country) Aquifer in Burnet County during the study period. Note that our analysis is limited to the portion of Burnet County south of the Colorado River. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

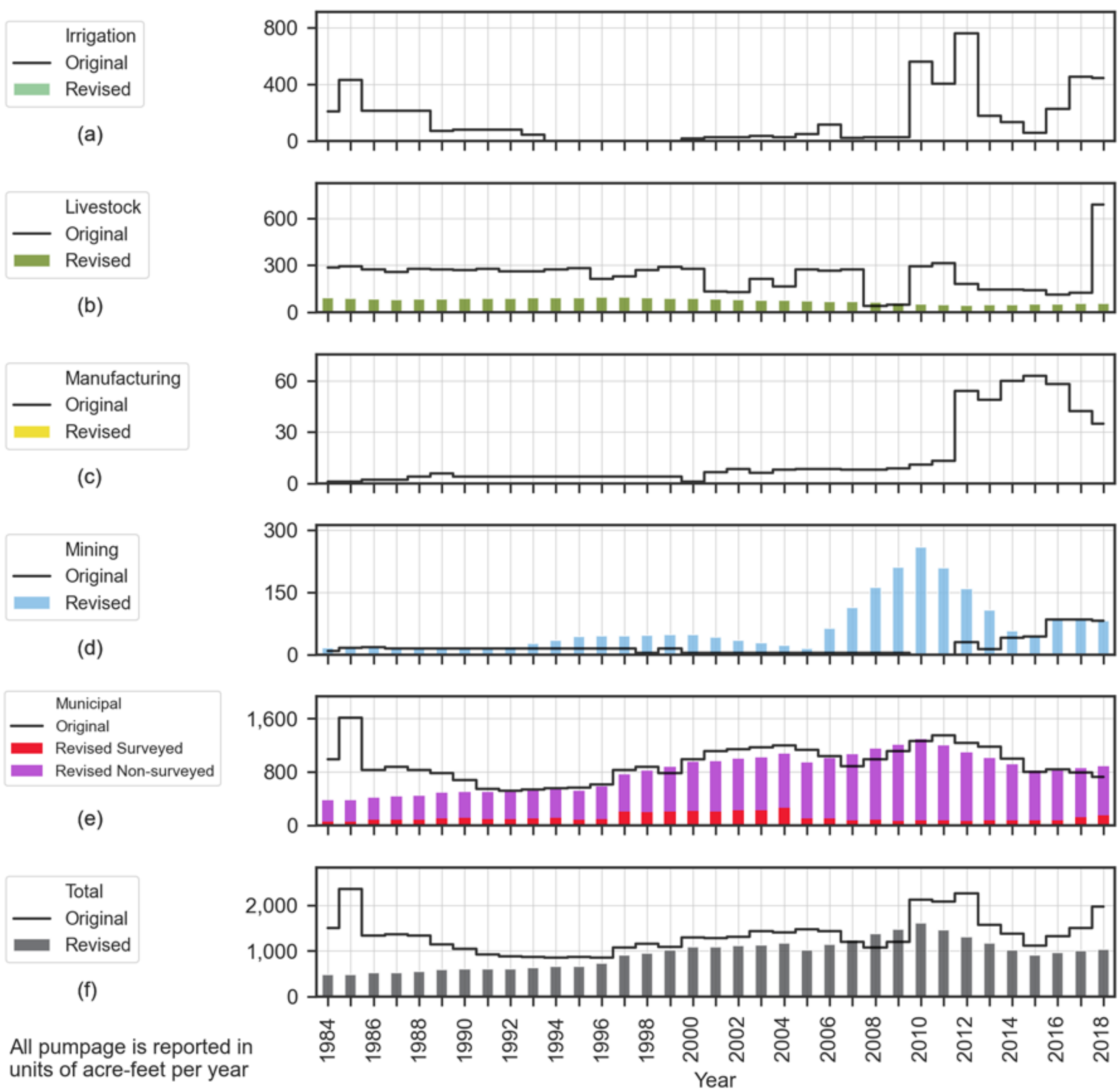


Figure 438. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Burnet County from 1984 through 2018.

Within the original TWDB Water Use Survey dataset, pumpage from Burnet County was occasionally (and in relatively small quantities of less than 20 acre-feet/year) attributed to the Edwards Trinity (Plateau) Aquifer and Edwards (Balcones Fault Zone) Aquifer. As neither of these aquifers are physically located within Burnet County, within our revised pumpage dataset we reassigned these small values to be from the Trinity (Hill Country) Aquifer.

Surveyed Municipal

All entities that reported surveyed municipal pumping within Burnet County during the study period are physically located north of the Colorado River and are therefore outside of the study area for this project. As a result, the revised pumpage dataset does not contain pumpage records under the surveyed municipal category for any of the aquifers present within the county.

Non-Surveyed Municipal

Figure 439 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Trinity (Hill Country) Aquifer in Burnet County during the study period. Our estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Burnet County for non-surveyed municipal use are generally consistent with the TWDB Water Use Survey data.

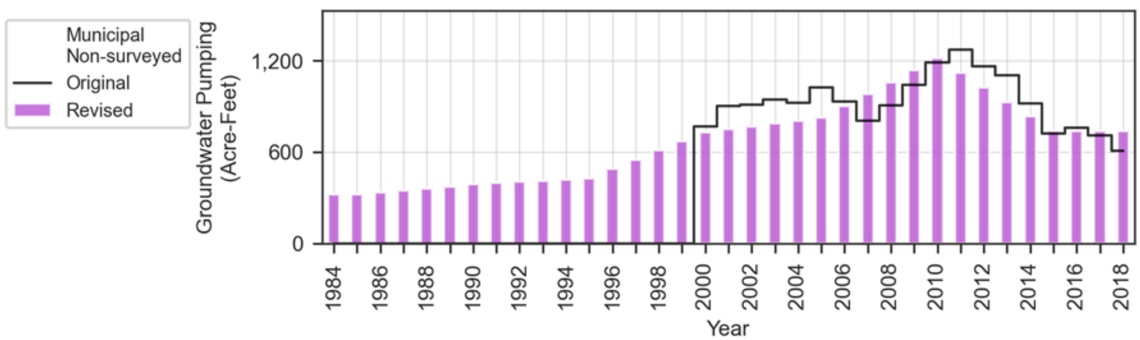


Figure 439. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Burnet County from 1984 through 2018.

Irrigation

Burnet County is underlain by the Trinity (Hill Country) Aquifer as well as the Ellenburger-San Saba Aquifer, the Marble Falls Aquifer, and the Hickory Aquifer (Figure 440). For this study, the area of focus was limited to the portion of Burnet County south of the Colorado River and underlain by the Trinity (Hill Country) Aquifer.

Wells within the Trinity (Hill Country) footprint south of the Colorado River are either screened within the Ellenburger-San Saba Aquifer or the Hickory Aquifer. Wells screened within the Trinity (Hill Country) Aquifer are all located north of the Colorado River. As such, for the purposes of this project with its defined study area, no pumpage occurred for irrigation from the Trinity (Hill Country) Aquifer in Burnet County south of the Colorado River.

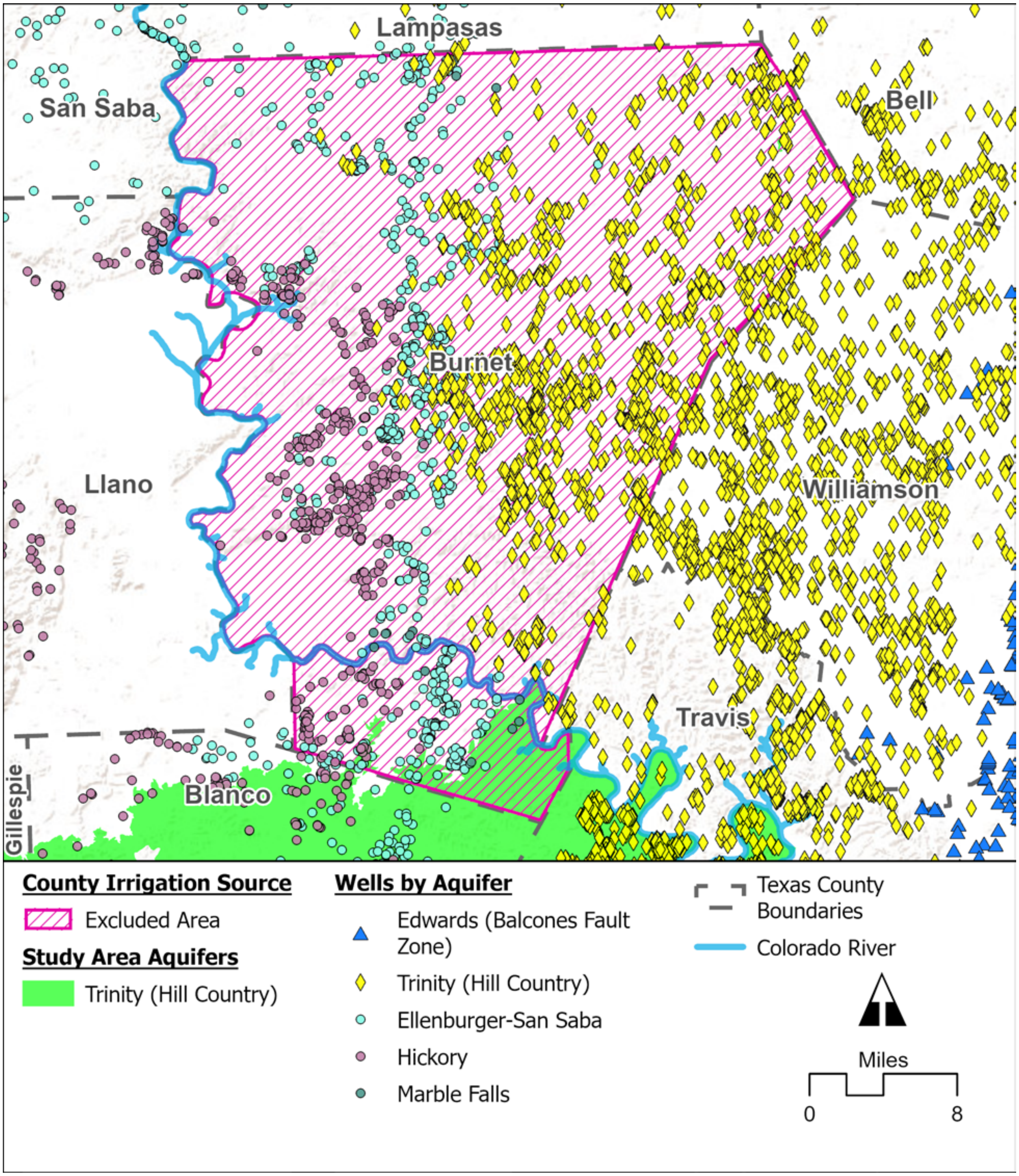


Figure 440. Burnet County map showing aquifers and wells used in assessing irrigation pumpage.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Burnet County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Burnet County.

Mining

Figure 438d illustrate the changes in groundwater pumping associated with mining use from Trinity (Hill Country) Aquifer within the study area portion of Burnet County during the study period. The U.S. Geological Survey estimates were used to obtain the groundwater pumping estimates for mining since no enhanced oil recovery wells were reported within Burnet County. Within the study area, little to no pumping for mining purposes is occurring.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Burnet County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Burnet County.

Livestock

Figure 438b illustrates the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer in Burnet County during the study period. Our estimates are lower than the TWDB Water Use Survey due to our study area only covering a portion of the county.

5.2.8 Caldwell County

Figure 441 and Figure 442 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Caldwell County during the study period. Our evaluation indicated there was no groundwater pumping associated with livestock use in Caldwell County. As only a small portion of the western corner of Caldwell County is underlain by the Trinity (Hill Country) Aquifer. Modeling suggests that up to 10 acre-feet per year would have been needed to meet irrigation demands on this portion of the county between 1984 and 2018. However, as wells are not known to be located within this area, we recommend ignoring computed irrigation needs and reporting zero groundwater withdrawals from the Trinity (Hill Country) Aquifer in Caldwell County.

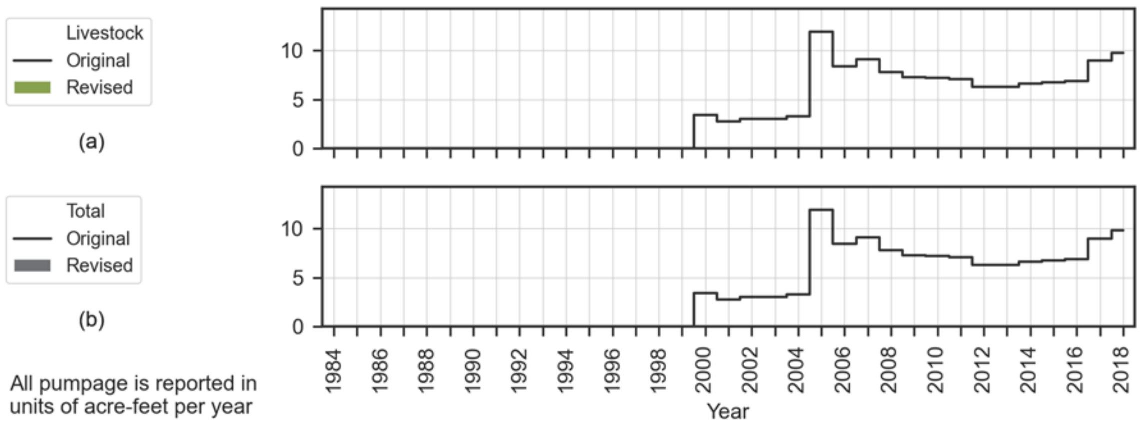


Figure 441. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Caldwell County from 1984 through 2018.

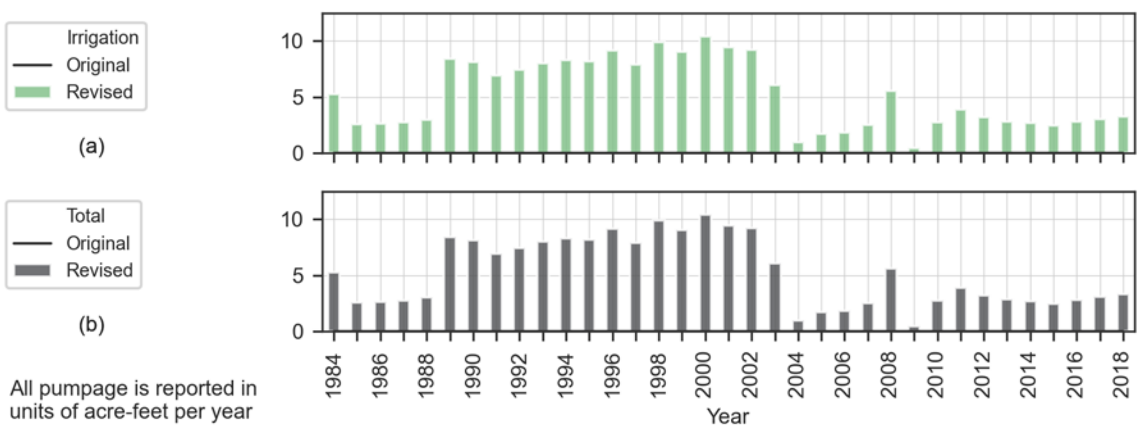


Figure 442. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Caldwell County from 1984 through 2018.

5.2.9 Coke County

Figure 443 and Figure 444 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer, respectively, in Coke County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

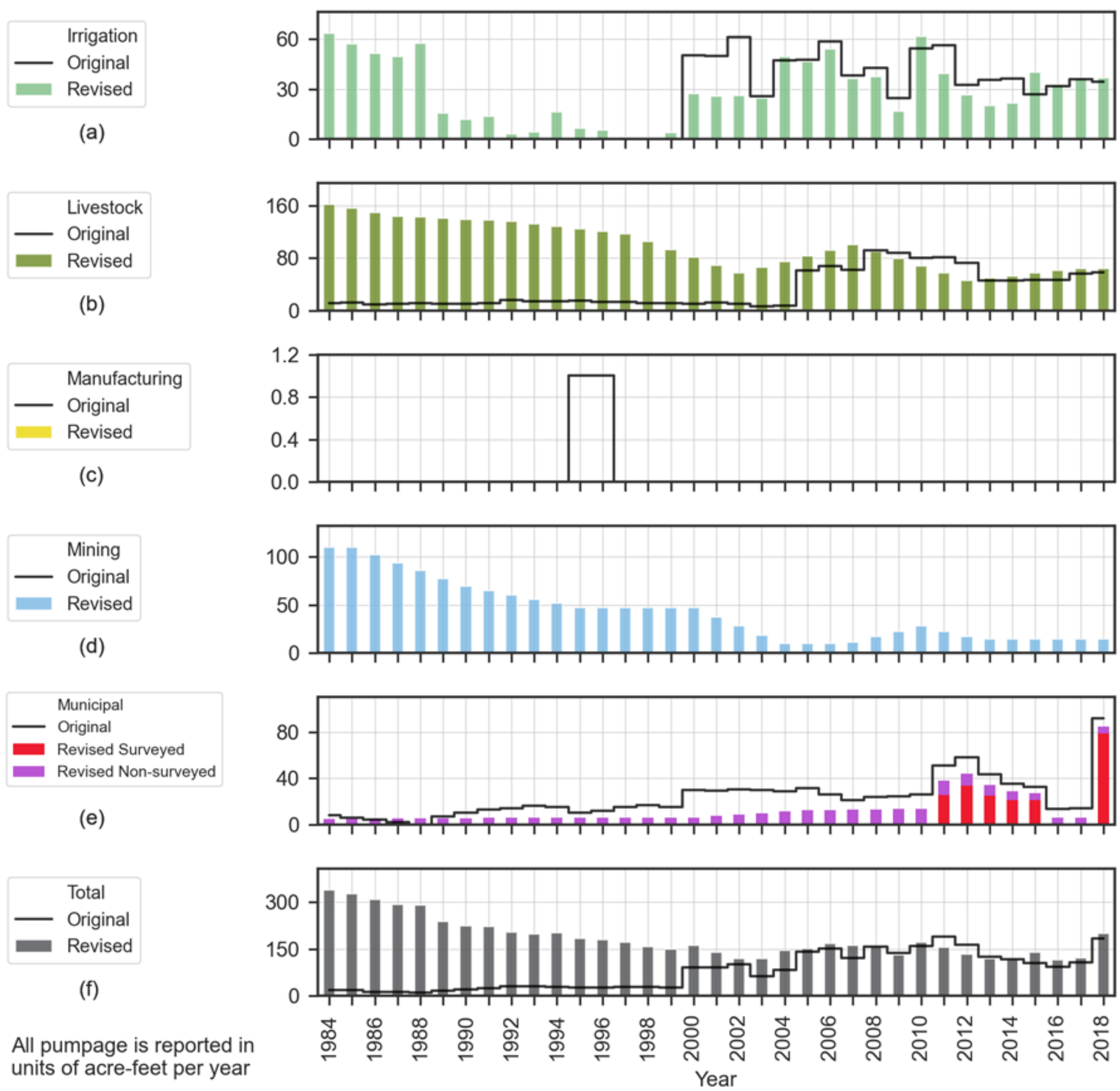


Figure 443. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Coke County from 1984 through 2018.

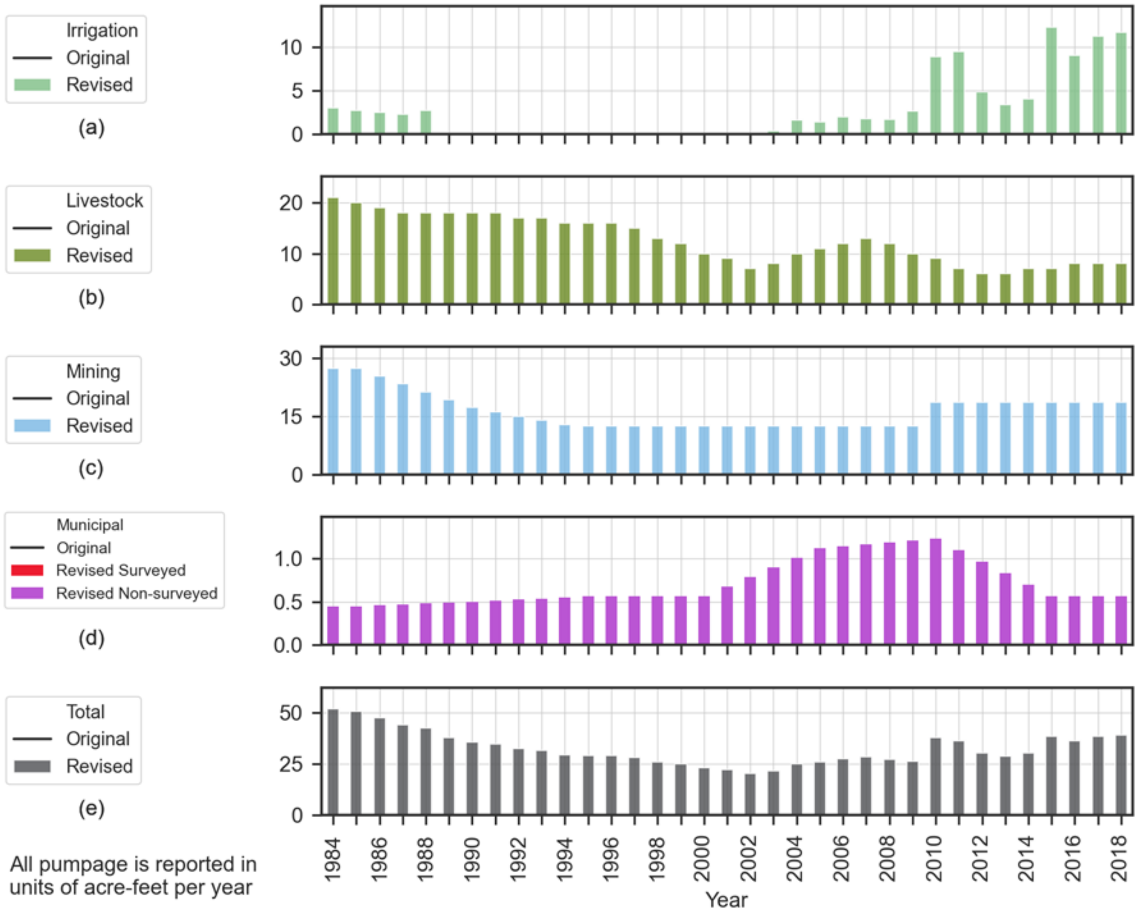


Figure 444. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Coke County from 1984 through 2018.

Surveyed Municipal

Revision of the surveyed municipal dataset for Coke County resulted in the reclassification of pumpage from the Edwards Trinity (Plateau) Aquifer to an "Other Aquifer." This is supported by the fact that the City of Bronte (the only reporting entity originally using the Edwards Trinity (Plateau) Aquifer) is not physically located near the aquifer footprint. The Region F 2021 regional water plan also reports that the city is using groundwater from an "unclassified" aquifer rather than the Edwards Trinity (Plateau) Aquifer.

Non-Surveyed Municipal

Figure 445 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) in Coke County during the study period. Our estimates are approximately two times less than the TWDB Water Use Survey data. Our review of the available data suggested the pumping for this use is less than previous estimates suggest.

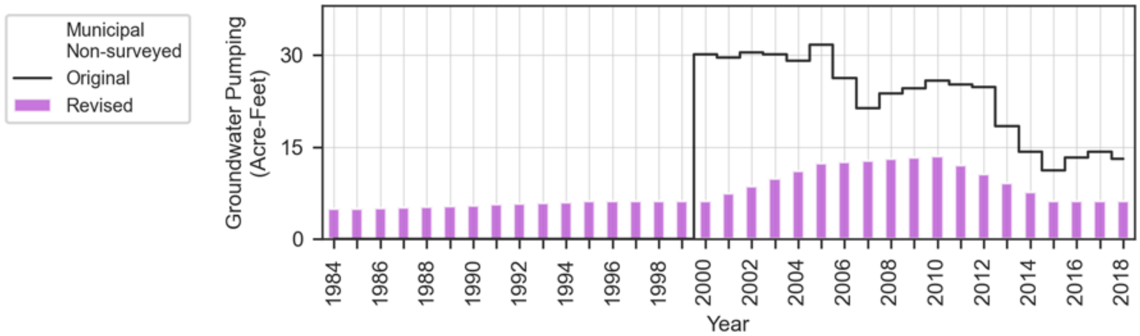


Figure 445. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) for non-surveyed municipal use in Coke County from 1984 through 2018.

Irrigation

Portions of Coke County are underlain by the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer. Wells exist within the county which are screened within the Lipan and the Edwards-Trinity (Plateau) aquifers. There do not exist any wells within the Lipan Aquifer footprint that are screened within the Edwards-Trinity (Plateau) Aquifer.

The original irrigation estimates for Coke County from the TWDB Water Use Survey did not indicate any usage from the Lipan Aquifer. However, usage was indicated from an “Other Aquifer” which could have included the Lipan Aquifer.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Coke County ranged from zero acre-feet per year to approximately 65 acre-feet per year over this study period (Figure 446). For the years from 1989 to 2008, a portion of the computed irrigation demand was satisfied through surface water usage. Computed irrigation pumpage from the Edwards-Trinity (Plateau) Aquifer for the years from 2000 to 2018 is largely comparable to the original estimated pumpage from the TWDB Water Use Survey dataset. This leads to confidence in the irrigation demand estimation method developed during this study, and in the computed irrigation demands from 1984 to 1999 (a period for which the original TWDB Water Use Survey dataset did not contain pumpage estimates). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Lipan Aquifer in Coke County ranged from zero acre-feet per year to approximately 12 acre-feet per year over this study period (Figure 447). Surface water usage was assumed to meet all computed irrigation demands for 1989-2002, thereby requiring zero acre-feet per year of groundwater usage for irrigation during this time.

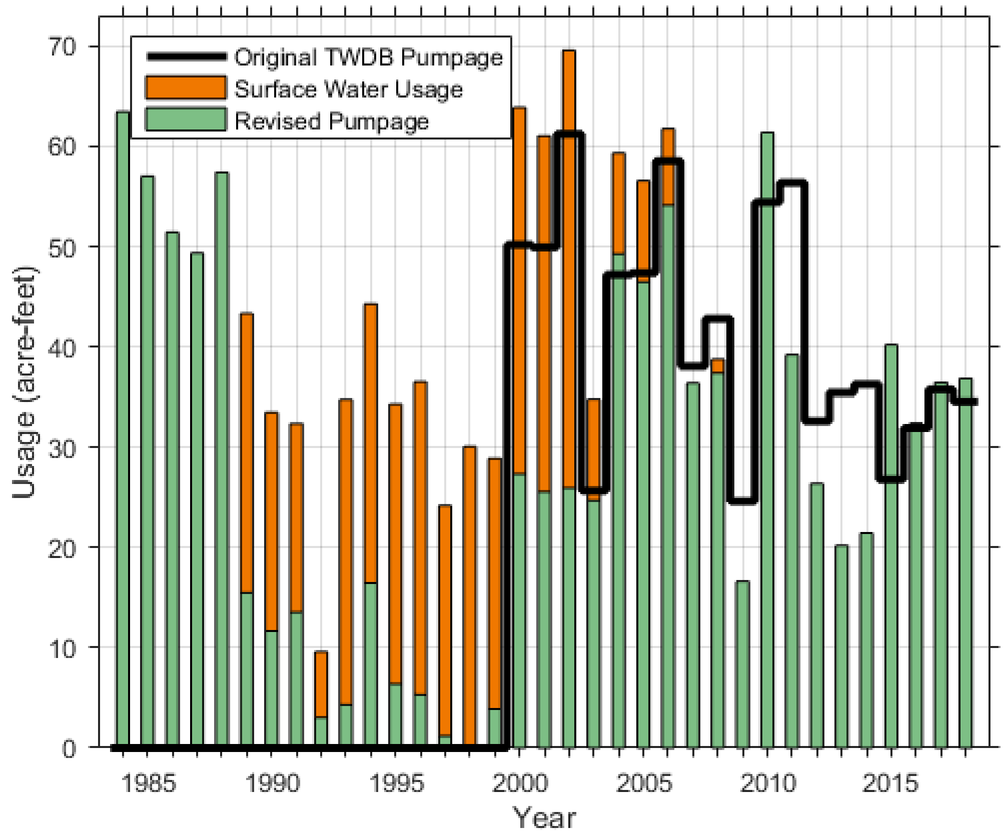


Figure 446. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Coke County.

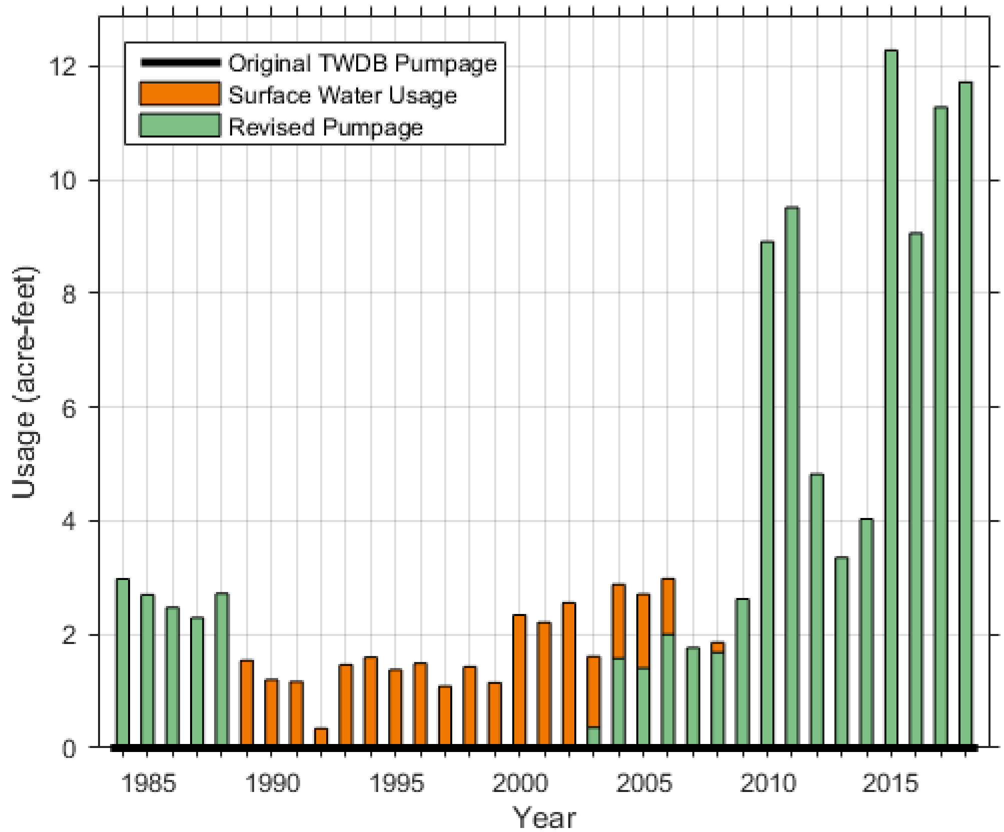


Figure 447. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Coke County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Coke County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Coke County.

Mining

Figure 443d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Coke County during the study period. The number of active enhanced oil recovery wells in Coke County was only eight in 2020 and the Bureau of Economic Geology methodology along with the Water Use Survey data was used to estimate pumpage for mining use. We estimated approximately 27 percent of groundwater for mining use is extracted from the Lipan Aquifer and 73 percent from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Coke County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Coke County.

Livestock

Figure 443b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Coke County during the study period. Results from our evaluation are in general agreement with TWDB Water Use Survey data from 2005 onwards. Prior to 2005, our estimates are significantly greater than the TWDB Water Use Survey data suggests due to the animal count from the county-wide census data.

5.2.10 Comal County

Figure 448 and Figure 449 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Comal County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

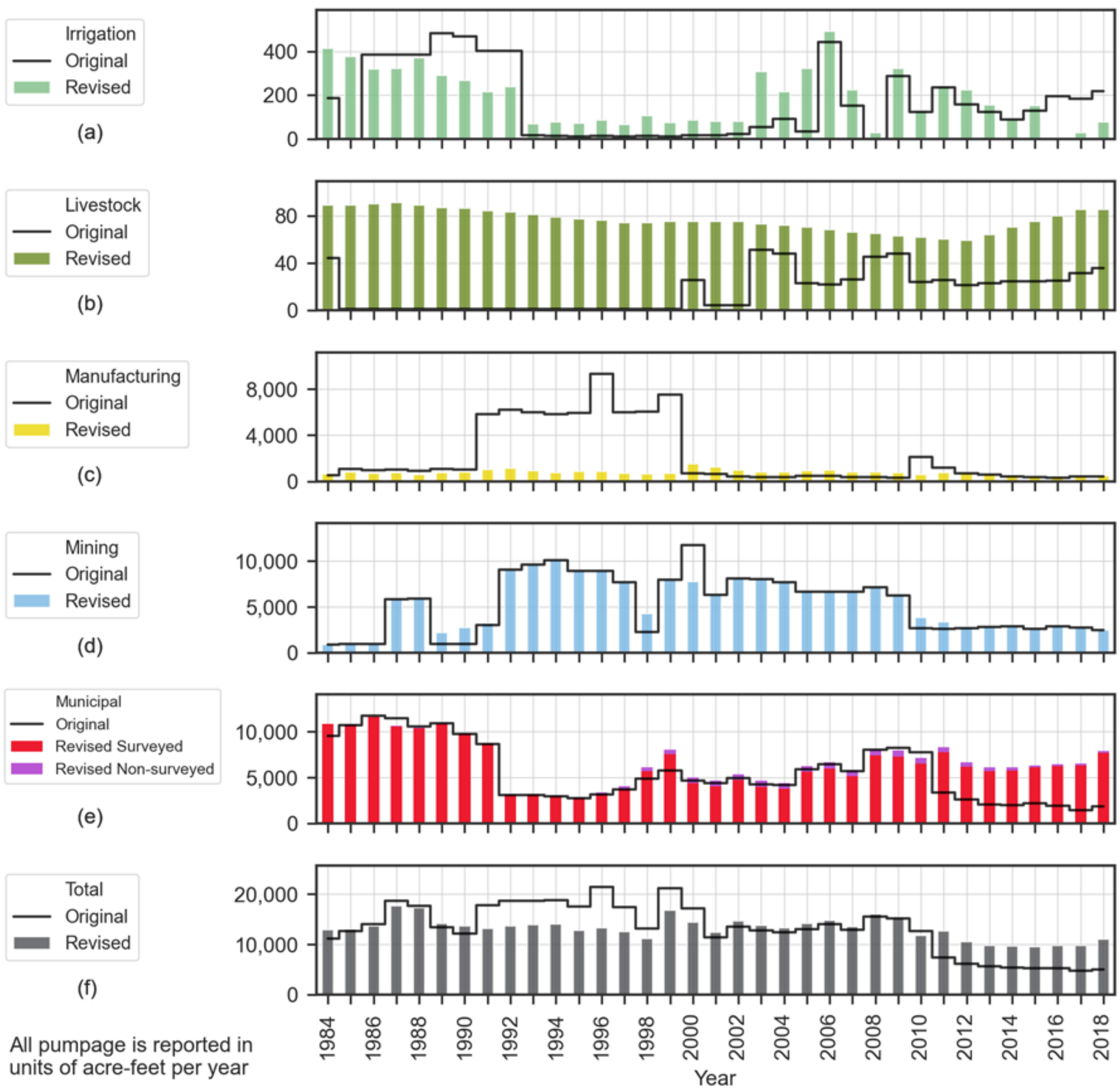


Figure 448. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Comal County from 1984 through 2018.

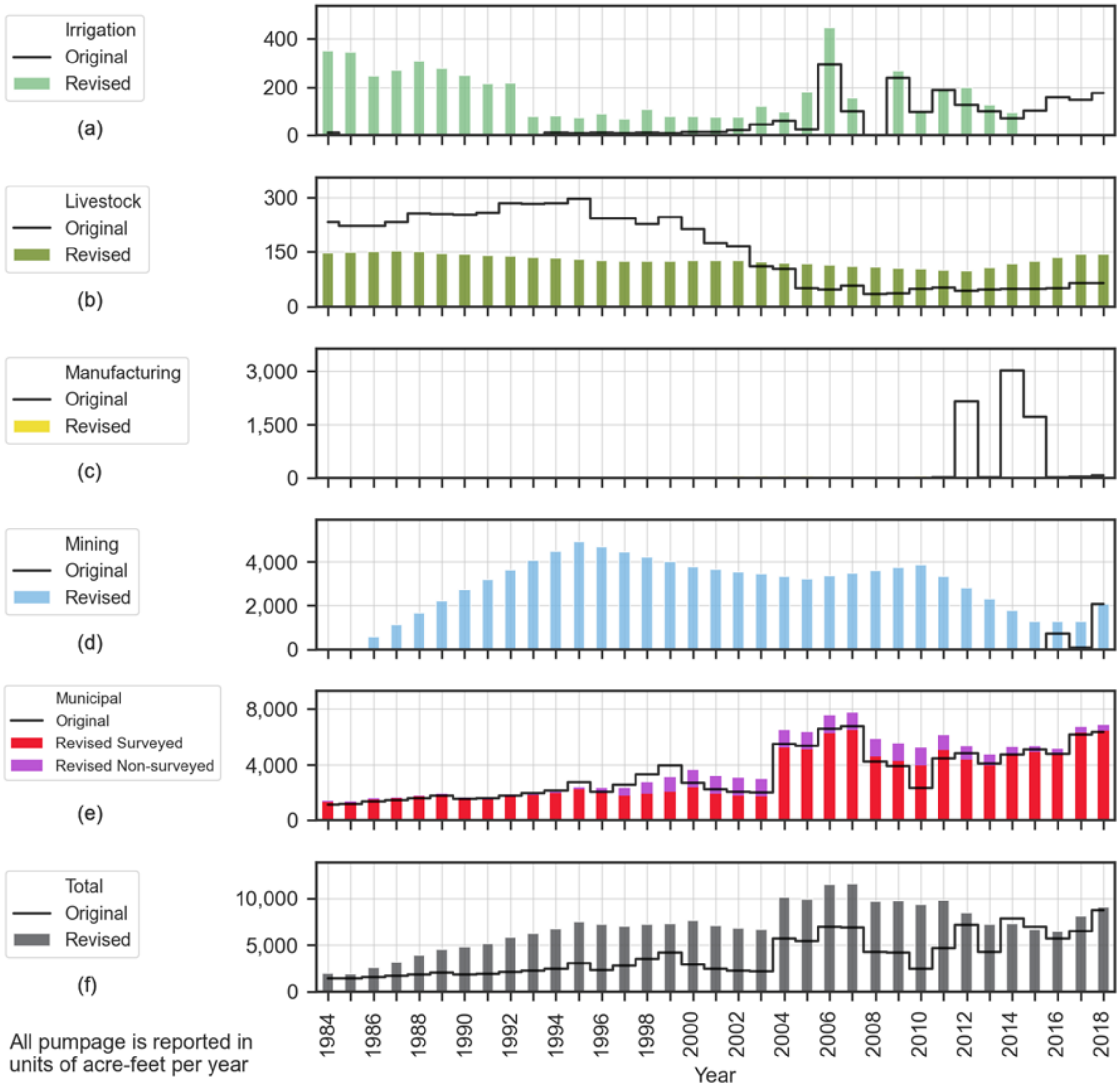


Figure 449. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Comal County from 1984 through 2018.

Surveyed Municipal

Changes to the original TWDB water use survey data for surveyed municipal pumpage in Comal County included re-allocating some pumping that was erroneously attributed to being from the Edwards Trinity (High Plains) Aquifer to the Edwards (Balcones Fault Zone Aquifer). This occurred for pumpage from 2011-2018. During this same time period, pumpage was reported from the Trinity (Hill Country) Aquifer, yet not from the Edwards (Balcones Fault Zone) Aquifer. We considered the designation of “Edwards Trinity (High Plains) Aquifer” to have been a clerical error. Pumpage changes from the Trinity (Hill Country) Aquifer resulted from the interpolation of data to fill in original gaps.

Non-Surveyed Municipal

Figure 450 and Figure 451 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Comal County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data. While our estimates are lower than the Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer from 2009 to 2012, they are higher for the Trinity (Hill Country) Aquifer during the entire study period.

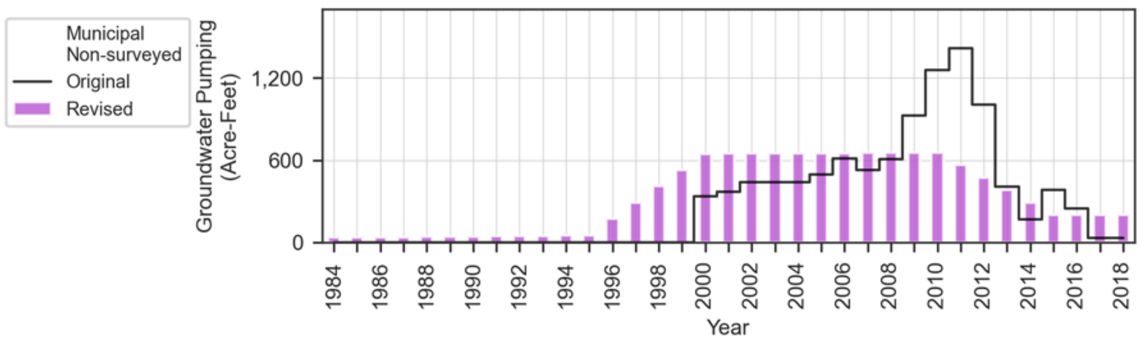


Figure 450. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Comal County from 1984 through 2018.

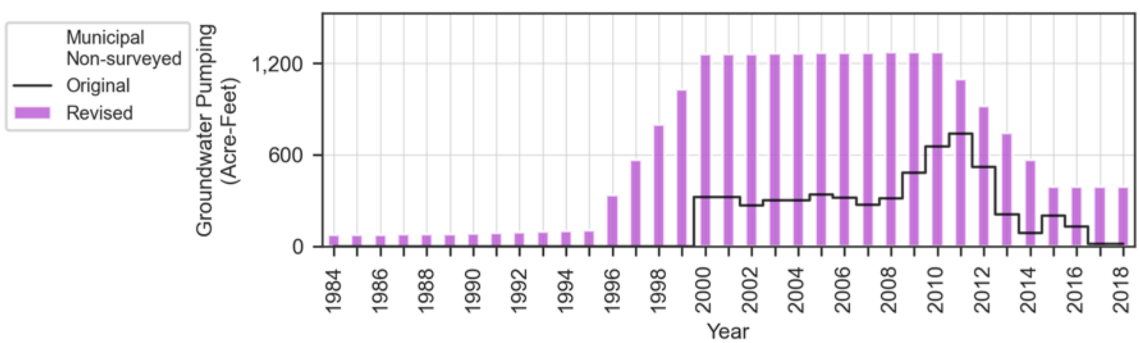


Figure 451. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Comal County from 1984 through 2018.

Irrigation

Comal County is underlain by the Trinity (Hill Country) Aquifer and the Edwards (Balcones Fault Zone) Aquifer. Wells exist within the county which are screened within each aquifer and the wells are generally geographically distinct. Wells within the northwestern half of the county are generally screened in the Trinity (Hill Country) Aquifer, whereas wells in the southeastern portion of the county are generally screened within the Edwards (Balcones Fault Zone) Aquifer. In revising irrigation pumpage estimates, all irrigation water demands in the northwestern portion of the county were allocated to the Trinity (Hill Country) Aquifer, and all those in the southeastern portion of the county were allocated to the Edwards (Balcones Fault Zone) Aquifer.

The original irrigation estimates for Comal County from the TWDB Water Use Survey from the Edwards (Balcones Fault Zone) Aquifer ranged from zero acre-feet per year to nearly 500 acre-feet per year, with less than 50 acre-feet per year used from 1993 to 2002 (Figure 452). Revised estimates based on crop spatial distribution data, rainfall patterns, computed evapotranspiration rates, and reported surface water usage for irrigation have a similar range and show relatively reduced usage for the 1993 to 2002 period. Surface water usage for irrigation occurred in all years and was sufficient to meet the entire irrigation demand in 2016.

The original irrigation estimates for Comal County from the TWDB Water Use Survey from the Trinity (Hill Country) Aquifer indicated minimal usage (less than 50 acre-feet per year) prior to 2005, and then between 75 and 300 acre-feet per year from 2006 to 2018 (Figure 453). In 2008, however, the original Water Use Survey data indicated zero acre-feet was used for irrigation pumpage. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Trinity (Hill Country) Aquifer in Comal County ranged zero acre-feet per year to approximately 450 acre-feet per year over this study period. Surface water usage for irrigation occurred in all years, with sufficient usage in 2008 and from 2015 to 2018 such that all irrigation demands could be satisfied without pumping groundwater from the Trinity (Hill Country) Aquifer.

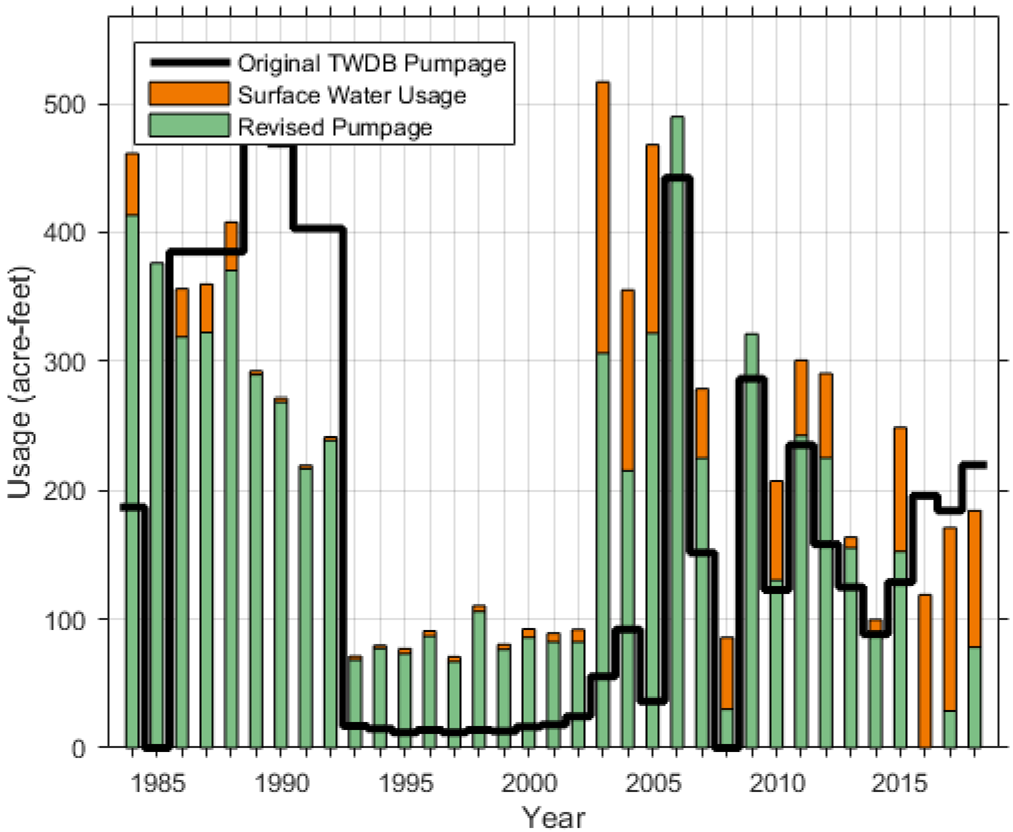


Figure 452. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Comal County.

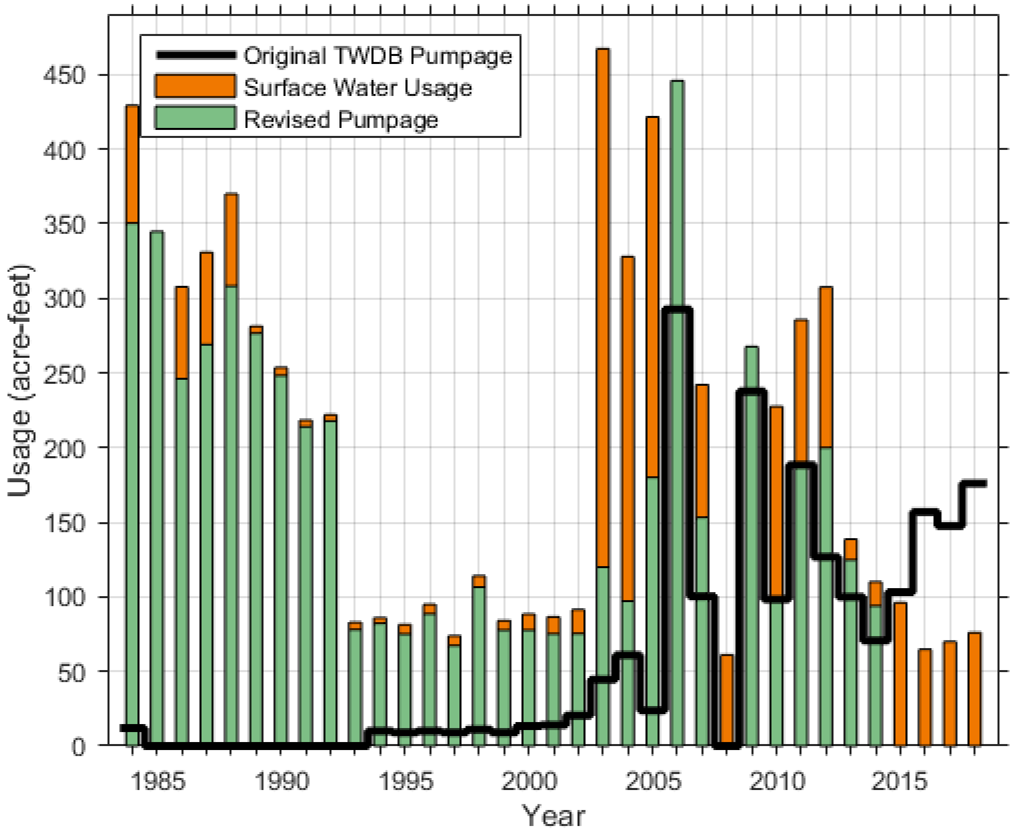


Figure 453. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Comal County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Comal County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Comal County.

Mining

Figure 448d and Figure 449d illustrate the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer, respectively, in Comal County during the study period. No enhanced oil recovery wells were reported within Comal County, and therefore only the U.S. Geological Survey and the Water Use Survey records were used to estimate groundwater pumping. We estimated approximately 41 percent of groundwater pumping for mining is sourced from the Trinity (Hill Country) Aquifer and the rest is from the Edwards (Balcones Fault Zone) Aquifer.

Water Use Survey data includes groundwater use from the Edwards (Balcones Fault Zone) and Trinity (Hill Country) aquifers. Reported pumping was compiled and added to the revised pumping estimate table. Note that year 2000 reported pumping by Flying W Properties Ltd was

4,914 acre-feet which we revised to 914 acre-feet for consistency with other reported pumping values by the entity.

Manufacturing

Figure 448c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards (Balcones Fault Zone) Aquifer in Comal County during the study period. Within the original TWDB Water Use Survey dataset, as included in Section 4.5, manufacturing estimates were specified by TWDB as "County Estimates." Yet TWDB also has usage reported by specific entities. Our revised estimates excluded county estimates, and only included estimates of reported manufacturing usage, revised as needed for consistency and based on research findings. This approach was different than the sample approach discussed within Section 4.5.

Figure 449c illustrates the changes in groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Comal County during the study period. The reduction in groundwater pumping estimates from the Trinity (Hill Country) Aquifer in Comal County are due to correcting the assigned aquifer for an entity. Section 4.5 discusses the updates to Comal County in greater detail.

Livestock

Figure 448b and Figure 449b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer, respectively, in Comal County during the study period. Our estimates for the Trinity (Hill Country) Aquifer are lower than the TWDB Water Use Survey through 2002 after which they are in general agreement. For the Edwards (Balcones Fault Zone) Aquifer, our estimates are in general agreement with the TWDB Water Use Survey data while filling in the missing data gaps from 1985 through 1999.

5.2.11 Concho County

Figure 454 and Figure 455 illustrate our revisions to the estimated in groundwater pumping from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Concho County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

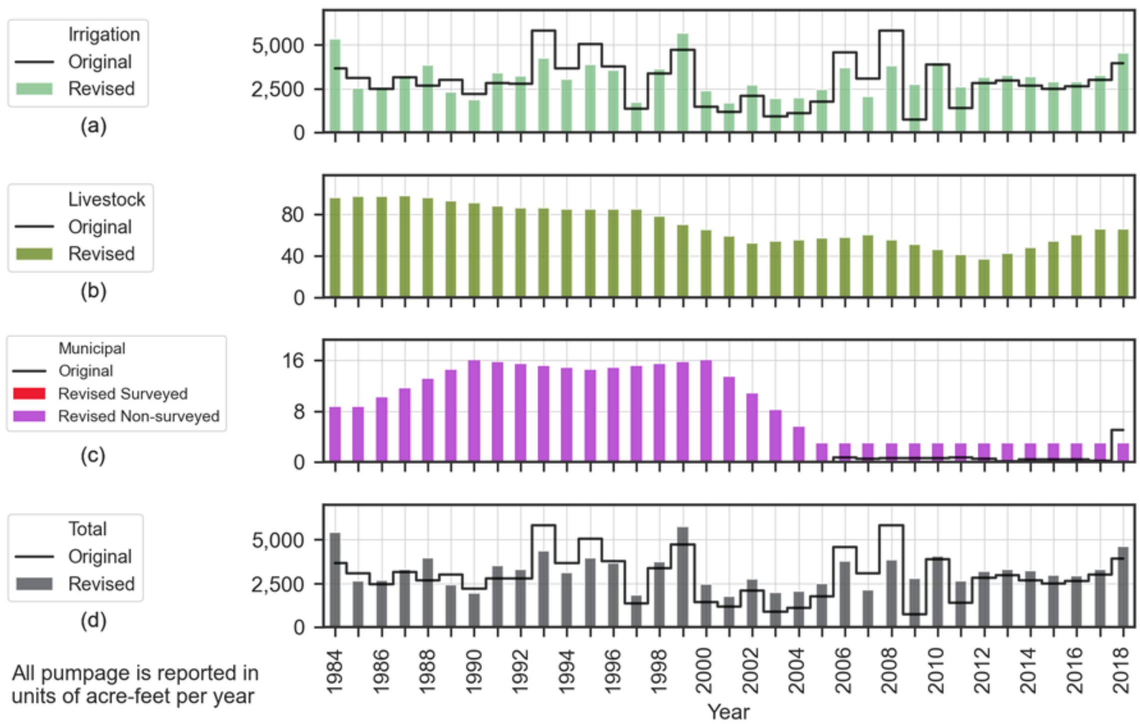


Figure 454. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Concho County from 1984 through 2018.

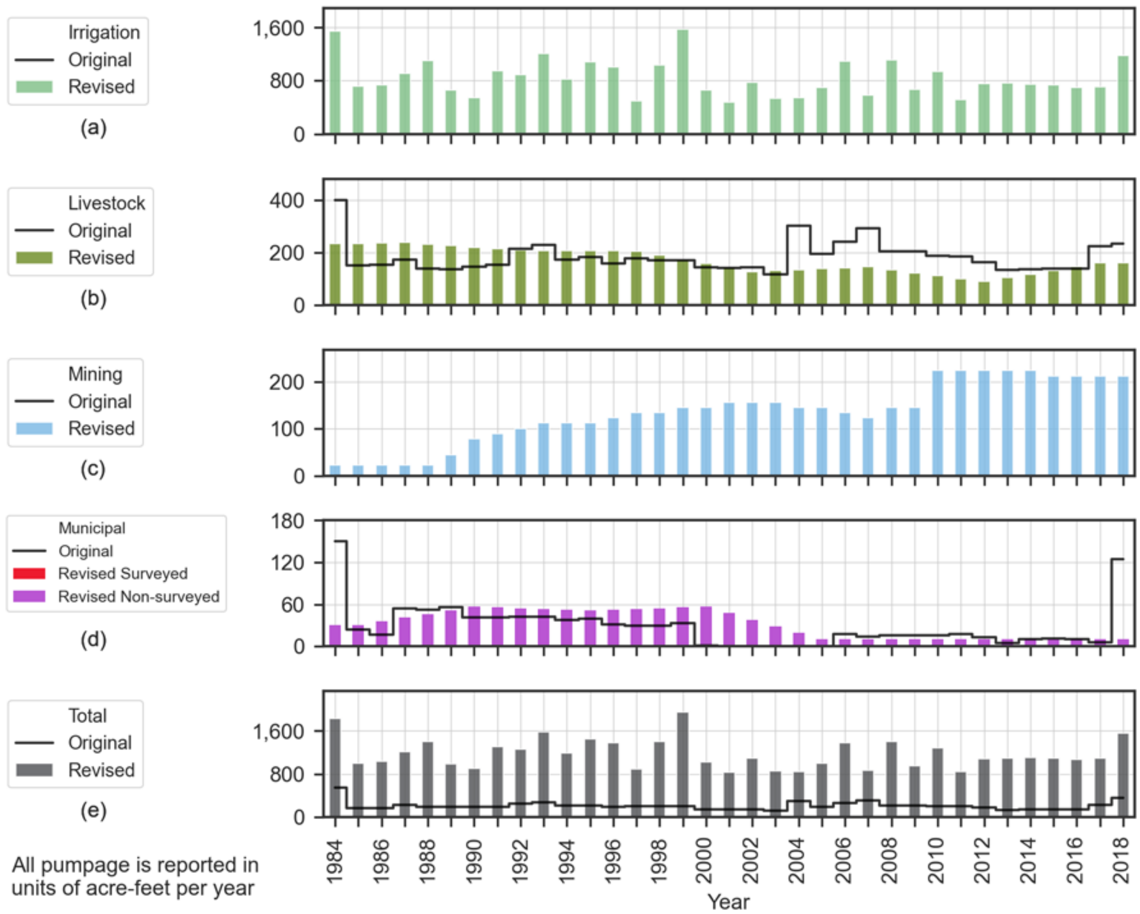


Figure 455. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Concho County from 1984 through 2018.

Surveyed Municipal

All entities reporting surveyed municipal pumping from within Concho County reported pumpage from either the Hickory Aquifer or "Other Aquifer." Locations of the entities did not suggest revisions to these aquifer designations were needed. The Region F 2021 water plan, however, indicates that the City of Eden does use water from the Edwards Trinity (Plateau) Aquifer for municipal purposes, but it does not disclose when such water was used or in what quantity.

Non-Surveyed Municipal

Figure 456 and Figure 457 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Concho County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data except for the peak in the Water Use Survey data in 2018 which is not present in our estimates. While our estimates are more than the Water Use Survey data for the Lipan Aquifer, they are less for the Edwards-Trinity (Plateau) Aquifer during the study period.

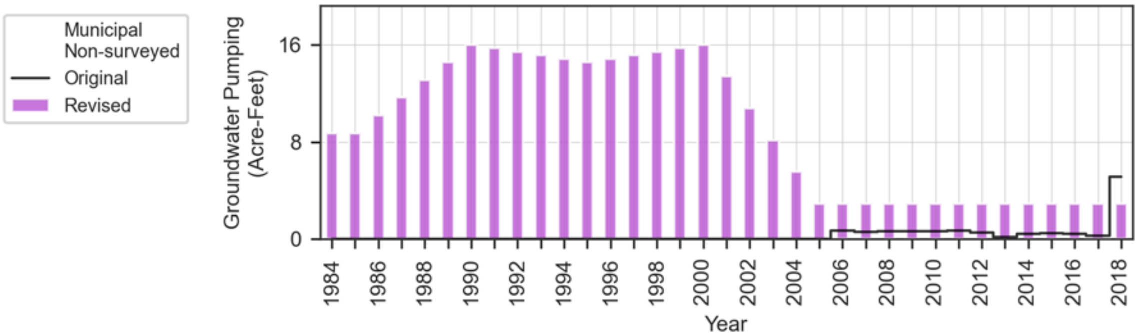


Figure 456. Original and revised estimates of groundwater pumping from Lipan Aquifer for non-surveyed municipal use in Concho County from 1984 through 2018.

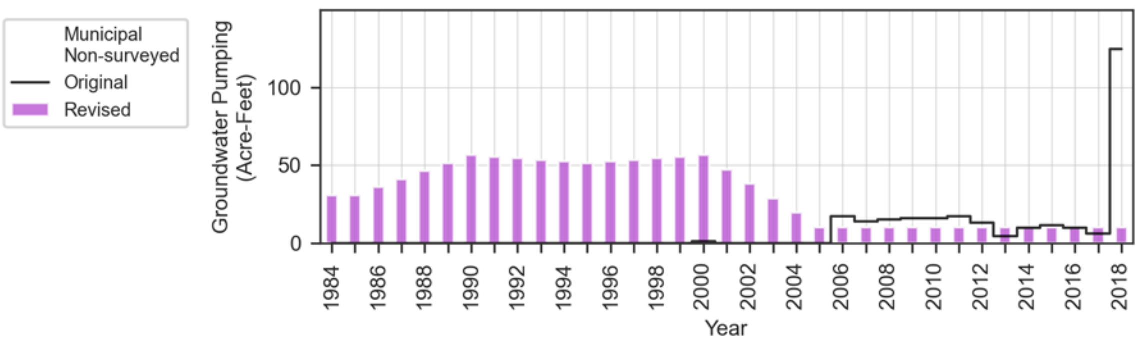


Figure 457. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Concho County from 1984 through 2018.

Irrigation

Concho County is underlain by the Lipan Aquifer along its western border with Tom Green County, and is underlain by the Edwards-Trinity (Plateau) Aquifer across much of the southern half of the county. The original TWDB Water Use Survey dataset contains pumpage estimates for irrigation for the Lipan Aquifer but not the Edwards-Trinity (Plateau) Aquifer. It does contain estimates attributed to “Other Aquifer” although it is not known if those estimates correspond the Edwards-Trinity (Plateau) Aquifer, the Hickory Aquifer, or the Cross Timbers Aquifer the latter two of which are within the county but not part of the subject aquifers for this study.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Lipan Aquifer in Concho County ranged from 1,675 acre-feet per year to 5,665 acre-feet per year over this study period (Figure 458). The year-to-year variation in computed pumpage reflects the spatial and temporal distribution of rainfall across the aquifer footprint over the study period. Similar fluctuations are evident in the original TWDB Water Use Survey data.

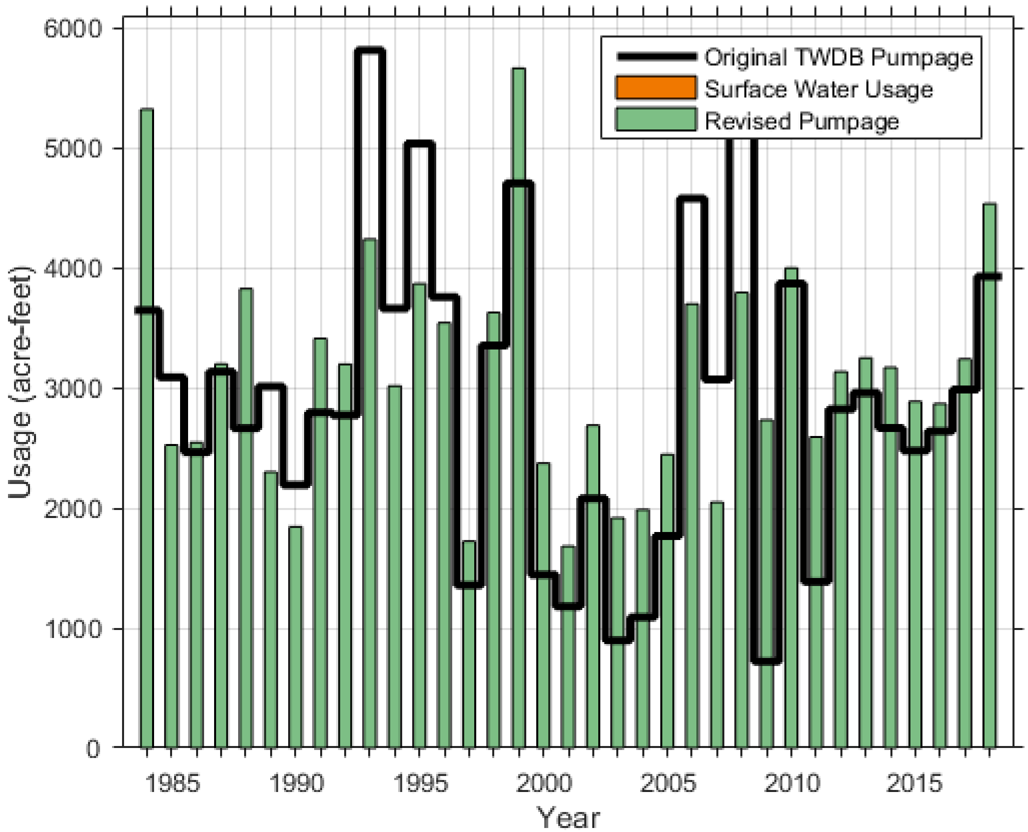


Figure 458. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Concho County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Concho County ranged from 480 acre-feet per year to 1,572 acre-feet per year over this study period (Figure 459). The year-to-year variation in computed pumpage reflects the spatial and temporal distribution of rainfall across the aquifer footprint over the study period.

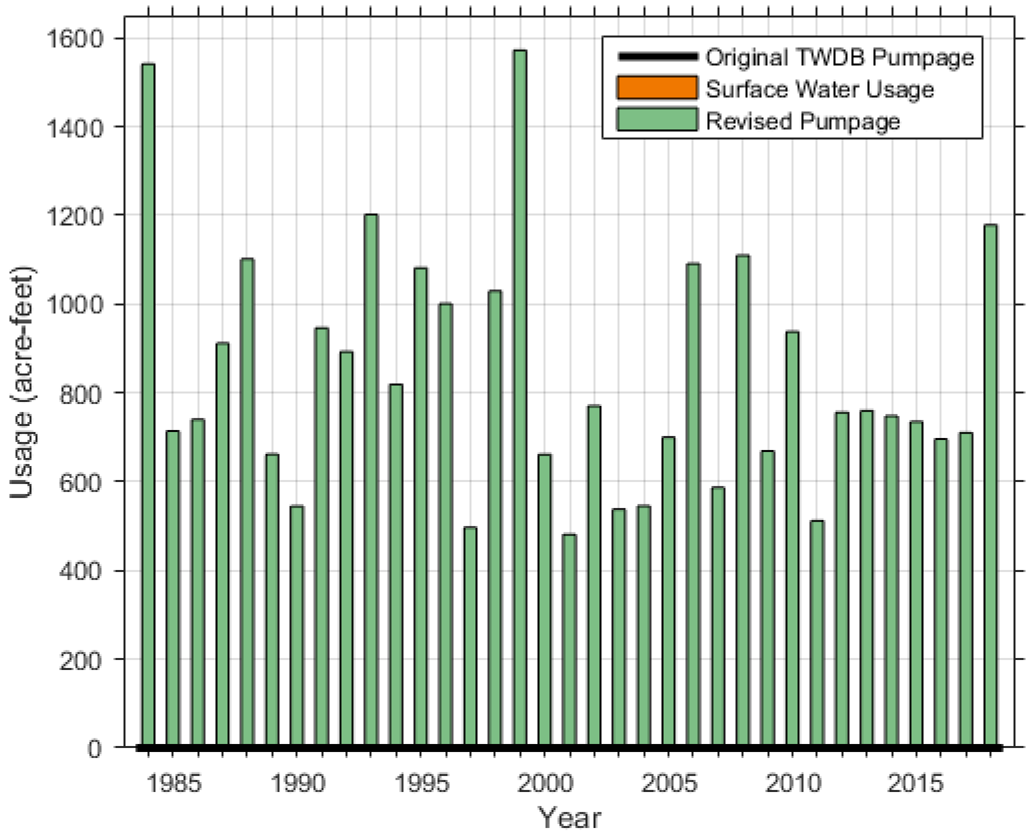


Figure 459. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Concho County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Concho County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Concho County.

Mining

Figure 455c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Concho County during the study period. There were only three active enhanced oil recovery wells in Concho County in 1980 which increased up to 77 wells in 2020. We estimate the entirety of groundwater pumping for mining from the wells in the study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Concho County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Concho County.

Livestock

Figure 454b illustrates the changes in groundwater pumping associated with livestock use from the Lipan Aquifer in Concho County during the study period. The TWDB Water Use Survey data does not contain groundwater pumpage estimates for livestock from the Lipan Aquifer in Concho County. Our revised estimates of groundwater pumping for livestock use in the county indicate a maximum groundwater pumpage of ~100 acre-feet which gradually decreased to 50 acre-feet by the end of the study period.

Figure 455b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Concho County during the study period. Results from our evaluation are in general agreement with TWDB Water Use Survey data through 2003 and corrects for the anomalous pumpage value in 1984. From 2004 onwards, our estimates of groundwater pumping for livestock use in the county are consistent with the trend of our estimates for previous years but are less than the TWDB Water Use Survey data.

5.2.12 Crane County

Figure 460 and Figure 461 illustrate our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau), respectively, in Crane County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

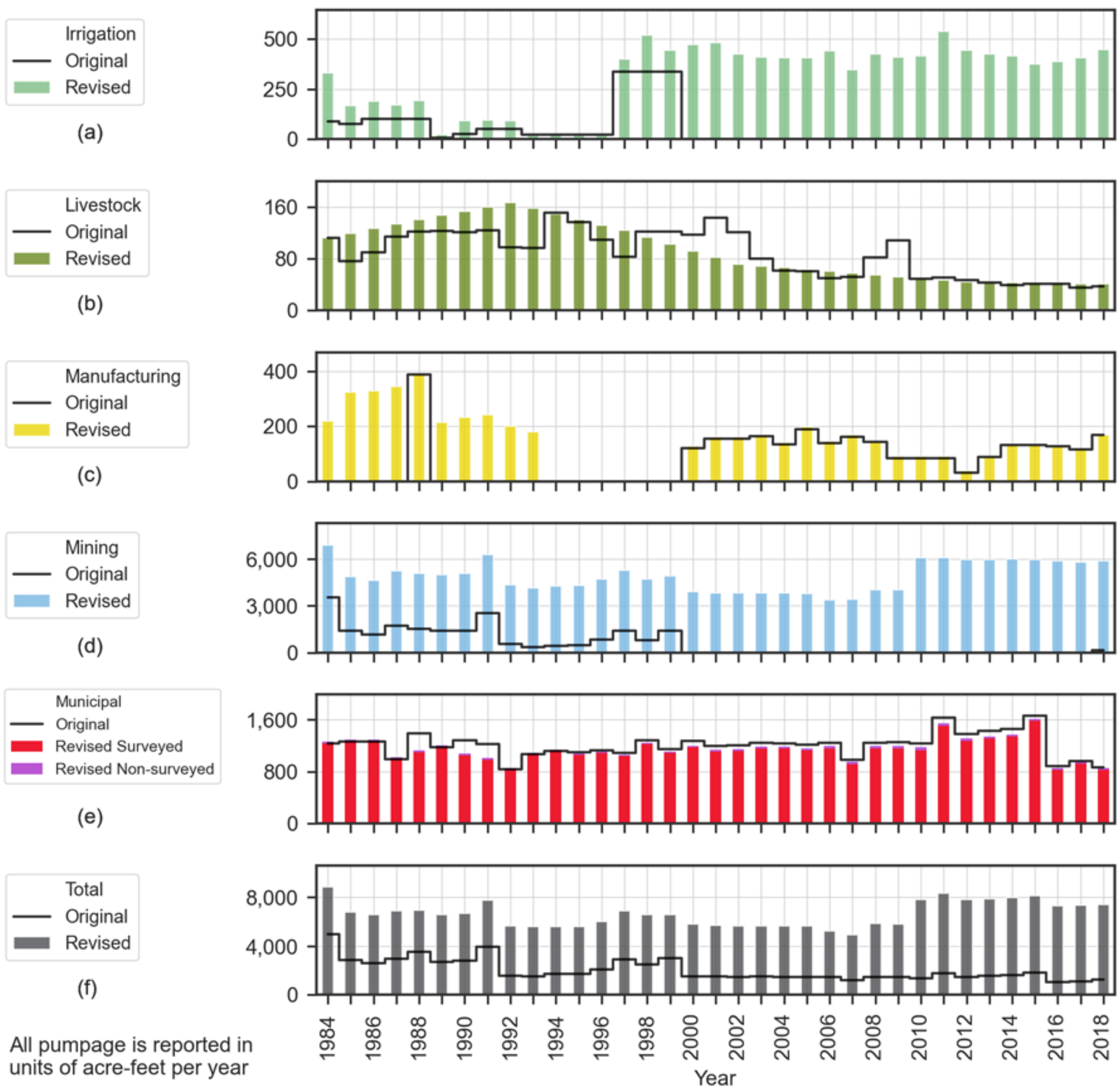


Figure 460. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Crane County from 1984 through 2018.

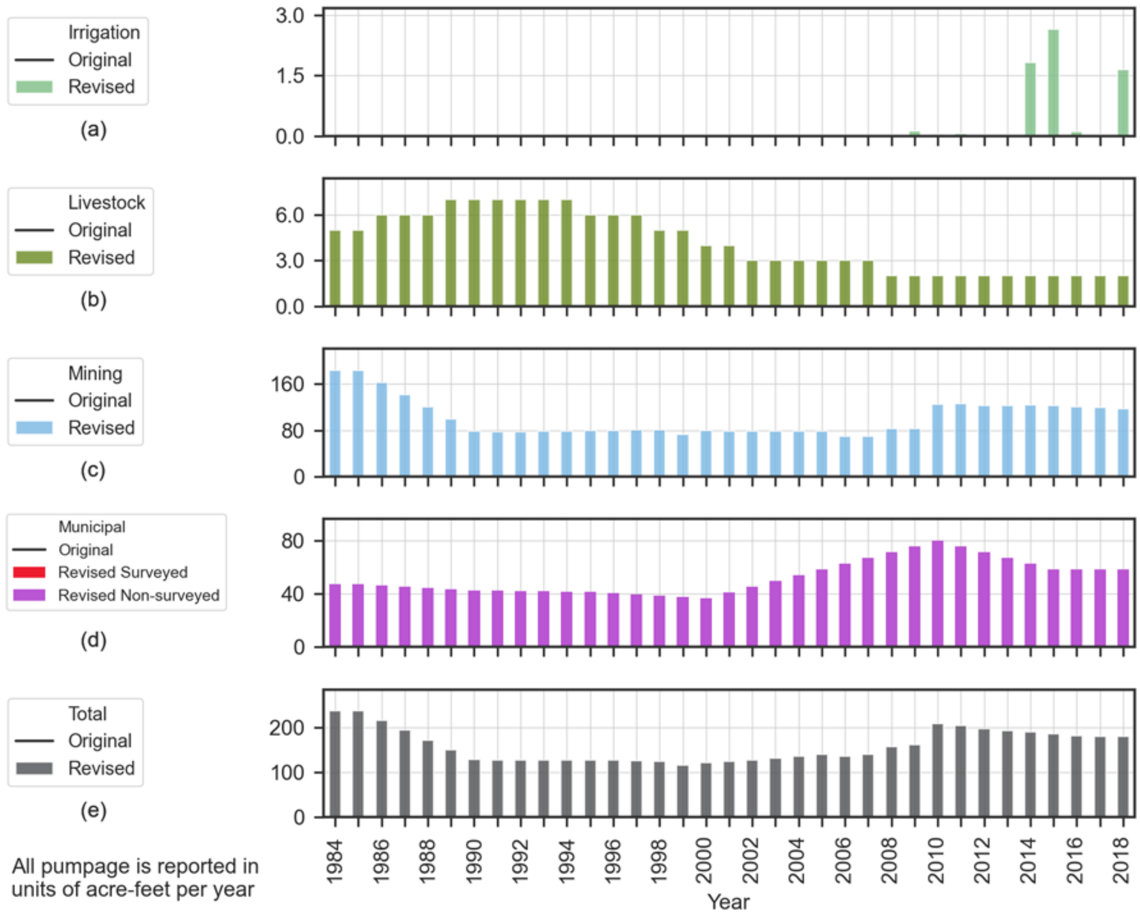


Figure 461. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Crane County from 1984 through 2018.

Surveyed Municipal

The City of Crane reported municipal pumpage from the Pecos Valley Aquifer for each year of the study period. The reported data exhibited plausible year-to-year fluctuations consistent with water use variations expected with population changes and climatic variability.

Non-Surveyed Municipal

Figure 462 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer in Crane County during the study period. Our estimates are several times less than the TWDB Water Use Survey data. Our review of the available data suggested the pumping for this use is less than previous estimates suggest.

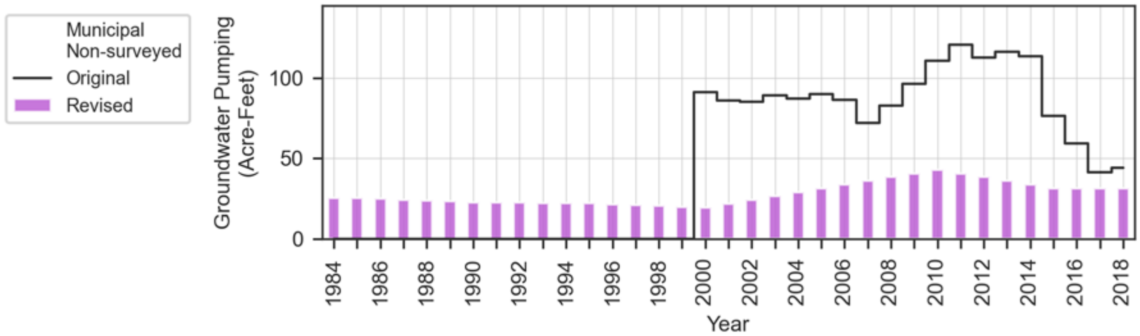


Figure 462. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Crane County from 1984 through 2018.

Irrigation

Crane County is nearly entirely underlain by the Pecos Valley Aquifer, yet also has portions underlain by the Edwards-Trinity (Plateau) Aquifer along its eastern boundary with Upton County. Portions of the county are also underlain by the Dockum Aquifer. Wells within the county that are located within the footprints of both the Dockum Aquifer and the Pecos Valley Aquifer are mainly screened within the Dockum Aquifer, yet there exists a region in the center of the county were Pecos Valley Aquifer Wells are prevalent. Upon review of well data within the TWDB groundwater data viewer, it was determined that the vast majority of wells identified as satisfying irrigation needs were screened within the Pecos Valley Aquifer and not within the Dockum Aquifer. As such, in revising the TWDB water usage survey estimates of irrigation pumpage for Crane County, it was assumed that all water was withdrawn from the Pecos Valley Aquifer.

The original TWDB Water Use Survey dataset included irrigation pumpage from the Pecos Valley Aquifer in Crane County within the range of seven acre-feet per year to 337 acre-feet per year from 1984 to 1999. The dataset did not contain any pumpage entries for this aquifer and county for the period from 2000 to 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, and reported surface water usage for irrigation, groundwater needs for irrigation of land above the footprint of the Pecos Valley Aquifer in Crane County ranged from 20 acre-feet per year to 537 acre-feet per year (Figure 463). Revised pumpage values for 1984 to 1992 were generally 50 percent higher than the original TWDB estimates, yet nearly identical estimates were obtained for the 1993 to 1996 period. It is also notable that both the original and revised pumpage datasets indicated a large increase in pumpage between 1996 and 1997. The revised dataset indicates that pumpage from 1997 to 2018 generally fluctuated around the 400 acre-feet per year pumpage value.

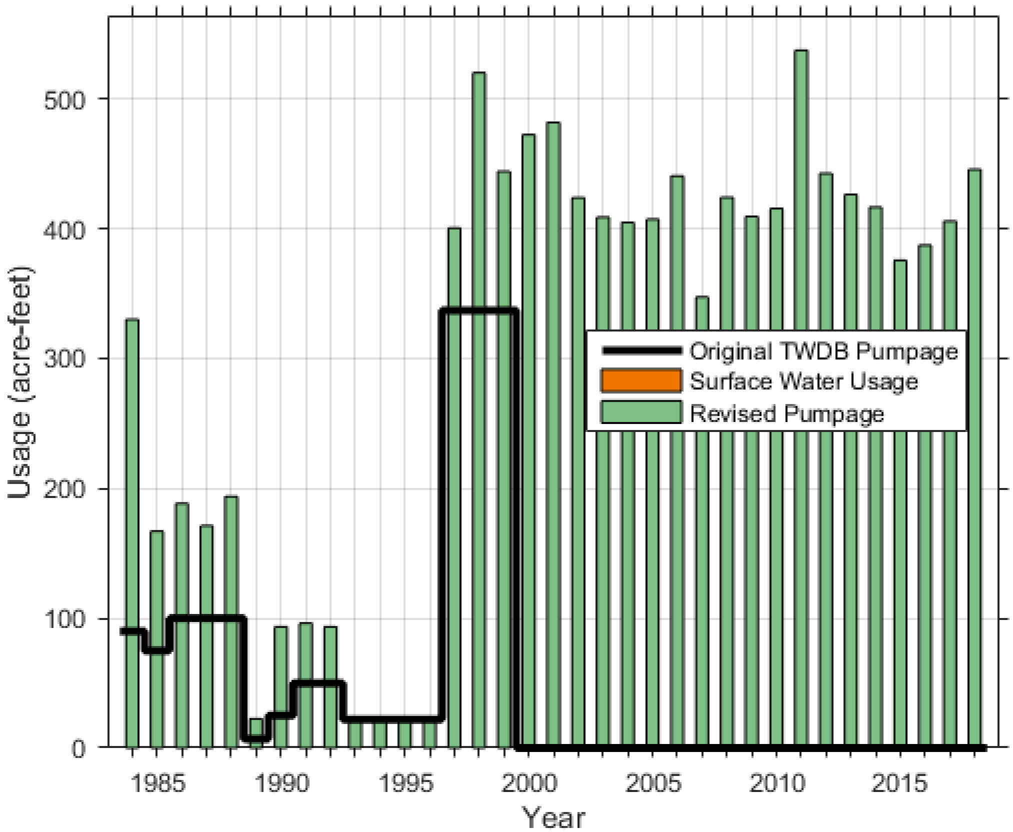


Figure 463. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Crane County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Crane County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Crane County.

Mining

Figure 460d illustrates the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer in Crane County during the study period. The number of active enhanced oil recovery wells in Crane County were around 1,449 in 1980 which increased to 1,699 wells in 2020. Since there are a significant number of Class II Injection wells in Crane County, we can infer that there is significant groundwater pumping related to oil and gas mining activities. Estimated water use indicates that almost all the groundwater for mining use is pumped from the Pecos Valley Aquifer and the remaining is sourced from the Edwards-Trinity (Plateau) Aquifer. Note that the U.S. Silica Company-Crane County Plant pumped more than 150 acre-feet of groundwater from the Pecos Valley Aquifer for mining use in the year 2018 according to the Water Use Survey data.

Manufacturing

Figure 460c illustrates the changes in groundwater pumping associated with manufacturing use from the Pecos Valley Aquifer in Crane County during the study period. The largest changes occur prior to 1994. After 1993, "GPM Gas Corporation-Crane Water Station GPOD" no longer reported pumping. Since it is possible the company is no longer in business, we left the pumping unchanged rather than assuming similar pumping from 1994 through 1999.

Livestock

Figure 460b illustrates the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer in Crane County during the study period. Results from our evaluation are in general agreement with the TWDB Water Use Survey data. Figure 461b illustrates our revisions to groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) in Crane County during the study period. The TWDB Water Use Survey dataset did not include any pumpage from the Edwards-Trinity (Plateau) whereas our revised estimates do include a small volume of groundwater pumped from this aquifer on an annual basis limited to less than 10 acre-feet.

5.2.13 Crockett County

Figure 464 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Crockett County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

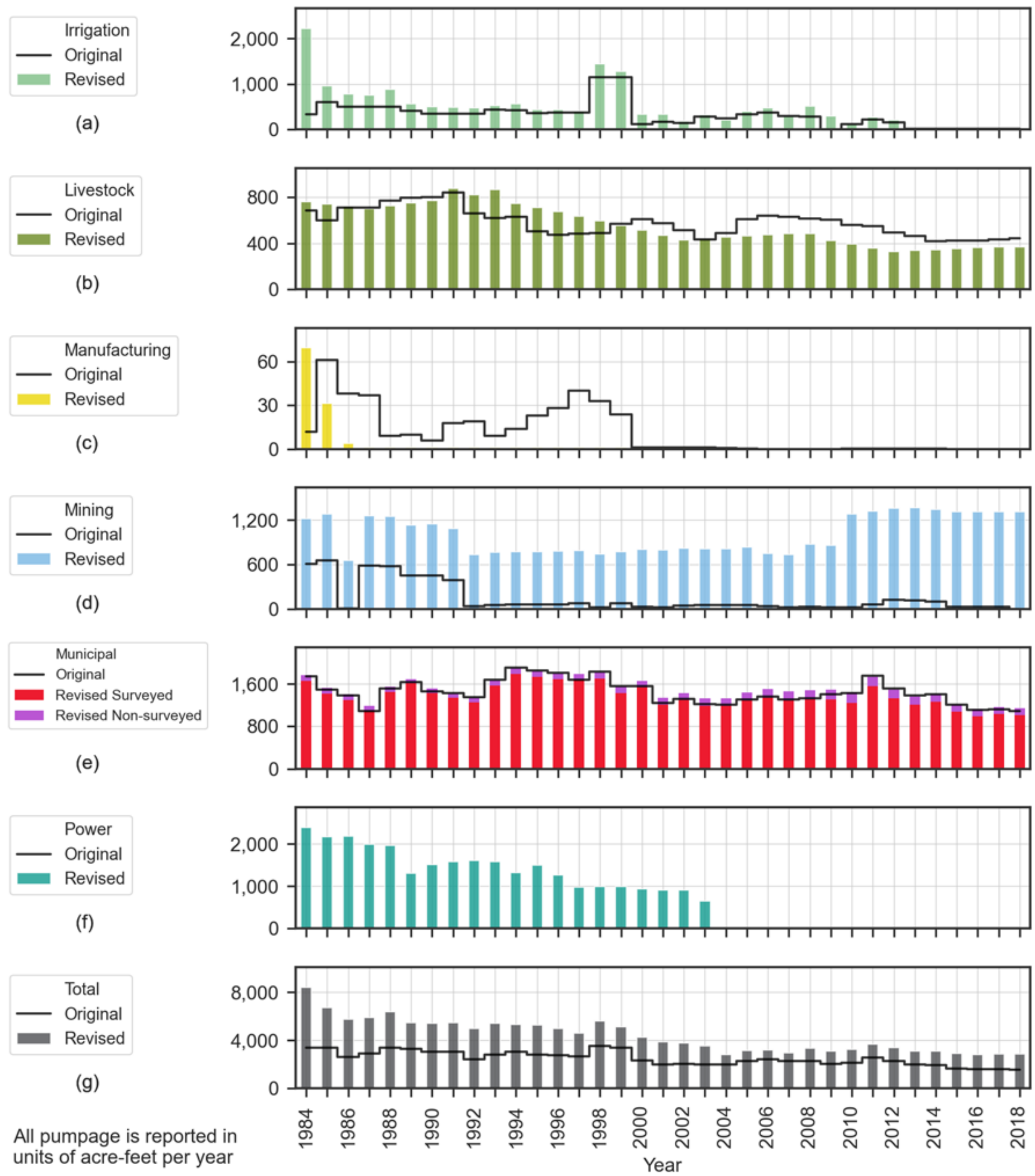


Figure 464. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Crockett County from 1984 through 2018.

Surveyed Municipal

Pumpage from within Crockett County for municipal purposes was reported from Crockett County WCID 1 (1984-2001) and from Crockett County WCID 1 Ozona (1984-2018). The reported data exhibited plausible year-to-year fluctuations consistent with water use variations expected with population changes and climatic variability.

Non-Surveyed Municipal

Figure 465 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Crockett County during the study period. Our estimates are several times more than the TWDB Water Use Survey data through 2009. Our review of the available data suggested the pumping for this use is more than previous estimates suggest for that time period.

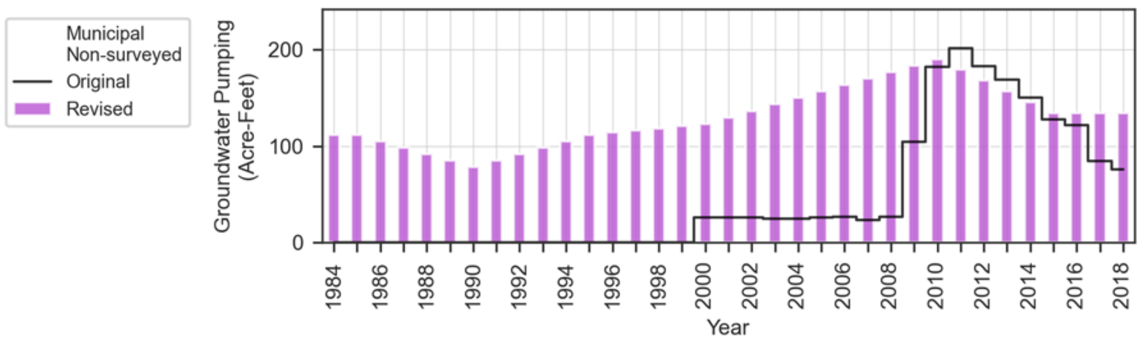


Figure 465. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Crockett County from 1984 through 2018.

Irrigation

Crockett County is almost entirely underlain by the Edwards-Trinity (Plateau) Aquifer, with the only exception being a small portion of the western edge of the county along the Pecos River (which is immediately underlain by the Pecos Valley Aquifer). The TWDB Water Use Survey dataset specifies irrigation usage for Crockett County derived from wells within the Edwards-Trinity (Plateau) Aquifer as well as "Other Aquifer." Based on the distribution of wells within the county, it appears that the "Other Aquifer" could be the Dockum Aquifer which underlies the Edwards-Trinity (Plateau) Aquifer within the northern portion of the county. Wells in the northern portion of the county are screened in either the Dockum Aquifer or the Edwards-Trinity (Plateau) Aquifer, and there is not any distinct geographic separation between wells screened in either aquifer. Within the submitted driller's report database, the few wells designated with the "Proposed Use" of irrigation are generally shallower wells, indicating that they are screened within the Edwards-Trinity (Plateau) Aquifer rather than the underlying Dockum Aquifer. Based on this observation, it is assumed that all irrigation pumpage from Crockett County is derived from wells screened within the Edwards-Trinity (Plateau) Aquifer.

The original TWDB Water Use Survey irrigation pumpage for Crockett County ranged from near zero (from 2013 to 2018) to approximately 1,150 acre-feet per year in 1998 and 1999

(Figure 466). Similar patterns are evident in the revised pumpage, with the exception that pumping during 1984 was computed to be the greatest. Both datasets show an increase in pumpage in 1998 and 1999, with a severe reduction in pumpage after 2013. Pumpage was distributed to locations where CropScape grids indicated irrigation water was required.

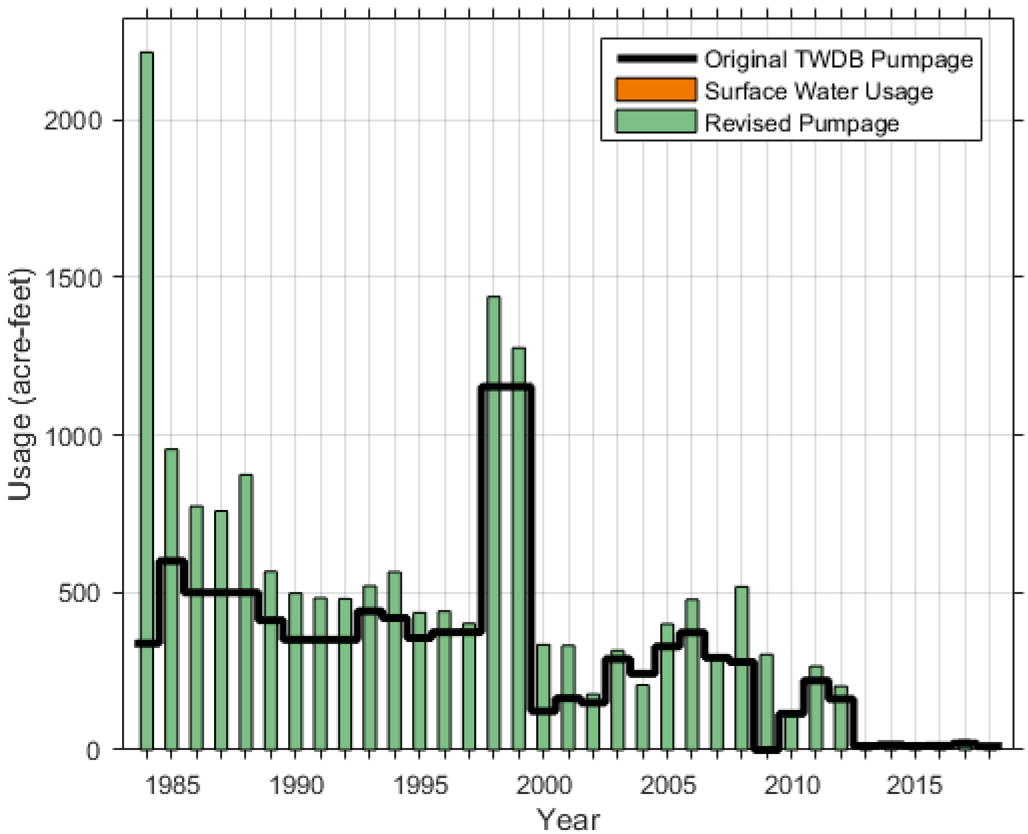


Figure 466. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Crockett County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater needs for irrigation of land above the footprint of the Pecos Valley Aquifer in Crockett County ranged from zero to eight acre-feet per year over this study period (Figure 467). No wells were identified within the footprint of the Pecos Valley Aquifer within Crockett County.

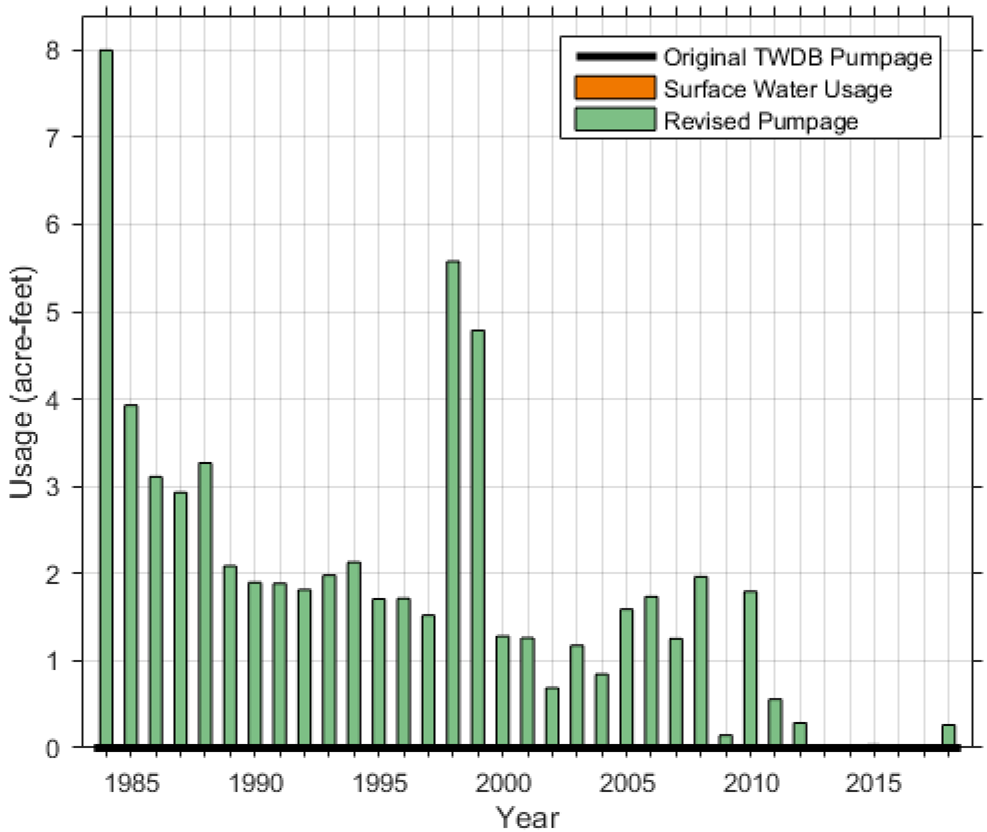


Figure 467. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Crockett County.

Power

As reported in Section 3.3.13 and illustrated on Figure 468, pumping from the Edwards-Trinity (Plateau) Aquifer in Crockett County for power use is negligible. However, in revising the original TWDB Water Use Survey pumpage, we determined that the Rio Pecos Power Plant was previously assigned to Pecos County when it is physically located within Crockett County. In fact, the power plant was reported as pumping from Crockett County during 2005, 2006 and 2007 (see Figure 468).

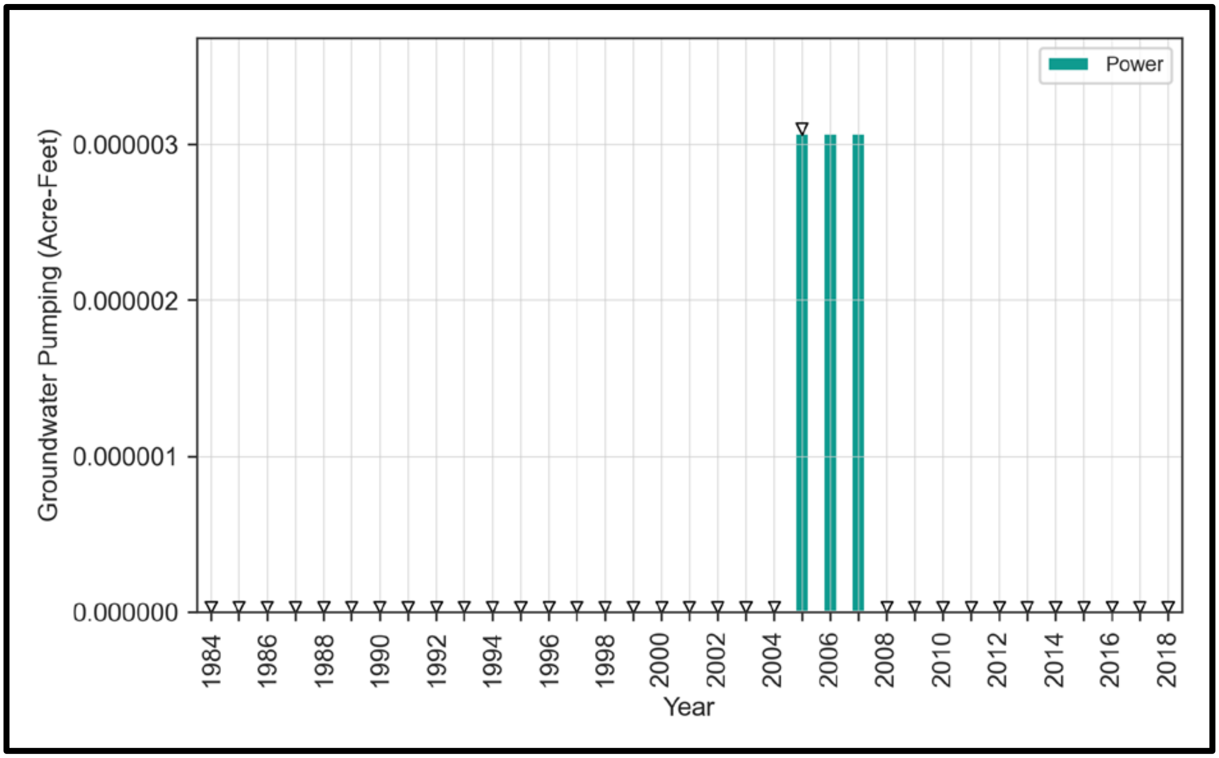


Figure 468. Edwards-Trinity (Plateau) Aquifer groundwater pumping for power use within Crockett County as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Edwards-Trinity (Plateau) Aquifer pumping for power use per entity in Crockett County, we determined there was only one surveyed entity reporting groundwater production. The sole reporting entity was Eagle Supply & Manufacturing LP – Rio Pecos Plant (hereafter referred to as “Rio Pecos Power Plant”). The location is shown in Figure 469. Table 70 presents the timeline of operation events as provided on form EIA-860 for the Rio Pecos Power Plant in Crockett County.

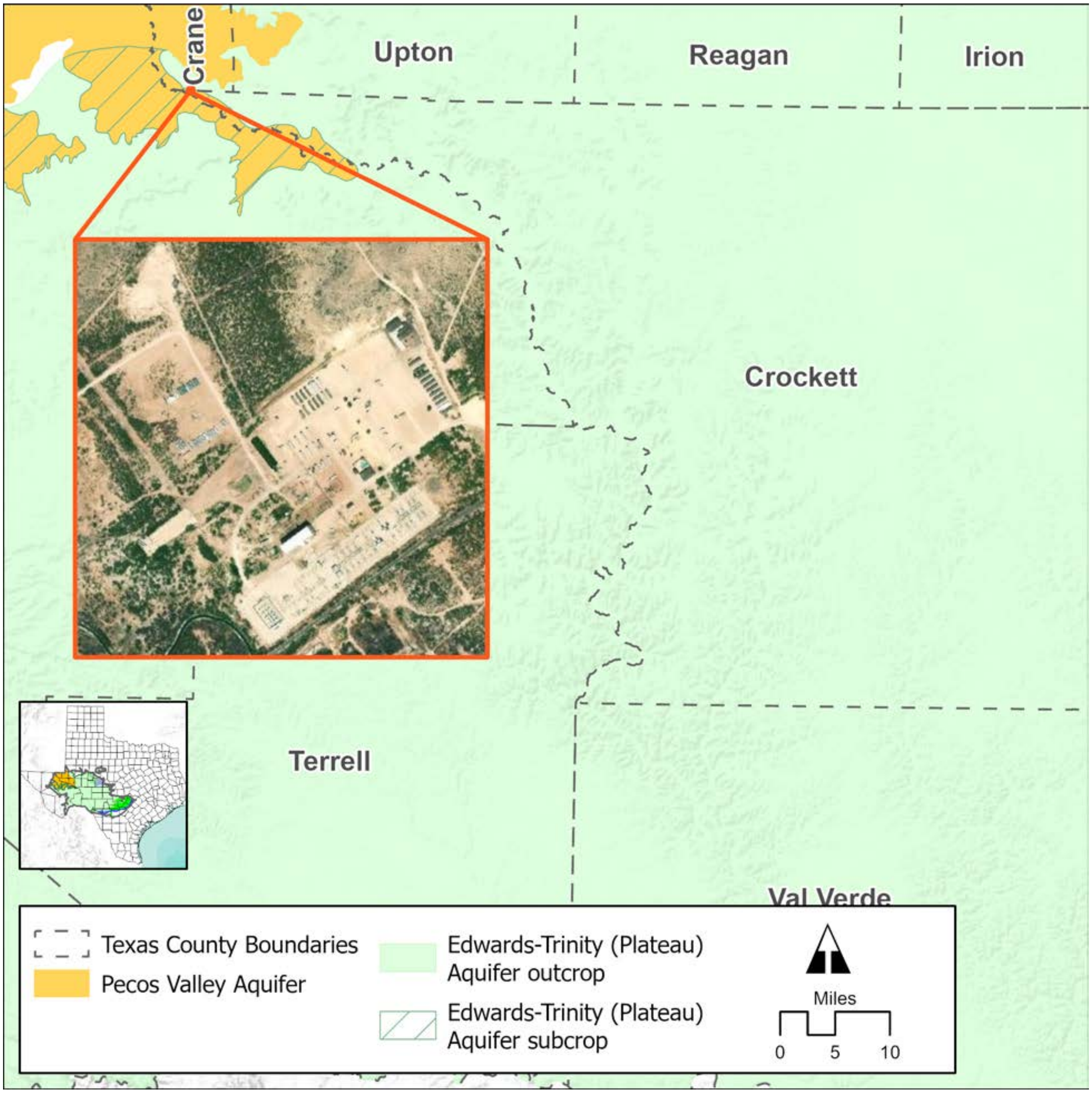


Figure 469. Location of the Rio Pecos Power Plant in Crockett County.

Table 70. Rio Pecos Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
1959	CA 4	Began Operation	Combined Cycle Combustion Turbine	Fossil fuels	Mechanical draft, wet process	Recirculating with induced draft cooling tower(s)
1969	CA 5	Began Operation	Combined Cycle Combustion Turbine	Fossil fuels	Mechanical draft, wet process	Recirculating with induced draft cooling tower(s)
1969	ST 6	Began Operation	Combined Cycle Combustion Turbine	Fossil fuels	Mechanical draft, wet process	Recirculating with induced draft cooling tower(s)
2007	ST 5	Retired	Steam Turbine	Fossil fuels	Mechanical draft, wet process	
2007	ST 6	Retired	Steam Turbine	Fossil fuels	Mechanical draft, wet process	

Steam turbines and boilers, such as Rio Pecos Power Plant units ST 5 and ST 6, heat water and subsequently condense the steam, and thus have cooling requirements much greater than combustion turbines CA 4 and CA 5. Using information gathered from EIA-860 (Table 70), we know that the Rio Pecos Power Plant steam turbines used a wet-type cooling tower. The Rio Pecos Power Plant would fall under the classification of a large power plant. Given that the power plant began operation in 1959 we can assume that it is not as efficient as a modern power plant. We therefore assigned it an average water use value of 0.69 gallons per kilowatt-hour (see Figure 380).

Combustion turbines, such as the Rio Pecos Power Plant unit CA 4 and CA 5, have much lower cooling requirements than steam turbines. Form EIA-860 did not specify if the gas turbine used a wet or dry nitrogen oxide control. Given that the gas turbines started operating in 1959 (EIA, 2020a), we can assume that the turbines used wet nitrogen oxides control. Based on our assumption, we assigned the years with gas turbine operation (1984-1999) an average water use value of 0.05 gallons per kilowatt-hour.

Figure 470 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Rio Pecos Power Plant. Figure 470d illustrates the pumpage based on the Water Use Survey. Given the agreement between the combined turbines pumpage and the reported pumpage, no further revisions were made to the Water Use Survey reported pumpage volumes.

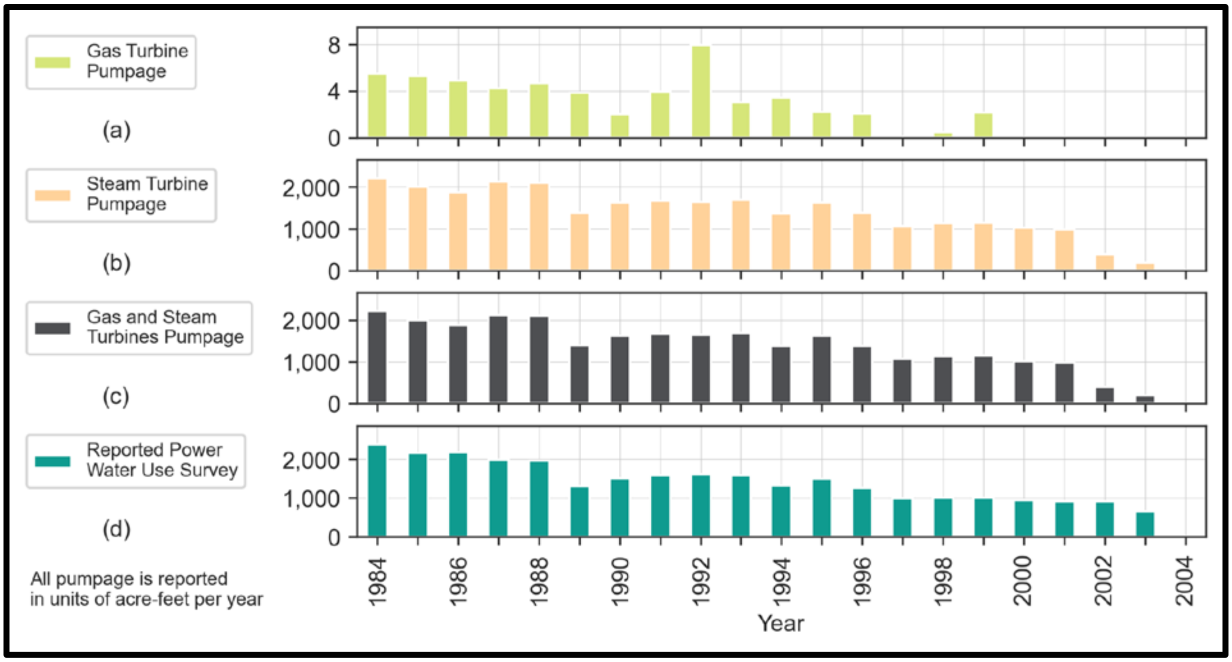


Figure 470. **Rio Pecos Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated groundwater pumping associated with steam turbine power generation, (c) Estimated combined groundwater pumping by both steam and gas turbines and (d) Reported groundwater pumping by the Water Use Survey.**

Mining

Figure 464d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Crockett County during the study period. The number of active enhanced oil recovery wells in Crockett was only 237 in 1980 which has now increased up to 334 wells in 2020. We estimated the entirety of groundwater pumping for mining use in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 464c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Crockett County during the study period. The change in pumping is partly due to a reassignment of the aquifer based on the available information. The change primarily affects the estimates prior to 2000 after which our estimates are consistent with the original estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for manufacturing use in Crockett County.

Livestock

Figure 464b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Crockett County during the study period. Results from our evaluation are in general agreement with the TWDB Water Use Survey data.

5.2.14 Culberson County

Figure 471 and Figure 472 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Pecos Valley Aquifer, respectively, in Culberson County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

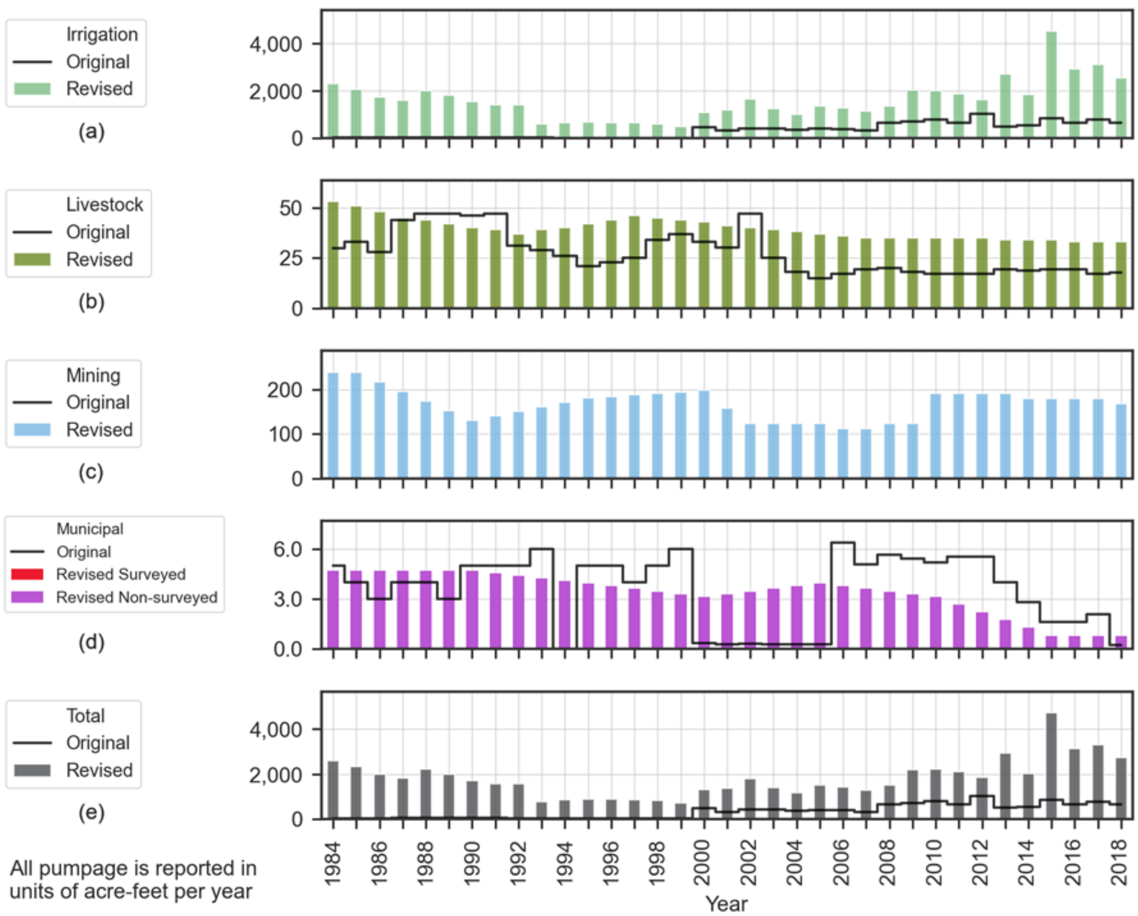


Figure 471. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Culberson County from 1984 through 2018.

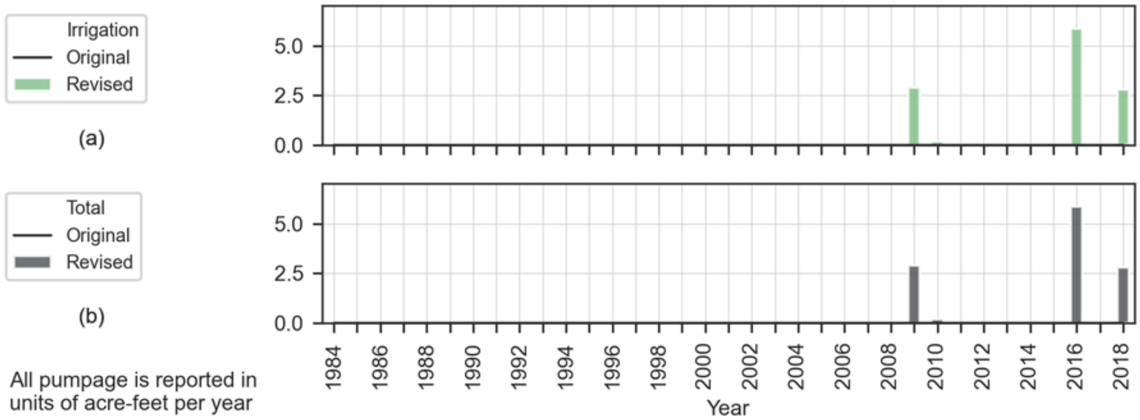


Figure 472. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Culberson County from 1984 through 2018.

Surveyed Municipal

All of the entities within Culberson County reporting municipal pumpage utilized wells located in aquifers other than the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer. As a result our revised dataset did not include surveyed municipal pumpage with the study area footprint within Culberson County.

Non-Surveyed Municipal

Figure 473 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Culberson County during the study period. While our estimates are more than the TWDB Water Use Survey data through 2005, they are less from 2006 through 2017. Note: the original TWDB Water use Survey data shown in Figure 471d contains both surveyed and non-surveyed estimates.

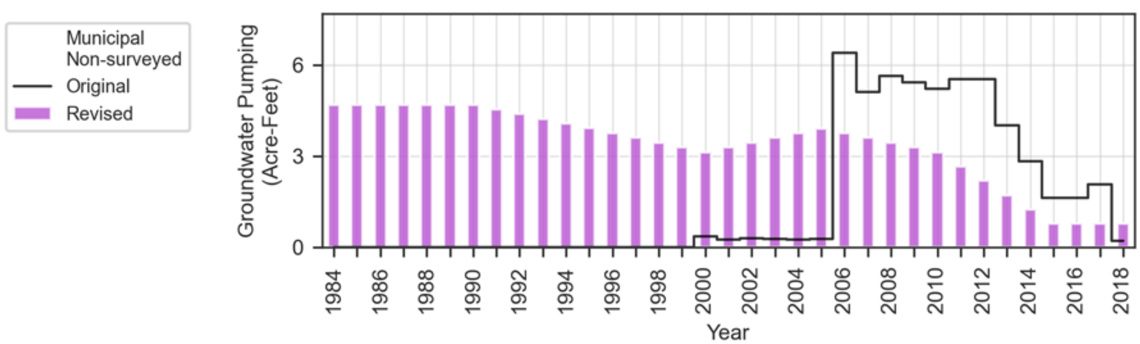


Figure 473. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Culberson County from 1984 through 2018.

Irrigation

The south-eastern portion of Culberson County is underlain by the Edwards-Trinity (Plateau) Aquifer, with a smaller section also underlain by the Pecos Valley Aquifer. This region is also underlain by the Rustler Aquifer and the Capitan Reef Complex which are not included in this study. All wells located near or within the footprints of the Pecos Valley Aquifer or the Edwards-Trinity (Plateau) Aquifer were identified as being screened within either the Rustler Aquifer or the Capitan Reef Aquifer. The original TWDB Water Use Survey dataset did not indicate groundwater pumpage for irrigation from the Pecos Valley Aquifer, yet it did include pumpage from the Edwards-Trinity (Plateau) Aquifer for the period from 2000 through 2018. Over this time, pumpage ranged from 500 acre-feet per year to 1,000 acre-feet per year.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater needs for irrigation of land above the footprint of the Pecos Valley Aquifer in Culberson County ranged from zero to eight acre-feet per year over this study period (Figure 474). No wells were identified within the footprint of the Pecos Valley Aquifer within Culberson County.

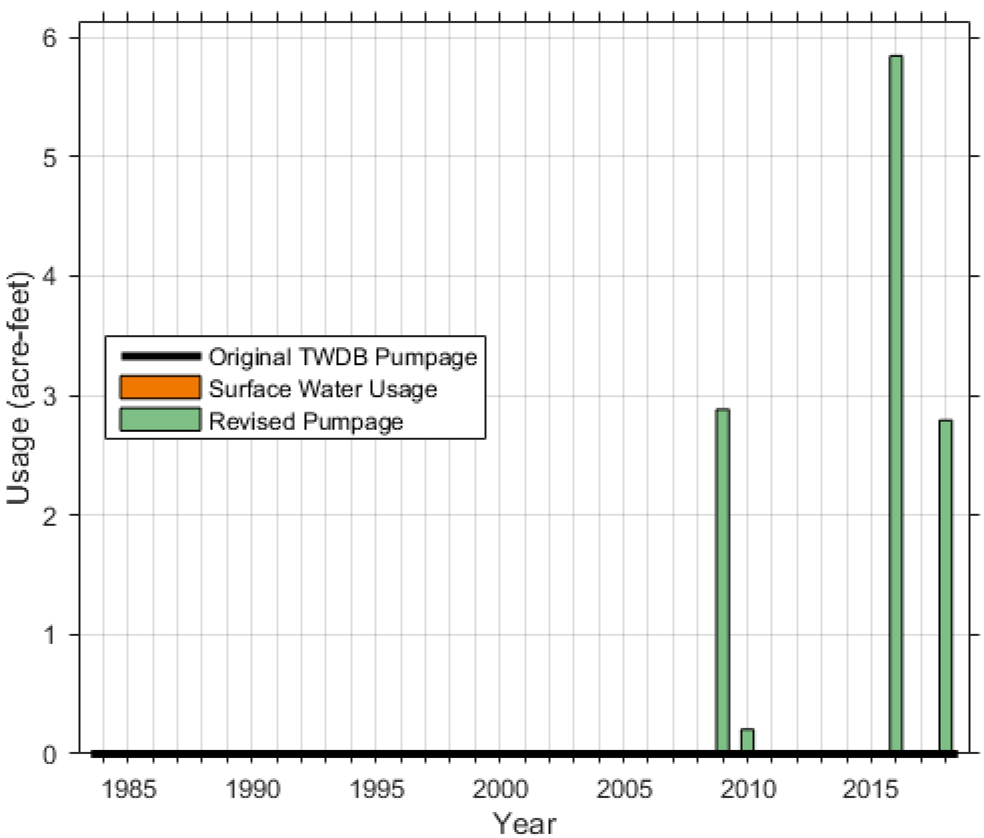


Figure 474. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Culberson County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Culberson County ranged from 500 acre-feet per year to over 4,500 acre-feet per year over this study period (Figure 475). This range is larger than the estimated pumpage from the original TWDB Water Use Survey dataset. It is possible that some of the increase in computed irrigation could be derived from wells screened within the Rustler Aquifer or the Capitan Reef Complex, yet insufficient evidence was identified to support this possibility. The original TWDB water use survey dataset consistently assigned 78.18% of all irrigation pumping in Culberson County to the West Texas Bolson Aquifer, 16.36% to the Capitan Reef Complex Aquifer, and 1.82% each to the Edwards Trinity (Plateau) Aquifer, Igneous Aquifer, and “Other Aquifer.” Our analysis, based on crop locations and climate patterns, did not support this distribution of pumpage amongst the various aquifers within Culberson County.

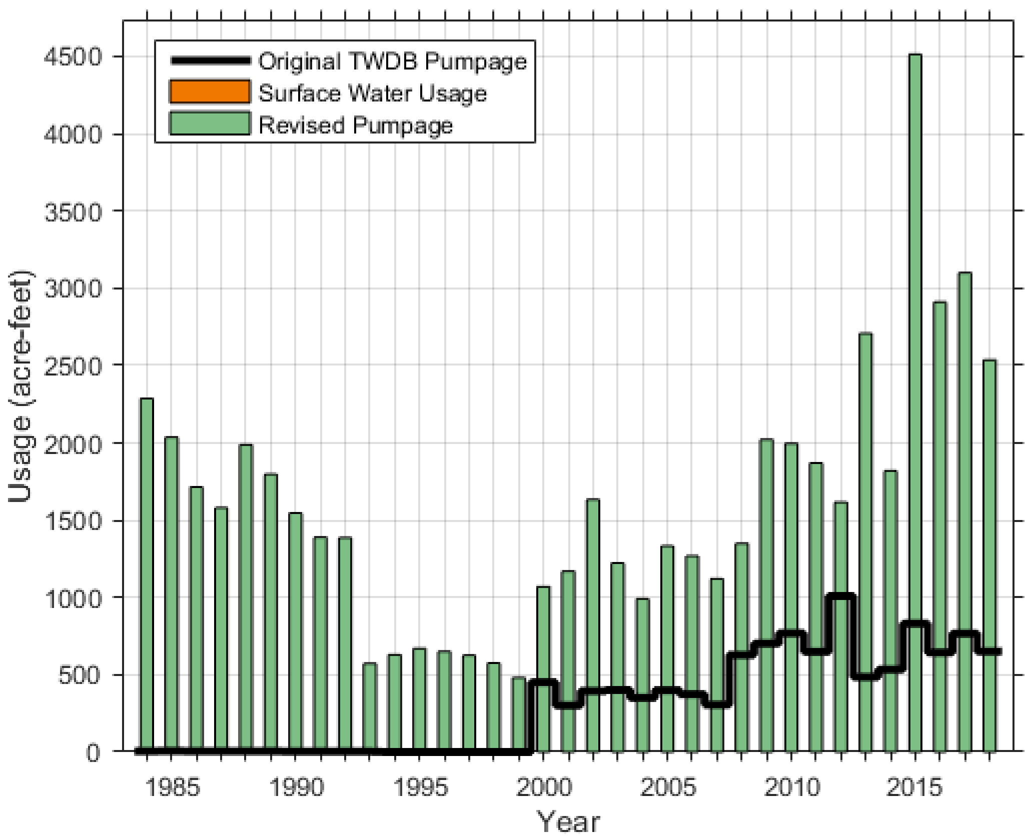


Figure 475. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Culberson County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Culberson County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Culberson County.

Mining

Figure 471b illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Culberson County during the study period. We noticed that there were no active enhanced oil recovery wells reported in Culberson in 1980 but in 2020 there were up to 13 wells. We estimate the entirety of groundwater pumping for mining in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Culberson County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Culberson County.

Livestock

Figure 471b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Culberson County during the study period. Results from our evaluation are slightly higher than the TWDB Water Use Survey data throughout the study period.

5.2.15 Ector County

Figure 476, Figure 477, and Figure 478 illustrate our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer, the Edwards-Trinity (Plateau) Aquifer, and the Trinity (Hill Country) respectively, in Ector County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

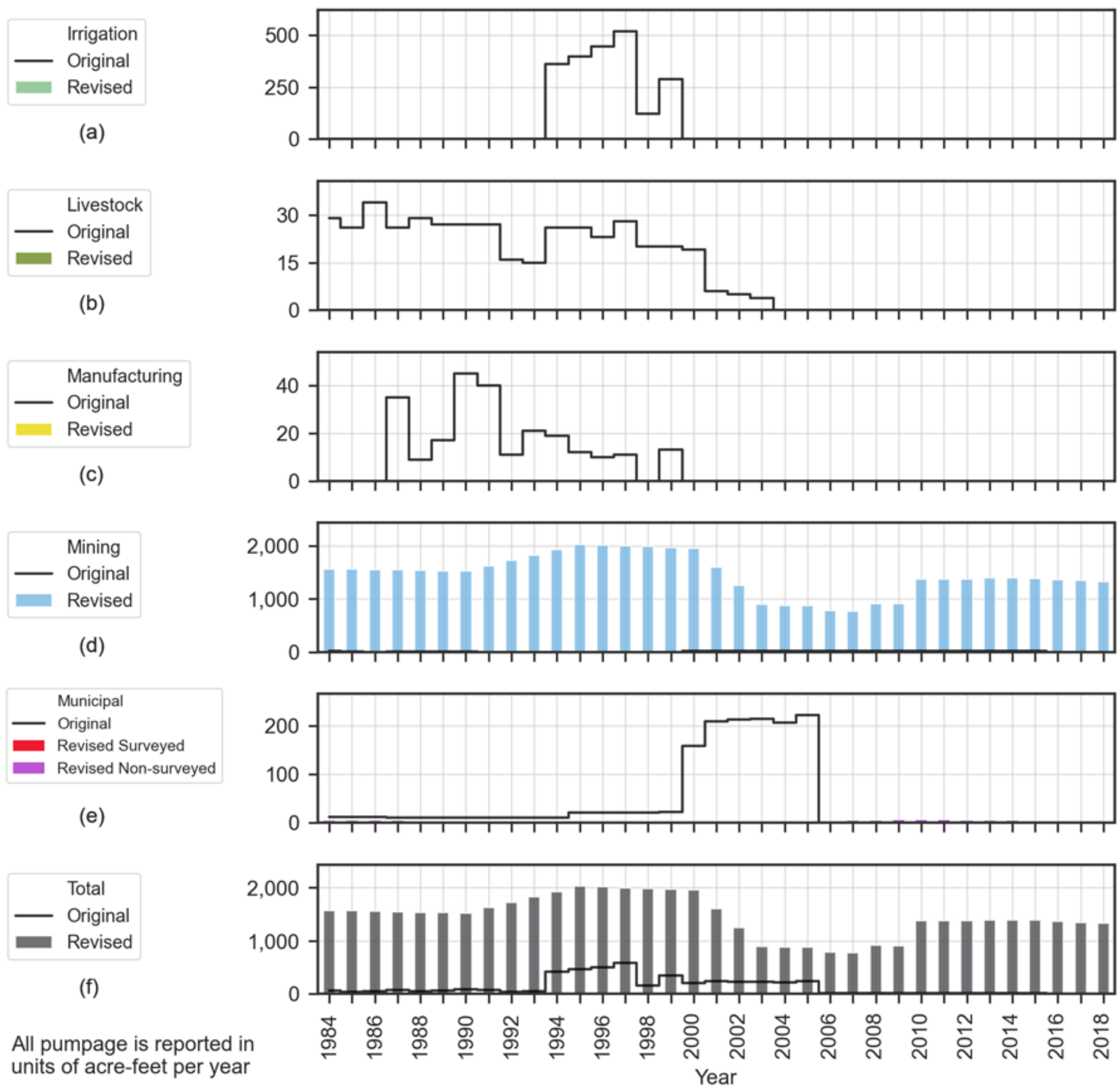


Figure 476. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Ector County from 1984 through 2018.

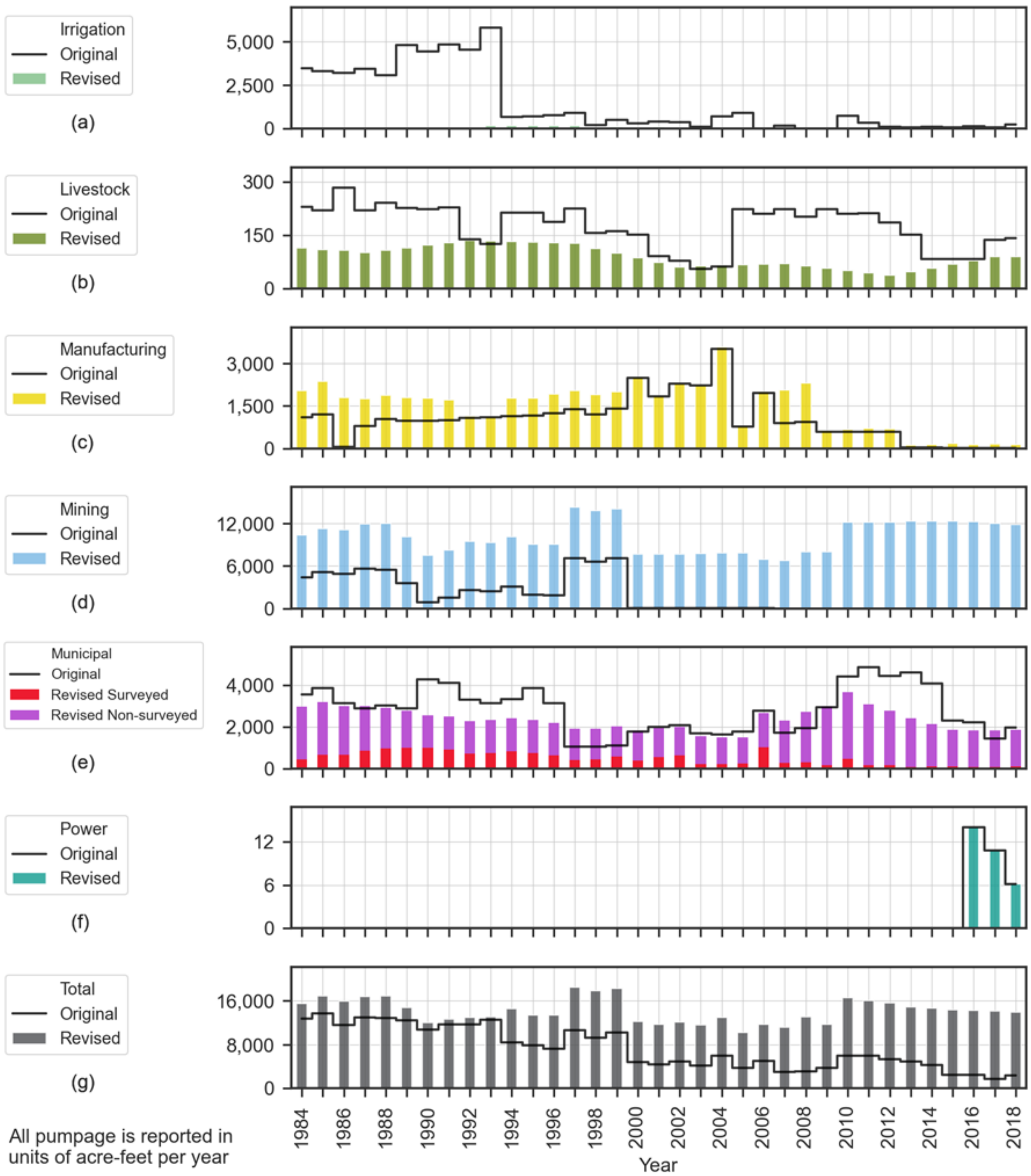


Figure 477. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Ector County from 1984 through 2018.

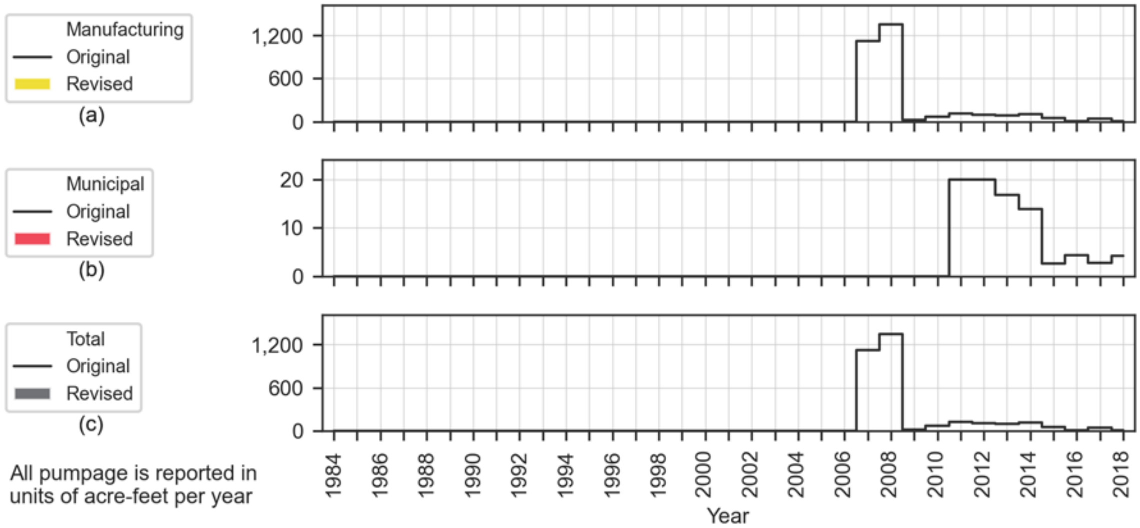


Figure 478. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Ector County from 1984 through 2018.

Surveyed Municipal

Surveyed municipal pumping for Ector County from the Edwards Trinity (Plateau) Aquifer was revised slightly downward as pumpage was re-allocated to the Dockum Aquifer for Northgate MHP. No pumpage is indicated as originating from the Pecos Valley Aquifer. Pumping originally reported from the Trinity (Hill Country) Aquifer was discarded as the aquifer does not exist within Ector County.

Non-Surveyed Municipal

Figure 479 and Figure 480 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Ector County during the study period. Our estimates are significantly lower than the Water Use Survey data for the Pecos Valley Aquifer. Our estimates of pumping for non-surveyed municipal use from the Edwards-Trinity (Plateau) appear to follow similar trends as the TWDB Water Use Survey data, except for the 2010 to 2016 period when our estimates are almost half that of the Water Use Survey data.

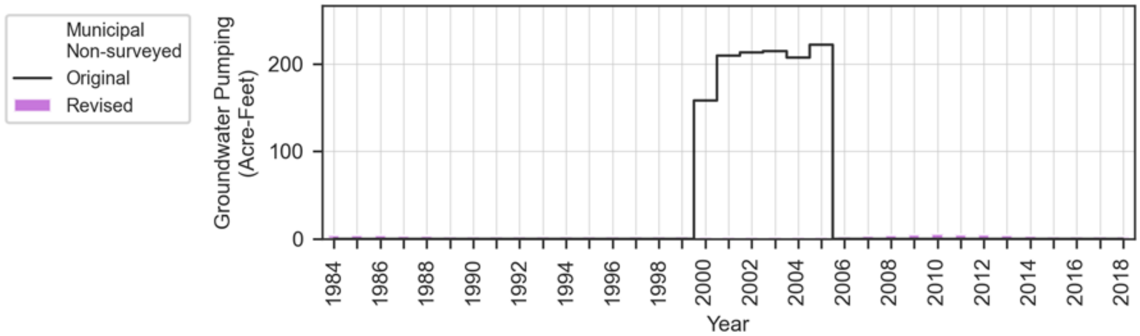


Figure 479. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Ector County from 1984 through 2018.

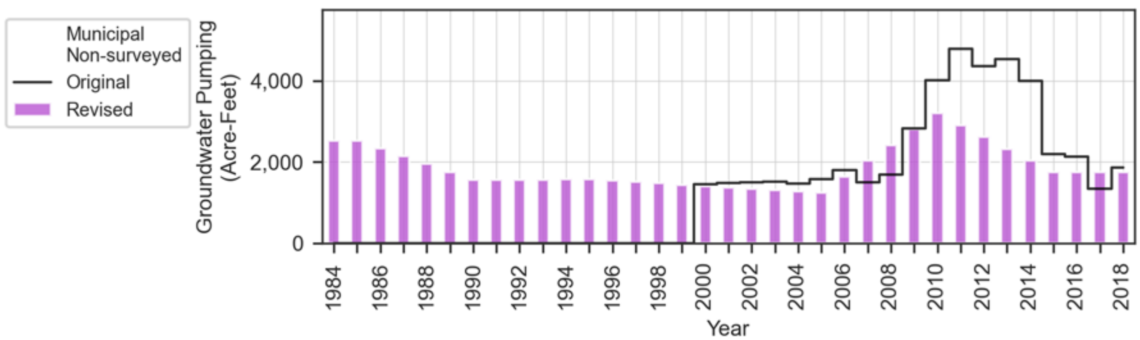


Figure 480. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Ector County from 1984 through 2018.

Irrigation

Ector County is underlain by the Edwards-Trinity (Plateau) Aquifer over a majority of the county and is underlain by the Pecos Valley Aquifer in the southwest corner of the county (Figure 481). Other aquifers located within the county footprint include the Dockum Aquifer (which underlies nearly the entire county) and the Ogallala Aquifer, which is located above the Edwards-Trinity (Plateau) Aquifer in the northeastern portion of the county.

Wells identified within the county suggest geographical preferences for aquifer pumpage, with wells screened within the Edwards-Trinity (Plateau) Aquifer located predominantly within the southeastern quadrant of the county, the center of the county, and a portion of the northeastern quadrant (see Figure 481). Land in the western half of the county contains wells generally screened within the Dockum Aquifer, and wells in the northeastern corner of the county are preferentially screened within the Ogallala Aquifer. To assign irrigation demands for the Edwards-Trinity (Plateau) Aquifer within Ector County, only the aquifer footprint shown in Figure 107 was used. This amounted to 21 percent of the county surface area. As none of the wells identified within the county were screened within the Pecos Valley Aquifer, it was assumed that pumpage for irrigation was not derived from the Pecos Valley Aquifer within Ector County. This assumption was somewhat verified through review of the TWDB groundwater data viewer, which indicated that some wells in the county withdraw water from the Pecos Valley Aquifer, but these wells are not specifically noted as being used for irrigation purposes.

The original TWDB Water Use Survey data for irrigation pumpage for Ector County includes pumpage from the Edwards-Trinity (Plateau) Aquifer and from the Ogallala Aquifer. Pumpage was not reported from the Pecos Valley Aquifer or from the Dockum Aquifer. Reported pumpage from the Edwards-Trinity (Plateau) Aquifer ranged from near zero (from 2008 to 2009) to approximately 5,800 acre-feet per year in 1993. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the modified footprint of the Edwards-Trinity (Plateau) Aquifer in Ector County (Figure 481) ranged from 12 acre-feet per year to 350 acre-feet per year over this study period. Surface water diversions were used to satisfy irrigation demands in many years, and these diversions eliminated the need for groundwater pumpage for irrigation during the periods from 1984 to 1989, 2003 to 2004, 2011 to 2013, and 2015 to 2018. It was assumed that 21 percent of all surface water diversions reported for Ector County within the TWDB Water Use Survey dataset were applied to land over the modified footprint of the Edwards-Trinity (Plateau) Aquifer.

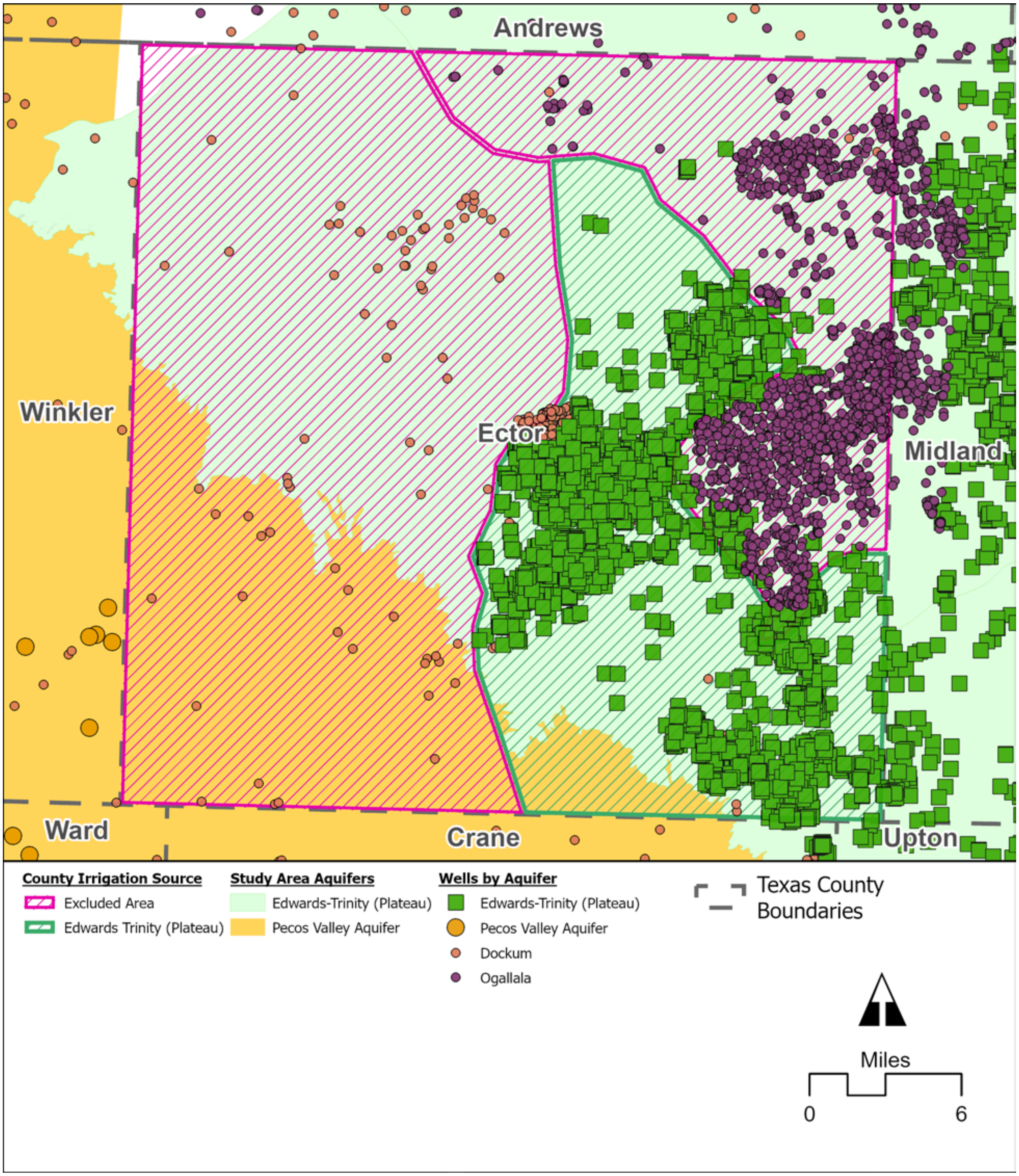


Figure 481. Ector County map showing aquifers and wells used in assessing irrigation pumpage.

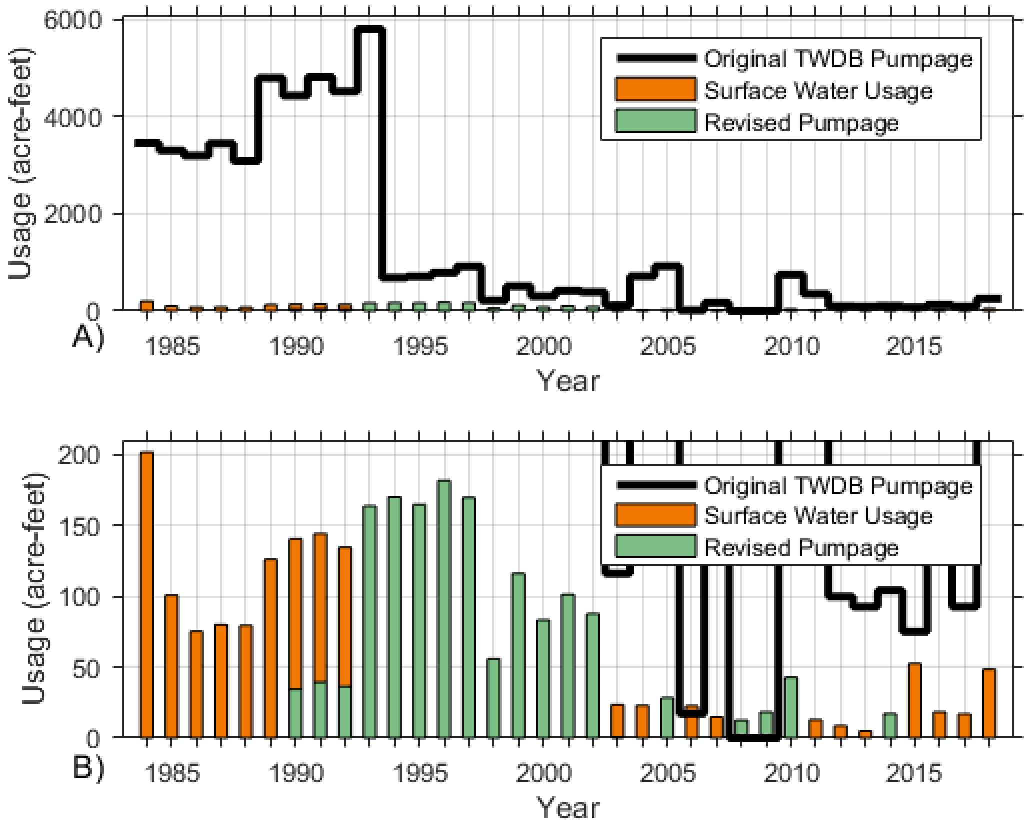


Figure 482. **Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Ector County.**

Power

As reported in Section 3.3.15 and illustrated on Figure 483, pumping from the Edwards-Trinity (Plateau) Aquifer in Ector County for power use was only reported for years 2016, 2017 and 2018. Groundwater pumpage remained below 20 acre-feet for the reported years. We found several anomalies in the data based on our manual review, year-to-year change, and standard deviation analyses.

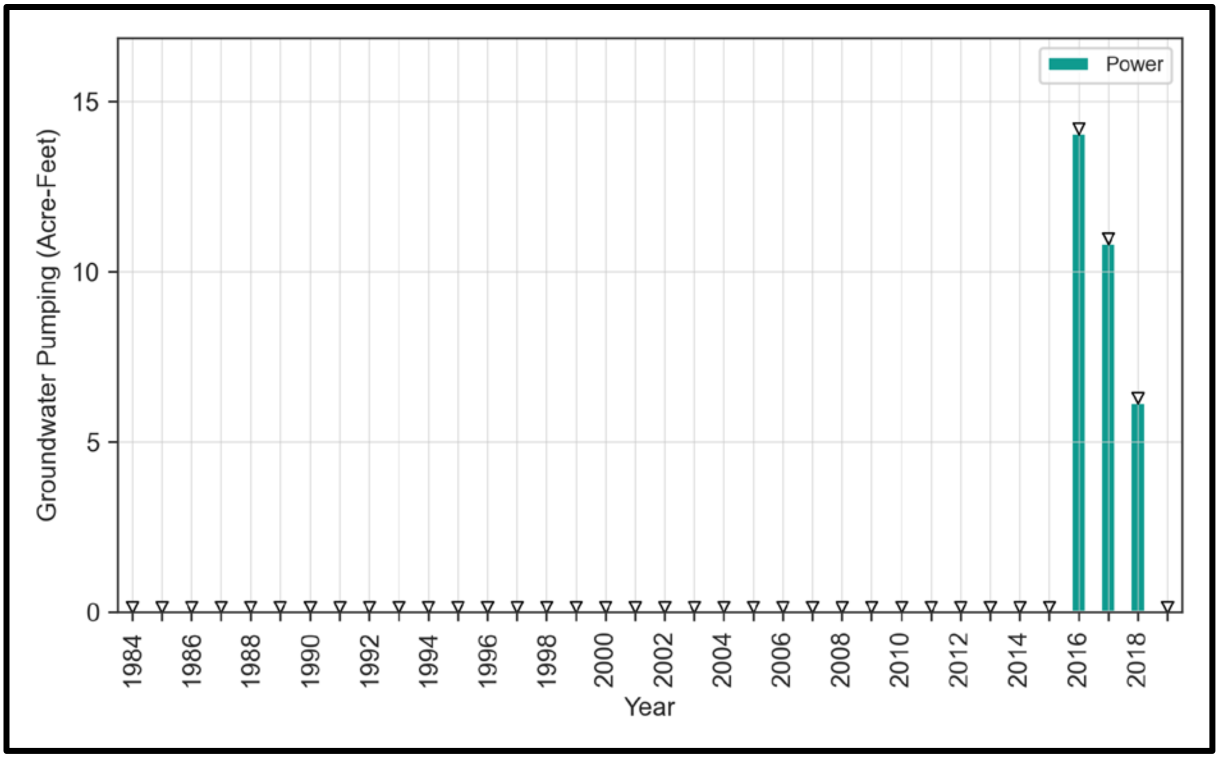


Figure 483. Ector County Edwards-Trinity (Plateau) Aquifer groundwater pumping for power use in Ector County as reported in the original TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Edwards-Trinity (Plateau) Aquifer pumping for power use per entity in Ector County, we determined there were two surveyed entities reporting groundwater production. The reporting entities were Invenergy Services LLC – Ector County Energy Center and Invenergy – Ector County Energy Center – Goldsmith Peaking Facility. However, both facilities shared the same Water Use Survey Number and are thus considered one entity (hereafter referred to as “Ector Energy Power Plant”). The location is shown in Figure 484. Table 71 presents the timeline of operation events as provided on form EIA-860 for the Ector Energy Power Plant in Ector County.

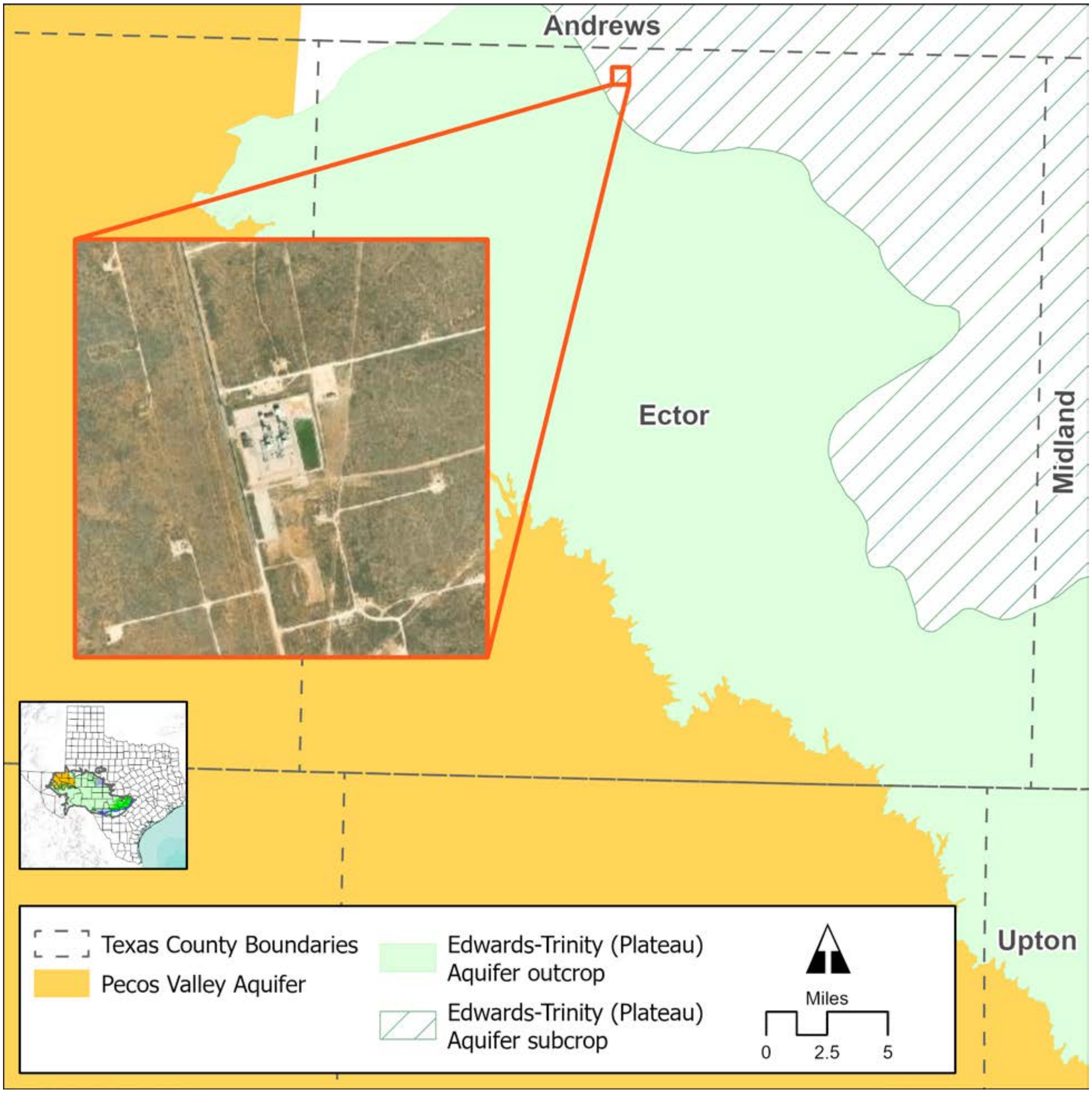


Figure 484. Location of the Ector Energy Power Plant in Ector County.

Table 71. Ector Energy Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
2015	CTG1	Began Operation	Gas Turbine	Fossil fuels	Dry (air) cooling	Mechanical draft, dry process
2015	CTG2	Began Operation	Gas Turbine	Fossil fuels	Dry (air) cooling	Mechanical draft, dry process

Gas turbines, such as the Ector Energy Power Plant units CTG1 and CTG2, have much lower cooling requirements than steam turbines. Given that the gas turbines started operating in 2015 (EIA, 2020a), and that the plant uses dry (air) cooling, we assigned gas turbine operation years an average water use value of 0.03 gallons per kilowatt-hour.

Figure 485 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Ector Energy Power Plant. Figure 485b illustrates the pumpage based on the Water Use Survey. Given the low pumpage values from both the original TWDB Water Use Survey and our pumpage estimates, no further revisions were made.

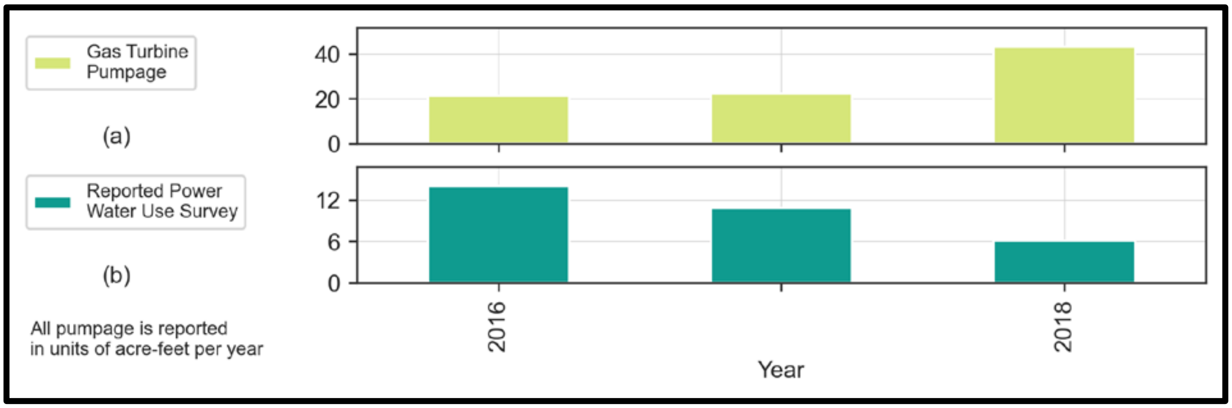


Figure 485. Ector Energy Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, and (b) Reported groundwater pumping by the Water Use Survey.

Mining

Figure 476d and Figure 477d illustrate the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Ector County during the study period. The number of active enhanced oil recovery wells in Ector County was only 15 in 1980 and increased up to 1,017 wells in 2020. We estimated approximately 85 percent of groundwater pumped for mining use is from the Edwards-Trinity (Plateau) Aquifer and the remaining is sourced from the Pecos Valley Aquifer.

Manufacturing

Figure 477c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Ector County during the study period. There are several entities for which we applied changes. Table 72 summarizes our revisions to the original estimates.

Table 72. Summary of revisions to groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for manufacturing use in Ector County from 1984 through 2018.

Standardized Name	Alternate Water Use Survey Names	Notes
Flint Hills Resources Odessa LLC – Odessa Complex	Rextac LLC Odessa Complex; Huntsman Polymers Corporation	Change Trinity (Hill Country) Aquifer designations to Edwards-Trinity (Plateau) Aquifer. No reported amounts after 2014; assumed continued pumping at 2014 rate.
GCC Permian LLC – Odessa Plant	Cemex Construction Materials South LLC – Odessa Plant; Cemex Construction Materials South LLC	Change Trinity (Hill Country) Aquifer designations to Edwards-Trinity (Plateau) Aquifer.
Martin Resources Inc – Odessa Plant	None	Pumpage is zero from 2016 through 2018; assumed continued pumping at 2015 rate.
Odessa Babbitt Bearing Company	None	No data after 2016 but entity is still in business; assumed continued pumping at 2016 rate.
Utex Industries Inc – Odessa Facility	None	No pumpage reported in 2018; assumed continued pumping at 2017 rate.

Livestock

Figure 476b and Figure 477b illustrate the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Ector County during the study period. We estimated no pumping for livestock use from the Pecos Valley Aquifer due to a lack of known wells in the aquifer for this use type. However, our estimated pumping from the Edwards-Trinity (Plateau) Aquifer is in general agreement with the TWDB Water Use Survey data.

5.2.16 Edwards County

Figure 486 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Edwards County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

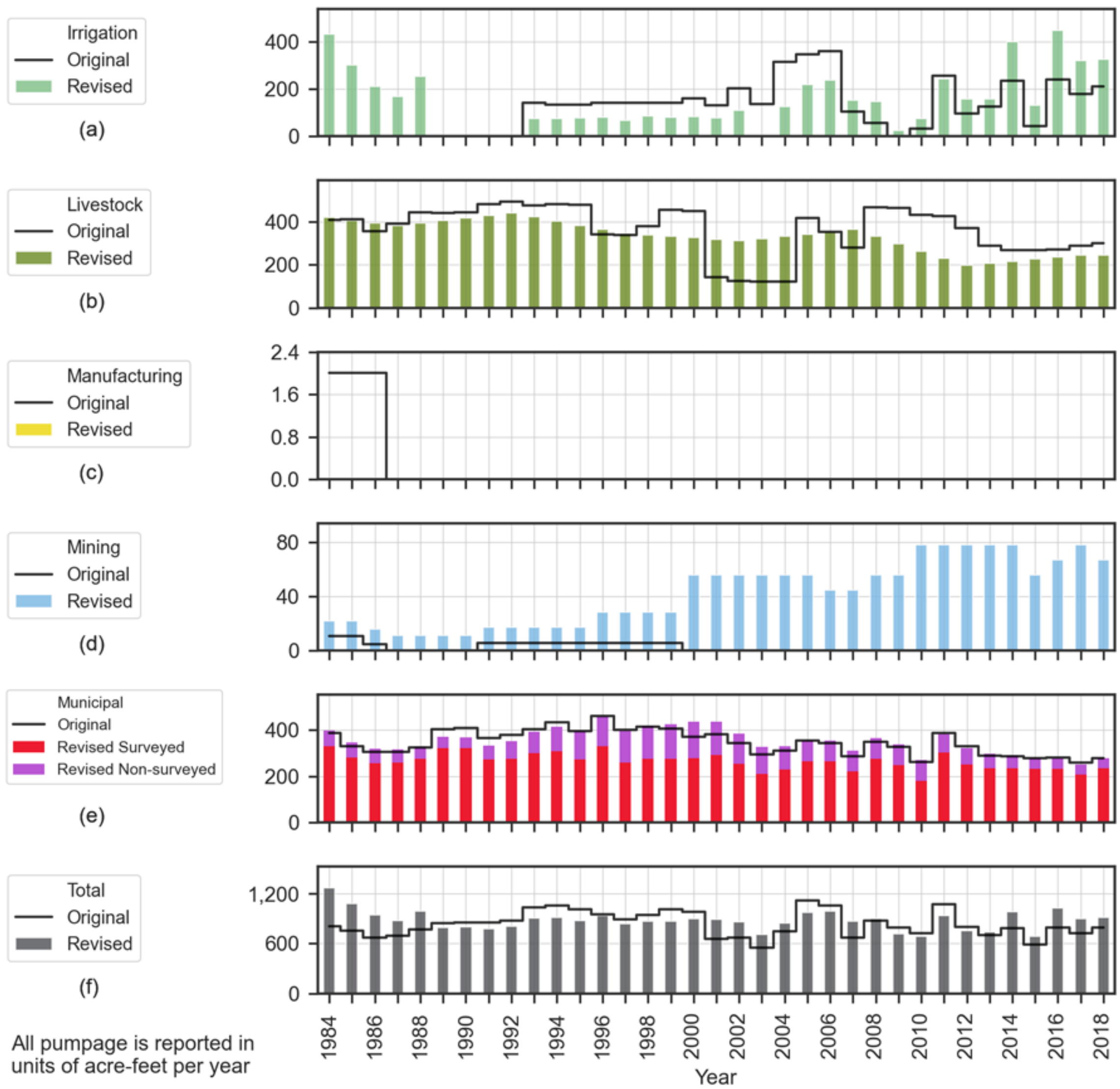


Figure 486. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Edwards County from 1984 through 2018.

Surveyed Municipal

Surveyed Municipal pumpage from the Edwards Trinity (Plateau) Aquifer in Edwards County remained unchanged through the revision process.

Non-Surveyed Municipal

Figure 487 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Edwards County during the study period. Our estimates are in general agreement with the TWDB Water Use Survey data.

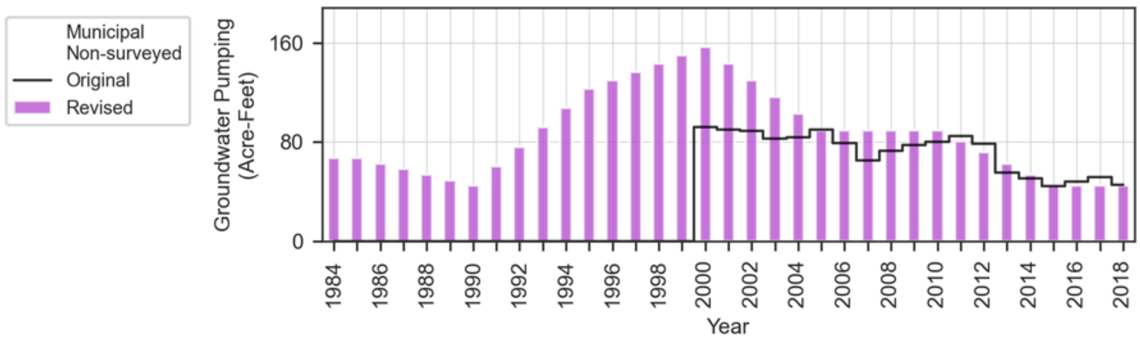


Figure 487. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Edwards County from 1984 through 2018.

Irrigation

Edwards County is entirely underlain by the Edwards-Trinity (Plateau) Aquifer, and all wells identified within the county are screened within this aquifer. Original TWDB Water Use Survey pumping estimates for irrigation ranged from zero acre-feet per year to just under 400 acre-feet per year, with "0" values reported from 1984 to 1992 and again in 2009 (Figure 488). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land in Edwards County ranged from under 100 acre-feet per year to nearly 600 acre-feet per year. Surface water was used to meet portions of the annual need from 1984 to 1992 and from 2003 to 2018. Sufficient surface water was available in some years to satisfy the demand for irrigation without the need for groundwater pumpage. Revised groundwater pumpage values ranged from zero acre-feet per year to approximately 450 acre-feet per year, with consistently low pumpage needs from 1993 to 2002. Surface water was not used for irrigation purposes during this time of relatively low demand for irrigation water.

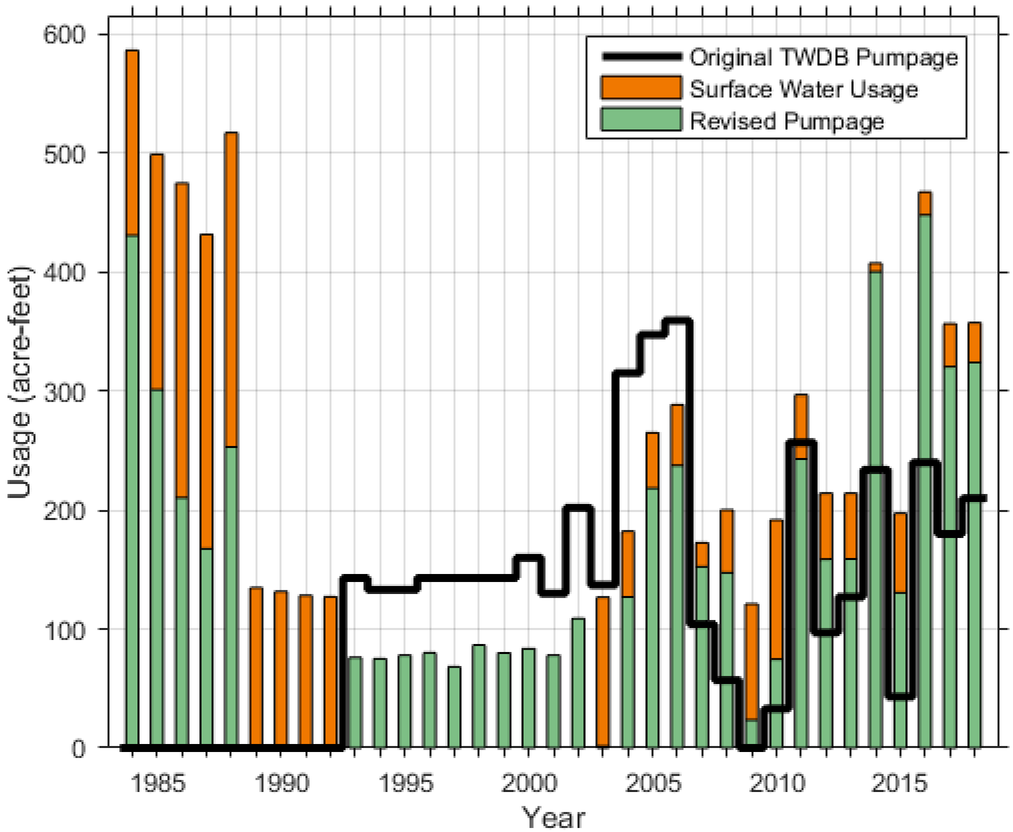


Figure 488. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Edwards County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Edwards County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Edwards County.

Mining

Figure 486d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Edwards County during the study period. As of 2020, there are 22 active enhanced oil recovery wells in Edwards County while there were zero in 1980. We estimate the entirety of groundwater pumping for mining use in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Edwards County (Figure 486c). Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Edwards County.

Livestock

Figure 486b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Edwards County during the study period. Results from our evaluation are in general agreement with the TWDB Water Use Survey data throughout the study period.

5.2.17 Gillespie County

Figure 489 and Figure 490 illustrate our revisions to the estimated in groundwater pumping from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Gillespie County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

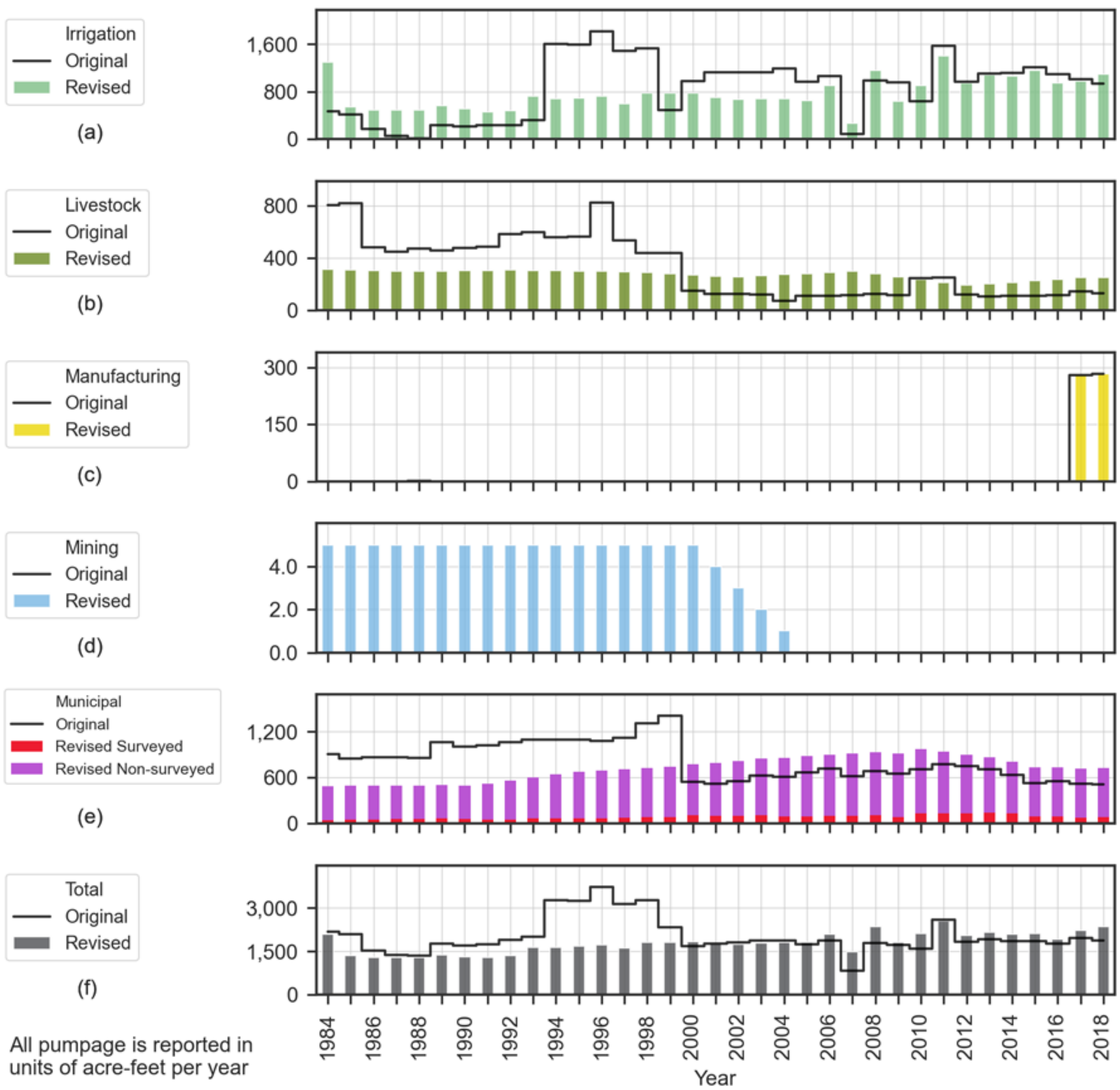


Figure 489. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Gillespie County from 1984 through 2018.

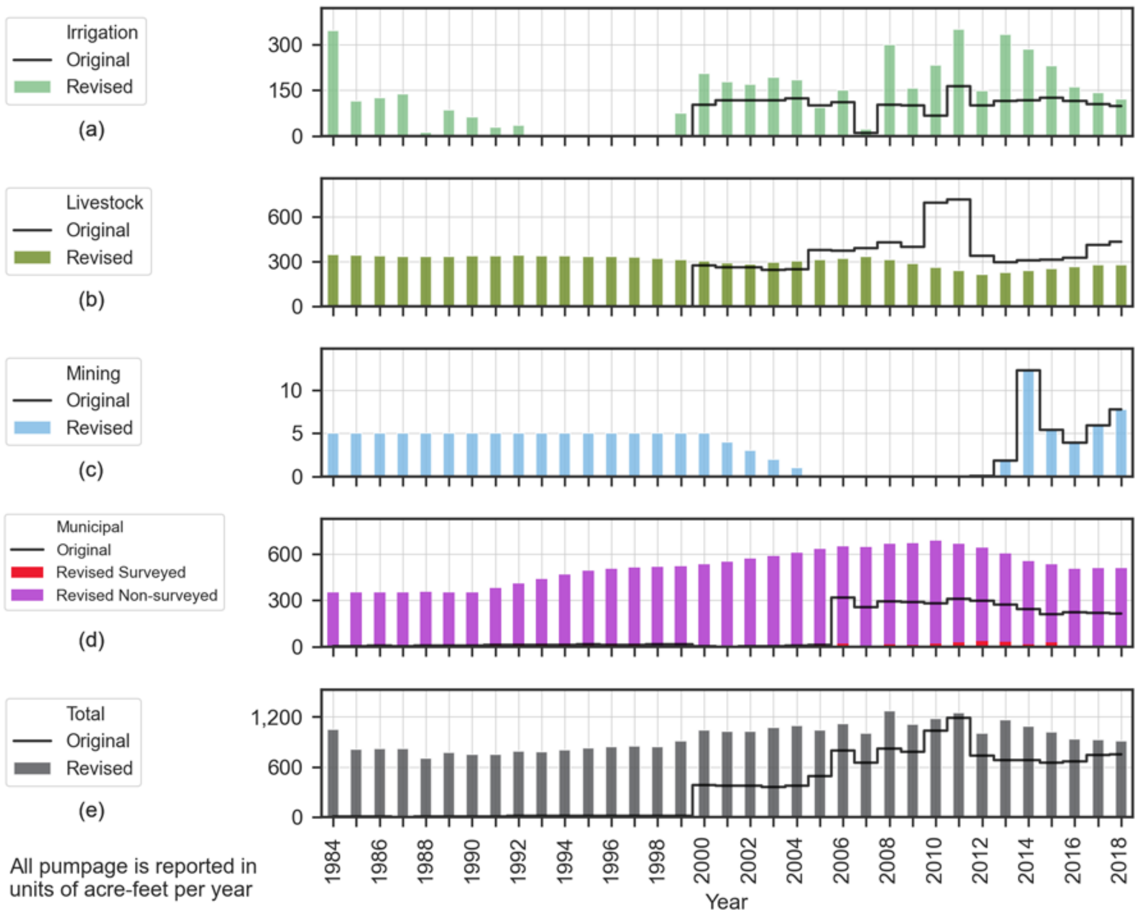


Figure 490. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Gillespie County from 1984 through 2018.

Surveyed Municipal

Pumpage for surveyed municipal from Gillespie County increased slightly as usage by Harper ISD was reclassified from the "Original Aquifer" to the Edwards Trinity (Plateau) Aquifer.

Non-Surveyed Municipal

Figure 491Figure 417 and Figure 492 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer and, respectively, in Gillespie County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data. Our estimates are more than the Water Use Survey data for both aquifers in Gillespie County.

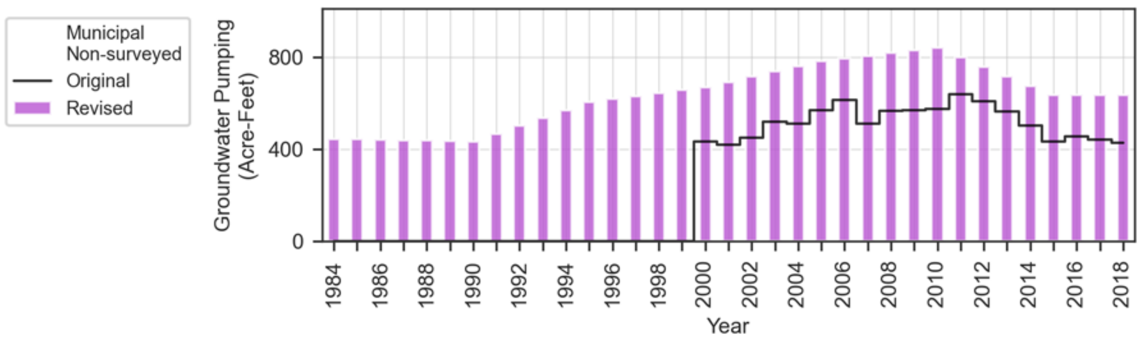


Figure 491. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Gillespie County from 1984 through 2018.

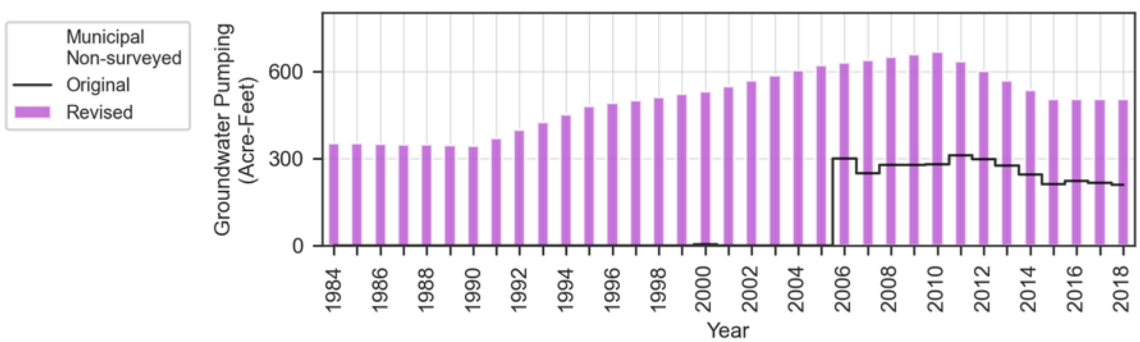


Figure 492. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Gillespie County from 1984 through 2018.

Irrigation

Gillespie County is underlain by the Edwards-Trinity (Plateau) Aquifer within the western and northern portions of the county. In the central and eastern portions of the county, the Trinity (Hill Country) Aquifer is present. Other aquifers within the Gillespie County footprint include the Hickory Aquifer and the Ellenburger-San Saba Aquifer, which are underneath the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer. Wells identified within Gillespie County do exhibit geographical preferencing in areas where multiple aquifers exist and overlap. As shown in Figure 493, the county footprint can be broken up into geographically distinct regions where wells are preferentially screened in individual aquifers. For this analysis, we determined approximate portions of the county footprint containing wells withdrawing from the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer. We determined that approximately 50 percent of the county footprint is withdrawing water from the Edwards-Trinity (Plateau) Aquifer, and 20 percent of the county footprint is withdrawing water from the Trinity (Hill Country) Aquifer.

The original TWDB Water Use Survey dataset estimated irrigation usage within Gillespie County from the Edwards-Trinity (Plateau) Aquifer to range from 10 acre-feet per year to 163 acre-feet per year (Figure 494). Pumpage estimates were not available for the period from 1984 to 1999. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands from the Edwards-Trinity (Plateau) Aquifer ranged from 92 acre-feet per year to 590 acre-feet per year. Surface water was used to meet demands in every year of the study period and was sufficient to meet all irrigation demands from 1993 to 1998. Groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer in Gillespie County ranged from zero to 345 acre-feet per year over this study period.

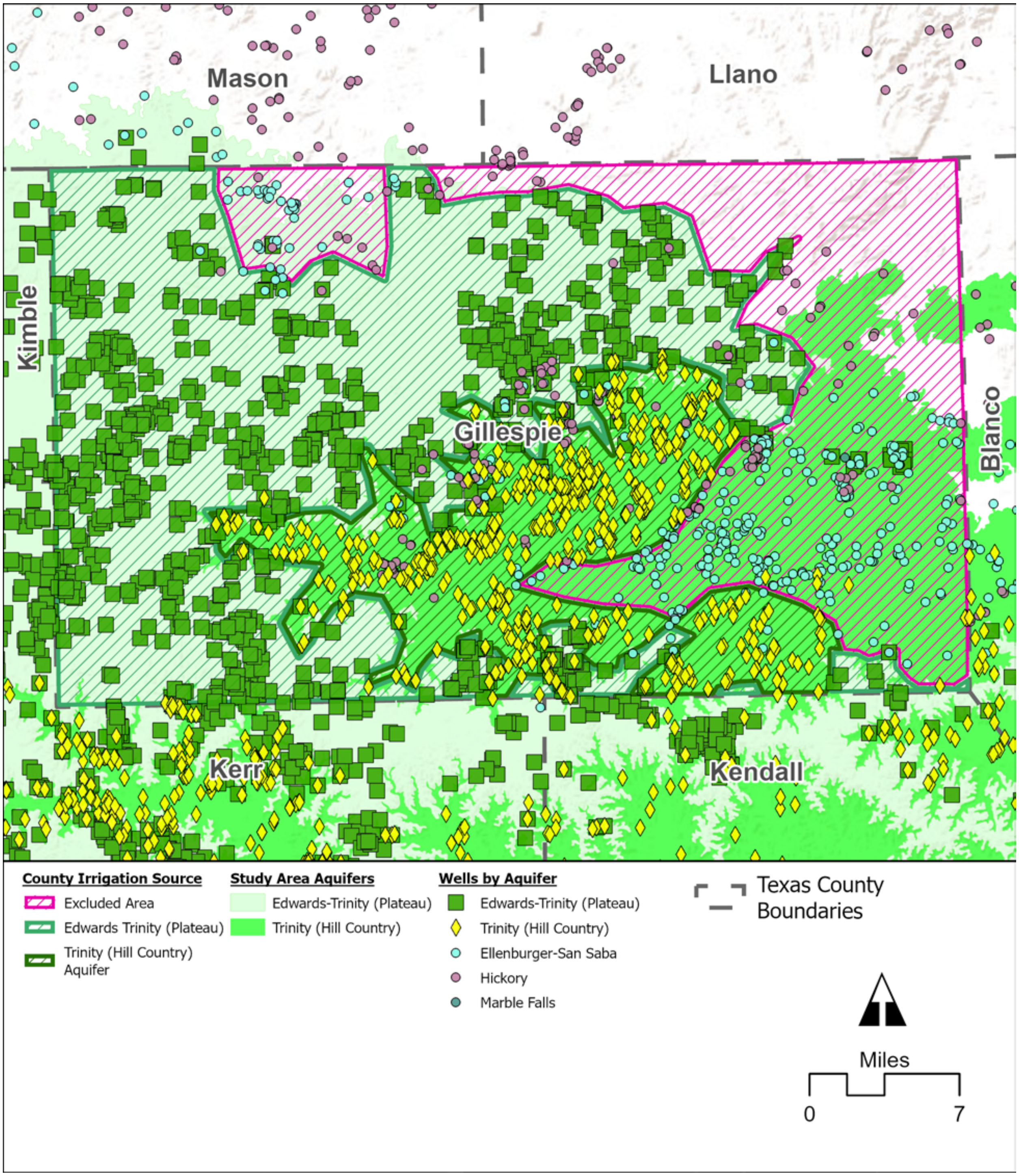


Figure 493. **Gillespie County map showing aquifers and wells used in assessing irrigation pumpage.**

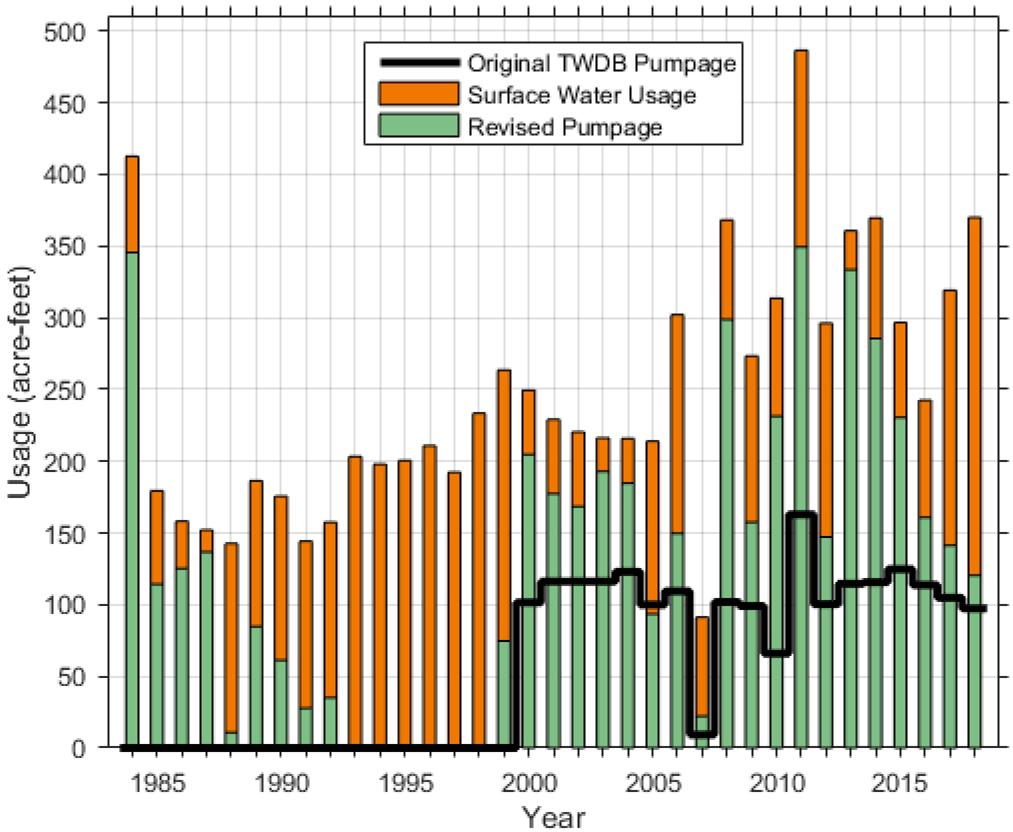


Figure 494. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Gillespie County.

The original TWDB Water Use Survey dataset estimated irrigation usage within Gillespie County from the Trinity (Hill Country) Aquifer to range from 15 acre-feet per year to 1,810 acre-feet per year (Figure 495). Pumpage generally increased over the study period, with year-to-year fluctuations evident. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands from the Trinity (Hill Country) Aquifer ranged from 293 acre-feet per year to 1,463 acre-feet per year. Surface water was used to meet demands in every year of the study period yet was not sufficient to meet all irrigation demands in any given year. Groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer in Gillespie County ranged from 265 to 1,408 acre-feet per year over this study period. The lowest computed groundwater pumpage occurred in 2007, when Gillespie County received significant rainfall during the summer months. The greatest computed groundwater pumpage occurred in 2011, when summer temperatures were especially high and water loss to evapotranspiration was also high.

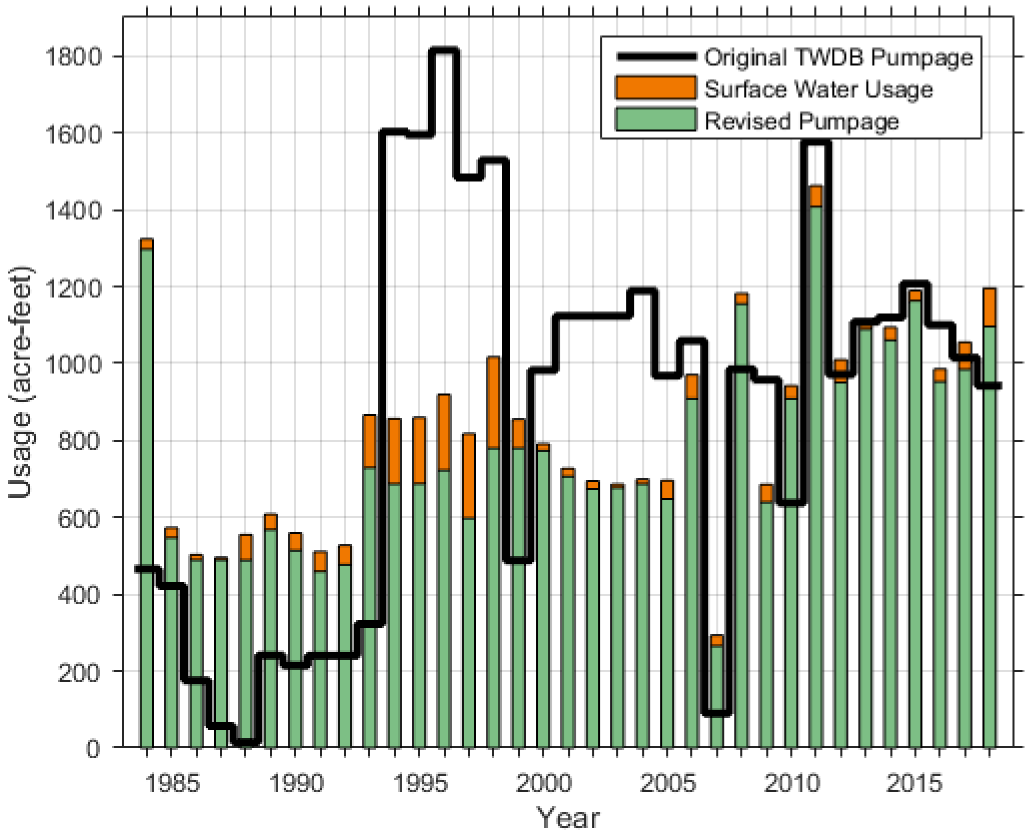


Figure 495. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Gillespie County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Gillespie County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Gillespie County.

Mining

Figure 489d and Figure 490c illustrate the changes in groundwater pumping associated with mining use from the Trinity (Hill Country) Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Gillespie County during the study period. No enhanced oil recovery wells were reported within the county and therefore the U.S. Geological Survey and Water Use Survey data were used to obtain the revised mining pumpage estimates. Spatial sourcing of the mining estimates indicates that about 58 percent of the water is sourced from the Edwards-Trinity (Plateau) Aquifer and remaining is from the Trinity (Hill Country) Aquifer.

Manufacturing

Figure 489c illustrates the groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Gillespie County during the study period. There was no estimated pumping prior to 2017 and we identified no changes for this use.

Livestock

Figure 489b and Figure 490b illustrate the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Gillespie County during the study period. Prior to year 2000, the TWDB Water Use Survey data does not contain estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Gillespie County, our revised estimates do include pumpage estimates for these years of missing pumpage. Our revised estimates are in general agreement with the TWDB Water Use Survey data for the Trinity (Hill Country) Aquifer from 2000 onwards. Prior to the year 2000, our estimates of pumping are approximately half that of the TWDB Water Use Survey data.

5.2.18 Glasscock County

Figure 496 and Figure 497 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer, respectively, in Glasscock County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

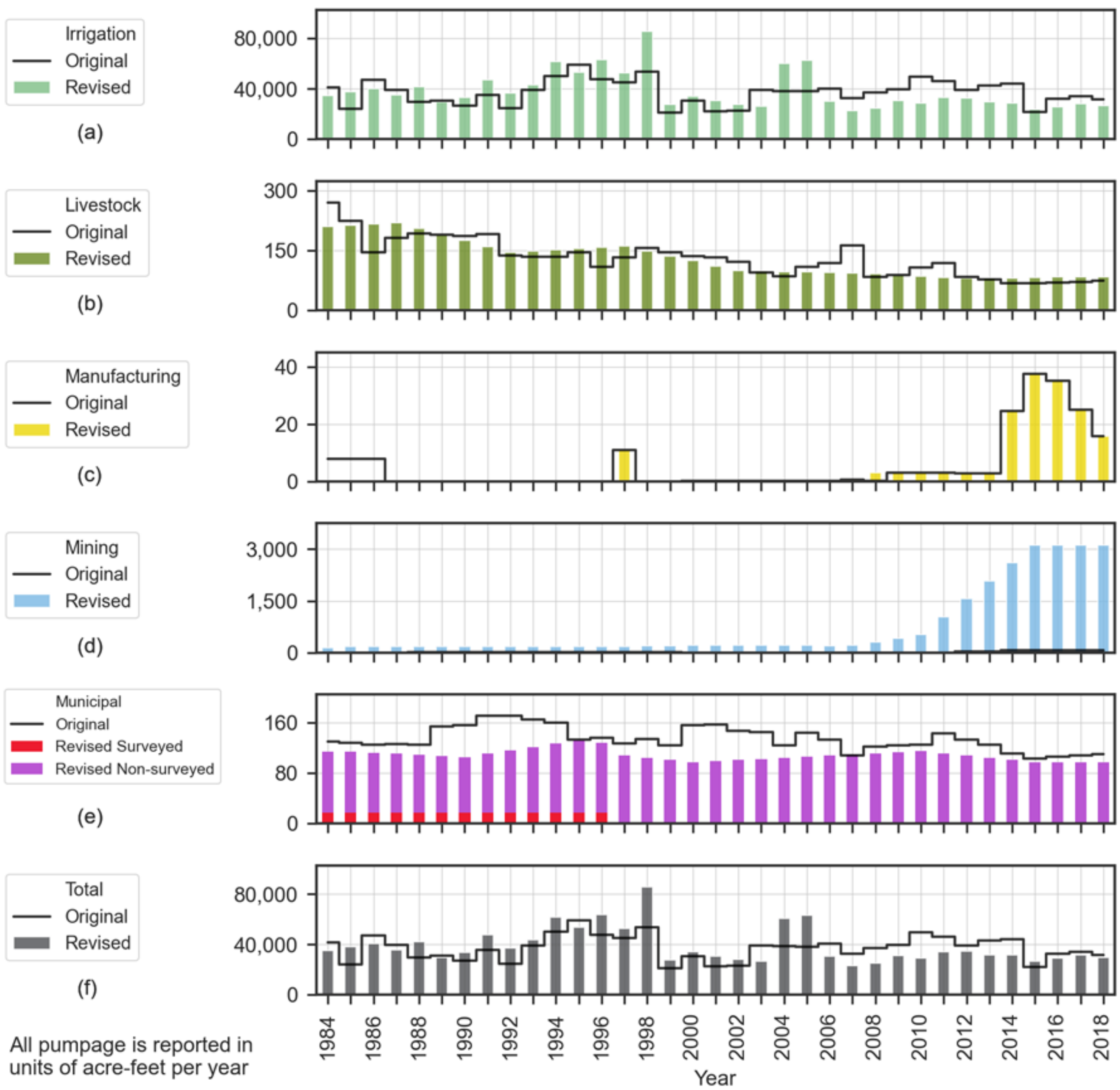


Figure 496. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Glasscock County from 1984 through 2018.

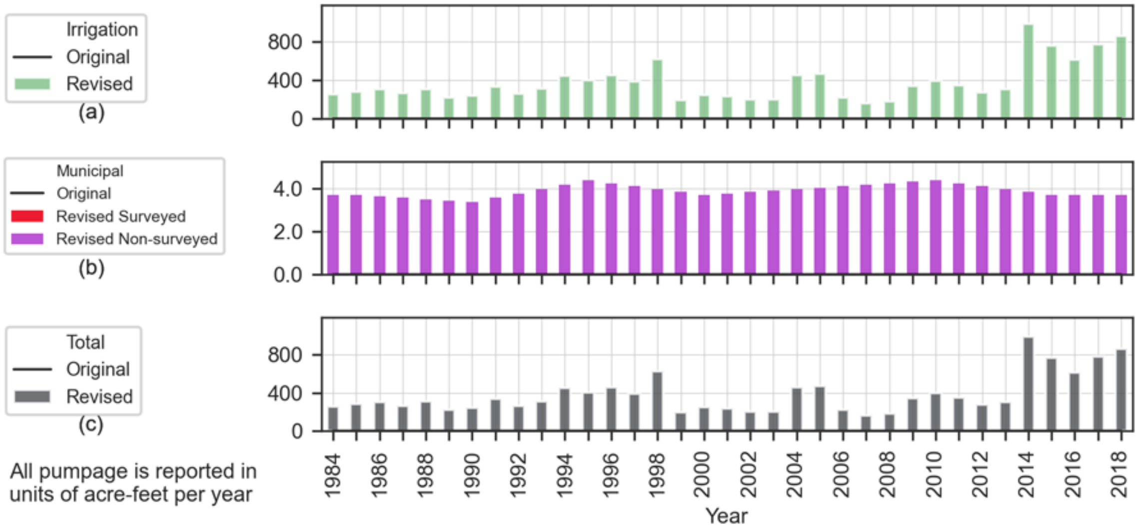


Figure 497. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Glasscock County from 1984 through 2018.

Surveyed Municipal

Surveyed municipal pumpage from the Edwards Trinity (Plateau) Aquifer within Glasscock County was reported from 1984-1996 by Glasscock County ISD. The pumpage remained unchanged from the original TWDB water use survey dataset. No entities reported pumping from the Lipan Aquifer for municipal use.

Non-Surveyed Municipal

Figure 498 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Glasscock County during the study period. Our estimates are in general agreement with the TWDB Water Use Survey data.

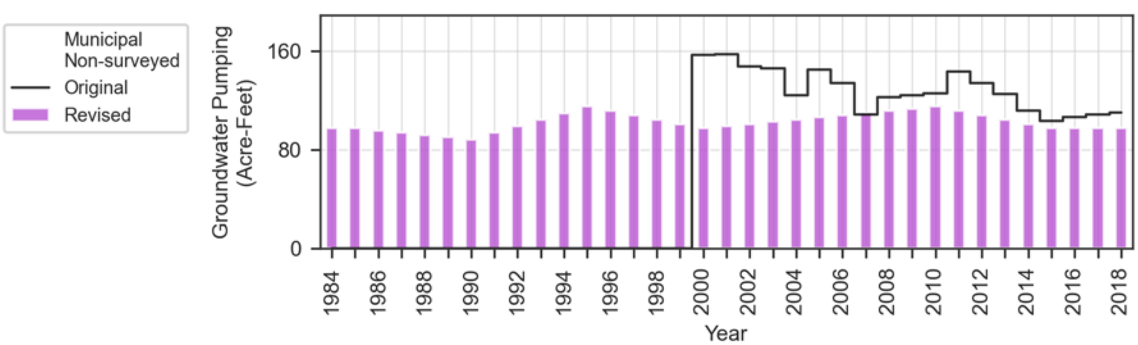


Figure 498. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Glasscock County from 1984 through 2018.

Irrigation

Glasscock County is nearly entirely underlain by the Edwards-Trinity (Plateau) Aquifer, with the exception of a portion along the northern border with Howard County. There is also a relatively small portion of the northeastern corner of the county that is underlain by the Lipan Aquifer. Other aquifers present within the county footprint include the Ogallala Aquifer, which spans the northwestern portion of the county and the Dockum Aquifer which underlies the entire eastern border of the county. The Dockum Aquifer is located below the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer. The Ogallala Aquifer, in contrast, is located above the Edwards-Trinity (Plateau) Aquifer. Wells identified within Glasscock County exhibit geographical sorting, with the exception that wells screened within the Edwards-Trinity (Plateau) Aquifer are often located within the footprint of the Dockum Aquifer, and wells screened within the Dockum Aquifer are also located within the Lipan Aquifer footprint.

Review of data from the TWDB groundwater data viewer suggests that irrigation is preferentially derived from shallower wells. Therefore, in estimating groundwater pumpage needs for irrigation, pumpage was assumed to be derived from the Edwards-Trinity (Plateau) Aquifer or Lipan Aquifer within the footprint of the Dockum Aquifer, and from the Ogallala Aquifer where the Ogallala Aquifer and Edwards-Trinity (Plateau) Aquifer overlap. The spatial extents of the preferred aquifer footprints for Glasscock County are shown in Figure 499.

The original TWDB Water Use Survey dataset estimated irrigation usage within Glasscock County from the Edwards-Trinity (Plateau) Aquifer to range from 21,060 acre-feet per year to 58,950 acre-feet per year (Figure 500). Pumpage estimates fluctuated over the study period, yet did not exhibit definitive increasing or decreasing trends. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater demands for irrigation from the Edwards-Trinity (Plateau) Aquifer ranged from 22,620 acre-feet per year to 85,150 acre-feet per year. Surface water was never used to meet these irrigation demands in Glasscock County. Revised pumpage estimates do suggest a generally decreasing trend in annual pumpage, with small year-to-year fluctuations due to annual variations in climate patterns.

The original TWDB Water Use Survey dataset did not include estimates of irrigation pumpage from the Lipan Aquifer. It did include, however, estimates for pumpage from the Ogallala Aquifer and from “Other Aquifer”. Estimates of groundwater withdrawals from the “Other Aquifer” for irrigation ranged from 262 acre-feet per year to 521 acre-feet per year between 2000 and 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater demands for irrigation from the Lipan Aquifer ranged from 158 acre-feet per year to 986 acre-feet per year (Figure 501). Surface water was never used to meet these irrigation demands in Glasscock County. Revised pumpage estimates for the Lipan Aquifer are of similar magnitude to the original TWDB water usage estimates for the “Other Aquifer.” Pumpage from the Lipan Aquifer remained fairly stable from 1984 to 2013, with annual fluctuations attributable to varying climate patterns. Pumpage increased within the period from 2014 to 2018, due to increased cultivated acreage and crop production within the Lipan Aquifer footprint.

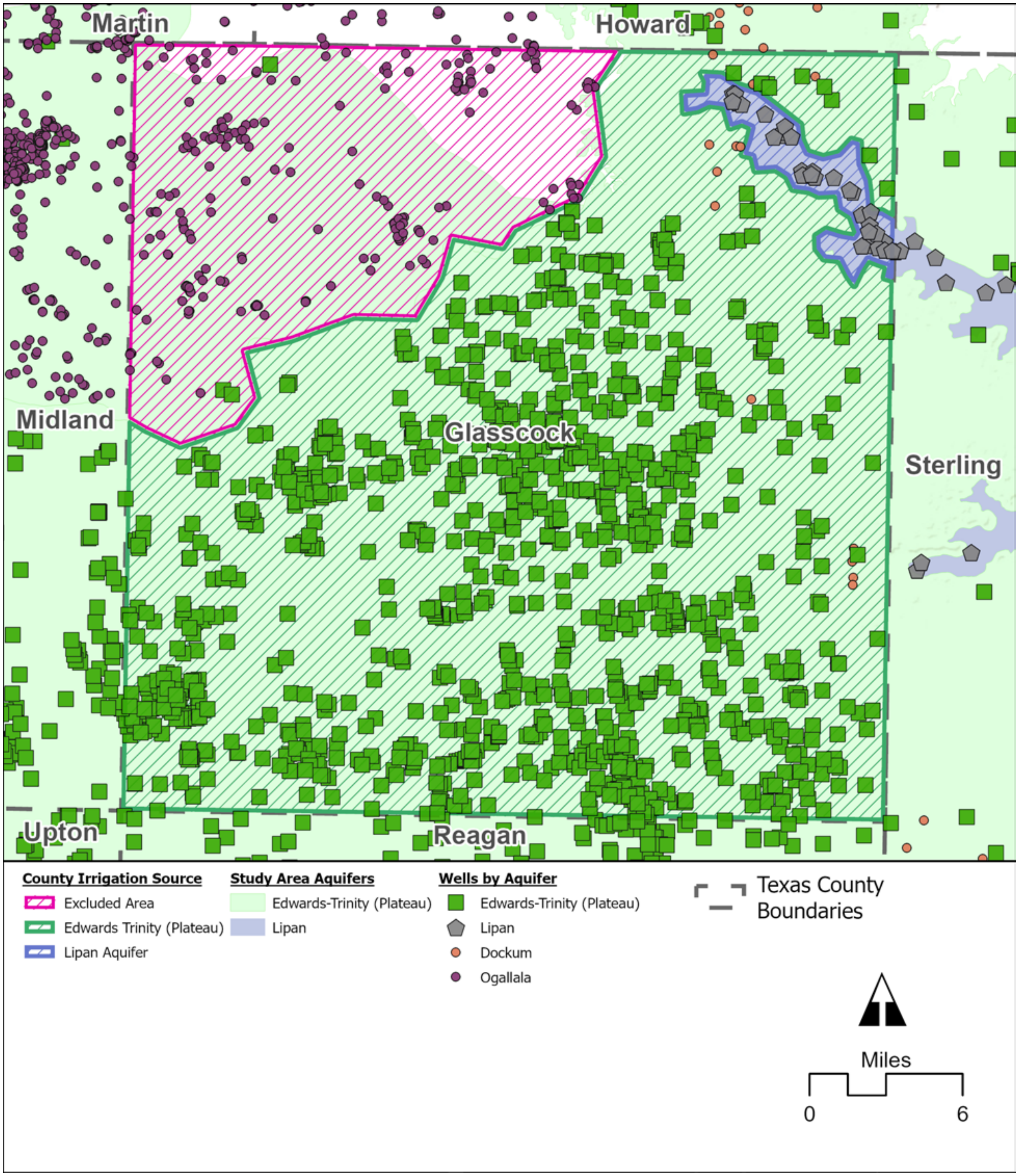


Figure 499. Glasscock County map showing aquifers and wells used in assessing irrigation pumpage.

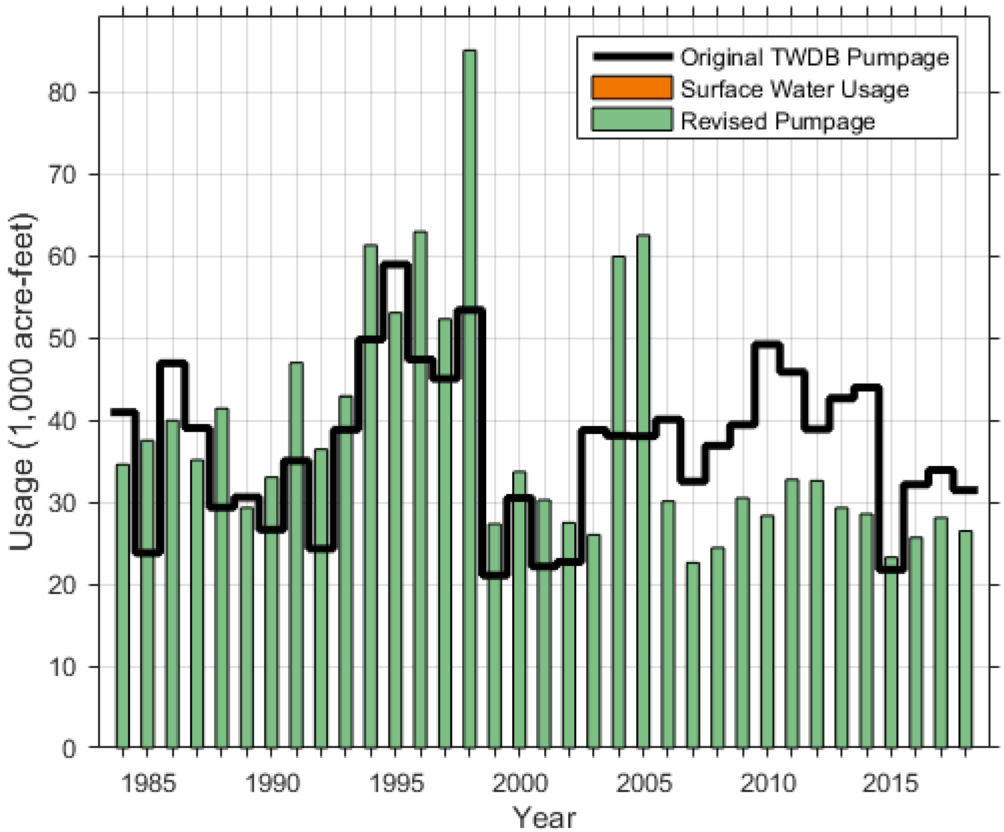


Figure 500. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Glasscock County.

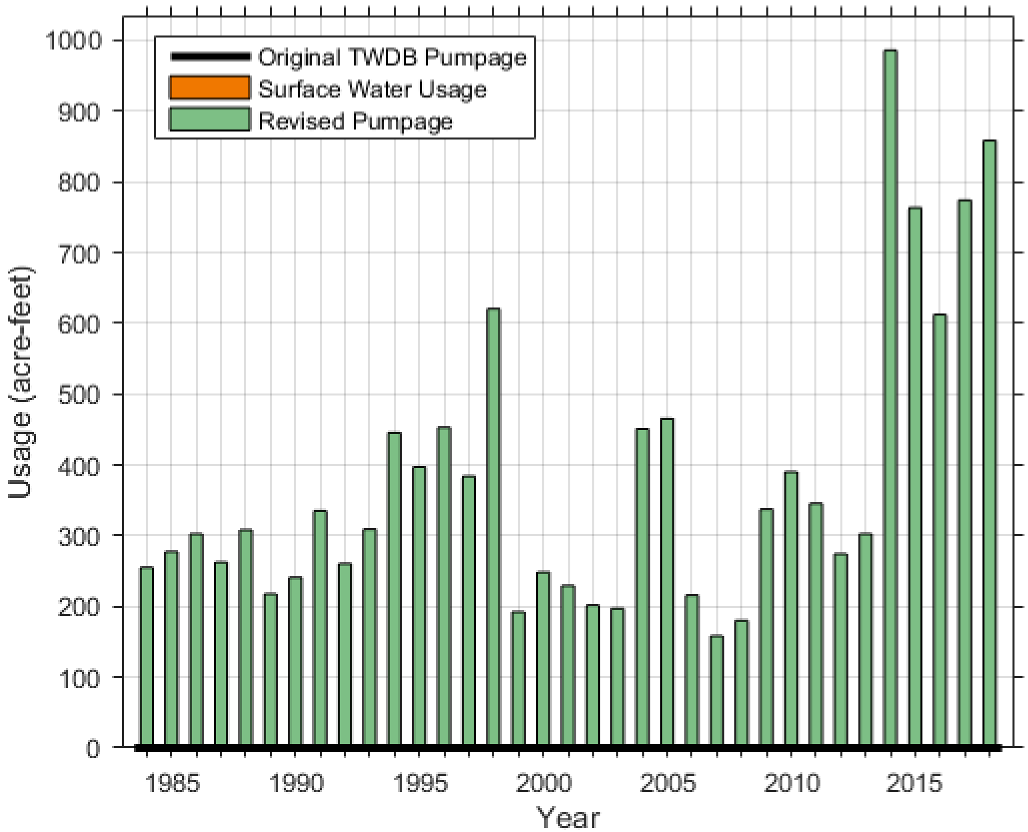


Figure 501. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Glasscock County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Glasscock County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Glasscock County.

Mining

Figure 496d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Glasscock County during the study period. Glasscock County had 54 active enhanced oil recovery wells in 1980 which increased up to 93 wells in 2020. We estimated the entirety of groundwater pumping for mining use in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 496c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Glasscock County during the study period. The anomalous pumping in 1997 is for a quarry. We did not revise the pumping as it is possible the pumping is associated with startup of the operation. A pumping amount was missing for 2008 for another entity; to address the missing value we assumed the pumping was the same as the year 2009 value.

Livestock

Figure 496b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Glasscock County during the study period. Results from our evaluation are in general agreement with the TWDB Water Use Survey data throughout the study period.

5.2.19 Guadalupe County

Figure 502 and Figure 503 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country), respectively, in Guadalupe County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

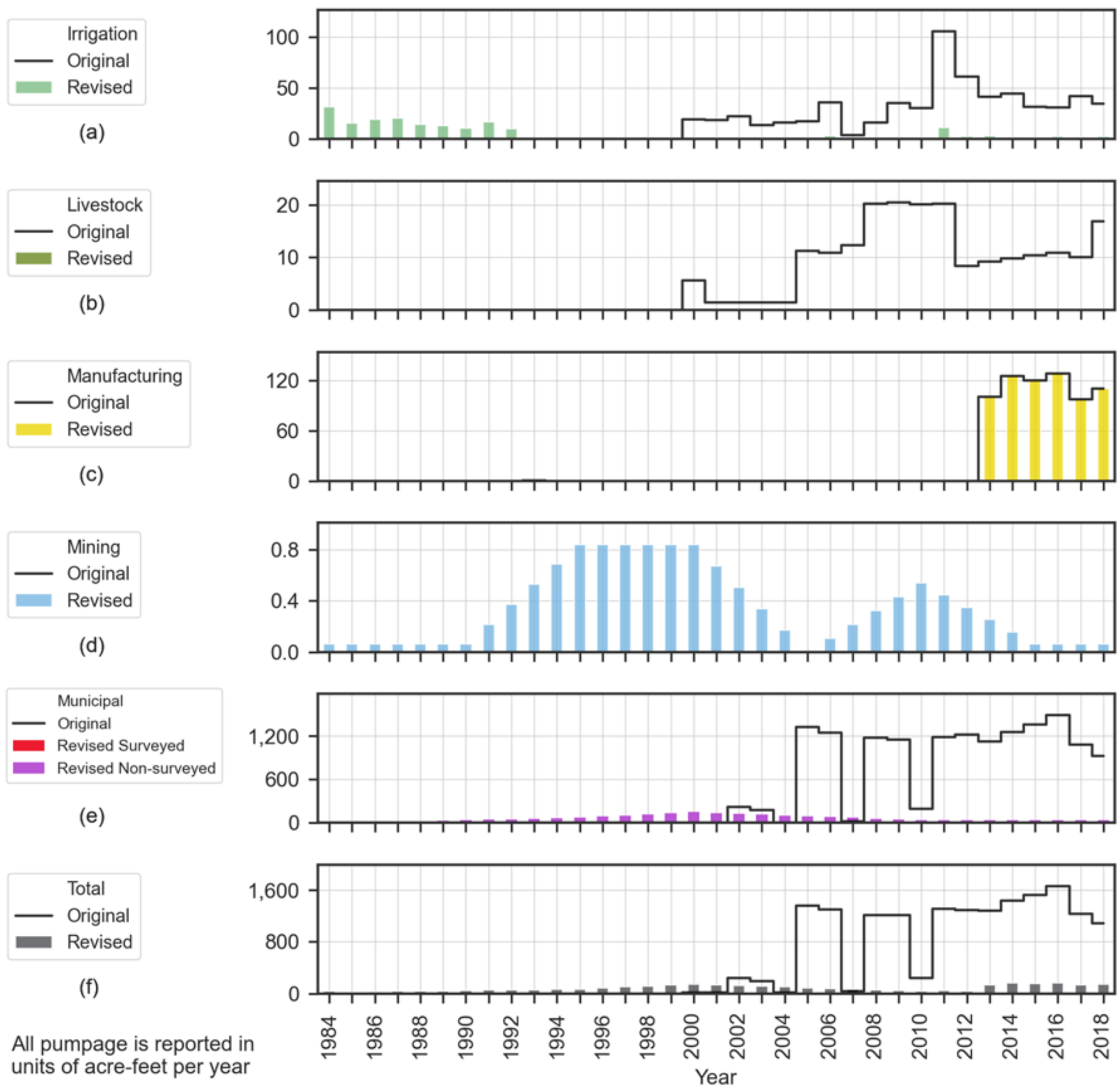


Figure 502. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County from 1984 through 2018.

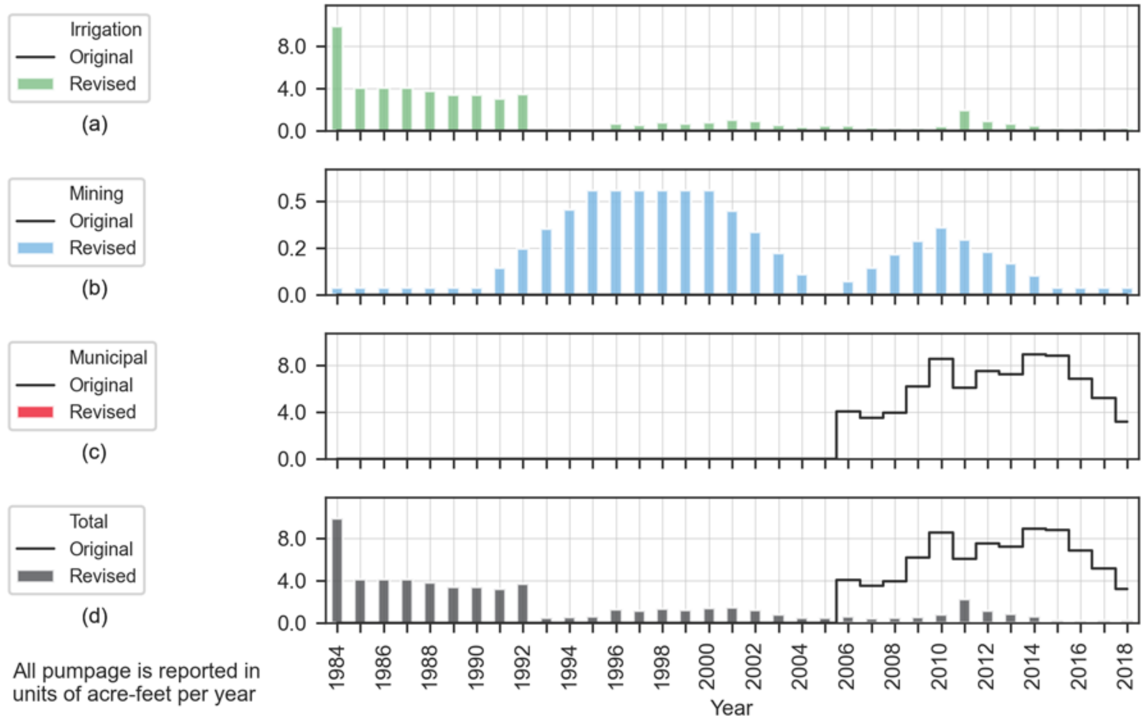


Figure 503. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Guadalupe County from 1984 through 2018.

Surveyed Municipal

Only pumpage reported by the City of Schertz was included in the revised surveyed-municipal dataset, based on the city's location with respect to the Edwards (Balcones Fault Zone) Aquifer within Guadalupe County.

Non-Surveyed Municipal

Figure 504 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County during the study period. Our estimates of pumping for non-surveyed municipal use are in general agreement with the TWDB Water Use Survey data. The TWDB Water Use Survey data includes up to about 10 acre-feet of pumping from the Trinity (Hill Country) from 2006 onwards. However, our estimates do not include any non-surveyed municipal use pumping from the Trinity (Hill Country) Aquifer in Guadalupe County.

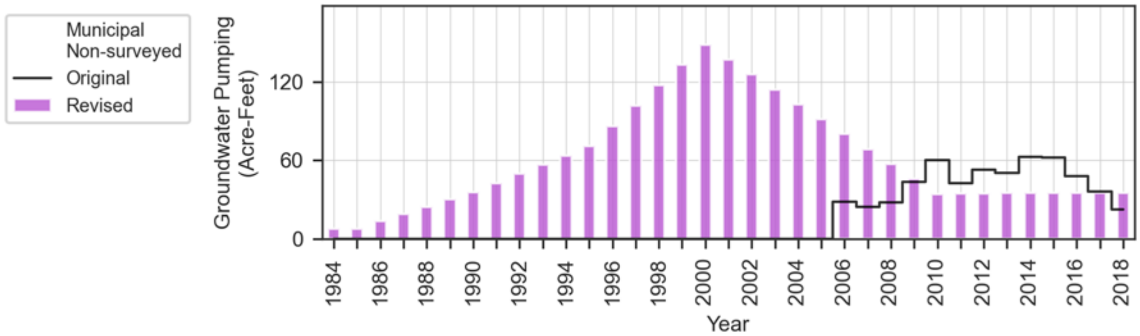


Figure 504. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Guadalupe County from 1984 through 2018.

Irrigation

The Edwards (Balcones Fault Zone) Aquifer underlies the western corner of Guadalupe County, along the borders with Comal County and Bexar County. Wells exist within the aquifer footprint in Guadalupe County, with the wells screened within the Edwards (Balcones Fault Zone) Aquifer. There is also a portion of the Trinity (Hill Country) Aquifer underlying Guadalupe County, yet no wells were identified within this aquifer footprint within the county. The original TWDB Water Use Survey dataset included irrigation pumping of up to 105 acre-feet per year from the Edwards (Balcones Fault Zone) Aquifer, with data only available for the years from 2000 to 2018.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County ranged from zero to 62 acre-feet per year over this study period (Figure 505). Surface water was used to meet irrigation needs within the county, and it reduced the computed groundwater needs in all years, including in 1995 when needs were completely eliminated. Computed pumpage for irrigation ranged from zero acre-feet per year to 31 acre-feet per year. The annual pattern of water usage differs between the original TWDB water use dataset and the revised pumpage dataset. Original TWDB pumpage estimates were generally 4 to 8 times higher than estimated irrigation water needs for the small aquifer footprint within Guadalupe County. Both datasets showed an increased need in the drought year of 2011, followed by higher needs from 2012-2018 than for the period from 2000-2009. Climactic patterns and crop histories do not suggest the required pumpage magnitude indicated by the original TWDB pumpage estimates.

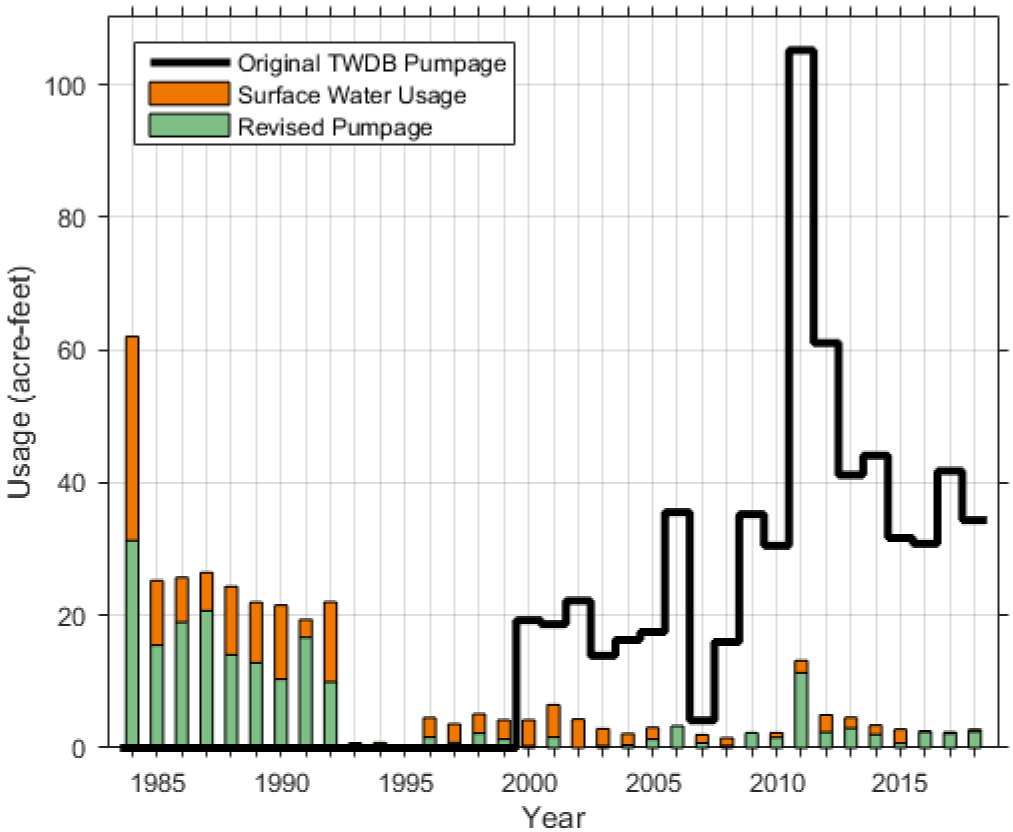


Figure 505. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Guadalupe County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Guadalupe County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Guadalupe County.

Mining

Figure 502d illustrates the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County during the study period. No enhanced oil recovery wells or Water Use Survey estimates were reported in the county. Therefore, the U. S. Geological Survey mining use estimates were used to obtain the revised mining pumpage that indicated that 60 percent of the water is sourced from the Edwards (Balcones Fault Zone) and the remaining is from the Trinity (Hill Country) Aquifer.

Manufacturing

Figure 502c illustrates the groundwater pumping associated with manufacturing use from the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County during the study period. There was no estimated pumping prior to 2013 and we identified no changes for this use.

Livestock

Figure 502b illustrates the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer in Guadalupe County during the study period. We estimated no pumping for livestock use from the Edwards (Balcones Fault Zone) Aquifer due to a lack of known wells in the aquifer for this use type.

5.2.20 Hays County

Figure 506, Figure 507 and Figure 508 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer, the Trinity (Hill Country) Aquifer, and the Edwards-Trinity (Plateau) Aquifer, respectively, in Hays County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

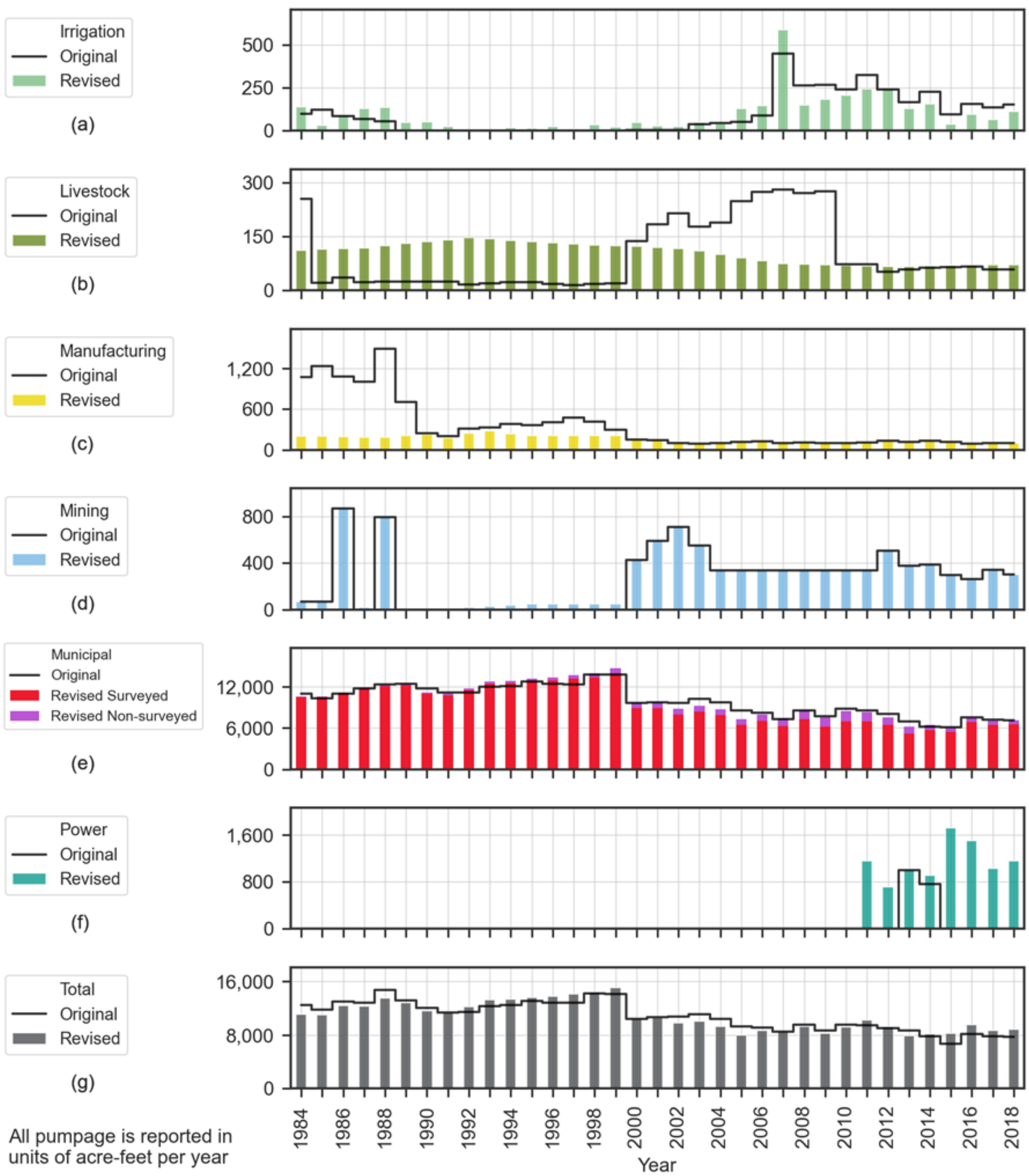


Figure 506. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Hays County from 1984 through 2018.

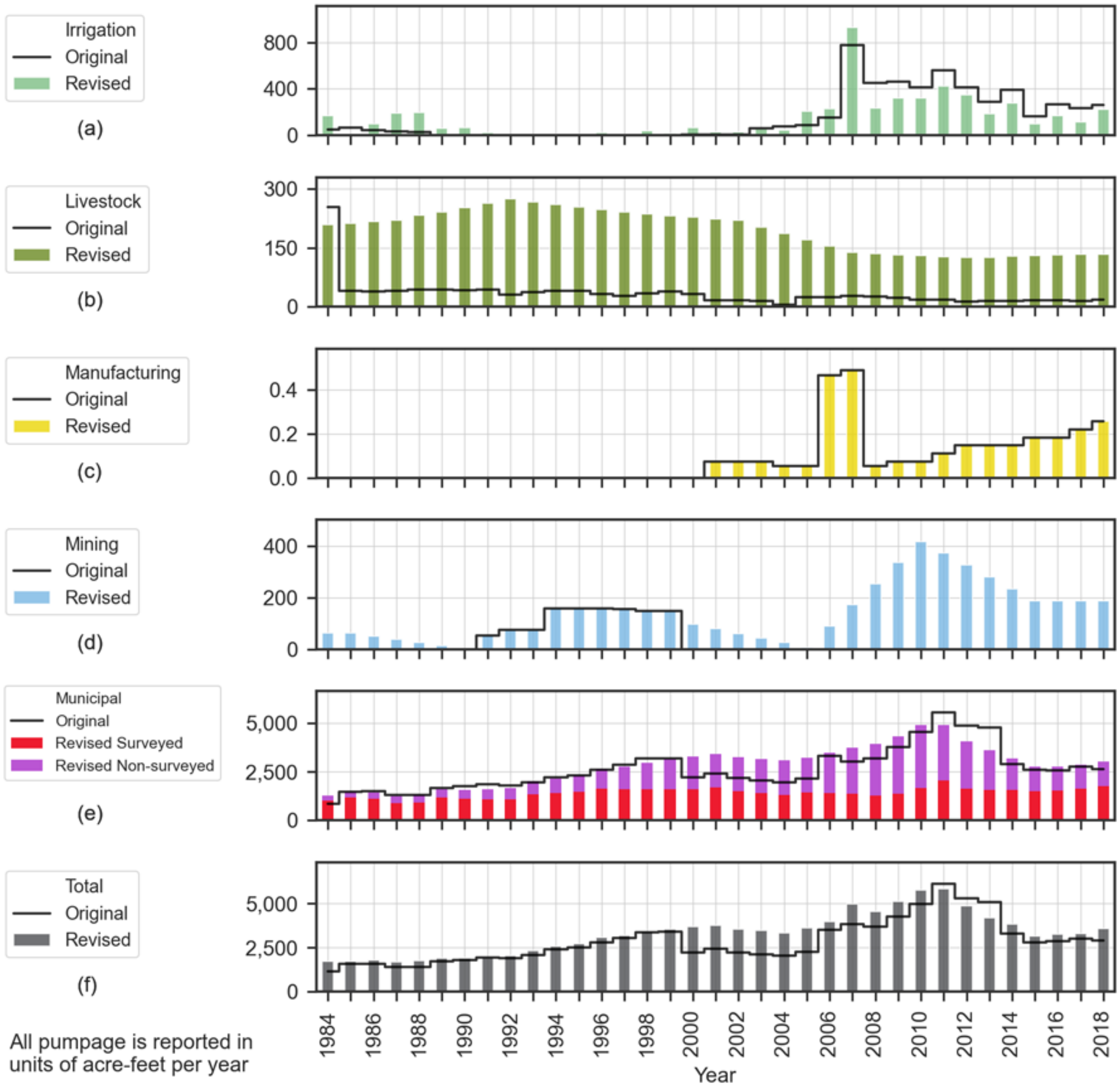


Figure 507. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Hays County from 1984 through 2018.

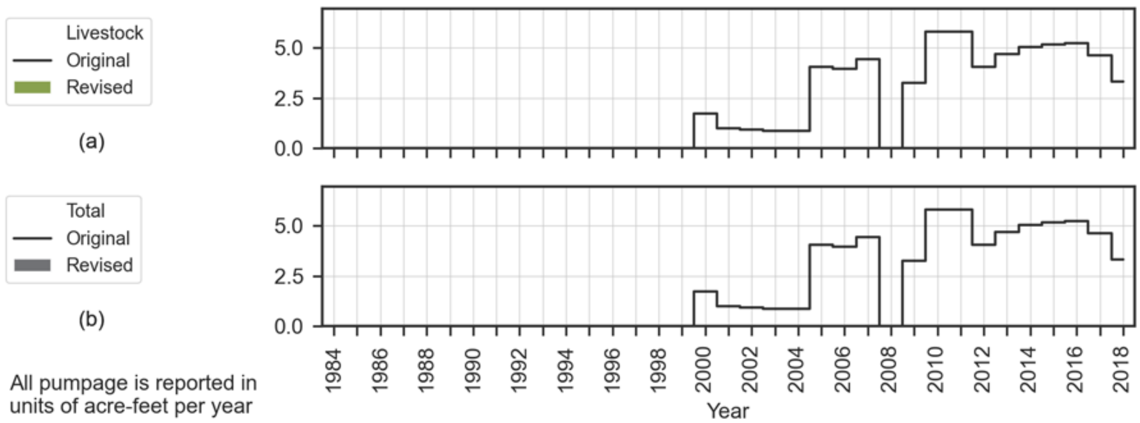


Figure 508. **Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Hays County from 1984 through 2018.**

Surveyed Municipal

Changes in surveyed municipal pumpage for Hays County resulted from the interpolation of data to fill gaps in the original TWDB water use survey dataset.

Non-Surveyed Municipal

Figure 509 and Figure 510 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Hays County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data. Our estimates are lower than the Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer by a factor of two.

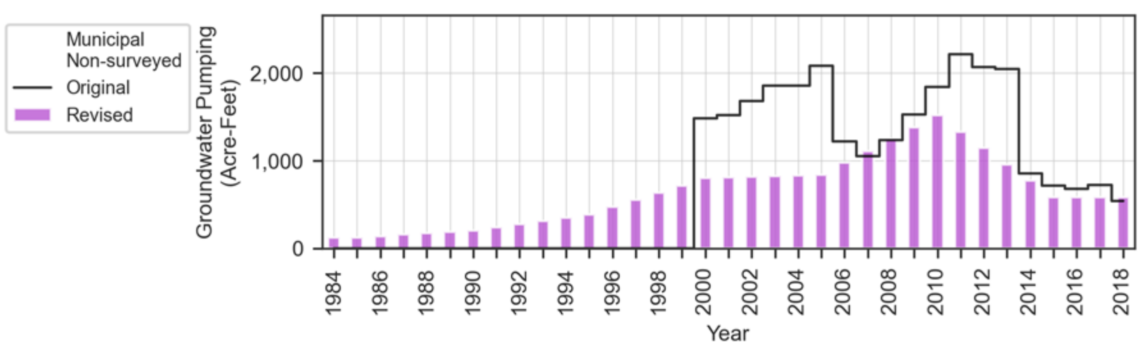


Figure 509. **Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Hays County from 1984 through 2018.**

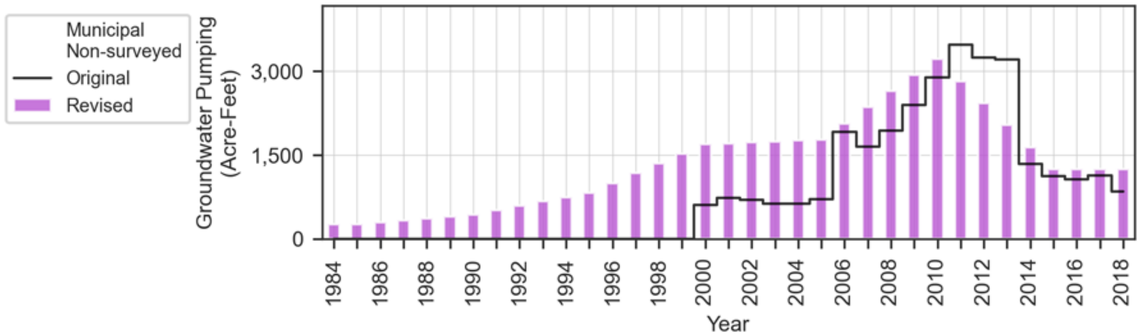


Figure 510. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Hays County from 1984 through 2018.

Irrigation

Hays County is underlain by the Edwards (Balcones Fault Zone), the Trinity (Hill Country) Aquifer, and the Carrizo Aquifer. Wells located within the county are geographically distinct in that wells within the footprint of the Edwards (Balcones Fault Zone) Aquifer are all screened within the aquifer. Similarly, all wells within the footprint of the Trinity (Hill Country) Aquifer and outside the footprint of the Edwards (Balcones Fault Zone) Aquifer are screened within the Trinity (Hill Country) Aquifer.

Original TWDB Water Use Survey data indicated groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer ranged from zero acre-feet per year to approximately 450 acre-feet per year (Figure 511). Pumpage from the Trinity (Hill Country) Aquifer (Figure 512) followed the same temporal pattern, ranging from zero acre-feet per year to approximately 775 acre-feet per year. Within the TWDB original Water Use Survey data, prior to 1989 pumping from the Trinity (Hill Country) Aquifer consistently was 52 percent of the pumpage from the Edwards (Balcones Fault Zone) Aquifer. In contrast, for the period from 2000 to 2018, pumpage from the Trinity (Hill Country) Aquifer was consistently 172 percent of the pumpage reported from the Edwards (Balcones Fault Zone) Aquifer. This suggests that within the TWDB Water Use Survey dataset, total county pumpage was estimated, and then routinely allocated to individual aquifers based on fixed ratios, rather than on crop location or climactic patterns.

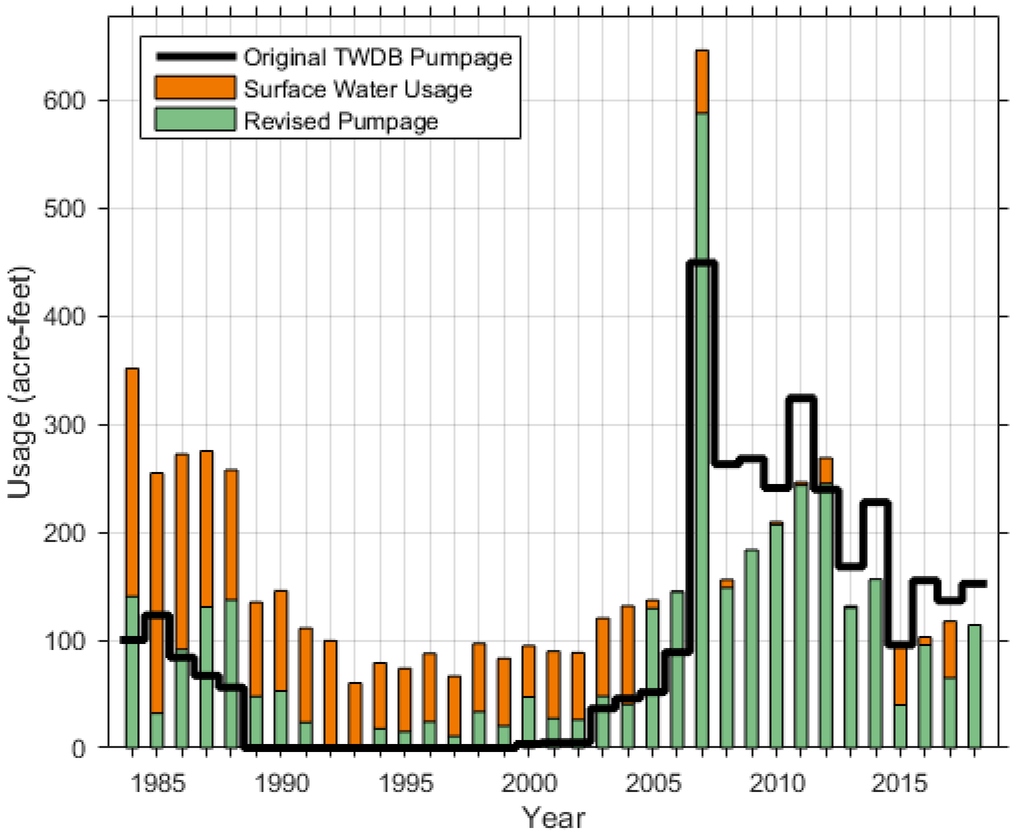


Figure 511. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Hays County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards (Balcones Fault Zone) Aquifer in Hays County ranged from approximately 77 to 645 acre-feet per year over this study period. Surface water was used to meet irrigation needs within the county, and it reduced the computed groundwater needs in nearly all years, including in 1992 and 1993 when needs were completely eliminated. Computed pumpage for irrigation ranged from zero acre-feet per year to 588 acre-feet per year. The annual pattern of water usage is similar between the original TWDB water use dataset and the revised pumpage dataset, with increased pumpage from 2005 through 2018. This increase in pumpage is due, in part, to a general reduction in surface water usage to meet irrigation needs over this period.

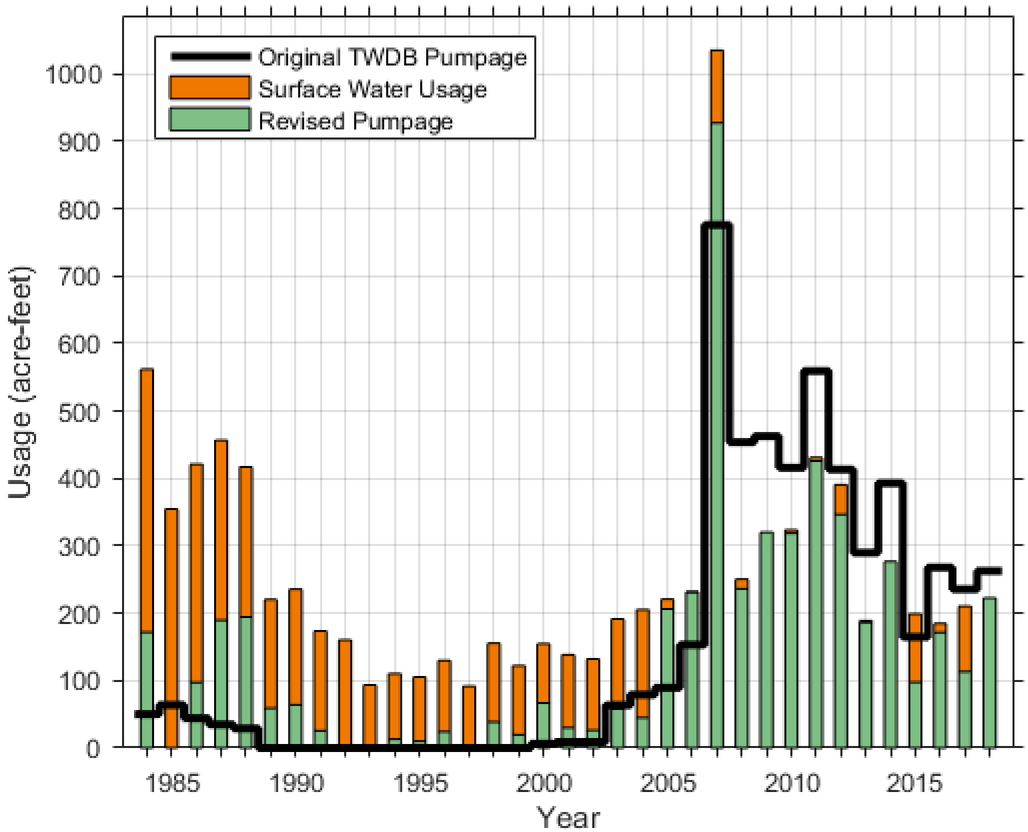


Figure 512. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Hays County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Trinity (Hill Country) Aquifer in Hays County ranged from approximately 150 to 1,030 acre-feet per year over this study period (Figure 512). Surface water was used to meet irrigation needs within the county, and it reduced the computed groundwater needs in nearly all years, including in 1992, 1993, and 1997 when needs were completely eliminated. Computed pumpage for irrigation ranged from zero acre-feet per year to 925 acre-feet per year. The annual pattern of water usage is similar between the original TWDB water use dataset and the revised pumpage dataset, with increased pumpage from 2005 through 2018. This increase in pumpage is due, in part, to a general reduction in surface water usage to meet irrigation needs over this period.

Power

As reported in Section 3.3.20 and illustrated on Figure 513, pumping from the Edwards (Balcones Fault Zone) Aquifer in Hays County for power use was reported only for years 2013 and 2014, and was approximately 800 acre-feet per year. As discussed in Section 3.3.20, we found several anomalies in the data based on our manual review, year-to-year change, and a standard deviation analyses.

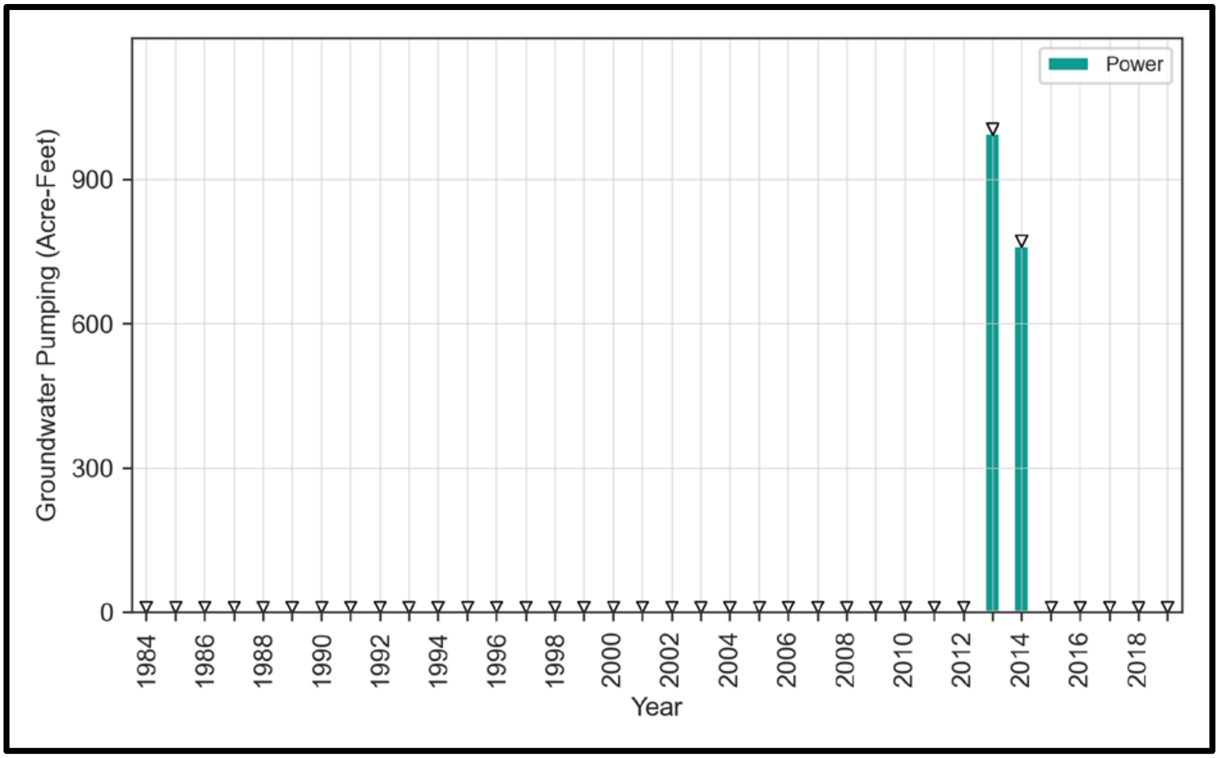


Figure 513. Edwards (Balcones Fault Zone) Aquifer groundwater pumping for power use in Hays County as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Edwards (Balcones Fault Zone) Aquifer pumping for power use per entity in Hays County, we determined there was only one surveyed entity reporting groundwater production. The sole reporting entity was Hays EDF Suez Energy North America – Hays Energy (hereafter referred to as "Hays Energy Power Plant"). The location is shown in Figure 514.

Table 73 presents the timeline of operation events as provided on form EIA-860 for the Hays Energy Power Plant in Hays County. Combined-cycle turbines such as the Hays Energy U1 and U2 have lower cooling requirements than steam turbines and greater cooling requirements than combustion turbines. Using information gathered from EIA-860 (Table 73), we know that the Hays Energy Power Plant used a dry-type cooling system which has a much lower water use than a wet-type cooling tower. We assigned it an average water use value of 0.15 gallons per kilowatt-hour for the combined cycle turbine generators.

Figure 515 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Hays Energy Power Plant. Even though the turbines were reported as starting to operate in 2002, there was no reported power generation until 2011 based on EIA-860. Figure 515b illustrates the pumpage based on the Water Use Survey. The reported pumpage values from the original TWDB Water Use Survey for 2013 was used to scale the rest of the pumpage estimates from the net power generation values and fill in for missing years.

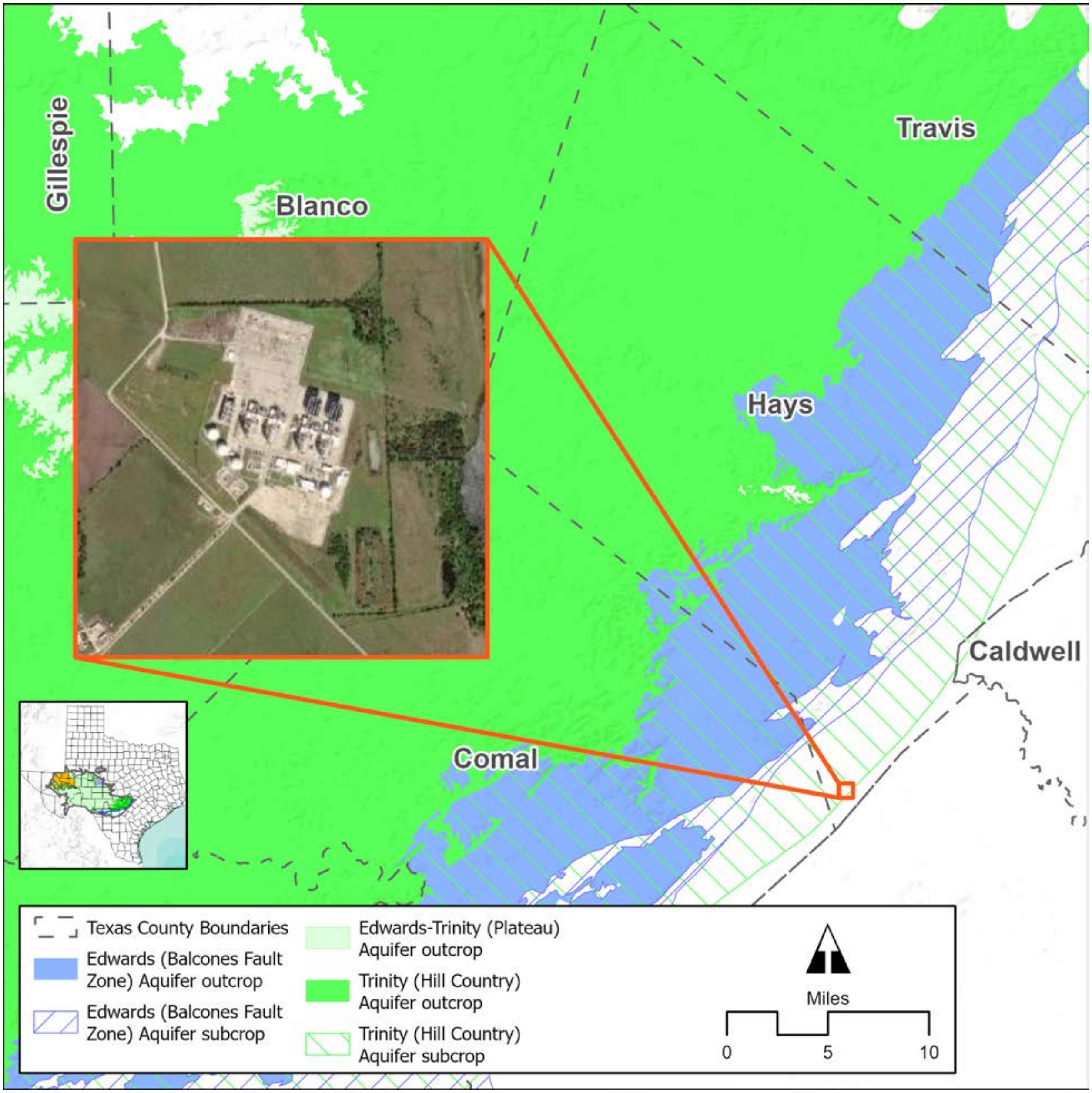


Figure 514. Location of the Hays Energy Power Plant in Hays County.

Table 73. Hays Energy Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
2002	U1	Began Operation	Combined-Cycle Single Shaft	Fossil fuels	Dry (air) cooling system	Mechanical draft, dry process
2002	U2	Began Operation	Combined-Cycle Single Shaft	Fossil fuels	Dry (air) cooling system	Mechanical draft, dry process
2002	U3	Began Operation	Combined-Cycle Single Shaft	Fossil fuels	Dry (air) cooling system	Mechanical draft, dry process
2002	U4	Began Operation	Combined-Cycle Single Shaft	Fossil fuels	Dry (air) cooling system	Mechanical draft, dry process

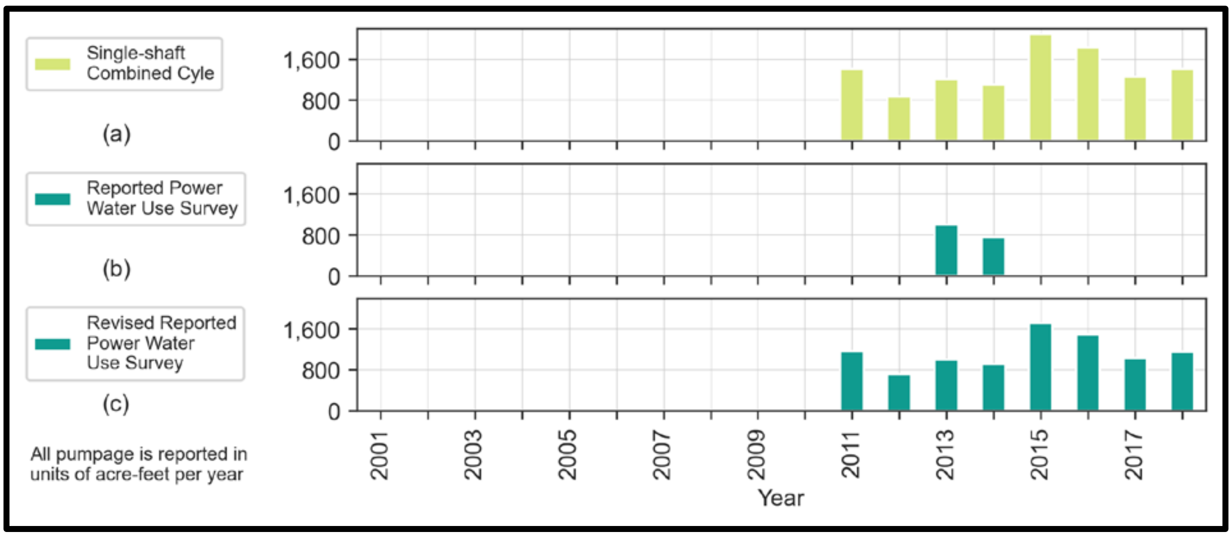


Figure 515. Hays Energy Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Reported groundwater pumping by the Water Use Survey, and (c) Revised groundwater pumping.

Mining

Figure 506d and Figure 507d illustrate the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer, respectively, in Hays County during the study period. No enhanced oil recovery wells were reported within the study area. Therefore, data from the Water Use Survey and the U.S. Geological Survey was used to obtain the mining pumpage estimates. We estimated approximately 38 percent of groundwater pumping for mining is sourced from the Trinity (Hill Country) Aquifer and the remaining is pumped from the Edwards (Balcones Fault Zone) Aquifer.

Manufacturing

Figure 506c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards (Balcones Fault Zone) Aquifer in Hays County during the study period. The largest changes occur prior to 1989 where the original estimates are several times more than the revised estimates. For these years we reduced the estimated pumping to a level that was consistent with the available data.

Figure 507c illustrates the groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Hays County during the study period. There was no estimated pumping prior to 2001 and we identified no changes for this use.

Livestock

Figure 506b and Figure 507b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country) Aquifer, respectively, in Hays County during the study period. Prior to 2000, our estimates are generally higher than the TWDB Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer; however, after year 2000 the TWDB Water Use Survey values are higher than our estimates of groundwater pumping from the aquifer. Our estimates of groundwater pumping from the Trinity (Hill Country) Aquifer are higher than the TWDB Water Use Survey data for the study period, and the magnitude matches the TWDB Water Use Survey data's pumpage value for 1984. The TWDB Water Use Survey data also includes estimates for the Edwards-Trinity (Plateau) Aquifer, but these estimates are likely mis-designated and we attributed the estimates to the Trinity (Hill Country) Aquifer in the county.

5.2.21 Howard County

Figure 516 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Howard County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

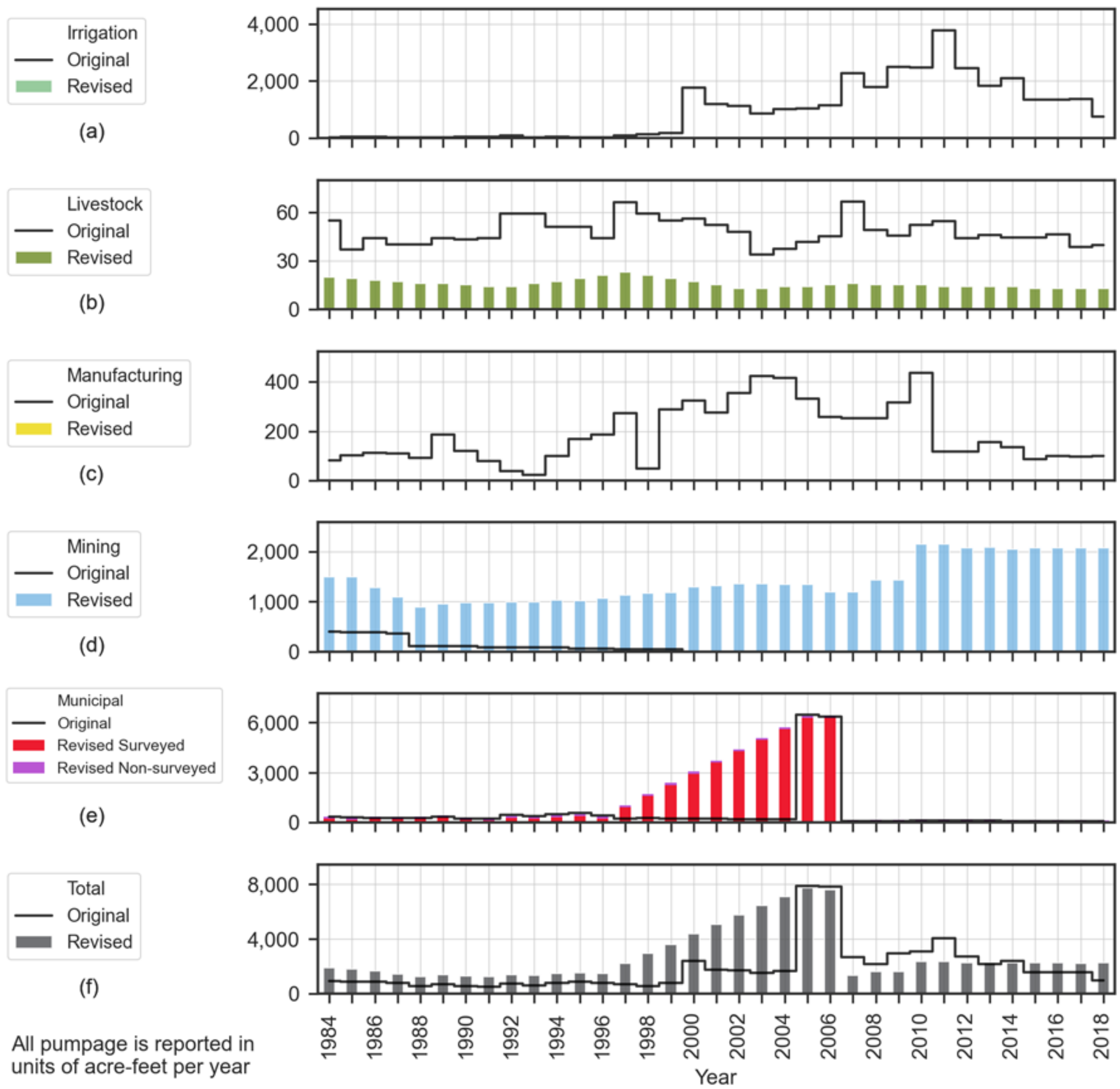


Figure 516. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Howard County from 1984 through 2018.

Surveyed Municipal

Changes in surveyed municipal pumpage resulted from the interpolation of data to fill gaps in the original TWDB water use survey dataset. Data interpolation for the entity "City of Big Spring – Howard County Field" resulted in a substantial increase in pumpage between the reported years of 1996 and 2005. The large volume of pumping reported in 2005-2006 was inconsistent with pumping reported by this entity from 1955-1996. We were also unable to determine a specific location for this pumpage, and were therefore unable to assess whether this pumpage should be attributed to the Ogallala Aquifer rather than the Edwards Trinity (Plateau) Aquifer.

Non-Surveyed Municipal

Figure 517 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Howard County during the study period. Our estimates appear to follow similar trends to the TWDB Water Use Survey data although our estimates are less than the Water Use Survey data prior to 2006 and more than the Water Use Survey data from 2006 onwards.

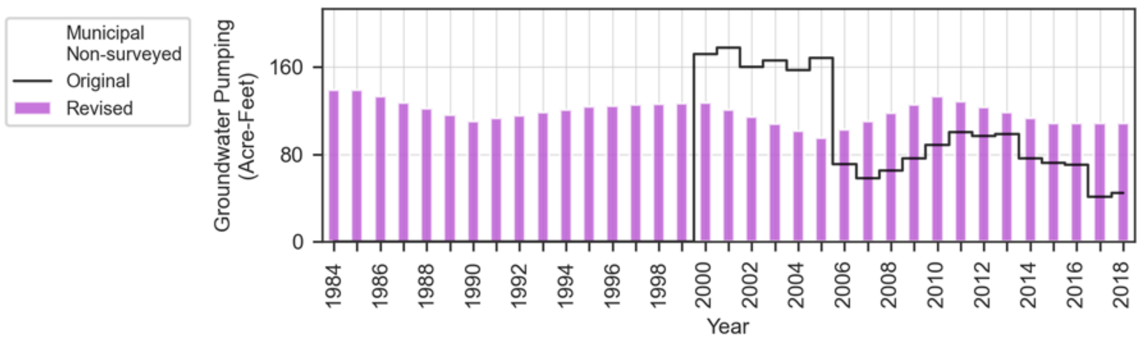


Figure 517. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Howard County from 1984 through 2018.

Irrigation

Howard County is underlain by the northern portion of the Edwards-Trinity (Plateau) Aquifer, as well as the Ogallala Aquifer and the Dockum Aquifer. The Dockum Aquifer exists below a portion of the Edwards-Trinity (Plateau) Aquifer, and wells located within the footprints of both the Dockum and Edwards-Trinity (Plateau) Aquifer appear to be screened within the Dockum Aquifer. There is a portion of the Edwards-Trinity (Plateau) Aquifer footprint within Howard County where all wells are screened within the aquifer and not within the Dockum Aquifer; this reduced aquifer footprint was used to estimate irrigation pumpage needs.

The original TWDB Water Use Survey data indicated that between 20 acre-feet per year and 3,760 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation within Howard County (Figure 518). Original TWDB Water Use Survey Pumpage greatly increased after 1999. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the modified footprint of the Edwards-Trinity (Plateau) Aquifer in Howard County ranged from one acre-foot per year to a maximum of approximately 75 acre-feet per year over this study period. This range is significantly smaller than the range included within the original TWDB Water Use Survey dataset. Historically, TWDB assigned 36.67% of total county pumpage to the Edwards Trinity (Plateau) Aquifer, 50.00% of total county pumpage to the Ogallala Aquifer, and 6.67% pumpage each to the Dockum Aquifer and "Other Aquifer." Pumpage estimation based on climactic patterns did not justify this distribution of pumping over Howard County aquifer footprints.

Reported surface water usage from 1984 to 1996 was sufficient to meet all irrigation demands within the modified aquifer footprint, thereby eliminating the need for groundwater pumpage during those years. Groundwater pumpage for irrigation within the Edwards-Trinity (Plateau) Aquifer modified footprint within Howard County ranged from zero acre-feet per year to a maximum of 35 acre-feet per year. This is a large reduction in pumpage compared to the original TWDB Water Use Survey dataset.

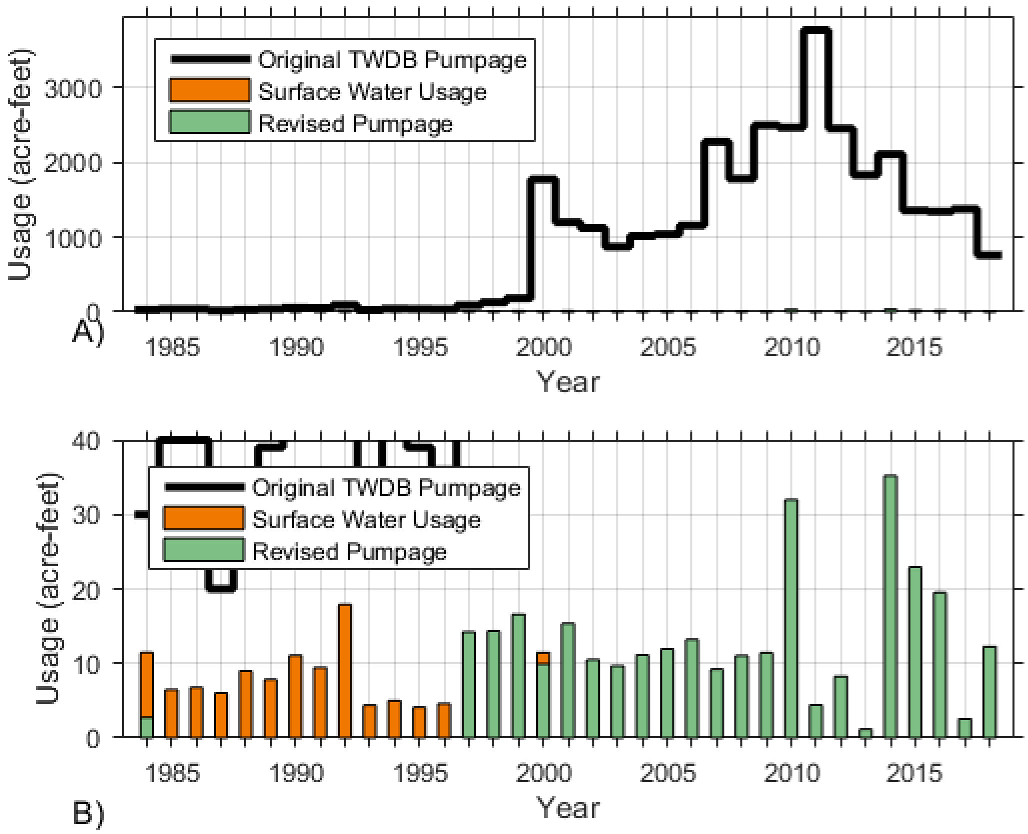


Figure 518. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Howard County. Graphic A and B show the same data with different vertical scales, so that the revised pumpage amounts become visible.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Howard County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Howard County.

Mining

Figure 516d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Howard County during the study period. There were 310 active enhanced oil recovery wells in Howard County as of 1980 which increased up to 700 wells in 2020. We estimate the entirety of groundwater pumping for mining use in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 516c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Howard County during the study period. The change in pumping is due to a change in the aquifer designation for "Sid Richardson Carbon & Energy Company-Big Spring Carbon Black Plant" from the Edwards-Trinity (Plateau) Aquifer to the Ogallala Aquifer.

Livestock

Figure 516b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Howard County during the study period. Our revisions to the estimated groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Howard County for livestock use are consistently lower than the TWDB Water Use Survey data.

5.2.22 Irion County

Figure 519 and Figure 520 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer, respectively, in Irion County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

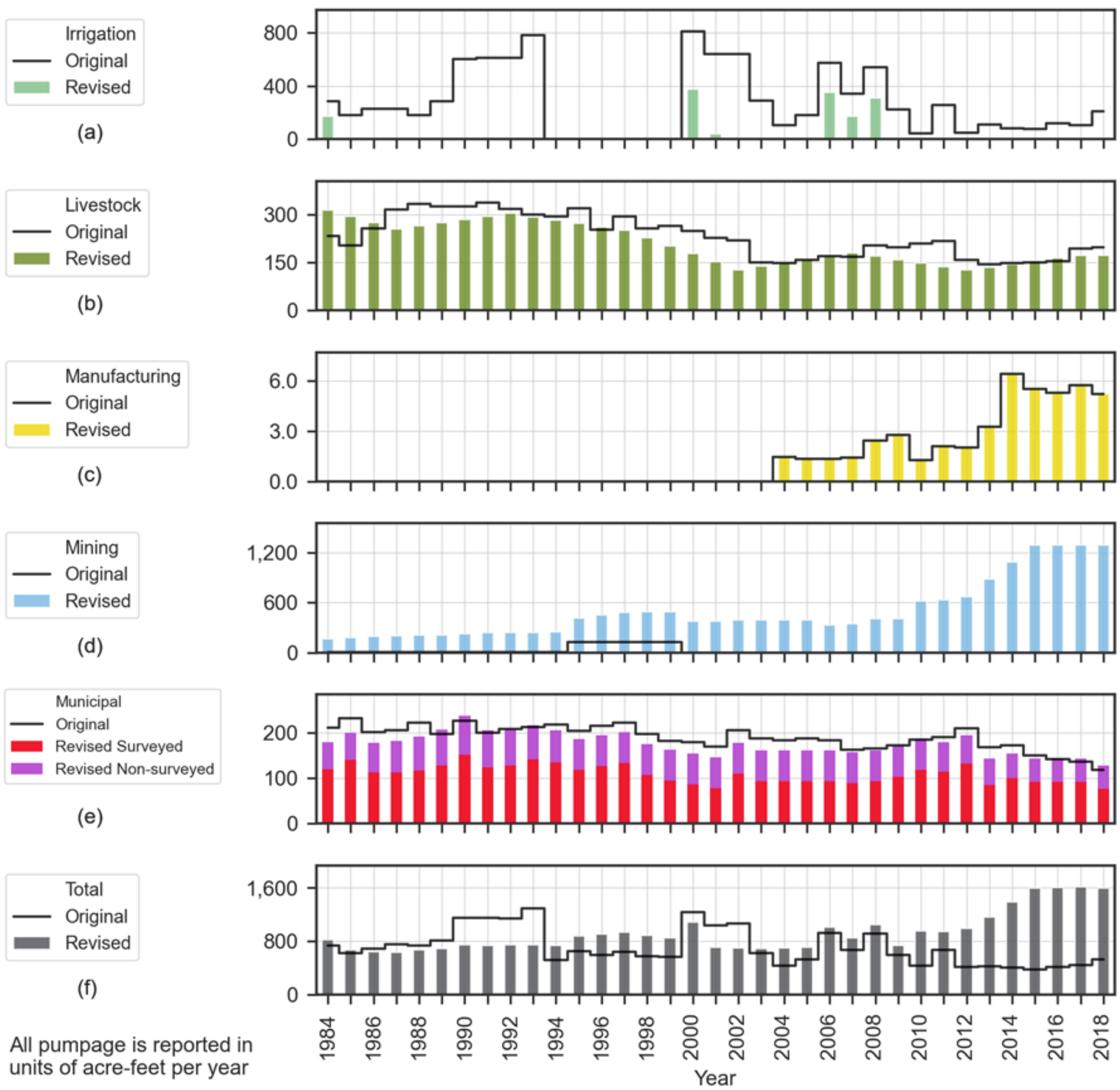


Figure 519. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Irion County from 1984 through 2018.

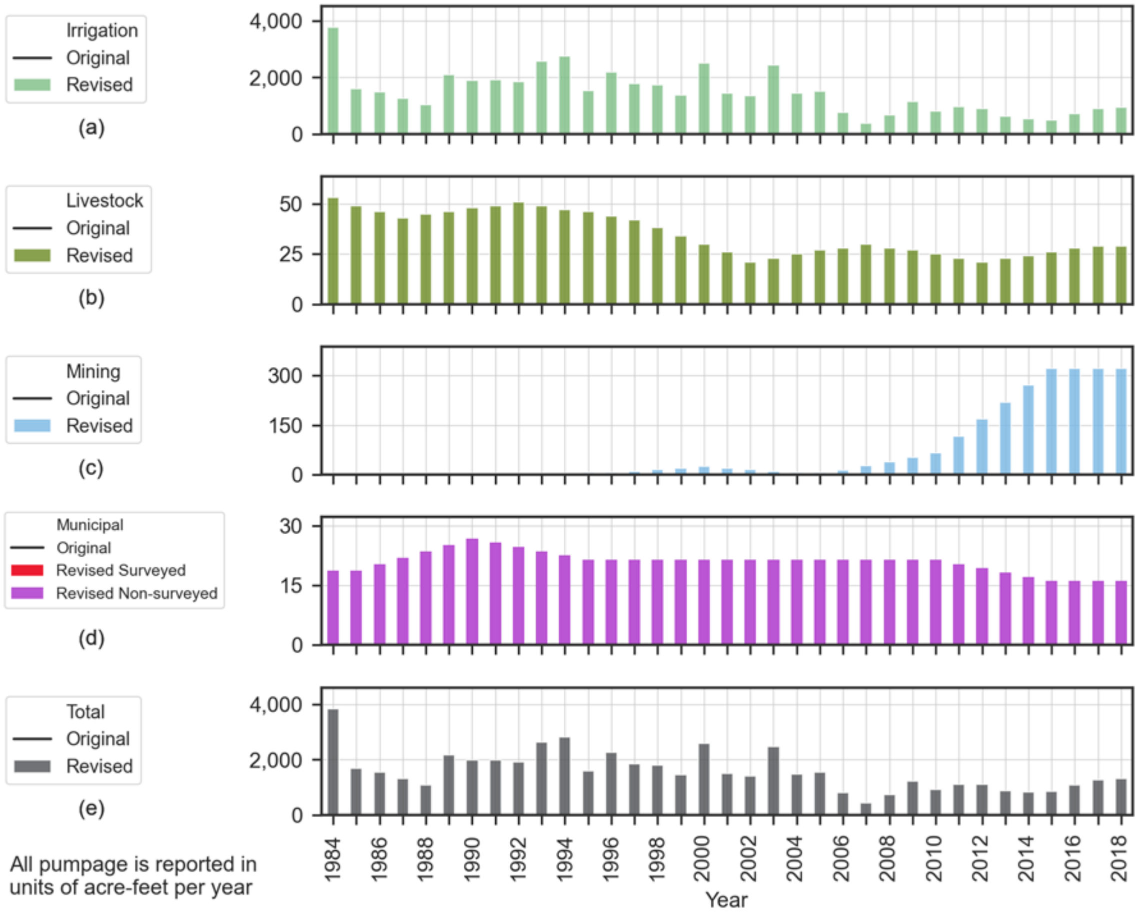


Figure 520. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Irion County from 1984 through 2018.

Surveyed Municipal

Surveyed municipal pumping from the Edwards Trinity (Plateau) Aquifer was reported by three entities: 1) Barnhart Water System, 2) City of Mertzon, and 3) Tom Thorp MHP. The majority of pumping was reported by the City of Mertzon, which reported for all years of the study period and exhibited annual fluctuations typical of the general climactic patterns of the region. Barnhart Water System reported declining pumping from 1984-1998, followed by near zero pumpage in 1999 and then constant pumpage from 2000-2007. The Texas Tribune published an article on 6/6/2013 indicating that the wells for Barnhart Water System failed in 2013, six years after the last reported pumpage for this entity. We conclude that pumpage reported by Barnhart Water System is likely suspect.

Municipal pumpage from the Lipan Aquifer was not reported by a single entity within Irion County during the study period.

Non-Surveyed Municipal

Figure 521 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Irion County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

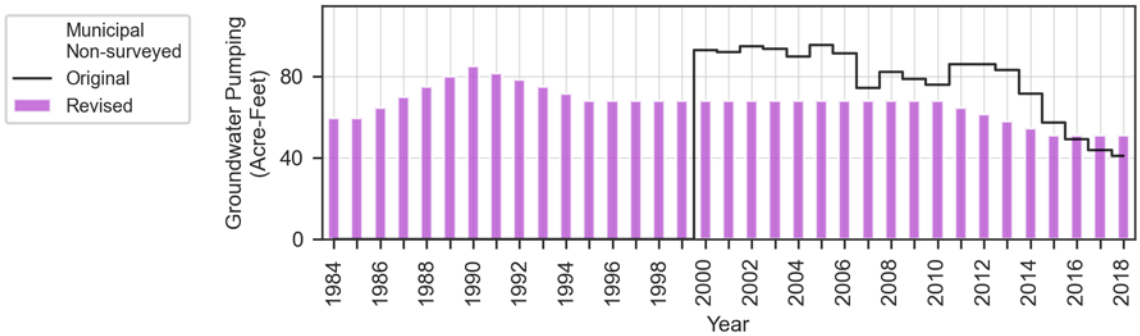


Figure 521. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Irion County from 1984 through 2018.

Irrigation

Irion County is completely underlain by the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer. The Dockum Aquifer underlies a majority of the county, yet is located deeper below the ground surface than the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer. Wells screened within the Dockum Aquifer are located near wells screened within the Edwards-Trinity Aquifer, and there is not any geographical separation between wells in locations where aquifer footprints overlap. Upon reviewing information within the TWDB groundwater data viewer, it was determined that wells for irrigation are more commonly screened within the shallower aquifers within Irion County. As such, this analysis assumed all pumpage for irrigation in Irion County was derived from either the Edwards-Trinity (Plateau) Aquifer or the Lipan Aquifer.

The original TWDB Water Use Survey dataset did not include estimates of irrigation pumpage from the Lipan Aquifer. It did include, however, estimates for pumpage from "Other Aquifer." Estimates of groundwater withdrawals from the "Other Aquifer" for irrigation ranged from 10 acre-feet per year to 179 acre-feet per year between 2000 and 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater demands for irrigation from the Lipan Aquifer in Irion County ranged from 370 acre-feet per year to 4,040 acre-feet per year (Figure 522). Surface water was used to meet irrigation demands in Irion County in every year of the study period other than the period from 2006 to 2008, yet never in sufficient quantities to eliminate the need for groundwater pumpage. Revised pumpage estimates for the Lipan Aquifer are larger than the original TWDB water usage estimates for the "Other Aquifer."

The original TWDB Water Use Survey dataset estimated irrigation usage within Irion County from the Edwards-Trinity (Plateau) Aquifer to range from zero acre-feet per year to 807 acre-feet per year (Figure 523). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, demands for irrigation from within the footprint of the Edwards-Trinity (Plateau) Aquifer ranged from 170 acre-feet per year to 1,896 acre-feet per year. Surface water was used to meet irrigation demands in Irion County in every year of the study period other than the 2006 to 2008. In most years, surface water usage was sufficient to meet the entire irrigation demand within the aquifer footprint. Revised pumpage estimates for irrigation from Edwards-Trinity (Plateau) Aquifer range from zero acre-feet per year to 375 acre-feet per year.

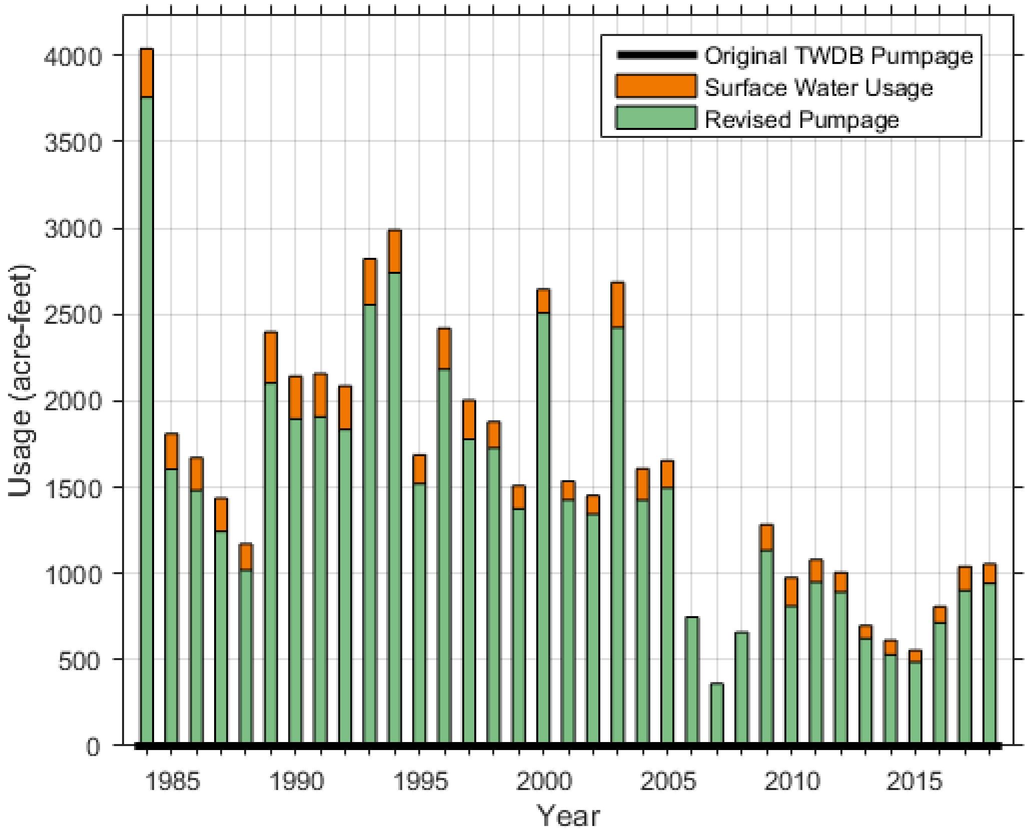


Figure 522. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Irion County.

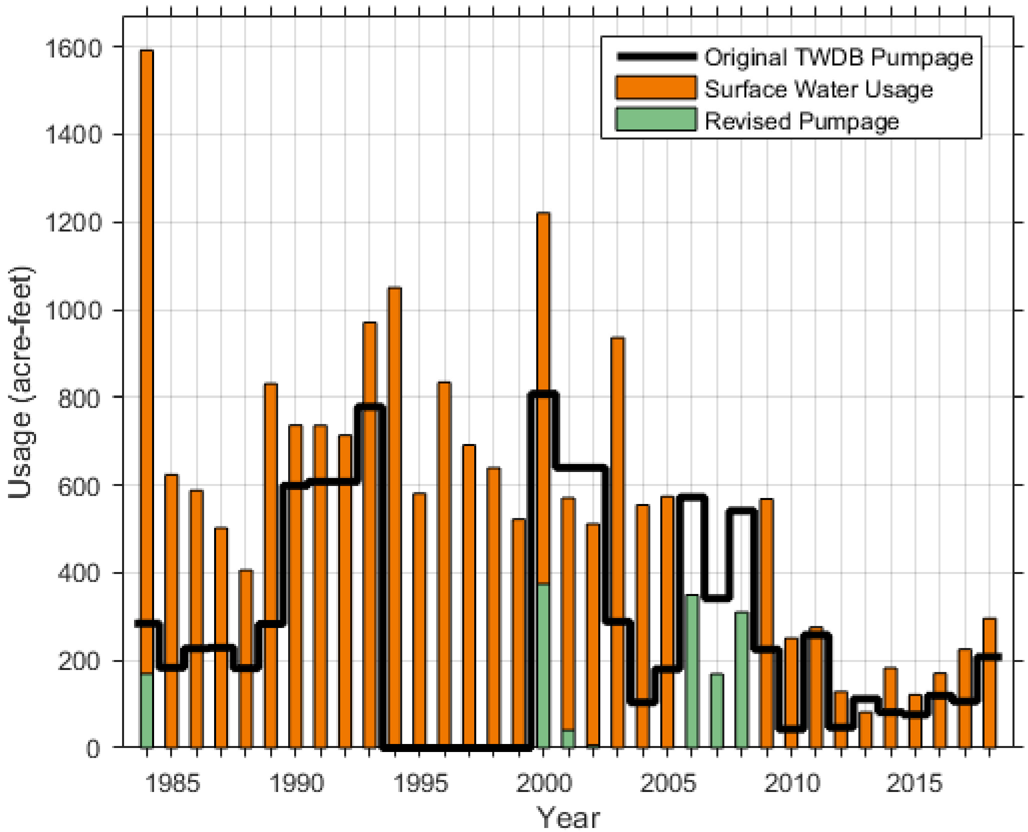


Figure 523. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Irion County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Irion County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Irion County.

Mining

Figure 519d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Irion County during the study period. In 1980 there were 42 active enhanced oil recovery wells in Irion County which increased up to 198 wells in 2020. Revised pumpage for mining use estimates indicate that 86 percent of the water for mining use is pumped from the Edwards-Trinity (Plateau) Aquifer and the remaining from the Lipan Aquifer.

Manufacturing

Figure 519c illustrates the groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Irion County during the study period. There was no estimated pumping prior to 2004 and we identified no changes for this use.

Livestock

Figure 519b and Figure 520b illustrate the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer, respectively, in Irion County during the study period. Our estimated pumping from the Edwards-Trinity (Plateau) Aquifer is in general agreement with the TWDB Water Use Survey data. There was no TWDB Water Use Survey pumpage estimates from the Lipan Aquifer in Irion County. We identified 83 wells completed in the Lipan aquifer for the study period associated to livestock. Our revised estimates start with a groundwater pumpage of 50 acre-feet in 1984 and gradually decreases to 25 acre-feet by 2018.

5.2.23 Jeff Davis County

Figure 524 and Figure 525 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Pecos Valley Aquifer, respectively, in Jeff Davis County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

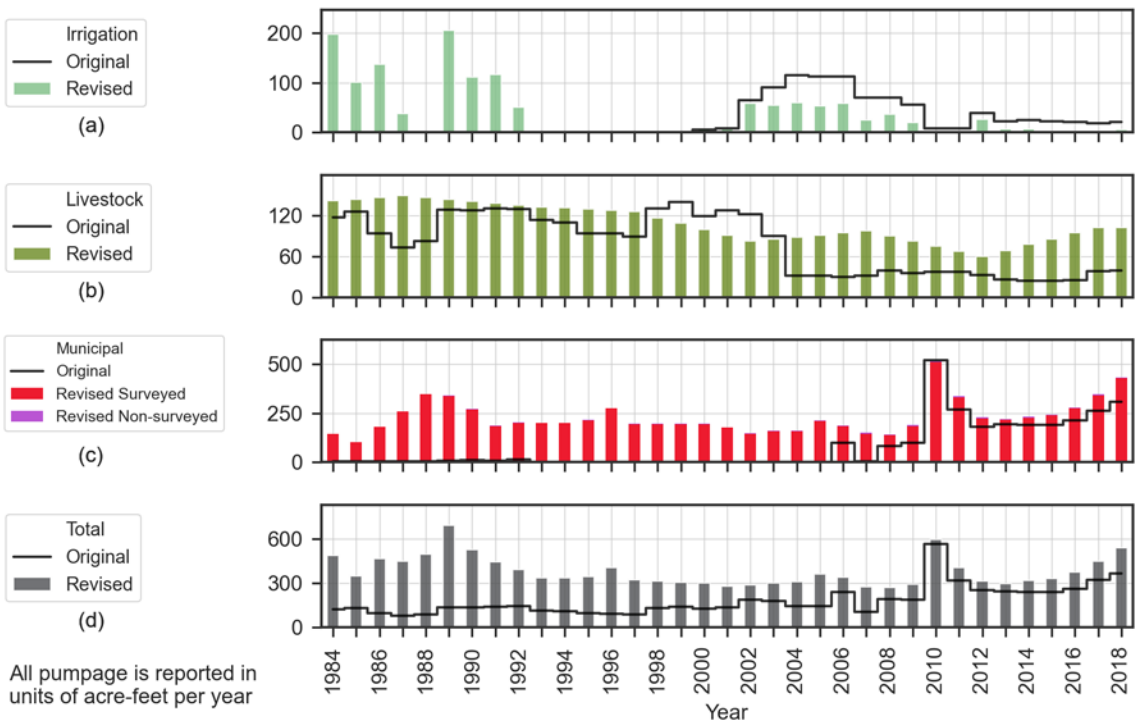


Figure 524. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Jeff Davis County from 1984 through 2018.

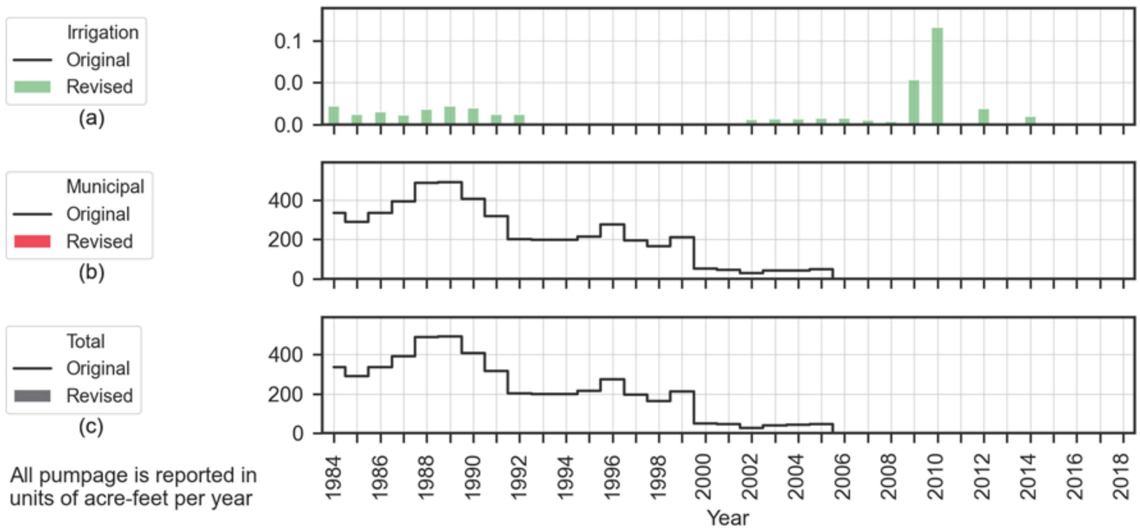


Figure 525. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Jeff Davis County from 1984 through 2018.

Surveyed Municipal

As shown in Figure 524c, the revised dataset for municipal surveys exhibits increased pumpage from the Edwards Trinity (Plateau) Aquifer. This increase arose through the re-classification of pumpage from Madera Valley WSC and the City of Balmorhea from the Pecos Valley Aquifer to the Edwards Trinity (Plateau) Aquifer. The Pecos Valley Aquifer has a very small footprint within Jeff Davis County, and the TWDB groundwater data viewer suggests all wells in the area are screened within the Edwards Trinity (Plateau) Aquifer. The Region F 2021 regional water plan asserts that both the Madera Valley WSC and City of Balmorhea receive water from the Balmorhea Alluvium in Northeastern Jeff Davis County. We assumed this alluvium to be a localized aquifer within the Edwards Trinity (Plateau) Aquifer. The revised dataset does not include municipal pumpage from the Pecos Valley Aquifer.

Non-Surveyed Municipal

Figure 526Figure 405 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Jeff Davis County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data. The TWDB Water Use Survey data includes up to about 50 acre-feet of pumping from the Pecos Valley Aquifer from 2000 to 2005. However, our estimates do not include any non-surveyed municipal use pumping from the Pecos Valley Aquifer in Jeff Davis County.

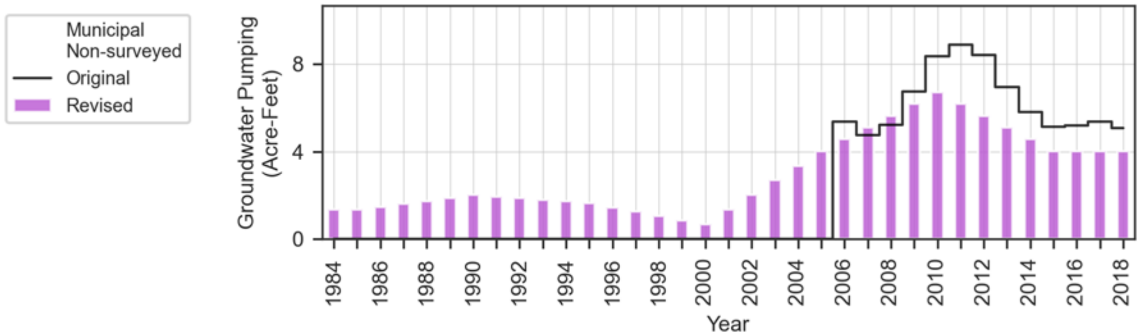


Figure 526. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Jeff Davis County from 1984 through 2018.

Irrigation

Jeff Davis County is partially underlain by the Edwards-Trinity (Plateau) Aquifer along its northeastern border with Reeves and Pecos Counties. There is also a small portion of the county underlain by the Pecos Valley Aquifer. Wells identified within the Edwards-Trinity (Plateau) Aquifer footprint are generally screened within the Igneous Aquifer, although some are screened within the Edwards-Trinity (Plateau) Aquifer. Upon review of the TWDB groundwater data viewer, it was determined that wells designated for irrigation purposes are generally screened within the Edwards-Trinity (Plateau) Aquifer rather than the Igneous Aquifer or within the Capitan Reef Complex. As such, it was assumed that all groundwater irrigation needs within the footprint of the Edwards-Trinity (Plateau) Aquifer within Jeff Davis County were satisfied by wells screened within this aquifer.

The original TWDB Water Use Survey dataset estimated irrigation usage within Jeff Davis County from the Edwards-Trinity (Plateau) Aquifer to range from zero acre-feet per year to 114 acre-feet per year. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, demands for irrigation from within the footprint of the Edwards-Trinity (Plateau) Aquifer ranged from five acre-feet per year to 210 acre-feet per year (Figure 527). Surface water was used to meet irrigation demands in Jeff Davis County in nearly every year of the study period, and was sufficient to eliminate groundwater pumpage needs in 1988, 1993 to 1999, 2010 to 2011, and 2015 to 2017. Revised pumpage estimates for irrigation from Edwards-Trinity (Plateau) Aquifer range from zero acre-feet per year to 206 acre-feet per year. Pumpage computed from the small footprint of the Pecos Valley Aquifer within Jeff Davis County was negligible (less than one acre-foot per year).

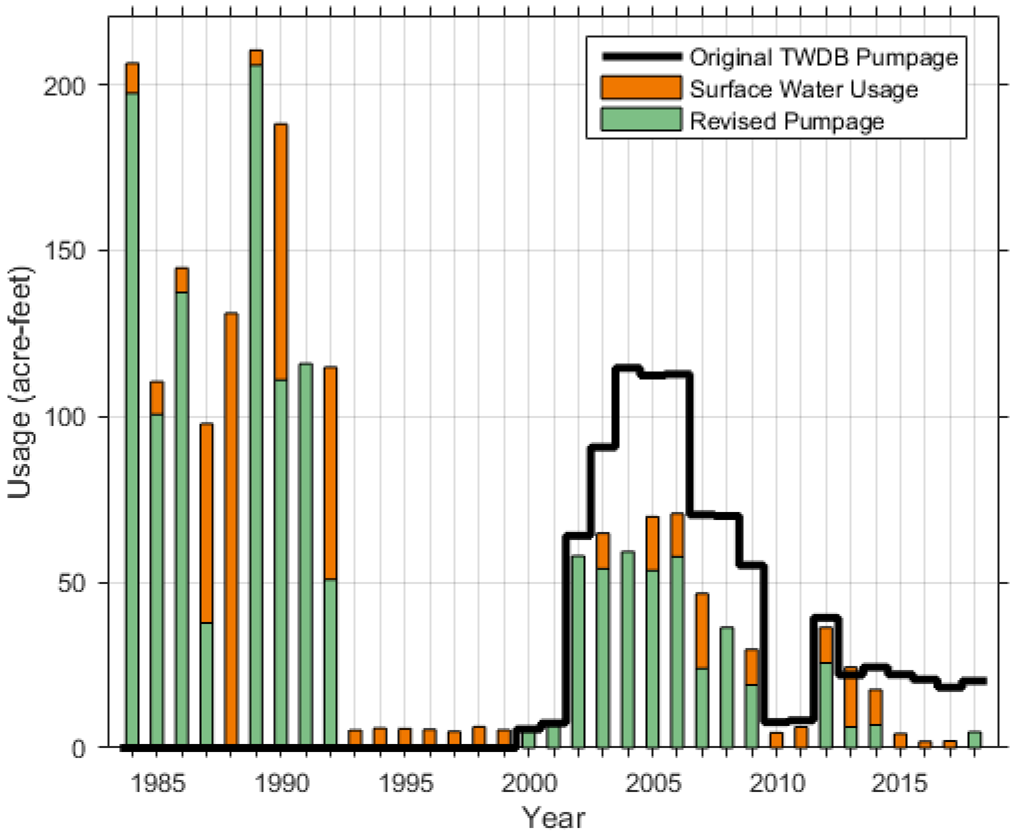


Figure 527. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Jeff Davis County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Jeff Davis County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Jeff Davis County.

Mining

For the study period and the study area aquifers, there are no enhanced oil recovery wells, Water Use Survey data, or U. S. Geological Survey data available for Jeff Davis County. Also, there is no indication unreported groundwater pumping associated with mining use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for mining use in Jeff Davis County.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Jeff Davis County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Jeff Davis County.

Livestock

Figure 524b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Jeff Davis County during the study period. Results from our evaluation are in general agreement with the TWDB Water Use Survey data throughout the study period.

5.2.24 Kendall County

Figure 528, Figure 529 and Figure 530 illustrate our revisions to the estimated in groundwater pumping from the Trinity (Hill Country) Aquifer, the Edwards-Trinity (Plateau) Aquifer, and the Edwards (Balcones Fault Zone) Aquifer, respectively, in Kendall County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

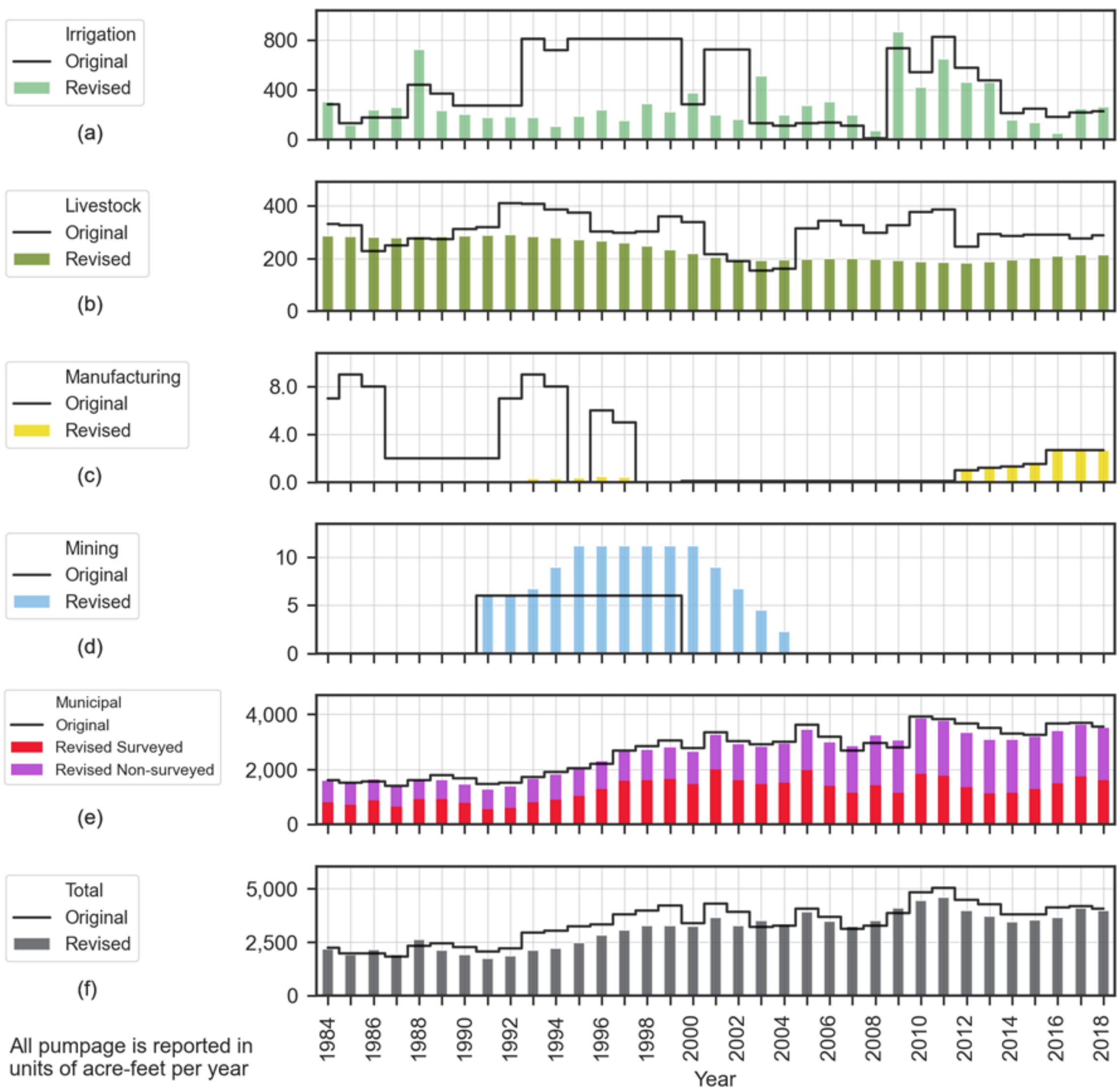


Figure 528. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Kendall County from 1984 through 2018.

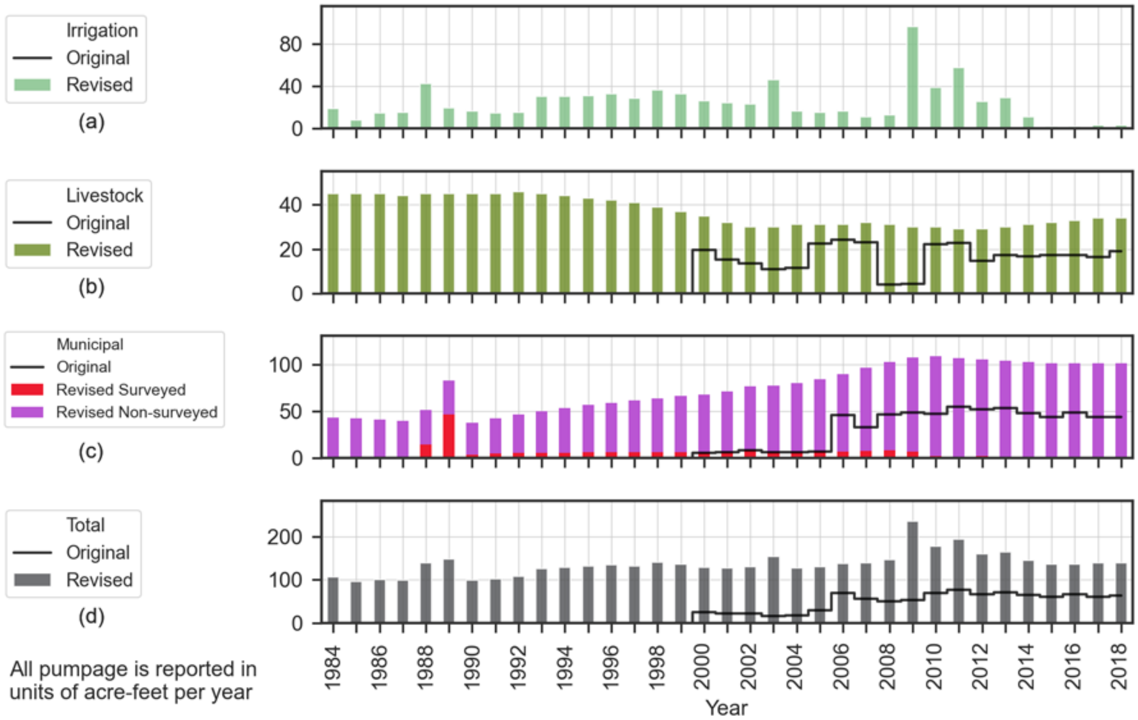


Figure 529. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Kendall County from 1984 through 2018.

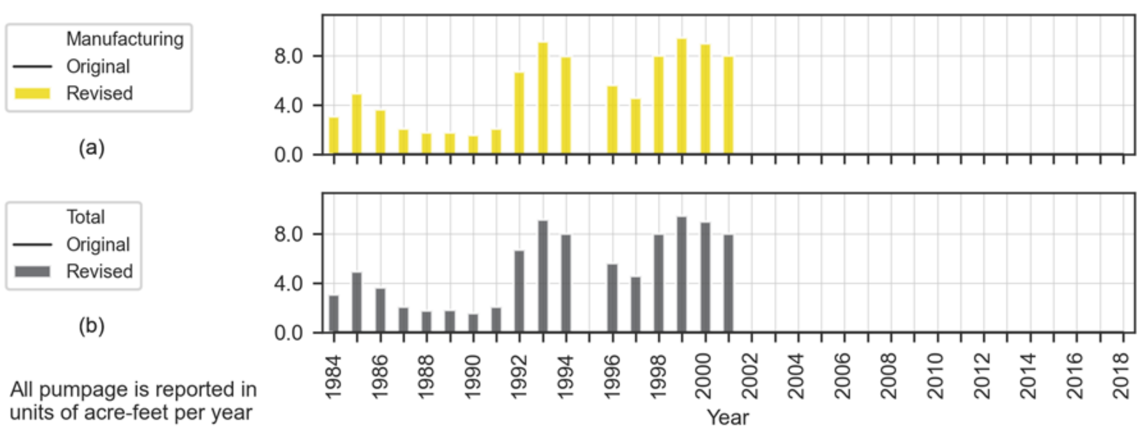


Figure 530. Original and revised estimates of groundwater pumping from the Edwards-(Balcones Fault Zone) Aquifer in Kendall County from 1984 through 2018.

Surveyed Municipal

Reported pumpage for municipal use from the Trinity (Hill Country) Aquifer within Kendall County was revised largely only through interpolation to fill occasional data gaps. Pumpage by the largest single user, the City of Boerne, demonstrated an increasing trend, with increasing inter-annual pumpage fluctuations. Such fluctuations are generally consistent with the increasingly variable temperature and precipitation patterns for the region. Pumpage reported for municipal use from the Edwards Trinity (Plateau) aquifer was generally smaller than the original TWDB Water Use Survey dataset, and contained an anomalous reporting of 45 acre-feet/year in 1989 by Merchants MHP. This entity did not report usage for years after 1989, and the accuracies of their reported values are unknown.

Non-Surveyed Municipal

Figure 531 and Figure 532 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kendall County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data for pumping from the Trinity (Hill Country) for non-surveyed municipal use. Our estimates for pumping from the Edwards-Trinity (Plateau) appear to follow similar trends as the TWDB Water Use Survey data although our estimates are about two times more than the TWDB Water Use Survey data. Our review of the available data suggested the pumping from this aquifer for non-surveyed municipal use is more than previous estimates suggest.

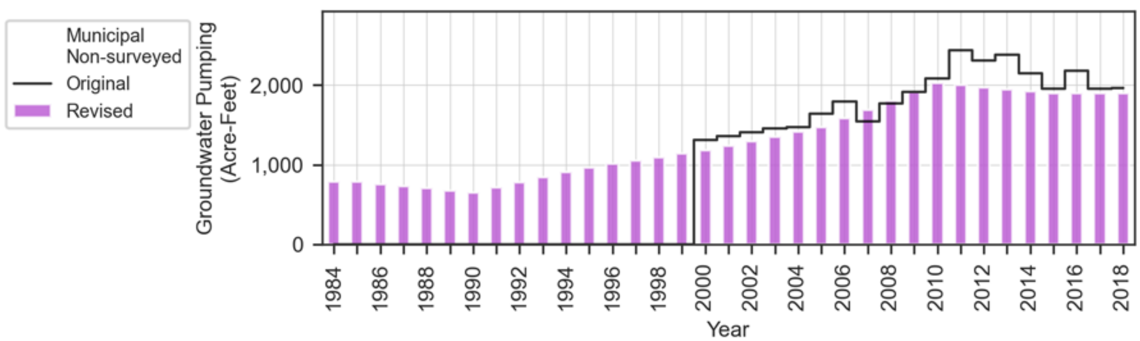


Figure 531. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Kendall County from 1984 through 2018.

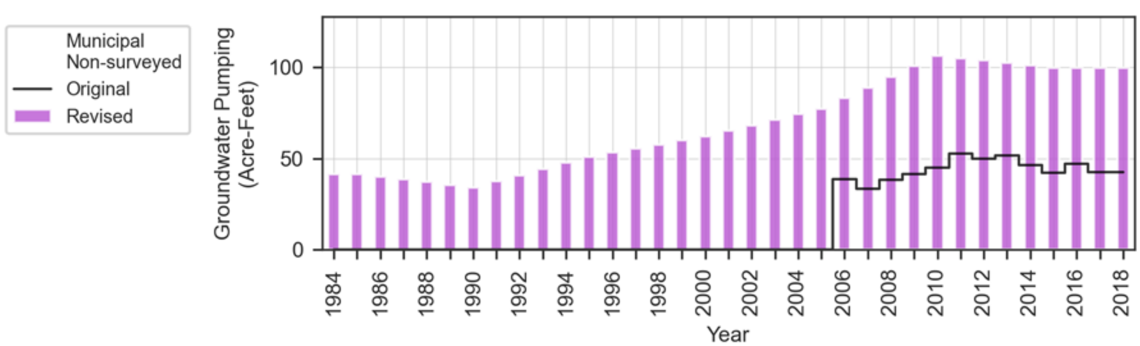


Figure 532. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Kendall County from 1984 through 2018.

Irrigation

The majority of Kendall County is underlain by the Trinity (Hill Country) Aquifer, yet is also underlain by the Edwards-Trinity (Plateau) Aquifer within the northern portion of the county. The Ellenburger-San Saba Aquifer and Hickory Aquifer are also located within the northern portion of the county, overlapping with the footprint of the Edwards-Trinity (Plateau) Aquifer. Wells within the county do appear to be geographically consistent with respect to the footprints of the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer.

Within the original TWDB Water Use Survey dataset, irrigation pumping in Kendall County only occurred from the Trinity (Hill Country) Aquifer. Reported pumpage ranged from 12 acre-feet per year in 2008 to over 800 acre-feet per year in multiple years (Figure 533). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Trinity (Hill Country) Aquifer in Hays County ranged from approximately 200 to 1,000 acre-feet per year over this study period. Surface water was used to meet irrigation needs within the county, and it reduced the computed groundwater needs in all years except from 2005 to 2007. Computed pumpage for irrigation ranged from 50 acre-feet per year to 864 acre-feet per year.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Kendall County ranged from approximately two to 97 acre-feet per year over this study period (Figure 534). Computed pumpage peaked in 2009 and decreased to consistently low levels from 2015 to 2018.

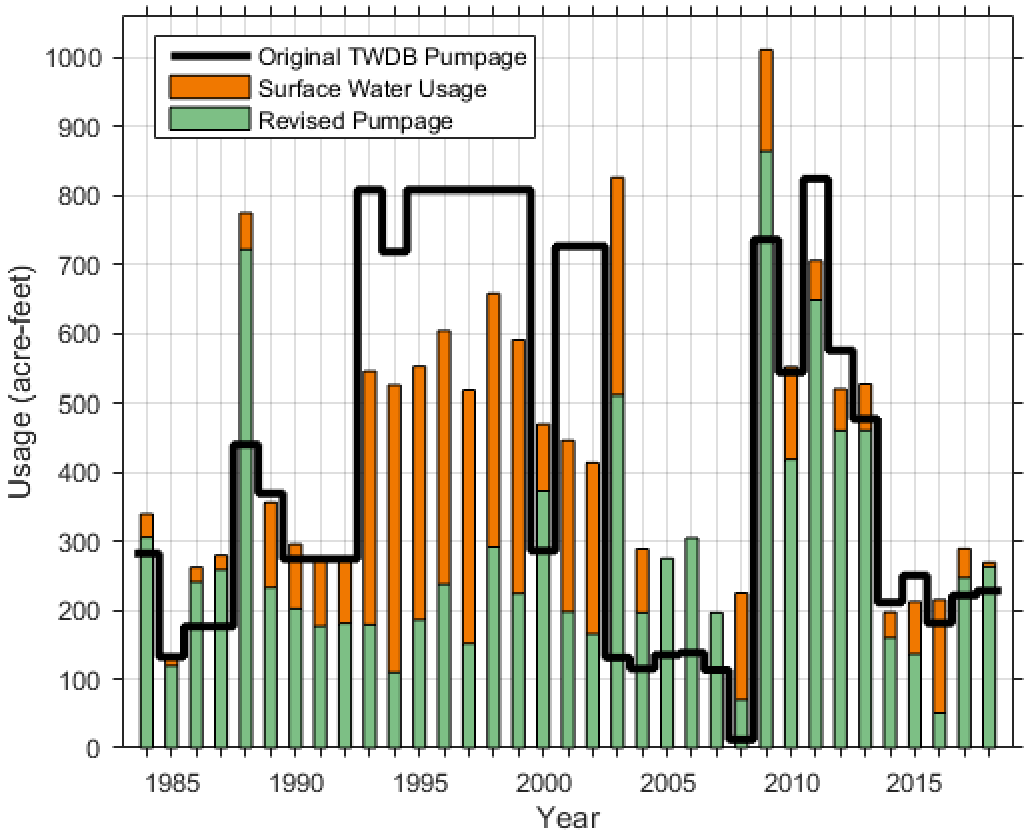


Figure 533. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Kendall County.

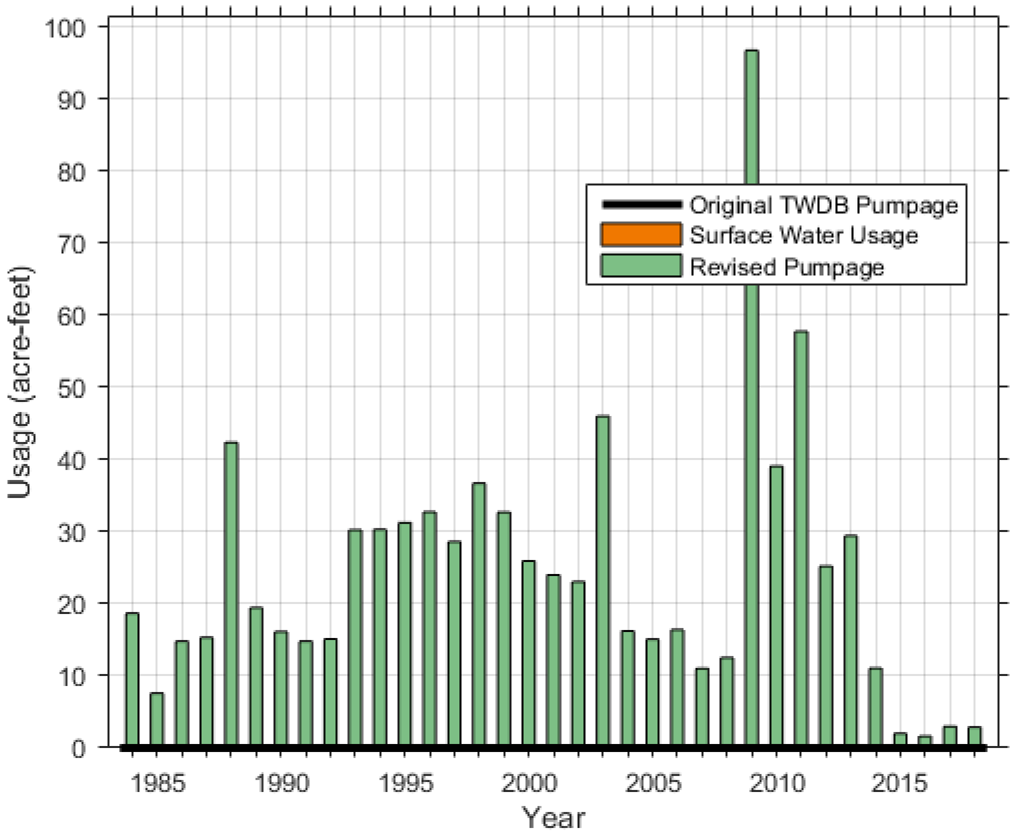


Figure 534. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Kendall County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Kendall County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Kendall County.

Mining

Figure 528d illustrates the changes in groundwater pumping associated with mining use from the Trinity (Hill Country) Aquifer in Kendall County during the study period. Neither enhanced oil recovery wells nor Water Use Survey are reported for Kendall County. Therefore, the U.S. Geological Survey mining use estimates were used which indicated that the entirety of groundwater pumping for mining in this area is sourced from the Trinity (Hill Country) Aquifer.

Manufacturing

Figure 528c illustrates the changes in groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Kendall County during the study period. The revisions reflect adjustments associated with the pre-2000 pumping estimates. We made no revisions to estimate groundwater pumping associated with manufacturing use from the Trinity (Hill Country) Aquifer in Kendall County after year 2000.

Livestock

Figure 528b and Figure 529b illustrate the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Kendall County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for the Trinity (Hill Country) Aquifer. Prior to year 2000, the TWDB Water Use Survey data does not contain estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Kendall County and our revisions add estimated pumping for this period.

5.2.25 Kerr County

Figure 535 and Figure 536 illustrate our revisions to the estimated in groundwater pumping from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kerr County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

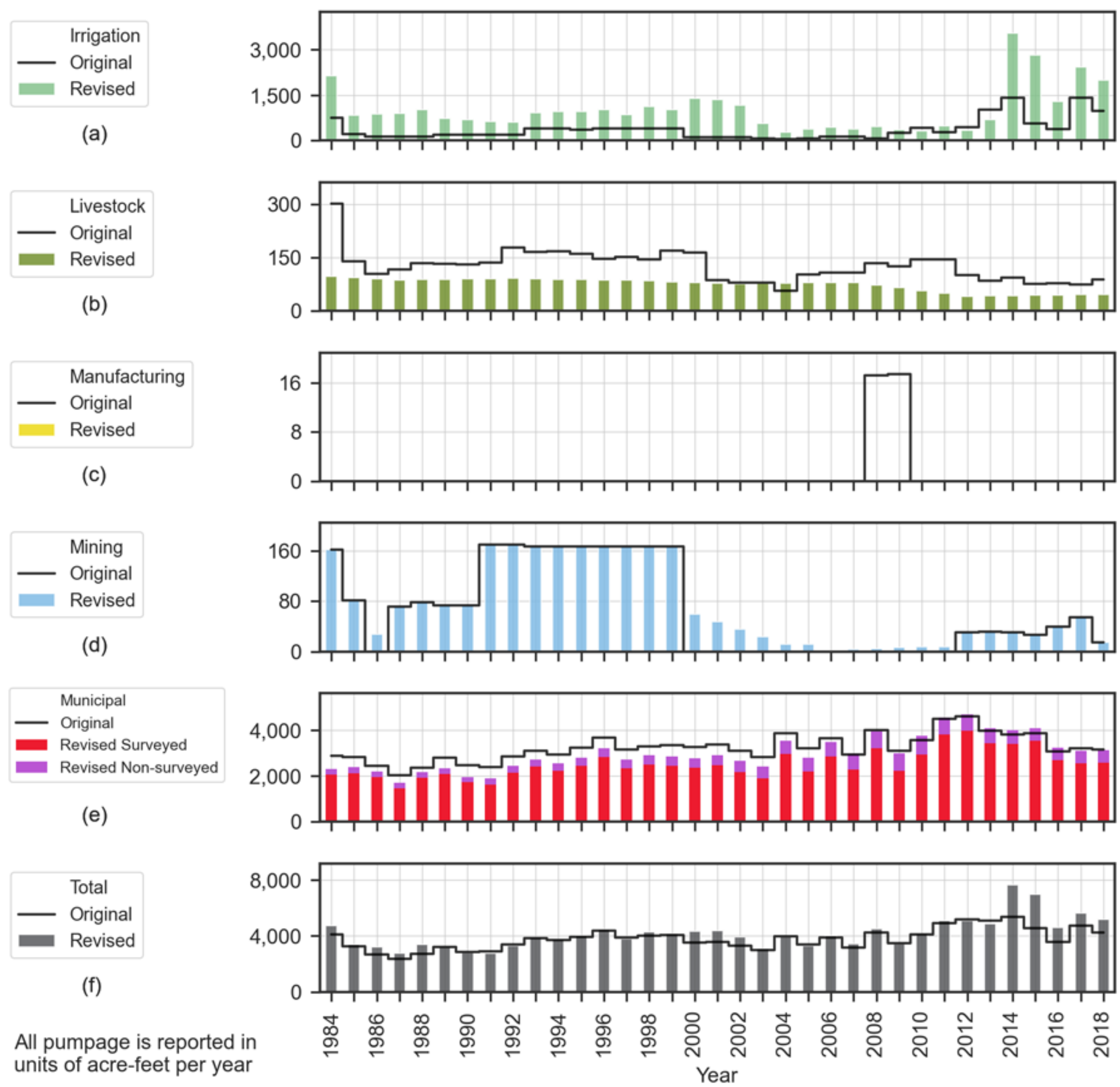


Figure 535. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Kerr County from 1984 through 2018.

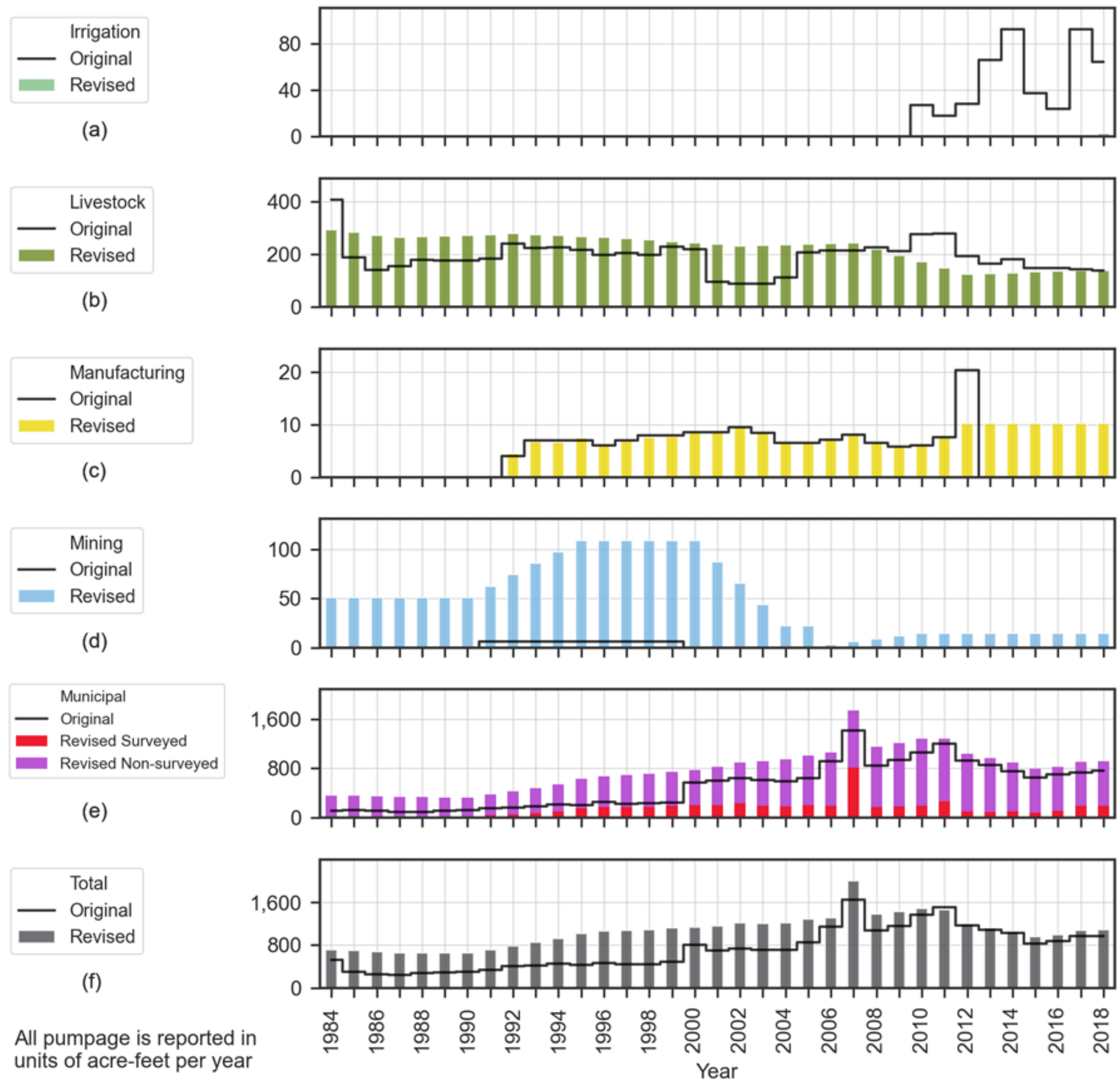


Figure 536. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Kerr County from 1984 through 2018.

Surveyed Municipal

Changes to the surveyed municipal pumpage from the Trinity (Hill Country) Aquifer within Kerr County were largely due to interpolation to fill data gaps, as well as due to re-allocation of pumpage previously attributed to "Other Aquifer." Such reallocations were based on identified locations of the reporting entity within the aquifer footprint in Kerr County. Data interpolation changes were made within the pumpage dataset for municipal reported use from the Edwards Trinity (Plateau) Aquifer. The anomalous 670 acre-feet/year pumpage for 2007 was reported by Vlasek Pump Company – Village West Water System, which reported pumpage on the order of 10 acre-feet/year for all years before and after 2007. In addition, we reclassified 2008-2009 reported pumpage by Generis Water Works from manufacturing (as in the original TWDB water use survey dataset) to municipal usage.

Non-Surveyed Municipal

Figure 537 and Figure 538 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kerr County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data for pumping for non-surveyed municipal use. While our estimates are lower than the Water Use Survey data for the Trinity (Hill Country) Aquifer, they are higher for the Edwards-Trinity (Plateau) Aquifer.

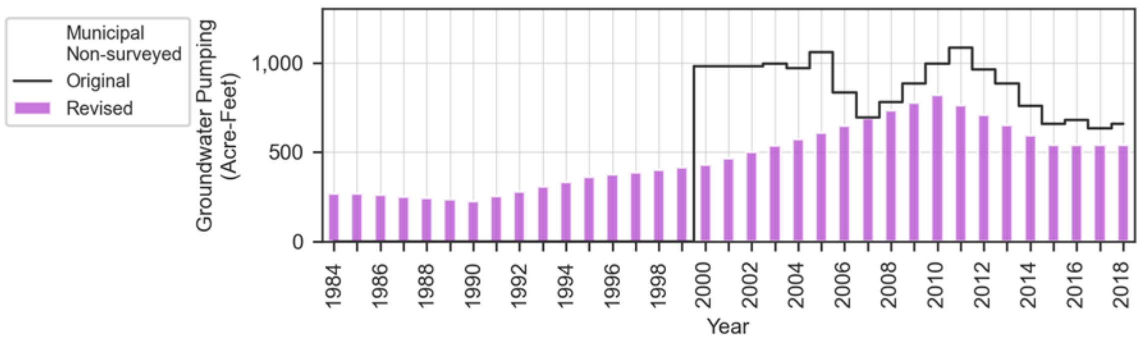


Figure 537. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Kerr County from 1984 through 2018.

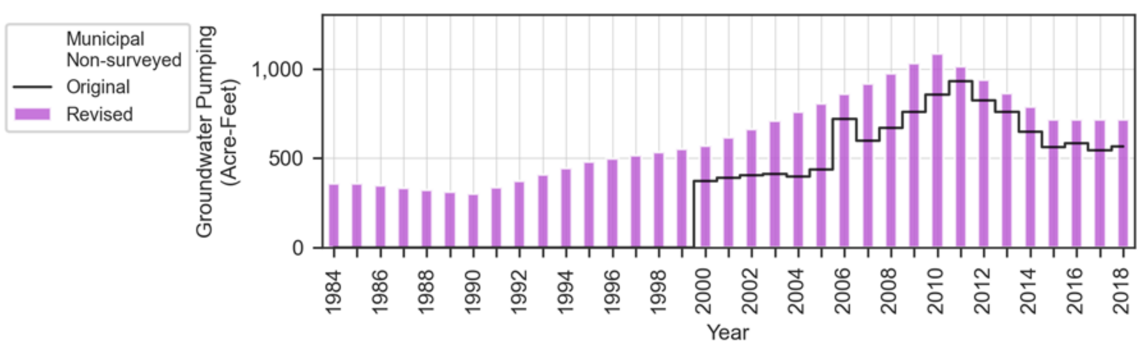


Figure 538. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Kerr County from 1984 through 2018.

Irrigation

Kerr County is underlain by the Edwards-Trinity (Plateau) Aquifer for most of the county footprint, with the Trinity (Hill Country) Aquifer underlying the majority of the eastern portion of the county. The Ellenburger-San Saba Aquifer and Hickory Aquifer also exist within the northeastern portions of the county. All wells identified within the county are screened within the Edwards-Trinity (Plateau) Aquifer or the Trinity (Hill Country) Aquifer. The wells screened within each aquifer are geographically distinct indicating irrigation pumpage from these wells is likely to be used to irrigate crops on the land surface within the aquifer footprint.

The original TWDB Water Use Survey data indicated that between zero acre-feet per year and 80 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation (Figure 539). Pumpage only was indicated from 2010 to 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Kerr County ranged from approximately 150 to 1,240 acre-feet per year over this study period. All of this irrigation demand could be satisfied using surface water, so that estimated groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Kerr County is zero for all study period years.

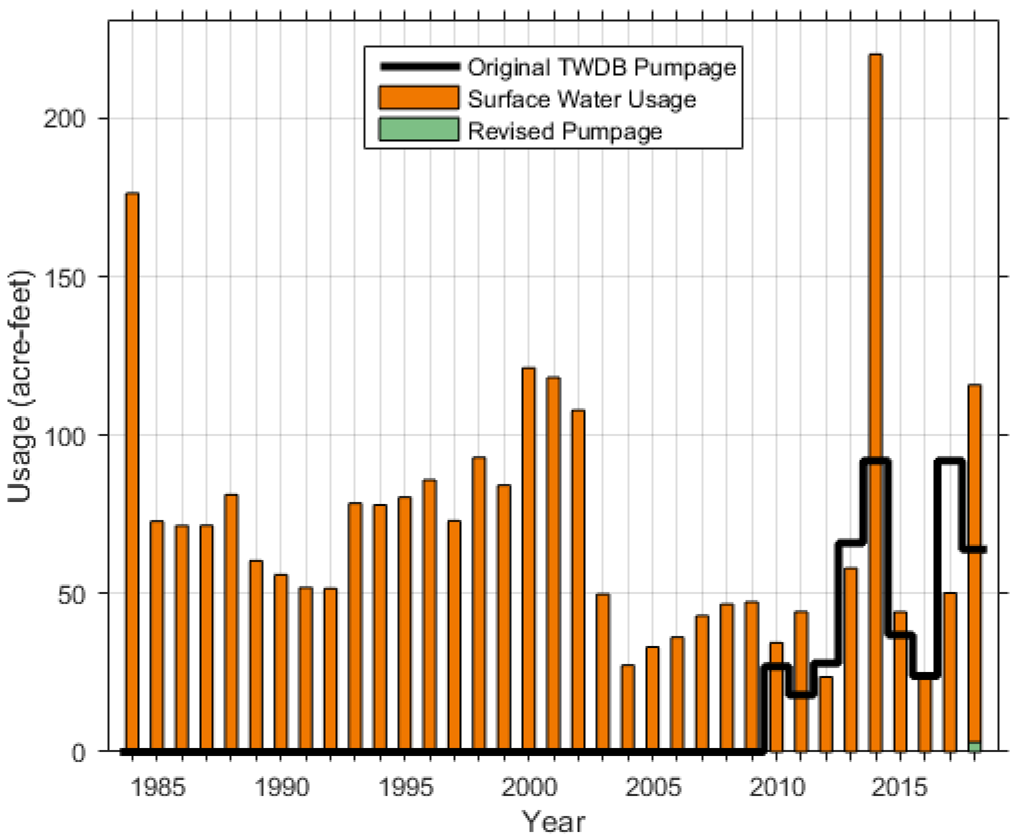


Figure 539. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Kerr County.

The original TWDB Water Use Survey data indicated that between 50 acre-feet per year and 1,420 acre-feet per year was historically pumped from the Trinity (Hill Country) Aquifer for irrigation (Figure 540). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Trinity (Hill Country) Aquifer in Kerr County ranged from approximately 390 to 3,660 acre-feet per year over this study period. Some of the irrigation demand was met using surface water for each year of the study period. Groundwater pumpage for irrigation above the footprint of the Trinity (Hill Country) Aquifer in Kerr County ranged from approximately 285 to 3,540 acre-feet per year over this study period. Both the TWDB Water Use Survey annual pumpage and the revised total pumpage show increased pumpage in 1984, followed by lower but consistent pumpage through 2002 and increased pumpage from 2013 to 2018.

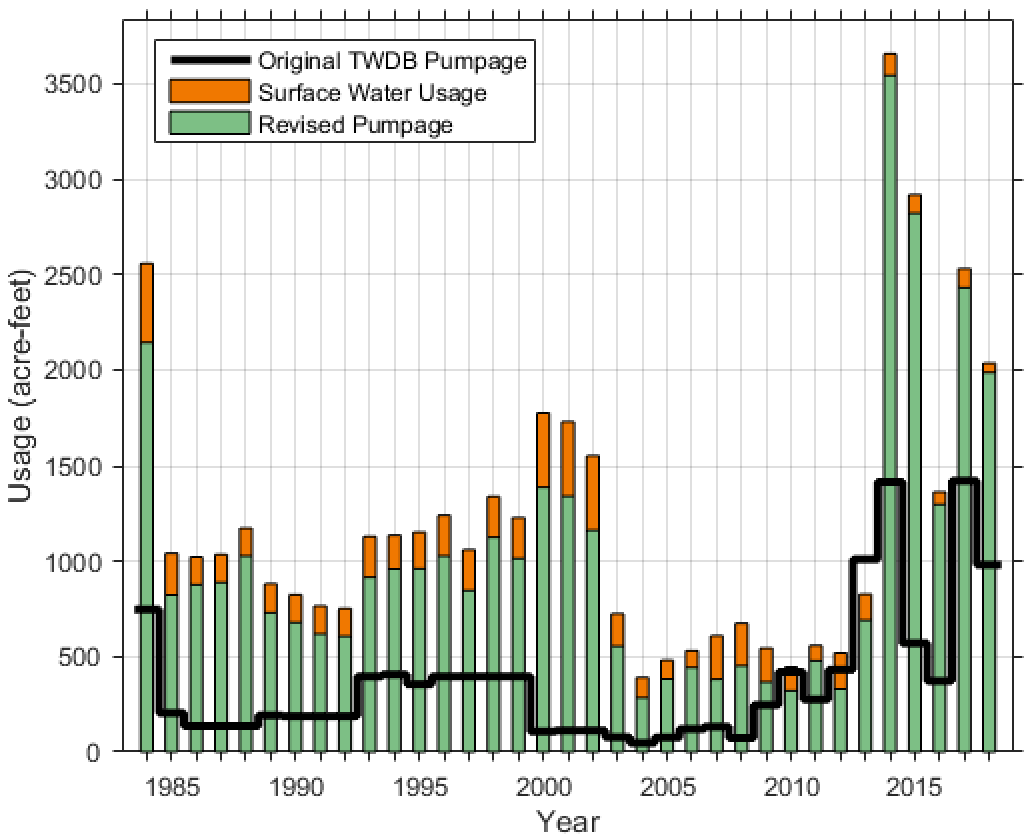


Figure 540. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Kerr County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Kerr County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Kerr County.

Mining

Figure 535d and Figure 536d illustrate the changes in groundwater pumping associated with mining use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kerr County during the study period. No enhanced oil recovery wells were reported within the study area. Therefore, we used the Water Use Survey data and the U.S. Geological Survey estimates to create the revised pumpage for mining use dataset. We estimate approximately 61 percent of groundwater is sourced from the Edwards-Trinity (Plateau) Aquifer and the remaining is sourced from the Trinity (Hill Country) Aquifer.

Manufacturing

As illustrated in Figure 533c, the revision reflects adjustments for the Generis Water Works Company which reported pumping associated with manufacturing use in 2008 and 2009 from the Trinity Hill Country Aquifer. The water use was changed from manufacturing to municipal.

Figure 536c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Kerr County during the study period. The revision reflects adjustments for the “James Avery Craftsman Inc – Kerrville Plant” data. Since records indicate the business is still active, we reduced the 2012 pumping by half and assumed the 2012 volume for subsequent years.

Livestock

Figure 535b and Figure 536b illustrate the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kerr County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer and slightly lower for the Trinity (Hill Country) Aquifer.

5.2.26 Kimble County

Figure 541 illustrates our revisions to the estimates in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Kimble County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

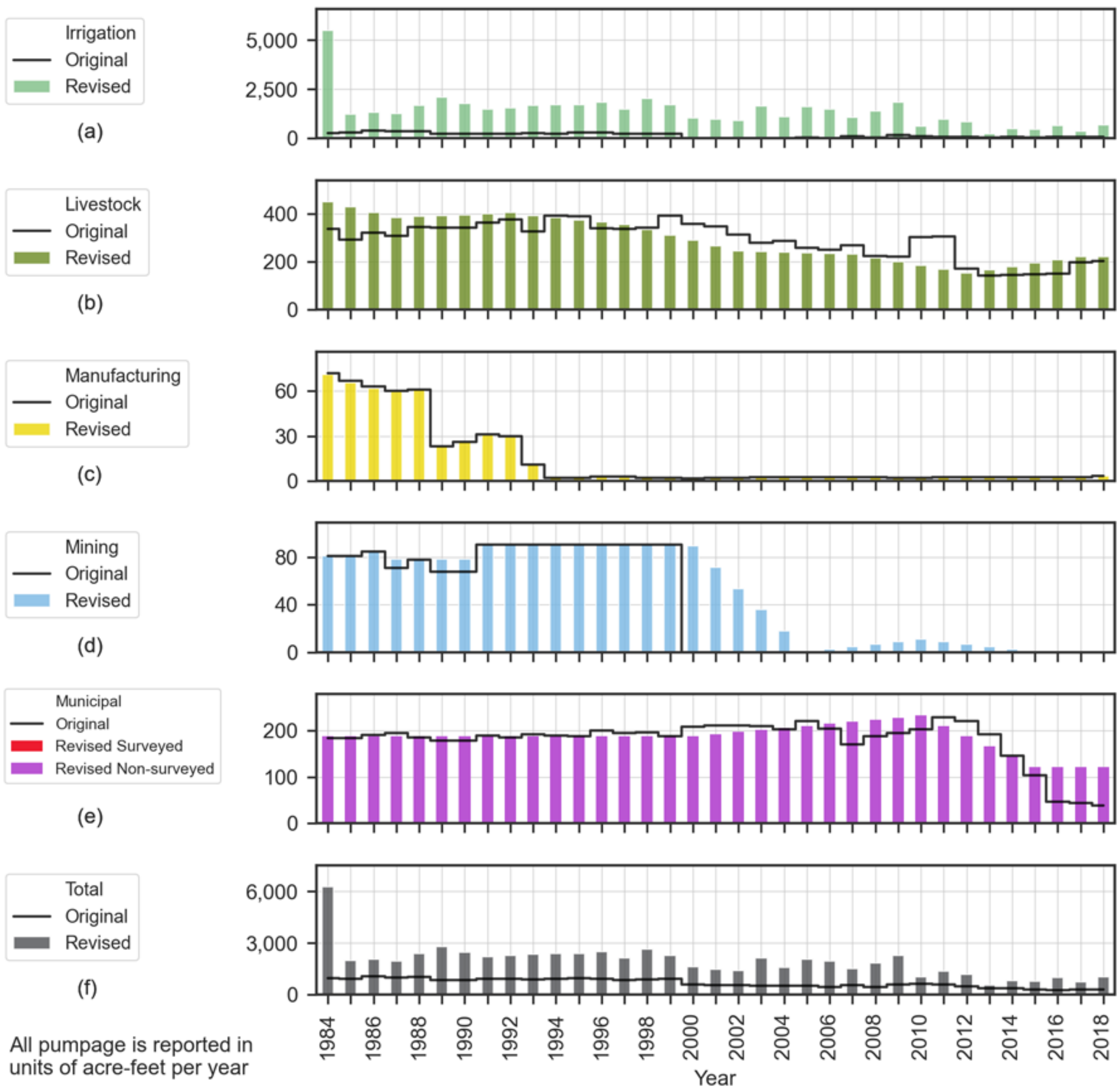


Figure 541. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Kimble County from 1984 through 2018.

Surveyed Municipal

The TWDB Water Use Survey dataset does not contain any reported municipal pumpage in Kimble County for the 1984-2018 study period. It does contain pumpage amounts of nearly 1,000 acre-feet/year for the City of Junction between 1955 and 1975. Per the 2016 Region F regional water plan, the City of Junction meets its municipal needs through usage of surface water sources.

Non-Surveyed Municipal

Figure 542 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Kimble County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data for pumping for non-surveyed municipal use. While the TWDB Water Use Survey data includes up to about three acre-feet of pumping from 2005 onwards, our estimates do not include any non-surveyed municipal use pumping from the Trinity (Hill Country) in Kimble County.

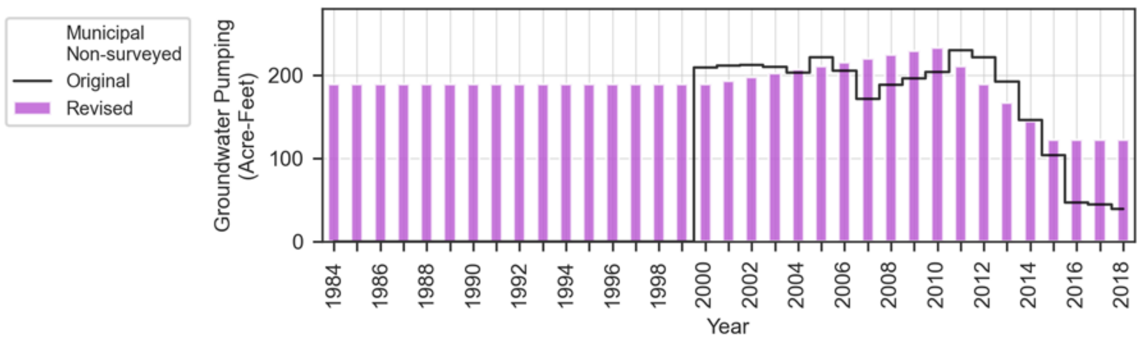


Figure 542. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Kimble County from 1984 through 2018.

Irrigation

Kimble County is nearly entirely underlain by the Edwards-Trinity (Plateau) Aquifer, with the aquifer not present only on small portions of the county along its northern and northeastern borders. The county is also underlain by the Ellenburger-San Saba Aquifer, the Hickory Aquifer, and the Marble Falls Aquifer. Wells identified within Kimble County are predominantly screened within the Edwards-Trinity (Plateau) Aquifer, although some wells in the northeast portion of the county are screened within the Ellenburger-San Saba Aquifer. There is a slight geographic overlap in the general locations of wells screened in each of these aquifers along north-eastern portion of Kimble County.

The original TWDB Water Use Survey data indicated that between 10 acre-feet per year and 400 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation (Figure 543). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Kimble County ranged from approximately 1,410 to 7,170 acre-feet per year over this study period. Some of the irrigation demand was met using surface water for each year of the study period, with greater surface water usage reported after 2003. Groundwater pumpage for irrigation above the footprint of the Edwards-Trinity (Plateau) Aquifer in Kimble County peaked at 5,465 acre-feet per year in 1984, and then ranged from 1,000 acre-feet per year to 2,100 acre-feet per year through 2009. From 2010 to 2018, pumpage was generally lower, ranging from 220 acre-feet per year to 980 acre-feet per year.

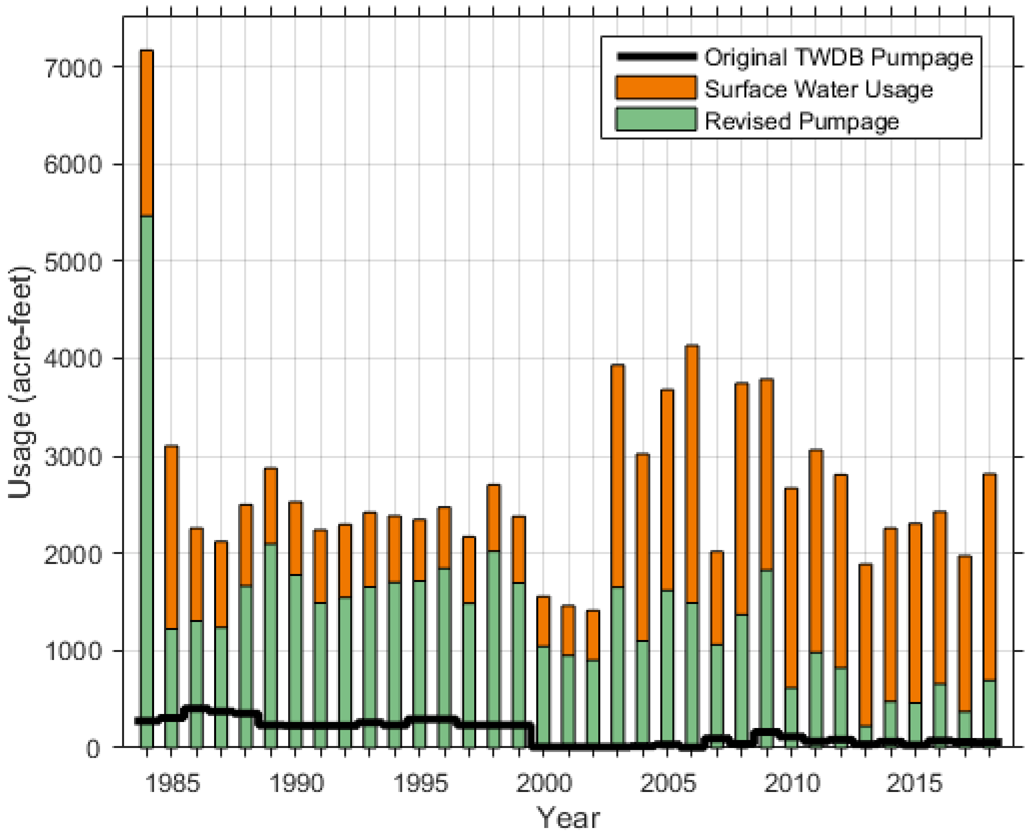


Figure 543. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Kimble.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Kimble County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Kimble County.

Mining

Figure 541d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Kimble County during the study period. The U. S. Geological Survey mining estimates were the only available dataset for developing the revised mining water use values. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 541c illustrates the groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Kimble County during the study period. We identified no changes for this use.

Livestock

Figure 541b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Kimble County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer. The original TWDB Water Use Survey data estimated a maximum of two acre-feet of groundwater pumping from the Trinity (Hill Country) Aquifer for livestock use. However, the footprint of Trinity (Hill Country) Aquifer does not extend to Kimble County. Our revisions do not indicate any groundwater pumping occurs from the Trinity (Hill Country) Aquifer for livestock use in Kimble County.

5.2.27 Kinney County

Figure 544 and Figure 545 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kinney County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

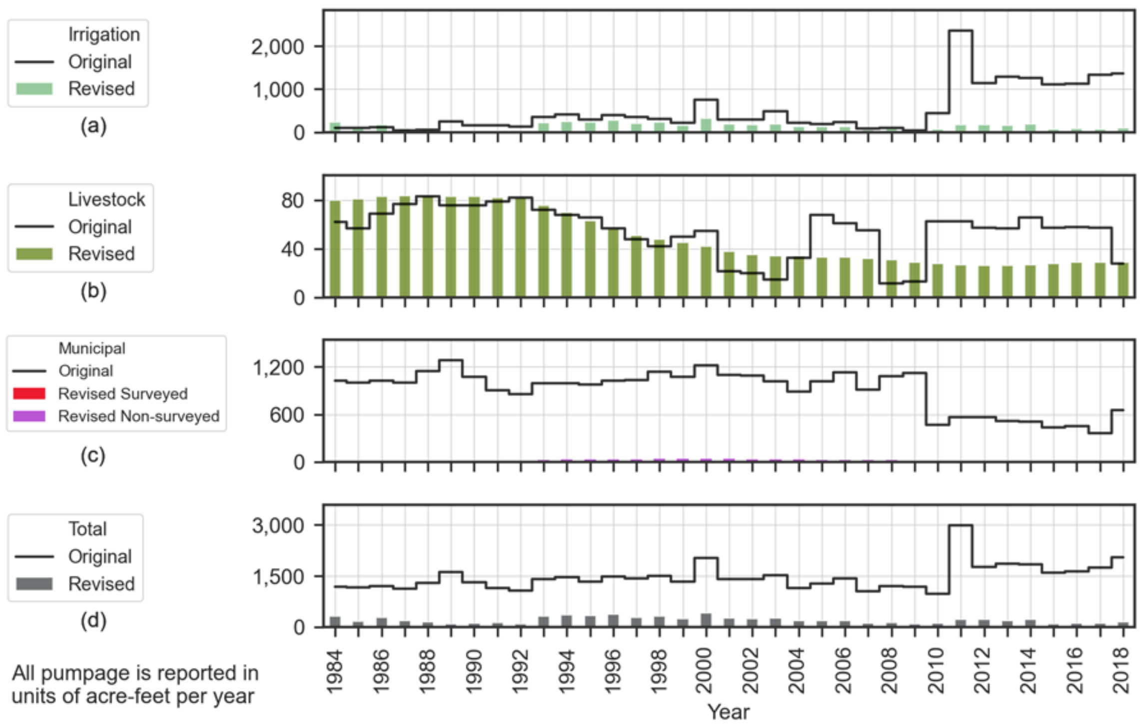


Figure 544. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Kinney County from 1984 through 2018.

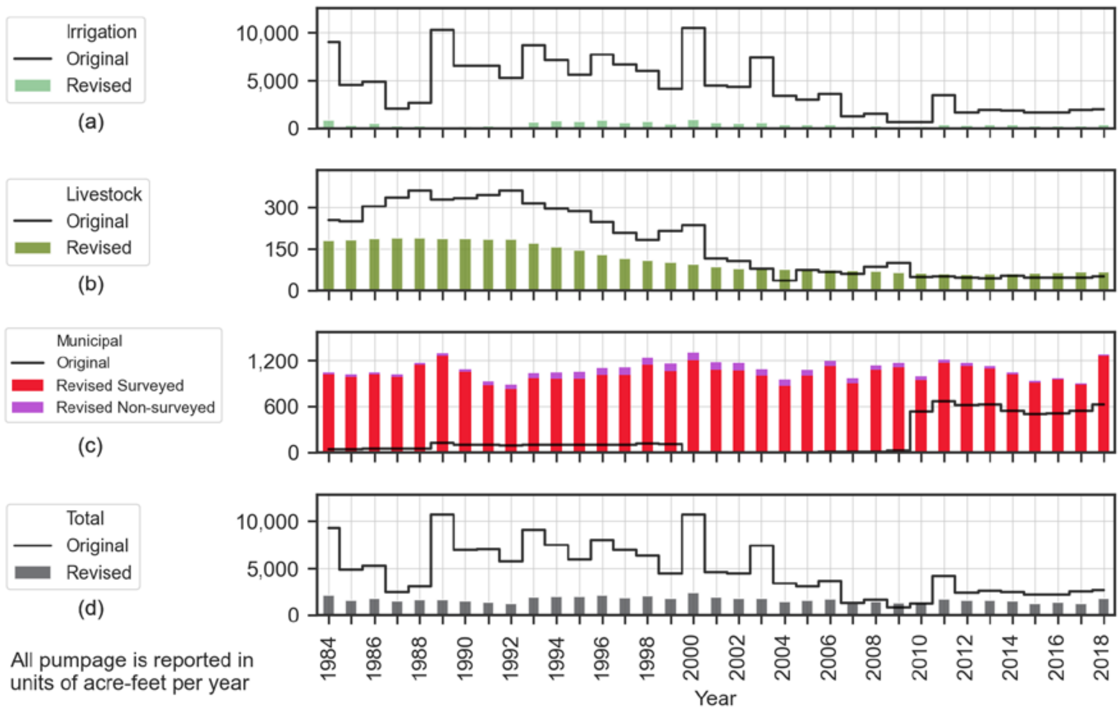


Figure 545. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Kinney County from 1984 through 2018.

Surveyed Municipal

All entities reporting municipal pumpage were reallocated to the Edwards Trinity (Plateau) Aquifer based on the entity location within the footprint of the aquifer as defined by the TWDB. As such, the revised dataset contains pumpage only from the Edwards-Trinity (Plateau) Aquifer and not from the Edwards (Balcones Fault Zone) Aquifer.

Non-Surveyed Municipal

Figure 546 and Figure 547 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kinney County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data from 2010 onwards. Our estimates are higher than the Water Use Survey data both aquifers prior to 2010. Our review of the available data suggested the pumping for this use is more than previous estimates suggest for this time period.

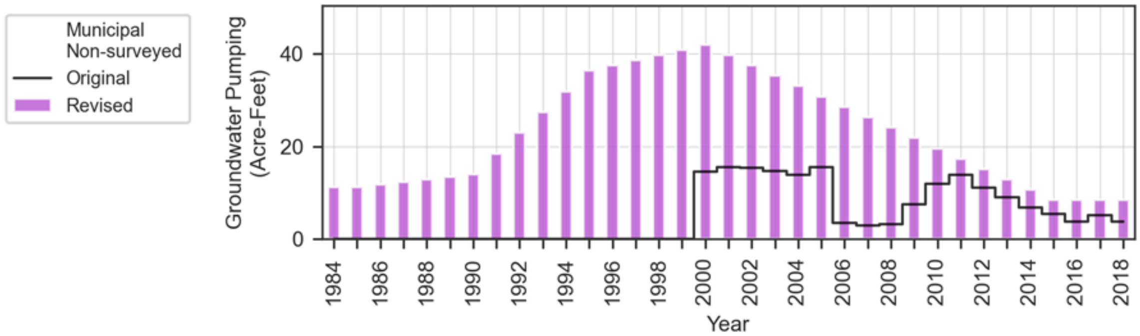


Figure 546. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Kinney County from 1984 through 2018.

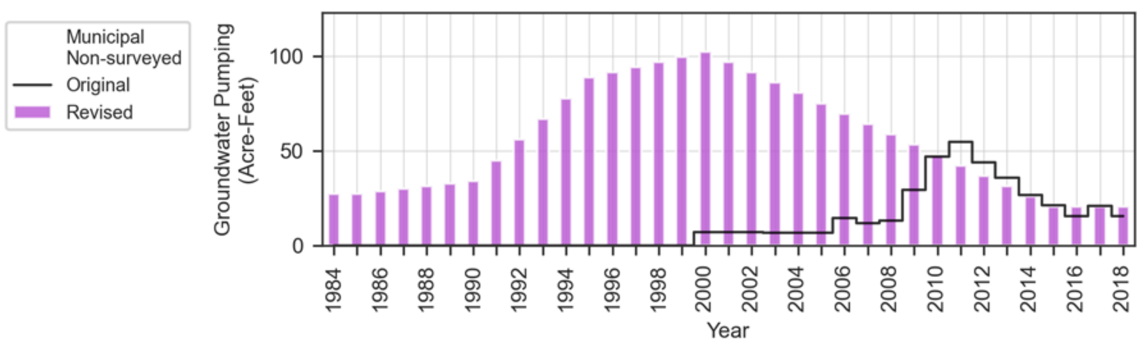


Figure 547. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Kinney County from 1984 through 2018.

Irrigation

Kinney County is underlain by the Edwards-Trinity (Plateau) Aquifer within the northwestern corner of the county and along the entire northern county border with Edwards County. The Edwards (Balcones Fault Zone) Aquifer extends into Kinney County along the center of the county's eastern boundary with Uvalde County. The county aquifers do not overlap in geographic extent, and wells within each aquifer footprint are screened within only their respective aquifers.

Original TWDB Water Use Survey estimates for pumpage from the Edwards-Trinity (Plateau) Aquifer within Kinney County ranged from approximately 1,000 acre-feet per year to over 10,000 acre-feet per year (Figure 548). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Kinney County would have been significantly smaller, ranging from 80 acre-feet per year to approximately 1,400 acre-feet per year. Surface water usage for irrigation occurred in some years prior to 1993 and reduced the groundwater pumpage accordingly. The original TWDB Water Use Survey dataset appears to have routinely distributed total county irrigation pumpage within Kinney County based on a set distribution amongst the three aquifers. From 2000-2009, 5% of pumpage was assigned to the Edwards (Balcones Fault Zone) Aquifer, 74% to the Edwards-Trinity (Plateau) Aquifer, and 21% to "Other Aquifer." From 2010-2018, 35% of total pumpage was allocated to the Edwards (Balcones Fault Zone) Aquifer, 51% to the Edwards-Trinity (Plateau) Aquifer, and 14% to "Other Aquifer." Irrigation estimation based on crop and climactic patterns does not conform to these set distributions. We could not identify an explanation for the large decrease in irrigation pumpage from the Edwards Trinity (Plateau) Aquifer between the original TWDB water use survey data and the revised pumpage data.

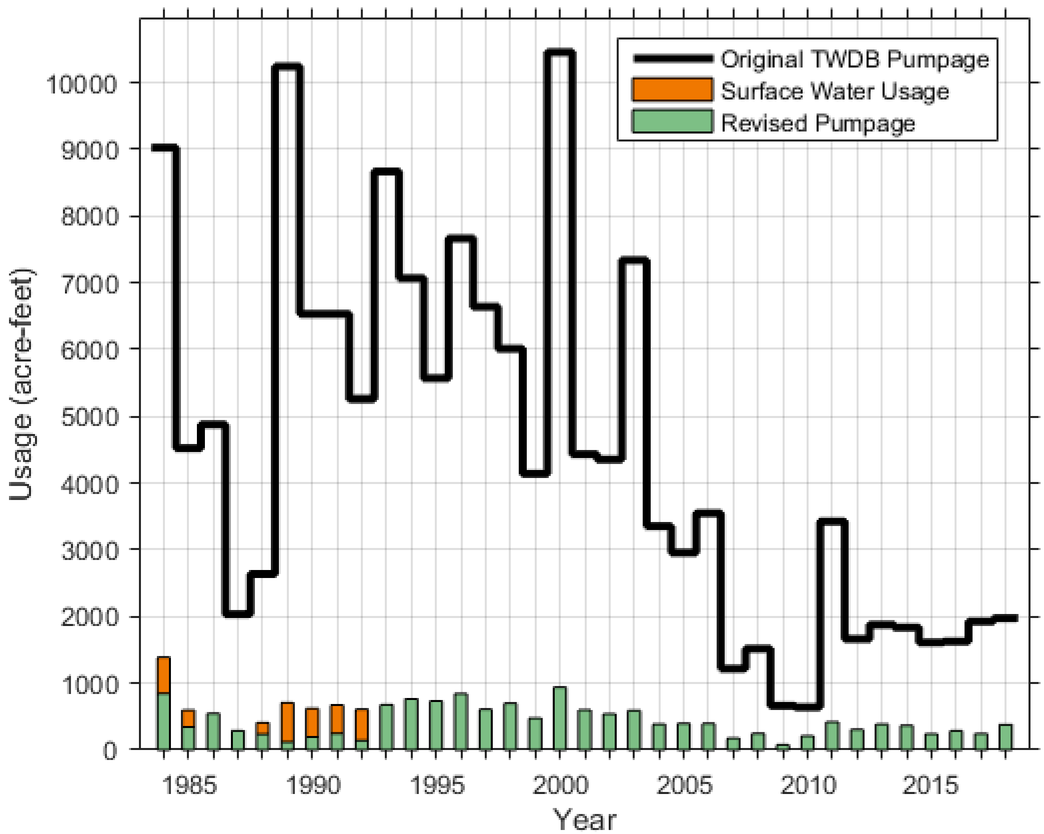


Figure 548. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Kinney County.

Comparisons between the original TWDB Water Use Survey estimates and revised pumpage estimates for irrigation from the Edwards (Balcones Fault Zone) Aquifer in Kinney County are better than those from the Edwards-Trinity (Plateau) Aquifer (Figure 549). General agreement in the magnitude of the annual water demands is found from 1984 to 2009. After 2009, however, original TWDB water use estimates increase from near 100 acre-feet per year to between 1,000 acre-feet per year and 1,500 acre-feet per year, with an anomalous peak estimate of approximately 2,350 acre-feet per year in 2011. Revised estimates based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards (Balcones Fault Zone) Aquifer in Kinney County are significantly smaller over this period, ranging from 70 acre-feet per year to 200 acre-feet per year.

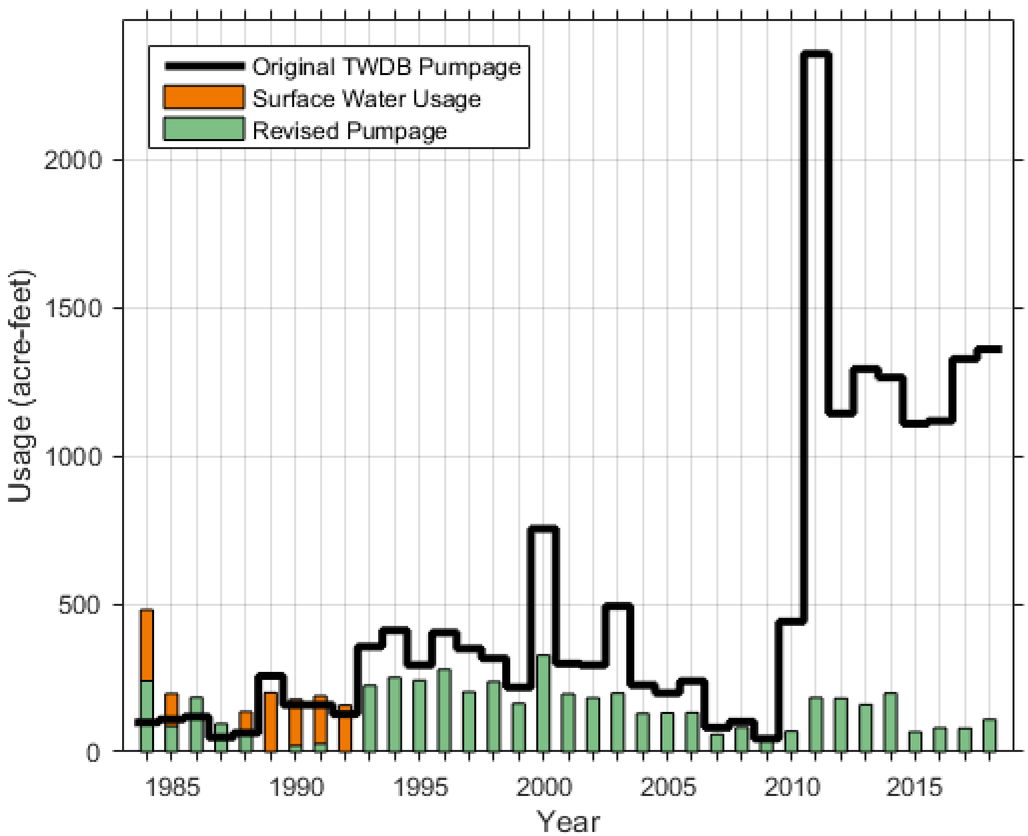


Figure 549. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Kinney County.

It is possible that crop distribution data is inaccurate for Kinney County for the time period from 2010 to 2018. If such data underrepresented crop growth during that time, then the revised pumpage results would be skewed lower per the adopted methodology.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Kinney County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Kinney County.

Mining

For the study period and the study area aquifers, there are no enhanced oil recovery wells, Water Use Survey data, or U. S. Geological Survey data available for Kinney County. Also, there is no indication unreported groundwater pumping associated with mining use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for mining use in Kinney County.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Kinney County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Kinney County.

Livestock

Figure 544b and Figure 545b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Kinney County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for both the Edwards (Balcones Fault Zone) Aquifer and the Edwards-Trinity (Plateau) Aquifer.

5.2.28 Loving County

Figure 550 illustrates our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer in Loving County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

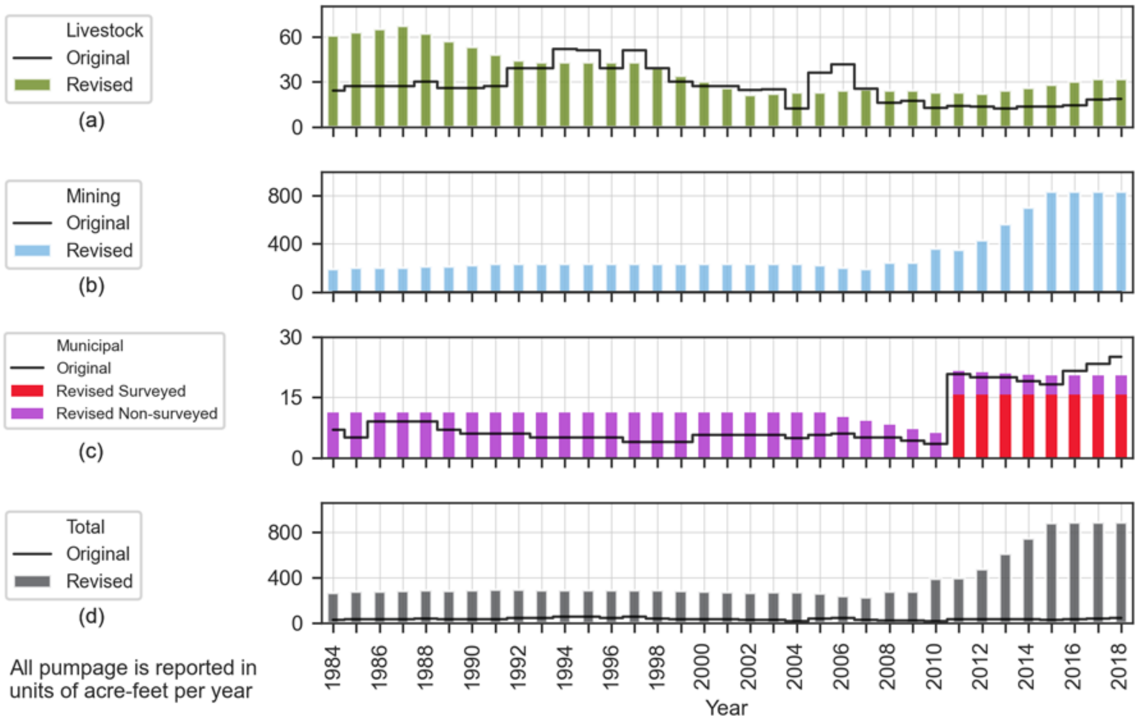


Figure 550. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Loving County from 1984 through 2018.

Surveyed Municipal

Pumpage has only been reported by Loving County WS for the years 2011-2018, and it is unlikely that the reported quantities are correct as they are exactly 15.7035 acre-feet for all years.

Non-Surveyed Municipal

Figure 551 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer in Loving County during the study period. Our estimates are more than the TWDB Water Use Survey data through 2015. While our review of the available data suggested the pumping for this use is more than previous estimates suggest prior to 2015, pumping is less than previous estimates suggest after 2015.

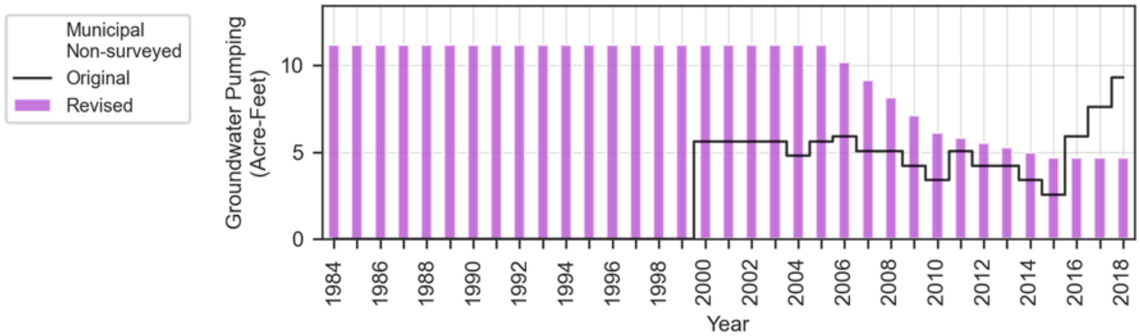


Figure 551. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Loving County from 1984 through 2018.

Irrigation

Loving County is nearly entirely underlain by the Pecos Valley Aquifer with the Rustler Aquifer and Dockum Aquifer (which are not subjects of this study) underlying the Pecos Valley Aquifer. The original TWDB Water Use Survey data did not contain any irrigation pumpage estimates for Loving County. The revised pumpage dataset confirms the lack of irrigation pumpage within the county, due largely to the lack of reported crop acreage historically. Data indicated a maximum of 300 acres of irrigated acreage occurred within any given year, and irrigated locations were not identifiable within the CropScape data (USDA-NASS, 2008-2019) used during this study.

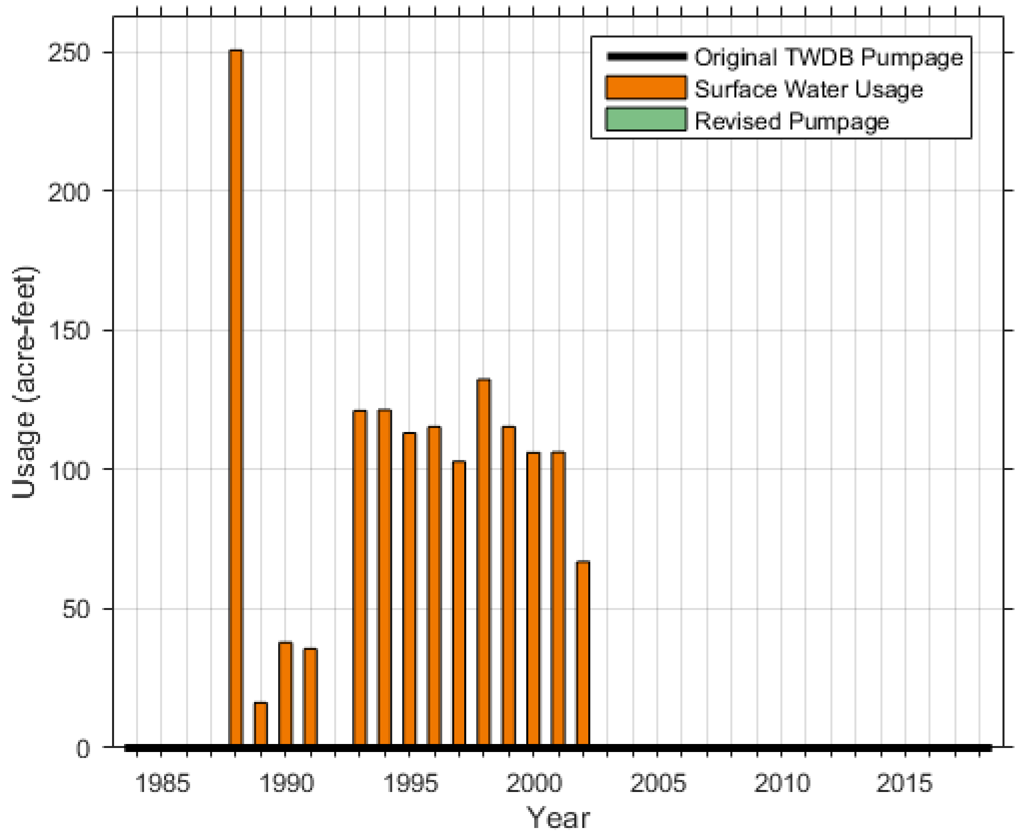


Figure 552 Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Loving County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Loving County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Loving County.

Mining

Figure 550b illustrates the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer in Loving County during the study period. There were 94 active enhanced oil recovery wells in Loving County in 1980 which increased to 105 wells by 2020. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Pecos Valley Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Loving County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Loving County.

Livestock

Figure 550a illustrates the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer in Loving County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for the Pecos Valley Aquifer.

5.2.29 Martin County

Figure 553 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Martin County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

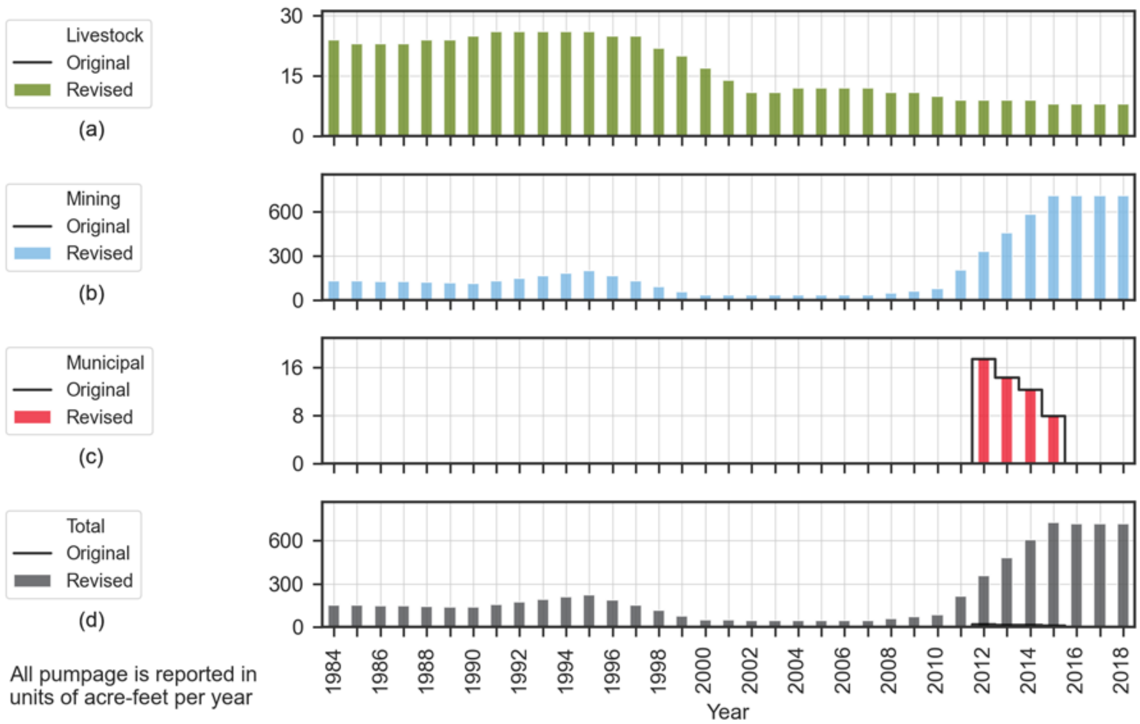


Figure 553. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Martin County from 1984 through 2018.

Surveyed Municipal

The original TWDB water use survey dataset contained pumping for Grady ISD in Martin County from 2012-2015. We determined that Grady ISD is not located within or near Martin County, and assessed this original data is improperly attributed. We revised the data so that no pumpage for municipal purposes is used from the Edwards Trinity (Plateau) Aquifer within Martin County.

Non-Surveyed Municipal

For the study period and the study area aquifers, there is no groundwater pumping associated with non-surveyed municipal use in Martin County. Also, there is no indication unreported groundwater pumping associated with non-surveyed municipal use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for non-surveyed municipal use in Martin County.

Irrigation

Martin County is underlain by the Edwards-Trinity (Plateau) Aquifer along its southern border with Midland County. The Ogallala Aquifer is also present throughout the entire county, and the Dockum Aquifer is present underneath the western portion of the county along the entire border with Andrews County.

The original TWDB Water Use Survey dataset indicated that all pumpage for irrigation in Martin County was derived from the Ogallala Aquifer. This is consistent with the theory that wells will be drilled into shallower, better producing aquifers whenever possible, which would favor usage of the Ogallala Aquifer over the Edwards-Trinity (Plateau) Aquifer within Martin County. Review of the submitted drillers reports and TWDB Database wells from the TWDB groundwater data viewer confirms that numerous irrigation wells exist within the Edwards-Trinity (Plateau) Aquifer footprint within Martin County, but that all of these wells are noted to be screened within the Ogallala Aquifer. As such, the revised pumpage dataset for Martin County does not contain any irrigation pumpage from the Edwards-Trinity (Plateau) Aquifer.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Martin County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Martin County.

Mining

Figure 553b illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Martin County during the study period. The number of active enhanced oil recovery wells in Martin rose from four to 27 between the years 1980-2020. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Martin County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Martin County.

Livestock

Figure 553a illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Martin County during the study period. Our revised estimates based on the animal count data reported by the agricultural census indicate that there is pumpage for livestock from the Edwards-Trinity (Plateau) Aquifer that does not surpass 30 acre-feet in Martin County.

5.2.30 Mason County

Figure 554 and Figure 555 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Mason County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

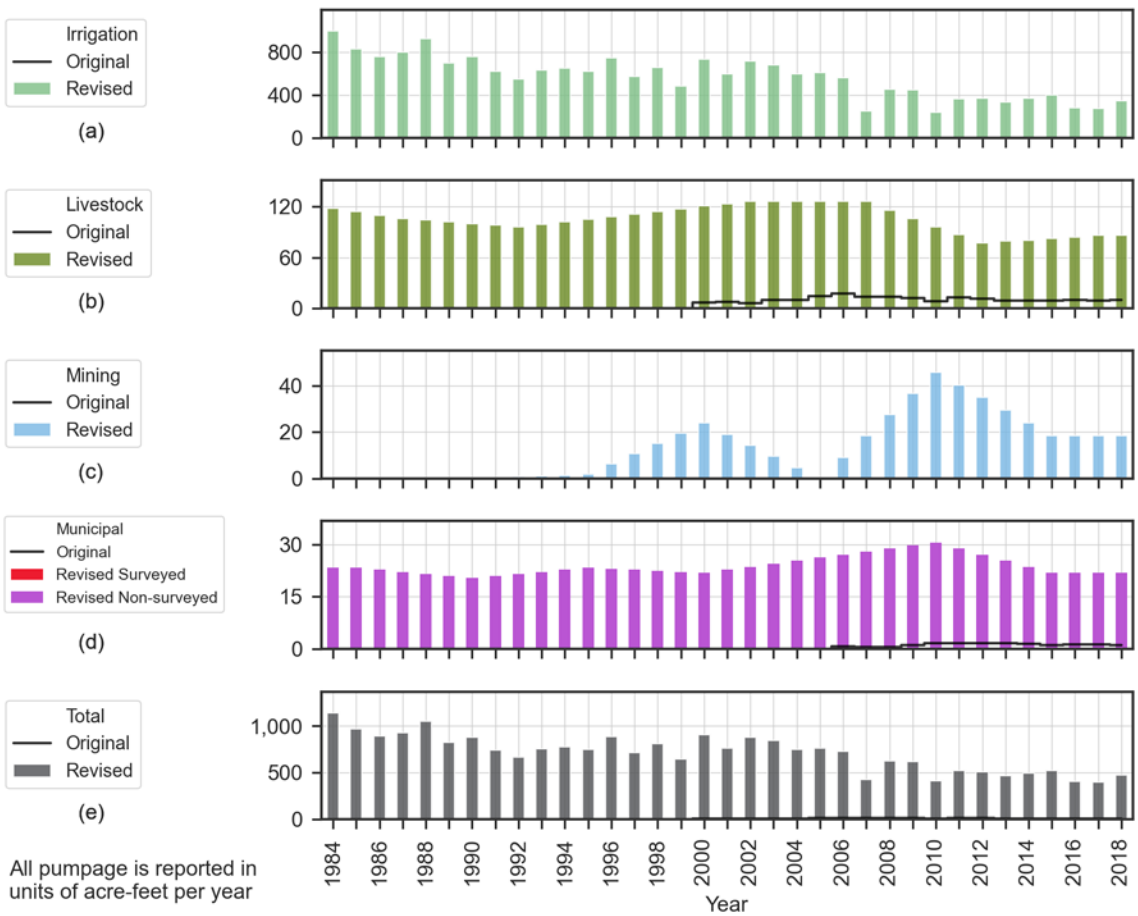


Figure 554. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Mason County from 1984 through 2018.

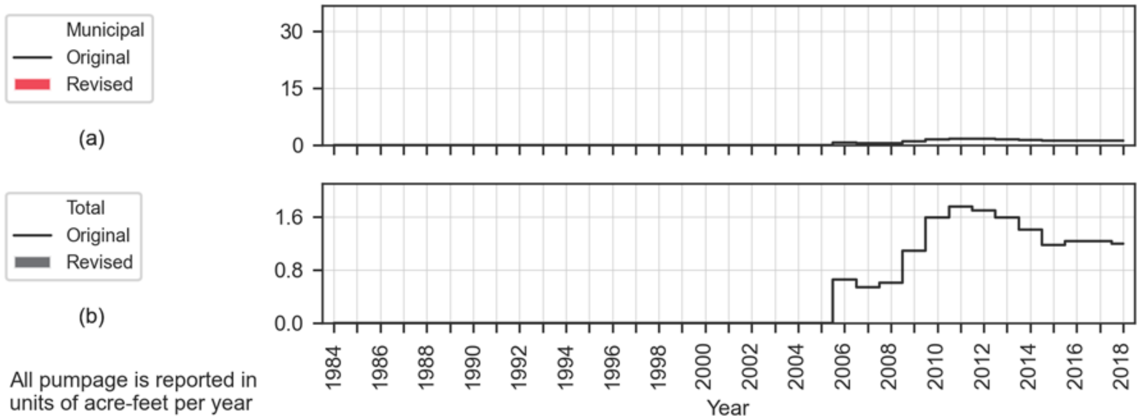


Figure 555. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Mason County from 1984 through 2018.

Surveyed Municipal

The only entity reporting municipal pumpage in Mason County is the City of Mason, and its pumpage is derived from the Hickory Aquifer. No surveyed municipal pumpage occurs from the Trinity (Hill Country) Aquifer or Edwards Trinity (Plateau) Aquifer within Mason County.

Non-Surveyed Municipal

Figure 556 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Mason County during the study period. Our estimates are one magnitude of order more than the TWDB Water Use Survey data. Our review of the available data suggested the pumping for this use is more than previous estimates suggest. While the TWDB Water Use Survey data includes up to about two acre-feet of pumping from the Trinity (Hill Country) Aquifer, our estimates do not include any non-surveyed municipal use pumping from this aquifer in Mason County.

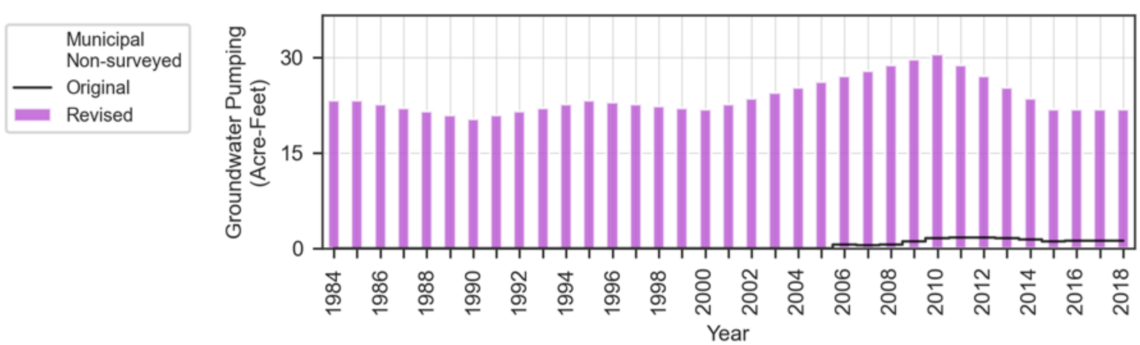


Figure 556. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Mason County from 1984 through 2018.

Irrigation

Portions of Mason County are underlain by the edges of the Edwards-Trinity (Plateau) Aquifer. The county is also underlain by the Ellenburger-San Saba Aquifer, the Hickory Aquifer, and the Marble Falls Aquifer. The original TWDB Water Use Survey dataset does not contain data allocating irrigation pumpage to the Edwards-Trinity (Plateau) Aquifer, and only allocates pumping of between 100 acre-feet per year to 267 acre-feet per year to an "Other Aquifer."

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater pumpage needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer ranged from approximately 1,000 acre-feet per year (in 1984) to less than 300 acre-feet per year in 2010 (Figure 557). In general, there is a decreasing historical pumpage trend, with inter-annual fluctuations due to the annual variability in rainfall and evaporation.

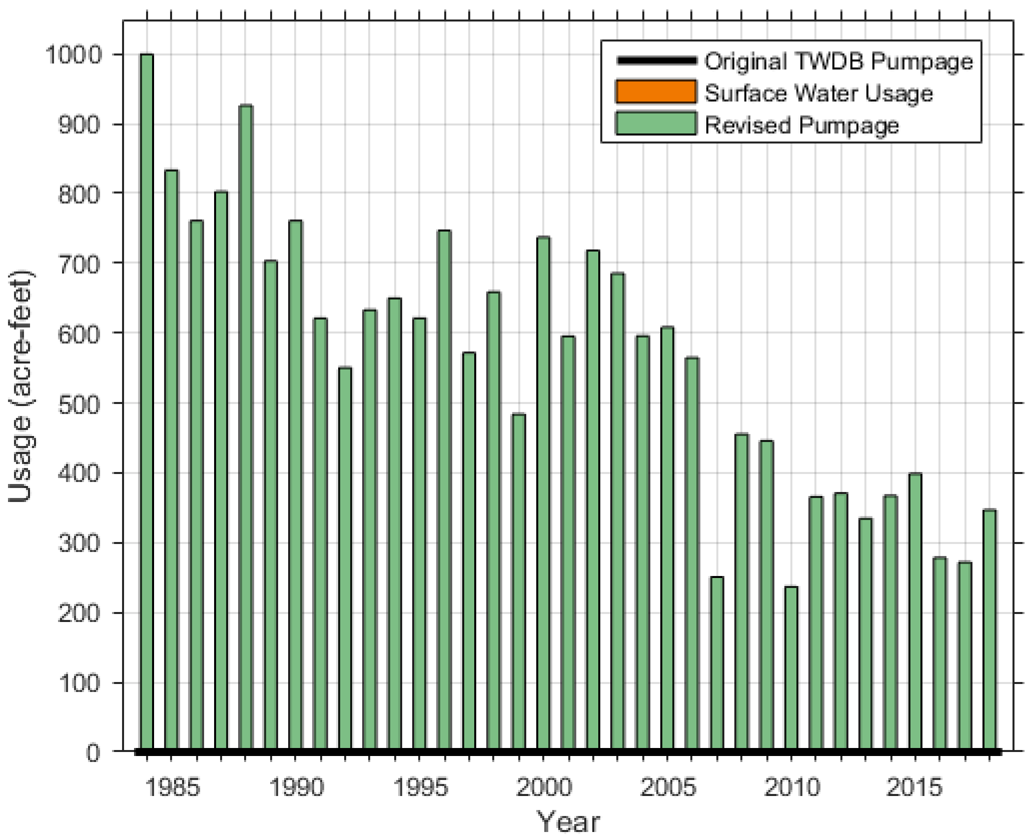


Figure 557. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Mason County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Mason County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Mason County.

Mining

Figure 554c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Mason County during the study period. Only the U.S. Geological Survey water use dataset was available for Mason County to obtain the revised mining water use estimates. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Mason County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Mason County.

Livestock

Figure 554b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Mason County during the study period. Our revised pumpage estimate is greater than the TWDB Water Use Survey estimate and includes groundwater pumping for livestock use prior to the year 1999 whereas the Water Use Survey data does not.

5.2.31 McCulloch County

Figure 558 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in McCulloch County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

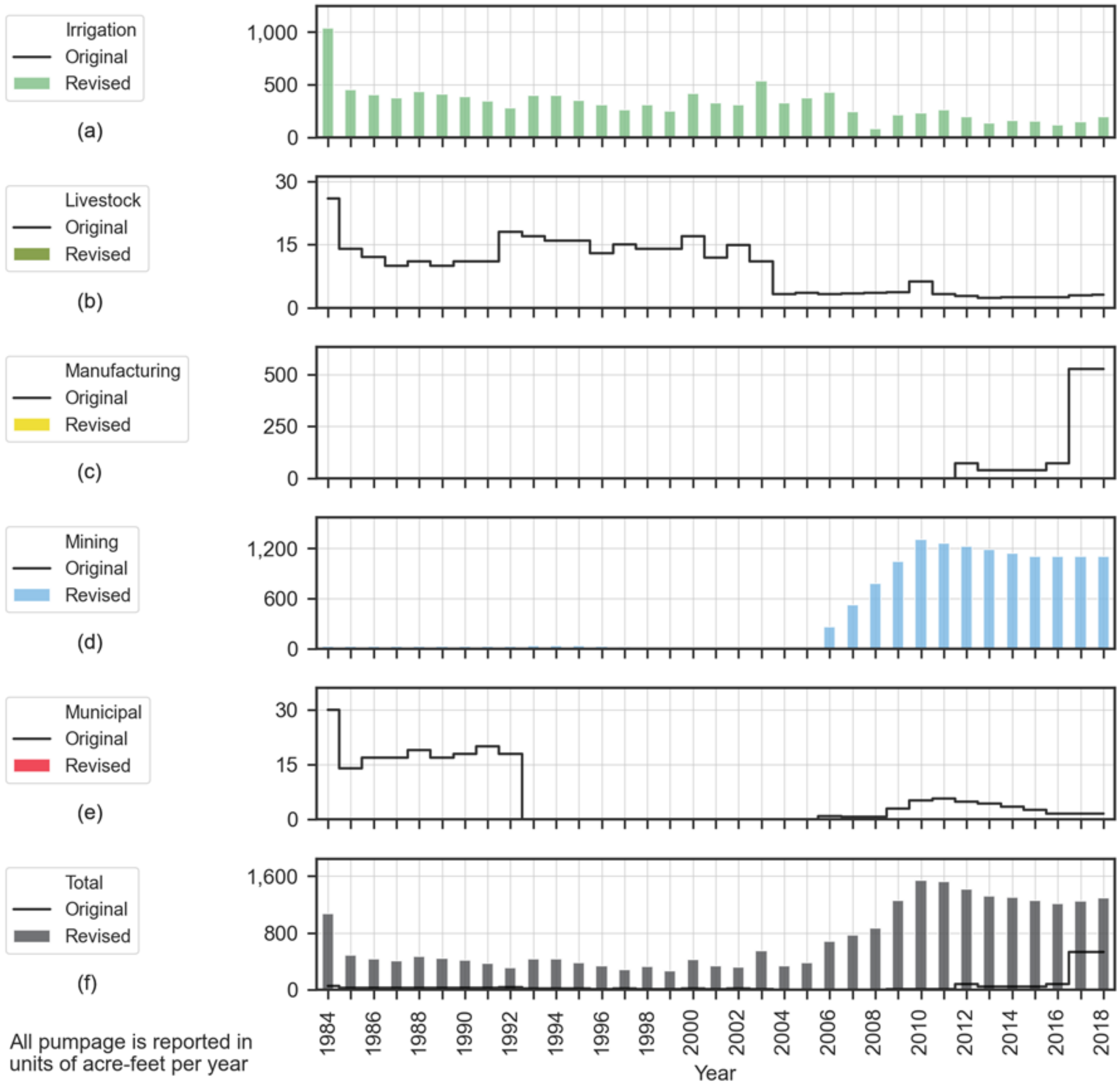


Figure 558. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in McCulloch County from 1984 through 2018.

Surveyed Municipal

All of the entities within McCulloch County which reporting pumpage for municipal purposes listed their pumpage from aquifers other than the Edwards Trinity (Plateau) Aquifer. These other aquifers included the Ellenburger-San Saba Aquifer, the Hickory Aquifer, and "Other Aquifer." Rochelle WSC reported pumpage from the Trinity (Hill Country) Aquifer from 2010-2018, yet this aquifer does not exist within McCulloch County. All entities which reported pumpage from

"Other Aquifer" were located outside of the footprint of the Edwards Trinity (Plateau) Aquifer, and we could not identify any evidence of pipelines transferring water to the entities from wells within the Edwards Trinity (Plateau) Aquifer. As such, the revised dataset does not contain surveyed municipal pumpage from McCulloch County for any aquifer included within this study.

Non-Surveyed Municipal

The TWDB Water Use Survey data includes up to about six acre-feet of pumping from the Edwards-Trinity (Plateau) Aquifer, our estimates do not include any non-surveyed municipal use pumping from this aquifer in McCulloch County.

Irrigation

McCulloch County is nearly 100 percent underlain by the Ellenburger-San Saba Aquifer, the Hickory Aquifer, the Marble Falls Aquifer, and the Cross Timbers Aquifer. The central and southwestern portion of the county are also underlain by the Edwards-Trinity (Plateau) Aquifer, which is located above the other aquifers in the county. Within the footprint of the Edwards-Trinity (Plateau) Aquifer, wells exist that are screened within all of these aquifers and the wells are generally located within geographically distinct regions. Figure 559 demonstrates how the footprint of the Edwards-Trinity (Plateau) Aquifer within McCulloch County was divided into regions where irrigation demands were likely to be preferentially satisfied by pumpage from the Edwards-Trinity (Plateau) Aquifer.

The original TWDB Water Use Survey dataset allocated all groundwater pumpage within McCulloch County to the Ellenburger-San Saba Aquifer, the Hickory Aquifer, and the Marble Falls Aquifer. It did not include listings for "Other Aquifer" or the Edwards Trinity (Plateau) Aquifer. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer ranged from approximately 1,045 acre-feet per year in 1984 to 240 acre-feet per year in 2018 (Figure 560). The estimates show a general decline in irrigation demand over the course of the study period, with year-to-year fluctuations that result from variations in climactic conditions. Surface water is used to partially meet irrigation demands in most years, however it was never sufficient to eliminate pumpage needs in a given year. Groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within McCulloch County ranged from 70 acre-feet per year to 1,038 acre-feet per year.

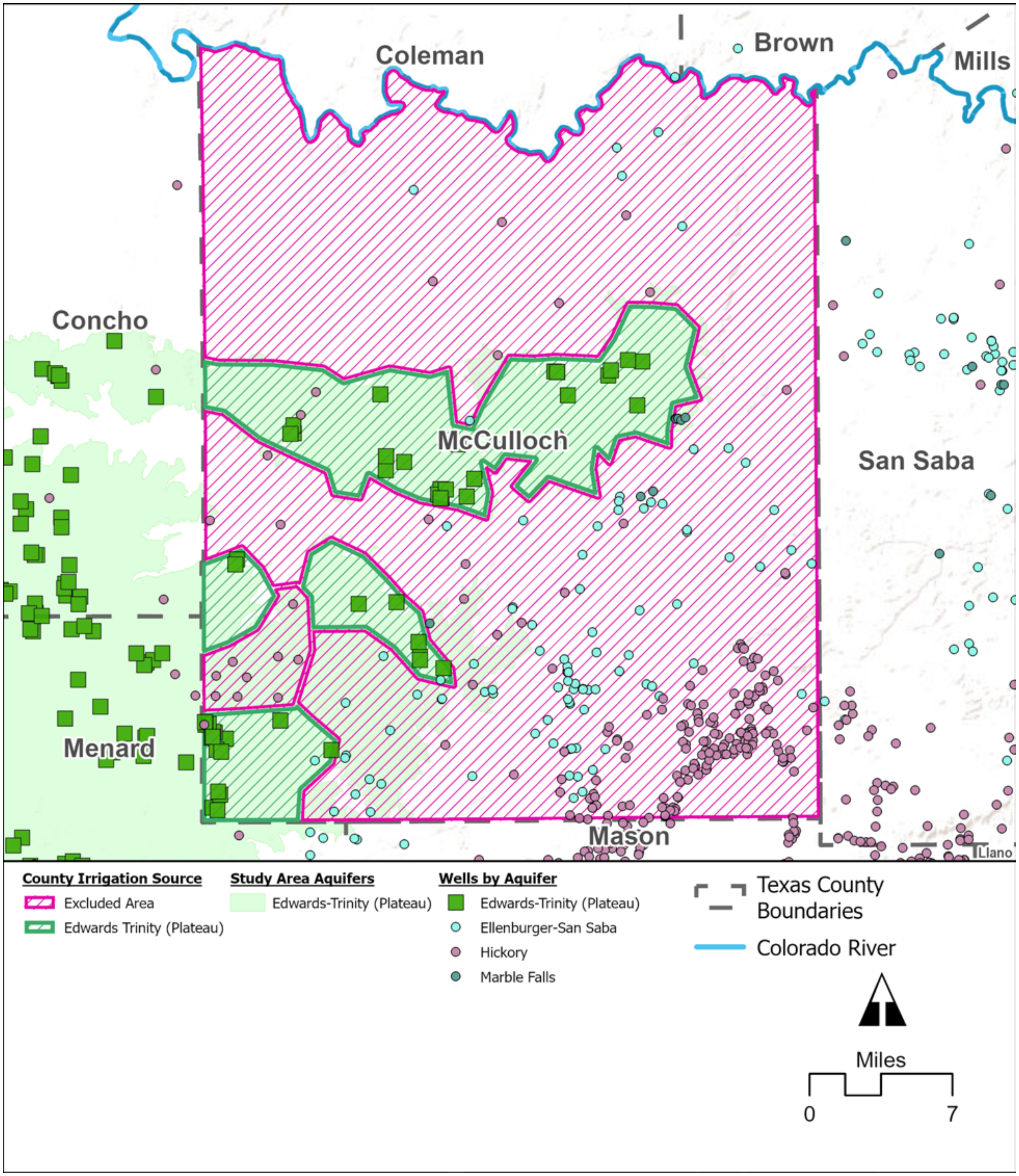


Figure 559. **McCulloch County map showing aquifers and wells used in assessing irrigation pumpage.**

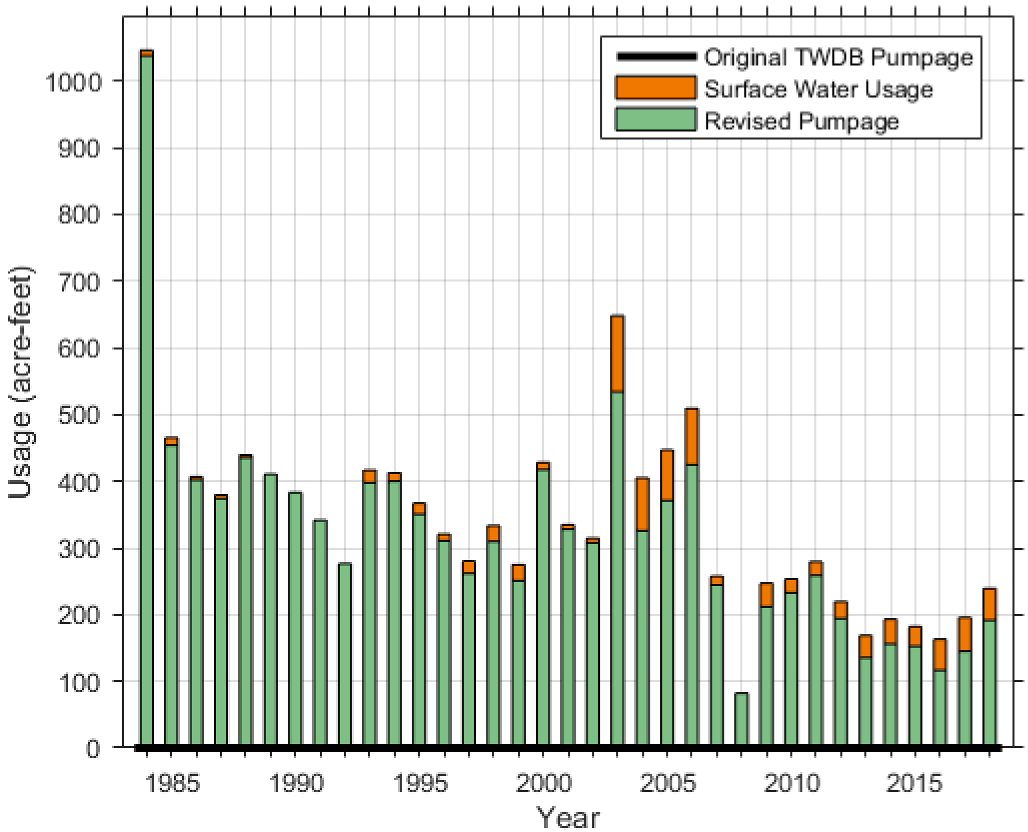


Figure 560. **Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within McCulloch County.**

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in McCulloch County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in McCulloch County.

Mining

Figure 558d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in McCulloch County during the study period. No Water Use Survey data for mining use was available for McCulloch County and the number of active enhanced oil recovery wells was also low. Both the modified Bureau of Economic Geology and the U. S. Geological Survey estimates were used to obtain the revised mining use. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 558c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in McCulloch County during the study period. The revision reflects a revision to the aquifer designation for the "Unimin Corporation – Voca Plant" data. The plant location is outside the boundary of the Edwards-Trinity (Plateau) Aquifer and pumping is more likely from the Hickory Aquifer.

Livestock

Figure 558b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in McCulloch County during the study period. The TWDB Water Use Survey contains estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in McCulloh County that does not surpass 30 acre-feet per year. Our revised pumpage does not include any groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in McCulloh County.

5.2.32 Medina County

Figure 561 and Figure 562 illustrate our revisions to the estimated groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Medina County during the study period. The original TWDB Water Use Survey dataset indicated that up to 80 acre-feet per year of pumpage from the Edwards-Trinity (Plateau) Aquifer was used for municipal purposes. As the Edwards-Trinity (Plateau) Aquifer footprint is not found within Medina County, we allocated this pumpage to the Edwards (Balcones Fault Zone) Aquifer. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

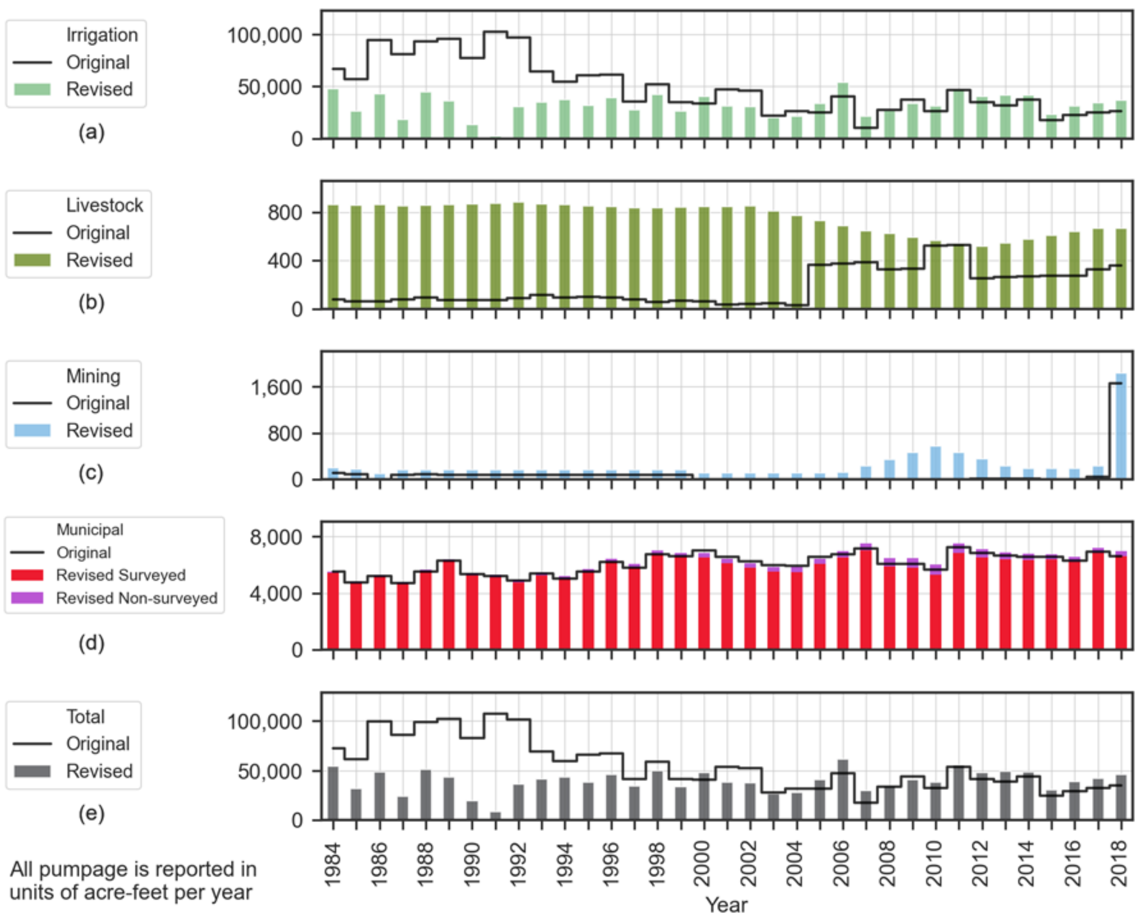


Figure 561. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Medina County from 1984 through 2018.

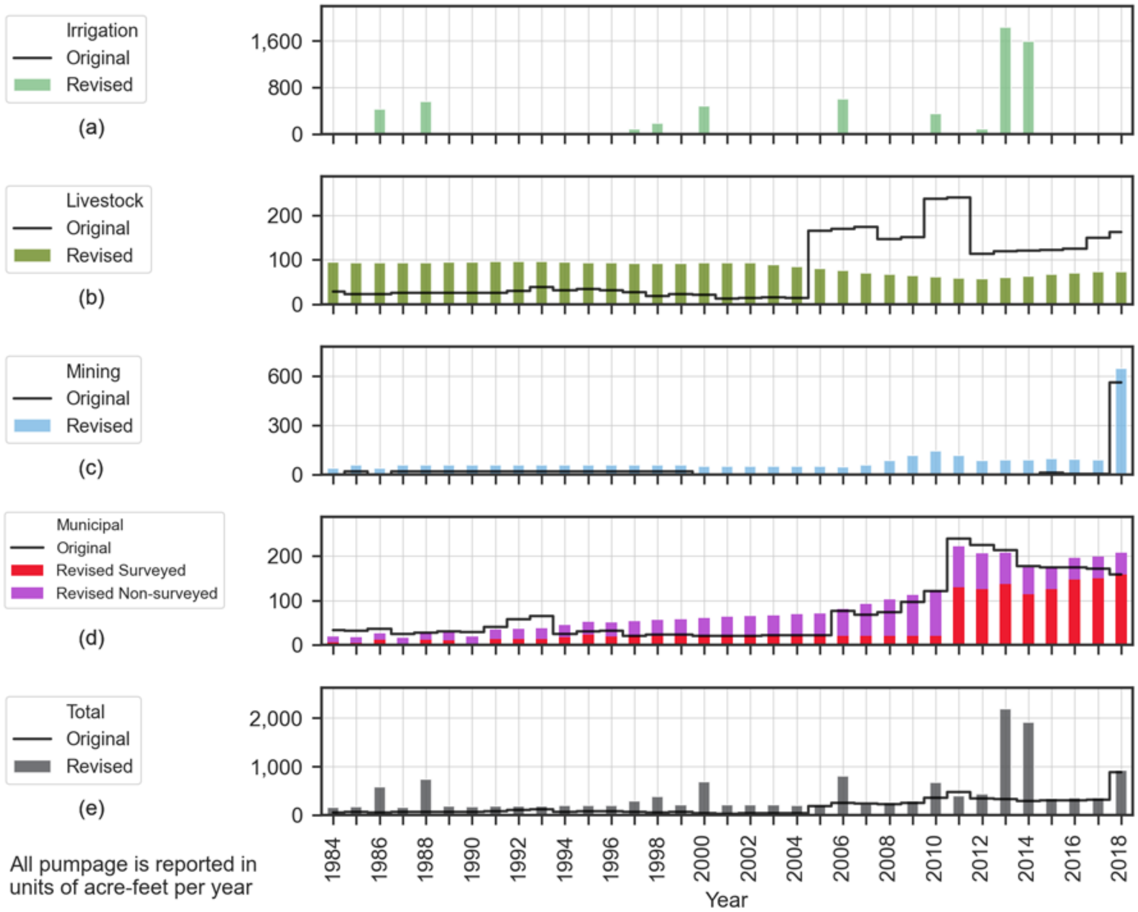


Figure 562. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Medina County from 1984 through 2018.

Surveyed Municipal

Revisions to reported municipal pumpage from Medina County were largely due to data interpolation to fill reporting gaps. The original TWDB Water Use Survey dataset contains multiple entities reporting pumpage from the Edwards Trinity (Plateau) Aquifer, which does not exist within the Medina County footprint. These entities include “Creekwood Ranches WSC” (Reported from 2015-2018), “Creekwood Water Supply” (Reported from 2009-2014), “Texas Water Services, Inc – Rocky Creek Subdivision Water System” (Reported from 2017-2018), and “Wiedenfeld Water Works Inc. – Rocky Creek Subdivision Water System (Reported from 1998-2016). We revised the pumpage from these entities to be included within the Edwards (Balcones Fault Zone) Aquifer, based on the approximate geographic location of the Rocky Creek Subdivision within Medina County.

Non-Surveyed Municipal

Figure 563 and Figure 564 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Medina County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data until 2015. After 2015, the TWDB Water Use Survey data suggests that pumping continues to decrease while our estimates indicate that groundwater pumping remains at 2015 levels until 2018. Note that our estimates are about two times higher than the Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer.

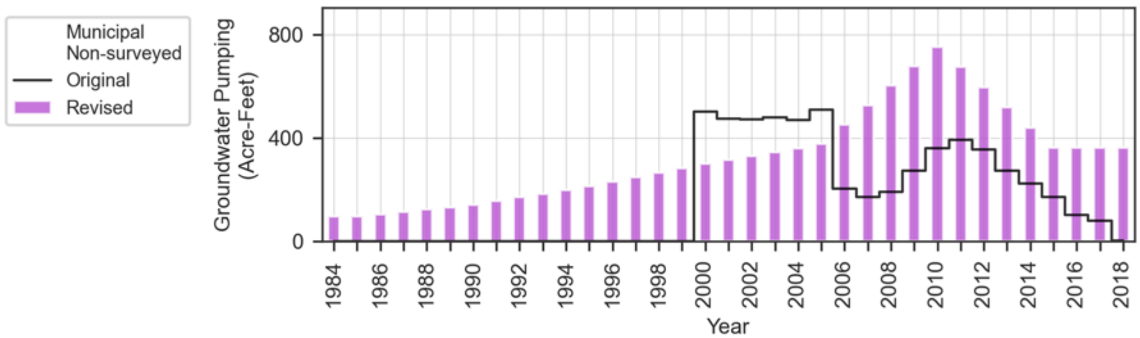


Figure 563. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Medina County from 1984 through 2018.

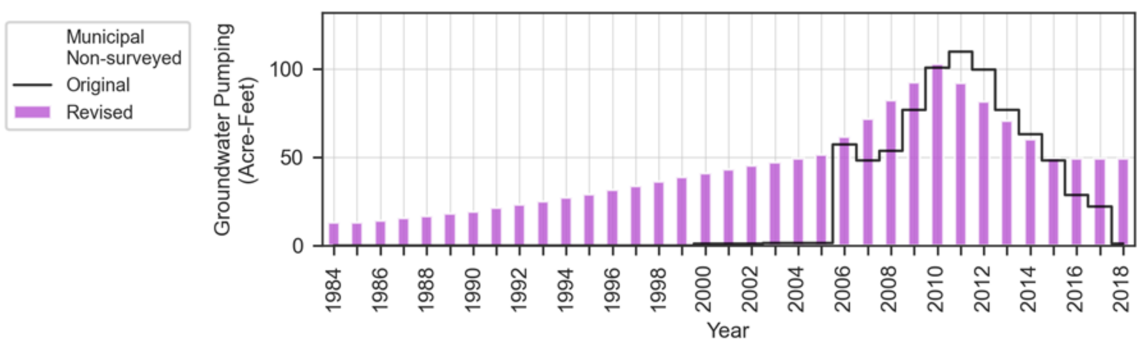


Figure 564. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Medina County from 1984 through 2018.

Irrigation

Medina County is primarily underlain by the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer. For a majority of the county footprint, the Edwards (Balcones Fault Zone) Aquifer lies above the Trinity (Hill Country) Aquifer. Wells located within the footprint of the Edwards (Balcones Fault Zone) Aquifer are almost uniformly screened to withdraw water from this aquifer and not to withdraw water from the deeper Trinity (Hill Country) Aquifer. Similarly, within the southern portion of the Edwards (Balcones Fault Zone) Aquifer footprint within the county, wells were preferentially screened within the Carrizo-Wilcox Aquifer. For the purposes of estimating irrigation pumpage, source aquifer footprints were modified based as shown in Figure 565. In this analysis, 75 percent of the Medina County footprint was modeled as receiving irrigation pumpage from the Edwards (Balcones Fault Zone) Aquifer, 10 percent received pumpage from the Trinity (Hill Country) Aquifer, and the remaining 15 percent received irrigation pumpage from the Carrizo-Wilcox Aquifer (which was not included in this study).

The original TWDB Water Use Survey data indicated that between 10,000 acre-feet per year and 100,000 acre-feet per year was historically pumped from the Edwards (Balcones Fault Zone) Aquifer for irrigation within Medina County (Figure 566). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards (Balcones Fault Zone) Aquifer ranged from approximately 28,500 acre-feet per year to 77,600 acre-feet per year over the study period. The estimates show a general decline in irrigation demand over the course of the study period, with year-to-year fluctuations that result from variations in climactic conditions. Surface water is used to partially meet irrigation demands in most years; however, it was never sufficient to eliminate pumpage needs in any given year. Groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Medina County ranged from approximately 2,100 acre-feet per year to 53,700 acre-feet per year.

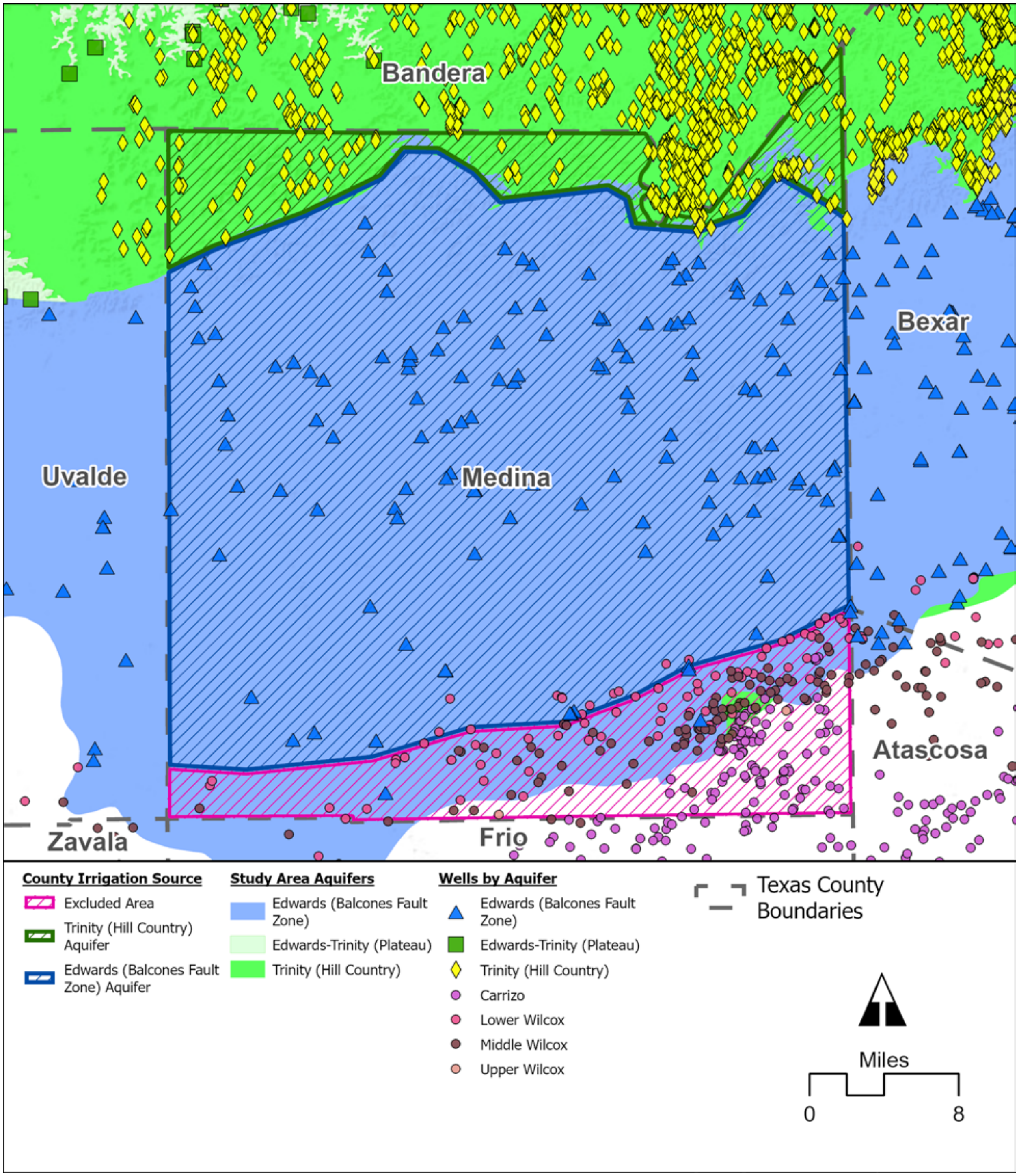


Figure 565. Medina County map showing aquifers and wells used in assessing irrigation pumpage

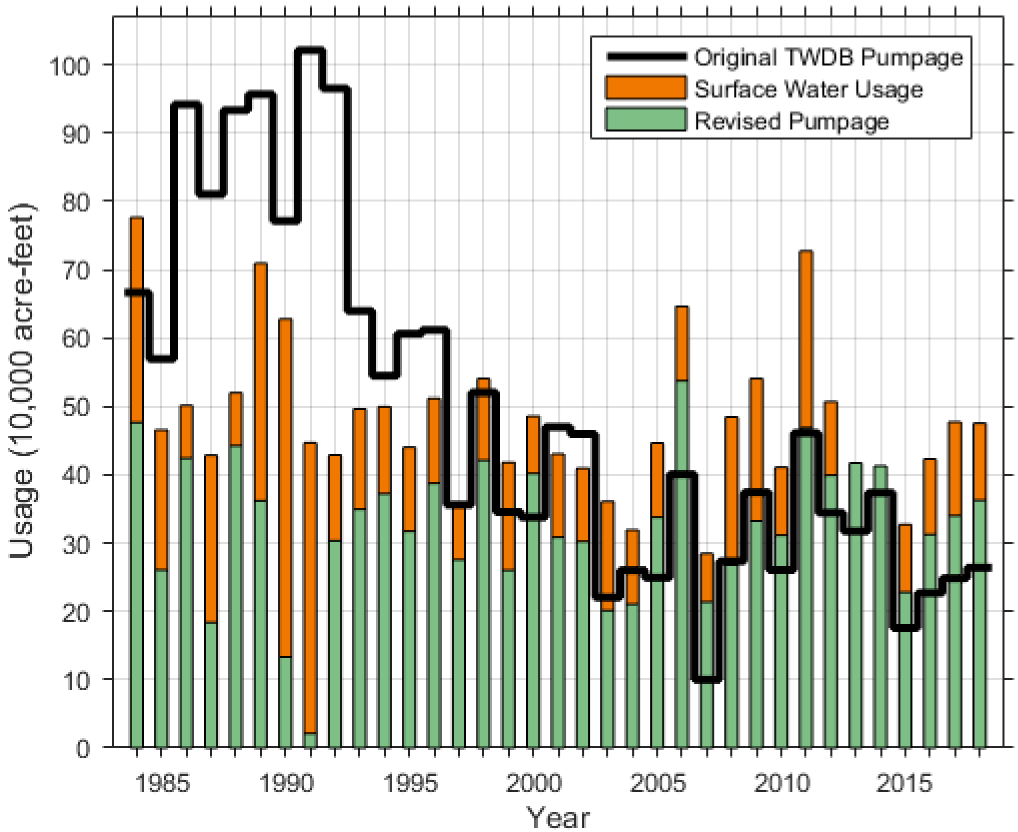


Figure 566. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Medina County.

The original TWDB Water Use Survey data did not indicate that irrigation needs within Medina County were met using pumpage from the Trinity (Hill Country) Aquifer. It did include, however, estimates for pumpage from the Carrizo-Wilcox Aquifer and from “Other Aquifer.” Estimates of groundwater withdrawals from the “Other Aquifer” for irrigation ranged from 487 acre-feet per year to 2,021 acre-feet per year between 2000 and 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Trinity (Hill Country) Aquifer ranged from approximately 950 acre-feet per year to over 7,000 acre-feet per year over the study period. Surface water is used to meet irrigation demands in most years and was often sufficient to eliminate pumpage needs in a given year. Groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Medina County ranged from zero acre-feet per year to approximately 1,800 acre-feet per year. It is likely that pumpage previously reported as being from the “Other Aquifer” within Medina County was from the Trinity (Hill Country) Aquifer.

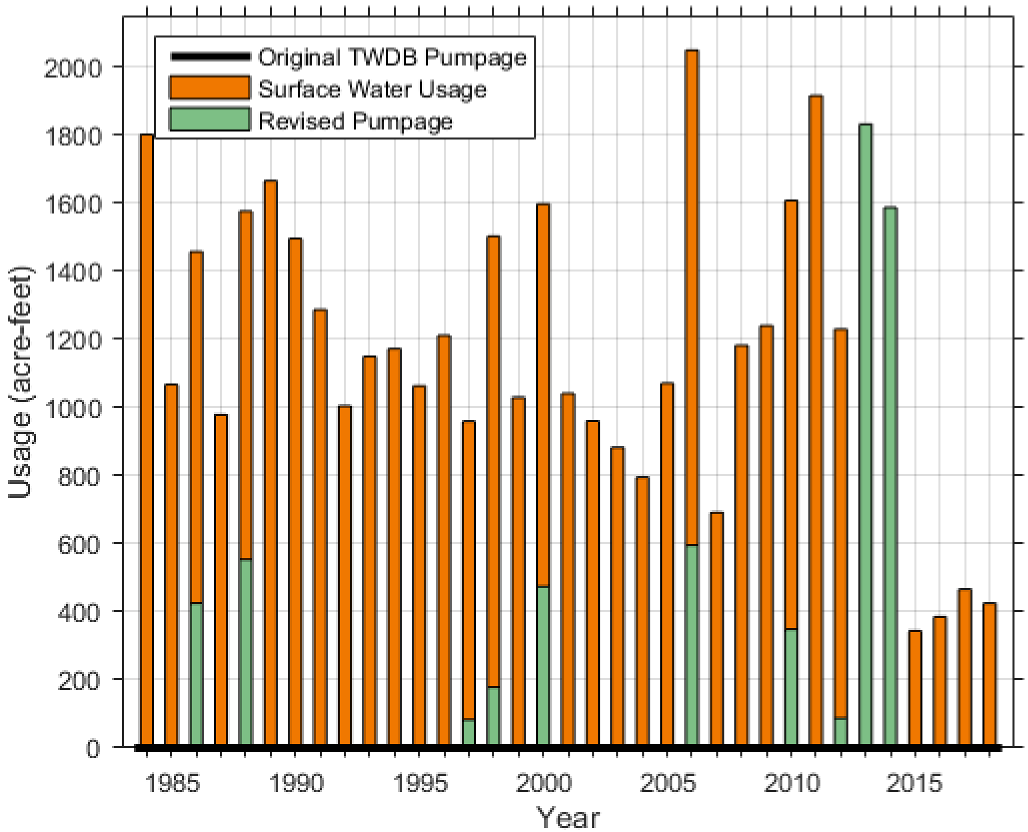


Figure 567. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Medina County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Medina County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Medina County.

Mining

Figure 561c and Figure 562c illustrate the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Medina County during the study period. The number of active enhanced oil recovery wells in Medina County increased from 33 wells in 1980 to 98 wells in 2020. The revised mining use estimates indicate that 71 percent of water for mining use is pumped from Edwards (Balcones Fault Zone) and the remaining from the Trinity (Hill Country) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Medina County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Medina County.

Livestock

Figure 561b and Figure 562b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Medina County during the study period. Our revised estimate of pumpage from the Edwards (Balcones Fault Zone) Aquifer is consistently greater than the TWDB Water Use Survey data, and does not contain the sudden pumpage change observed within the original TWDB data between 2004 and 2005. The revised pumpage estimates demonstrate overall gradual decrease in pumpage for livestock use from the Edwards (Balcones Fault Zone) Aquifer in Medina County. Our revised pumpage estimates from the Trinity (Hill Country) Aquifer are greater than the estimates within the original TWDB Water Use Survey for the period from 1984 to 2005. After 2005, however, the revised estimates are lower than the original TWDB data, often by 50% or more. The revised pumpage estimates from the Trinity (Hill Country) Aquifer suggest a decreasing pumpage trend with time over the study period.

5.2.33 Menard County

Figure 568 and Figure 569 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Menard County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

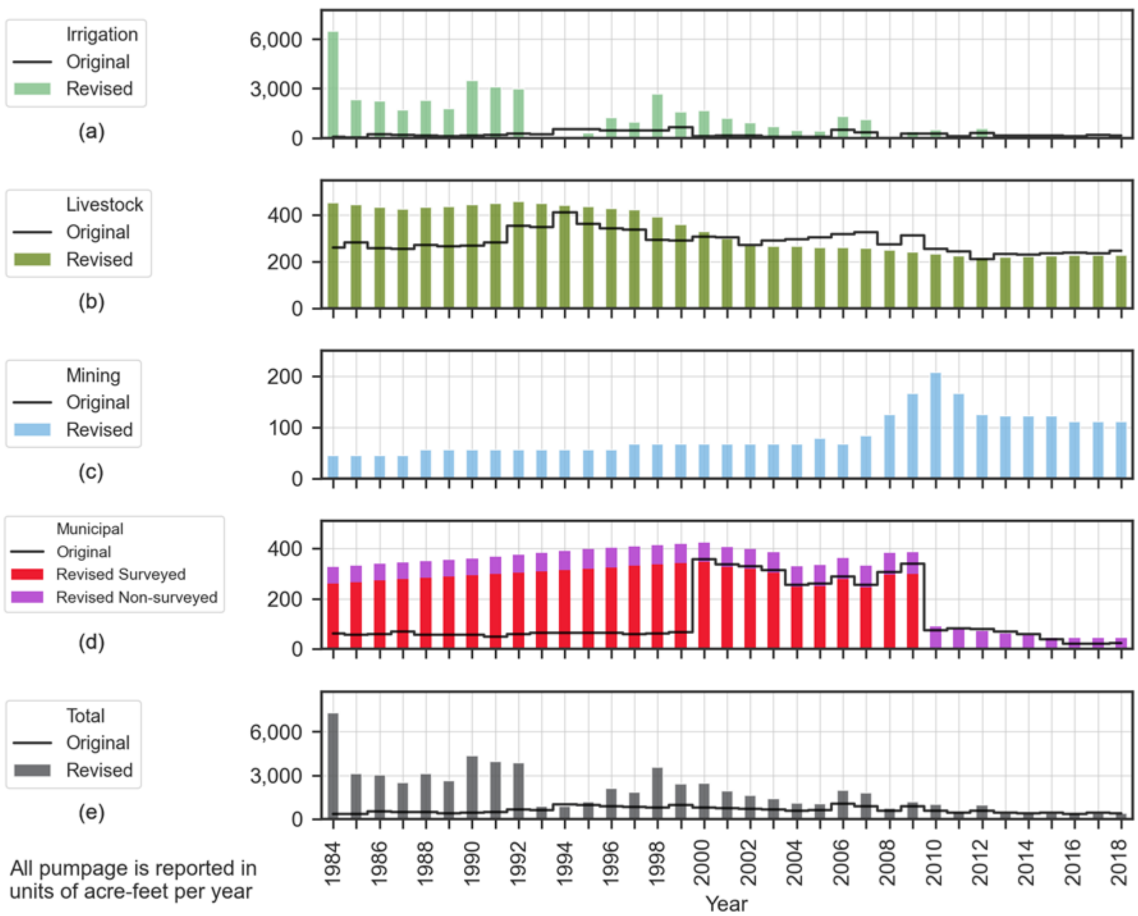


Figure 568. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Menard County from 1984 through 2018.

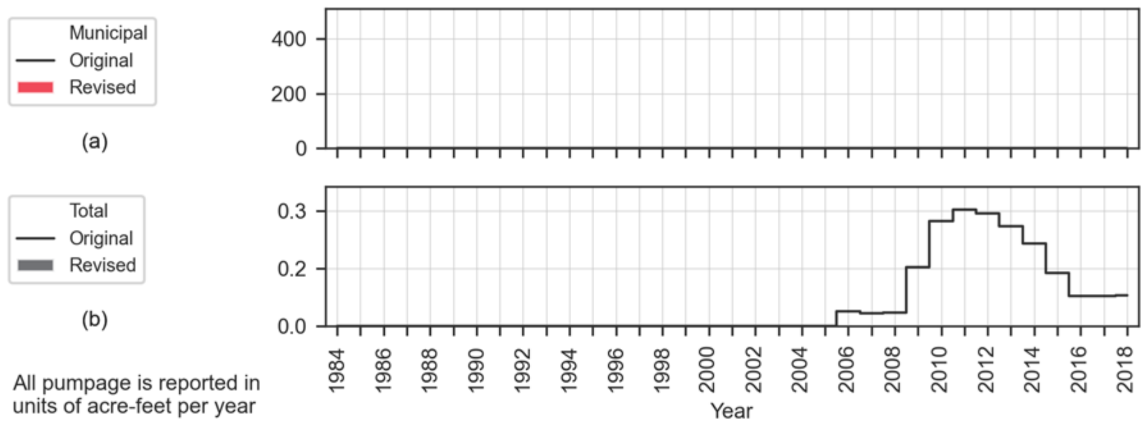


Figure 569. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Menard County from 1984 through 2018.

Surveyed Municipal

Figure 568d and Figure 569a illustrate our revisions to the estimated in groundwater pumping for surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Menard County during the study period. The only entity reporting municipal usage from the Edwards Trinity (Plateau) Aquifer within Menard County is the City of Menard. They reported pumpage from 1955-1983 and from 2000-2009. We interpolated pumpage between 1983 and 2000 as the reported values for those years were similar. Per the Region F 2016 water plan, municipal groundwater usage for the entire county was 390 acre-feet/year, with the City of Menard preferentially using groundwater pumped from alluvial wells adjacent to the San Saba River. The plan does indicate that the City may be developing a wellfield with groundwater sourced from the Hickory Aquifer. No pumpage data is available for the period 2009-2018, which may simply indicate that the City of Menard is utilizing surface water to meet its needs, and has not yet developed the Hickory Aquifer wellfield.

Non-Surveyed Municipal

Figure 570 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Menard County during the study period. Our estimates are two times more than the TWDB Water Use Survey data through 2009. Our review of the available data suggested the pumping for this use is more than previous estimates suggest for that time period. The TWDB Water Use Survey data includes up to about 0.3 acre-feet of pumping from the Trinity (Hill Country) Aquifer, our estimates do not include any non-surveyed municipal use pumping from this aquifer in Menard County.

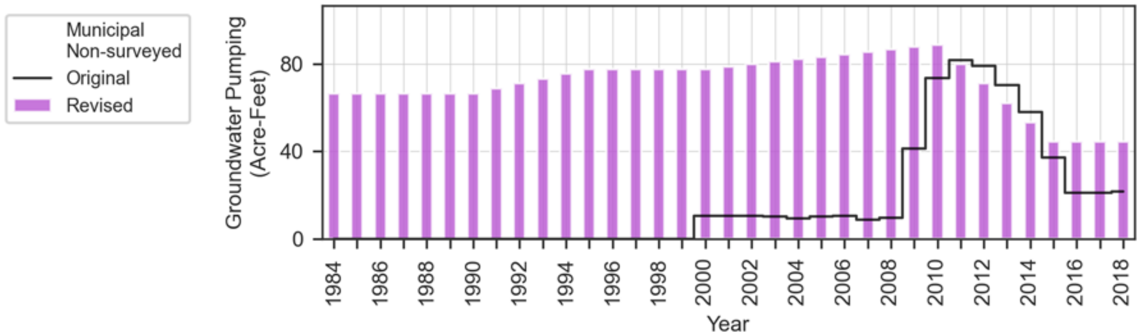


Figure 570. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Menard County from 1984 through 2018.

Irrigation

Menard County is nearly completely underlain by the Edwards-Trinity (Plateau) Aquifer, and is also underlain on the eastern half of the county by the Hickory Aquifer and Ellenburger-San Saba Aquifer. Wells screened within the Edwards-Trinity (Plateau) Aquifer are generally located throughout the county, although more wells along the eastern county border with Mason County appear to be screened within the Ellenburger-San Saba Aquifer, and there is a portion of the county area near the border with McCulloch County which appears to contain wells preferentially screened within the Hickory Aquifer. The areas of Menard County which appear to have wells preferentially screened within aquifers other than the Edwards-Trinity (Plateau) Aquifer were excluded from this irrigation pumpage assessment (Figure 571).

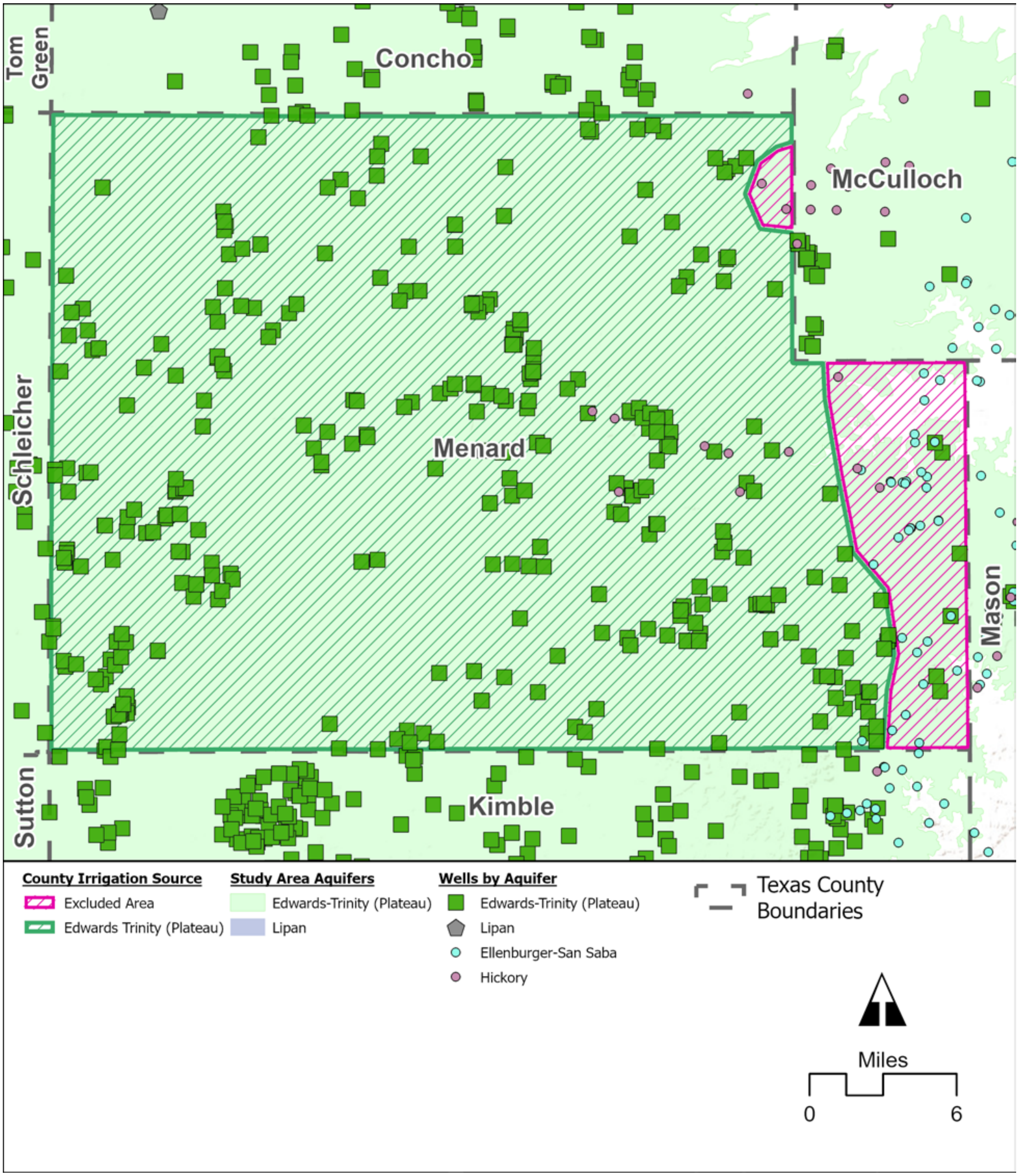


Figure 571. Menard County map showing aquifers and wells used in assessing irrigation pumpage.

The original TWDB Water Use Survey data indicated that between zero acre-feet per year and 628 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation purposes within Menard County. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer within the county ranged from approximately 800 acre-feet per year to 8,000 acre-feet per year over this study period (Figure 572). Some of the irrigation demand was met using surface water for each year of the study period, with sufficient surface water available to eliminate pumpage needs from 1993 to 1994, 2008, and from 2013 to 2018. Groundwater pumpage for irrigation above the footprint of the Edwards-Trinity (Plateau) Aquifer in Menard County peaked at 6,450 acre-feet per year in 1984, and then ranged from between zero acre-feet per year and 3,500 acre-feet per year through the rest of the study period. Pumpage estimates generally declined with time over the study period.

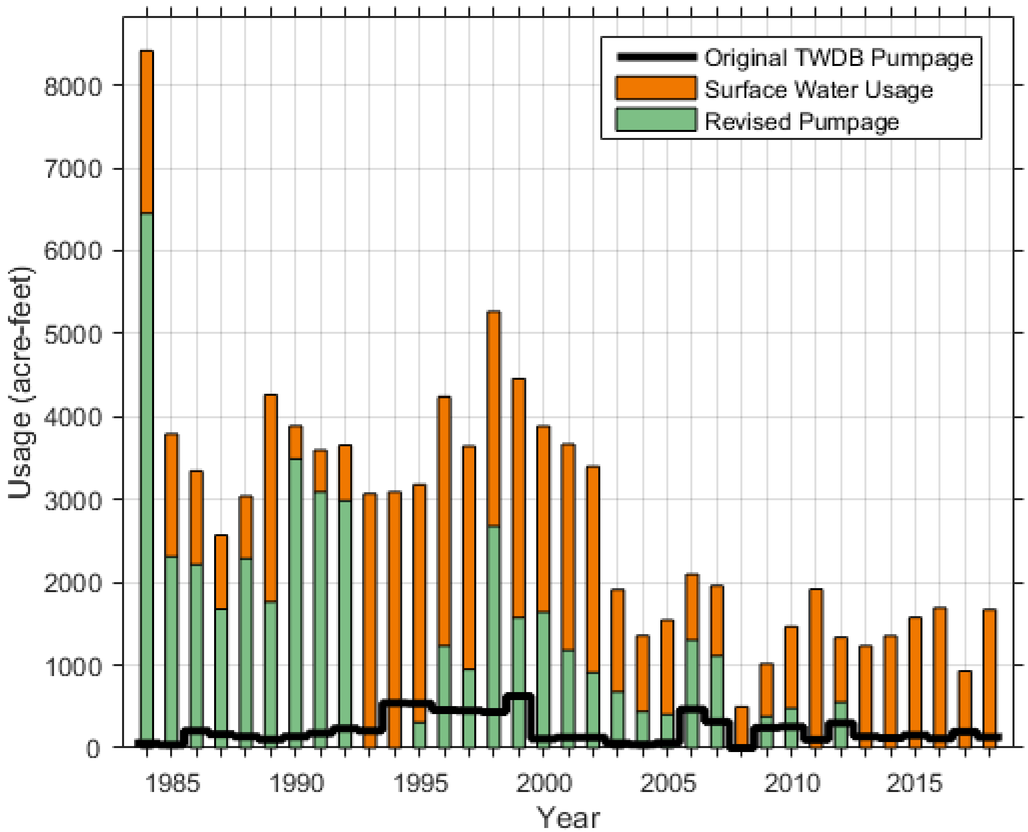


Figure 572. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Menard County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Menard County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Menard County.

Mining

Figure 568c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Menard County during the study period. There were nine active enhanced oil recovery wells in Menard County in 1980 which rose to 40 wells in 2020. No Water Use Survey data was available, however, the estimates obtained using the Bureau of Economic Geology and the U.S. Geological Survey methodology provided comparable results. We estimate the entirety of groundwater pumping for mining use in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Menard County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Menard County.

Livestock

Figure 568b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Menard County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Menard County.

5.2.34 Midland County

Figure 573 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Midland County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

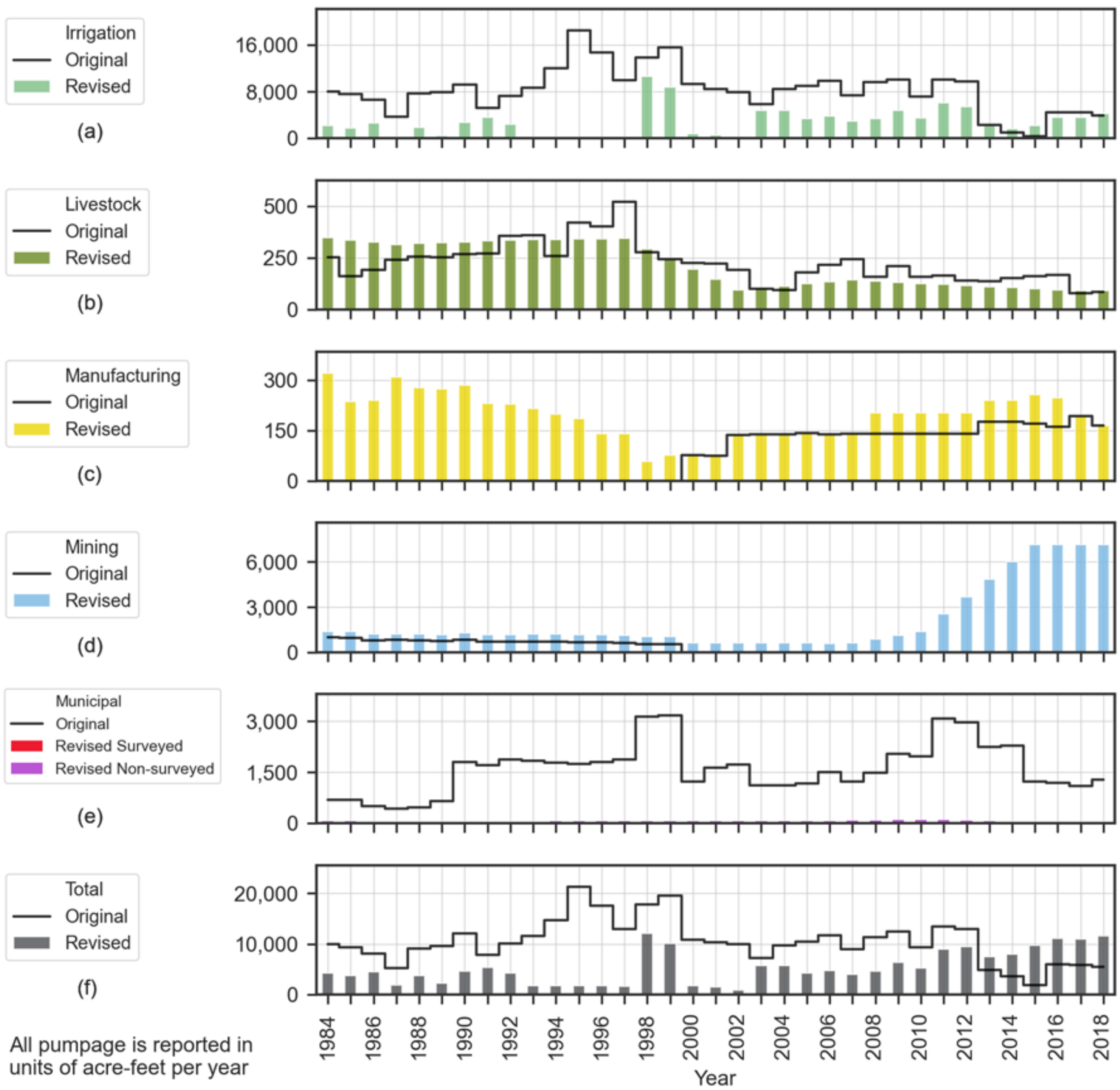


Figure 573. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Midland County from 1984 through 2018.

Surveyed Municipal

The revised surveyed municipal dataset (Figure 573e) for Midland County allocated all pumping to the Ogallala Aquifer, based on the locations of the reporting entities as identified via Google Earth and within ArcGIS maps. All entities were located within the overlapping footprints of the Ogallala Aquifer and the Edwards Trinity (Plateau) Aquifer, and all wells in these areas included in the TWDB groundwater data viewer were screened within the Ogallala Aquifer.

Non-Surveyed Municipal

Figure 574 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Midland County during the study period. Our estimates are significantly less than the TWDB Water Use Survey data. Our review of the available data suggested the pumping for this use is less than previous estimates suggest.

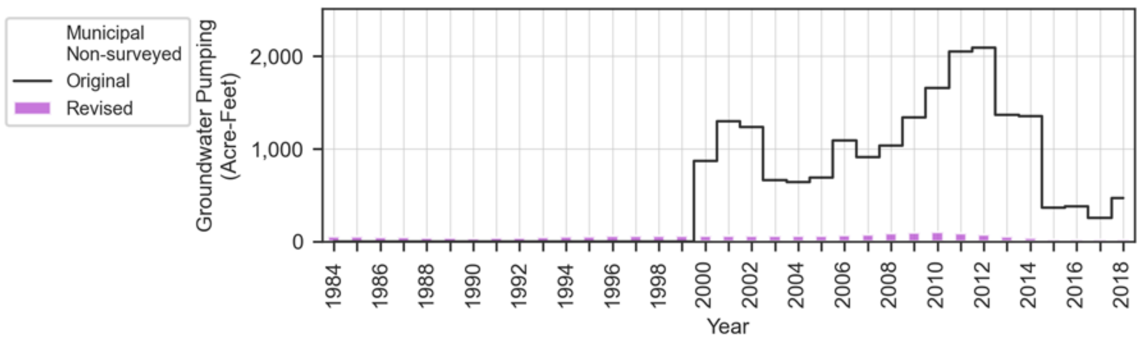


Figure 574. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Midland County from 1984 through 2018.

Irrigation

Midland County is completely underlain by the Edwards-Trinity (Plateau) Aquifer, yet it is also underlain by the Dockum Aquifer along the western boundary with Ector County, as well as by the Ogallala Aquifer across much of the northern half of the county. Review of the TWDB groundwater data viewer indicates that wells located within the footprint of the Ogallala Aquifer will preferentially be screened within that aquifer. As such, for this analysis of irrigation pumpage demands, pumpage from the Edwards-Trinity (Plateau) Aquifer was assumed to occur to meet irrigation demands only for the portion of Midland County not underlain by the Ogallala Aquifer (Figure 575).

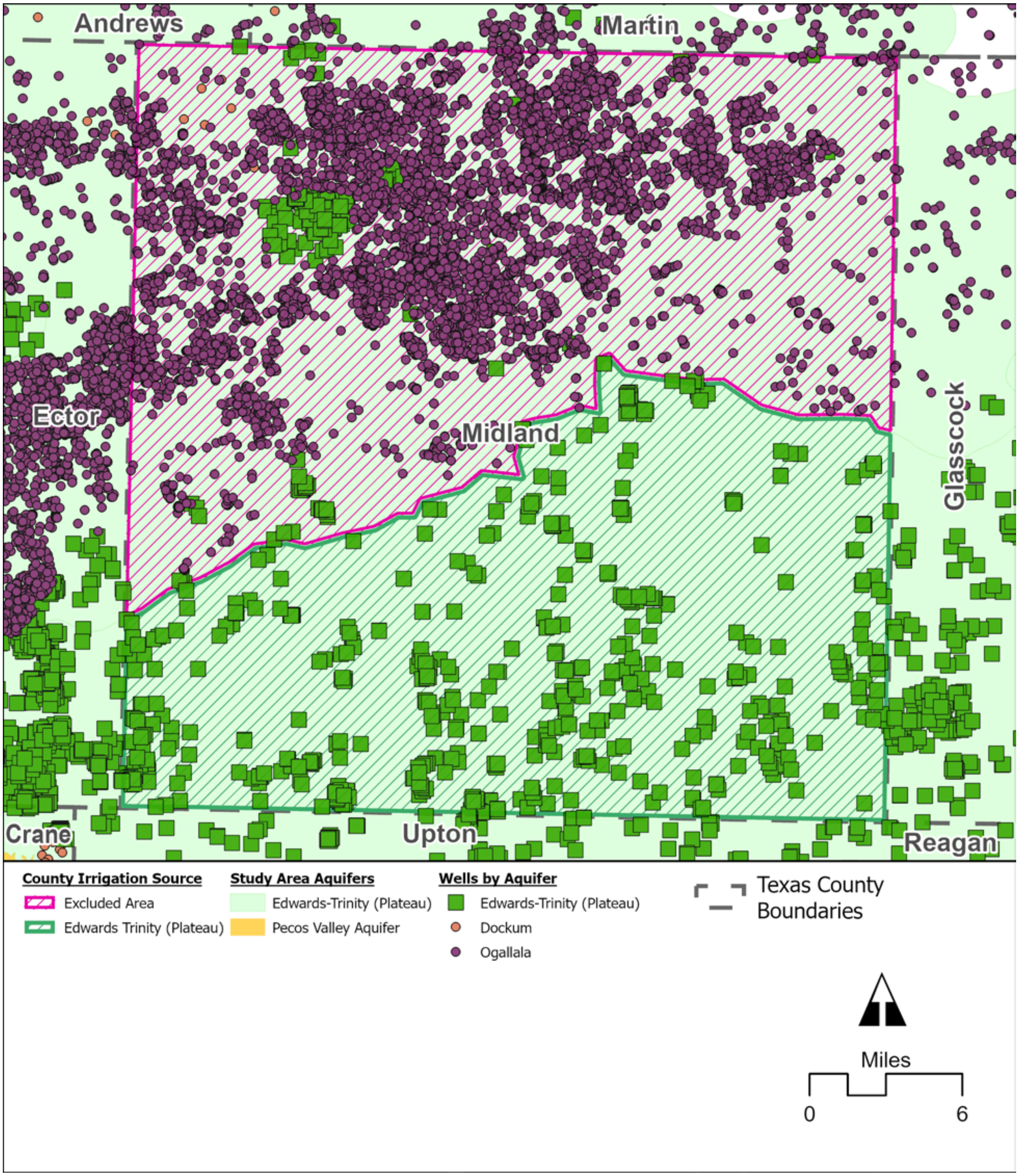


Figure 575. Midland County map showing aquifers and wells used in assessing irrigation pumpage.

The original TWDB Water Use Survey data indicated that between 340 acre-feet per year and 18,420 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation purposes within Midland County (Figure 576). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the effective footprint of the Edwards-Trinity (Plateau) Aquifer within the county ranged from approximately 1,600 acre-feet per year to 16,000 acre-feet per year over this study period. Surface water was used to meet some of the irrigation demand prior to 2003, and was sufficient to entirely eliminate pumpage needs in 1987, 1993 to 1997, and in 2002. Groundwater pumpage for irrigation above the footprint of the Edwards-Trinity (Plateau) Aquifer in Midland County peaked at 10,630 acre-feet per year in 1998, and then ranged from between 1,600 acre-feet per year and 6,000 acre-feet per year between 2004 and 2018 (when surface water was not used for irrigation purposes).

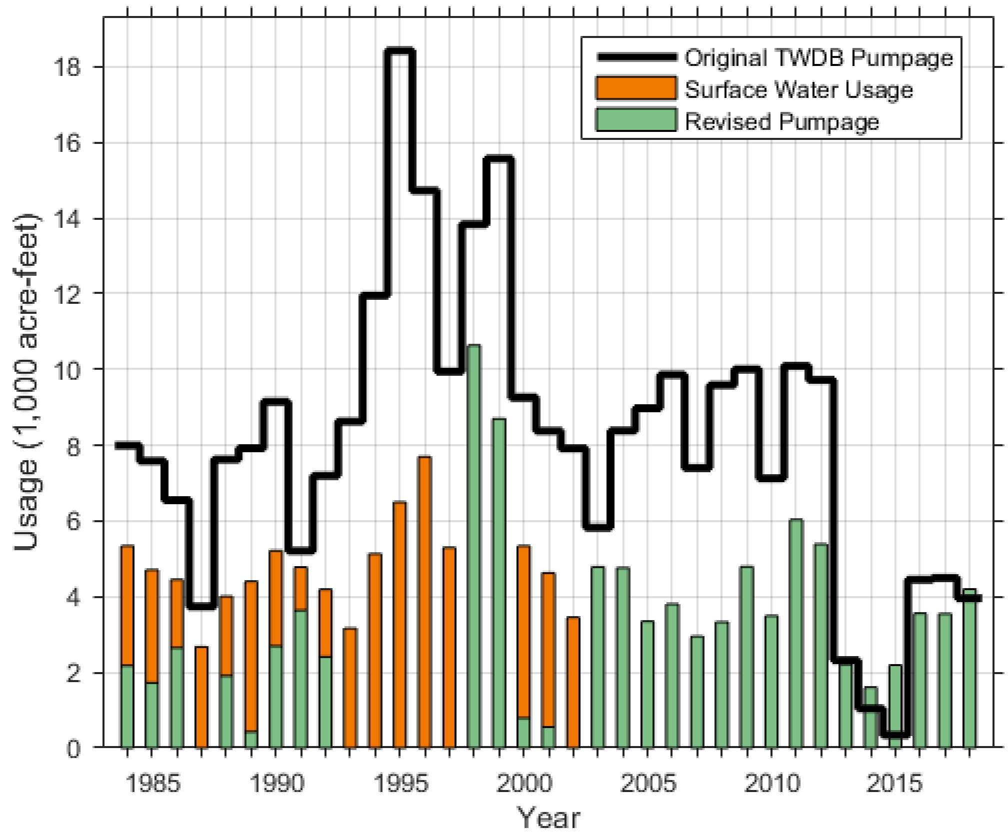


Figure 576. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Midland County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Midland County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Midland County.

Mining

Figure 573d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Midland County during the study period. The number of active enhanced oil recovery wells in Midland was 156 in 1980 which has now increased to 338 wells in 2020. Little Water Use Survey data was available for Midland County and it differed by orders of magnitude when compared to the estimates obtained from the Bureau of Economic Geology and the U. S. Geological Survey methodologies. Comparison between the estimates from the U. S. Geological Survey and the Bureau of Economic Geology methodologies tend to be within a factor of two of each other until about 2010 and then diverge quickly with the U.S. Geological Survey's estimates being almost a factor of seven higher than those obtained from the modified Bureau of Economic Geology methodology. However, considering the limited amount of data available, we are confident in using the higher pumping values from the U.S. Geological Survey. We estimate the entirety of groundwater pumping for mining use in our study area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 573c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Midland County during the study period. There are several entities for which we applied changes. Table 74 summarizes our revisions to the original estimates.

Table 74. Summary of revisions to groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for manufacturing use in Midland County from 1984 through 2018.

Standardized Name	Alternate Water Use Survey Names	Notes
DCP Midstream – Pegasus Gas Plant	None	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present
DCP Midstream – Roberts Ranch Gas Plant	None	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present
Navitas Midstream Partners – Midland Gas Plant	BP American Production Company – Midland Gas Plant	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present
Navitas Midstream Partners – Sprayberry Plant GPOD	DCP Midstream – Sprayberry Plant GPOD; Navitas Midstream Midland Basin, LLC – Spraberry Plant GPOD; Navitas Midstream Midland Basin, LLC – Sprayberry Plant GPOD	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present

Livestock

Figure 573b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Midland County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Midland County.

5.2.35 Nolan County

Figure 577 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Nolan County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

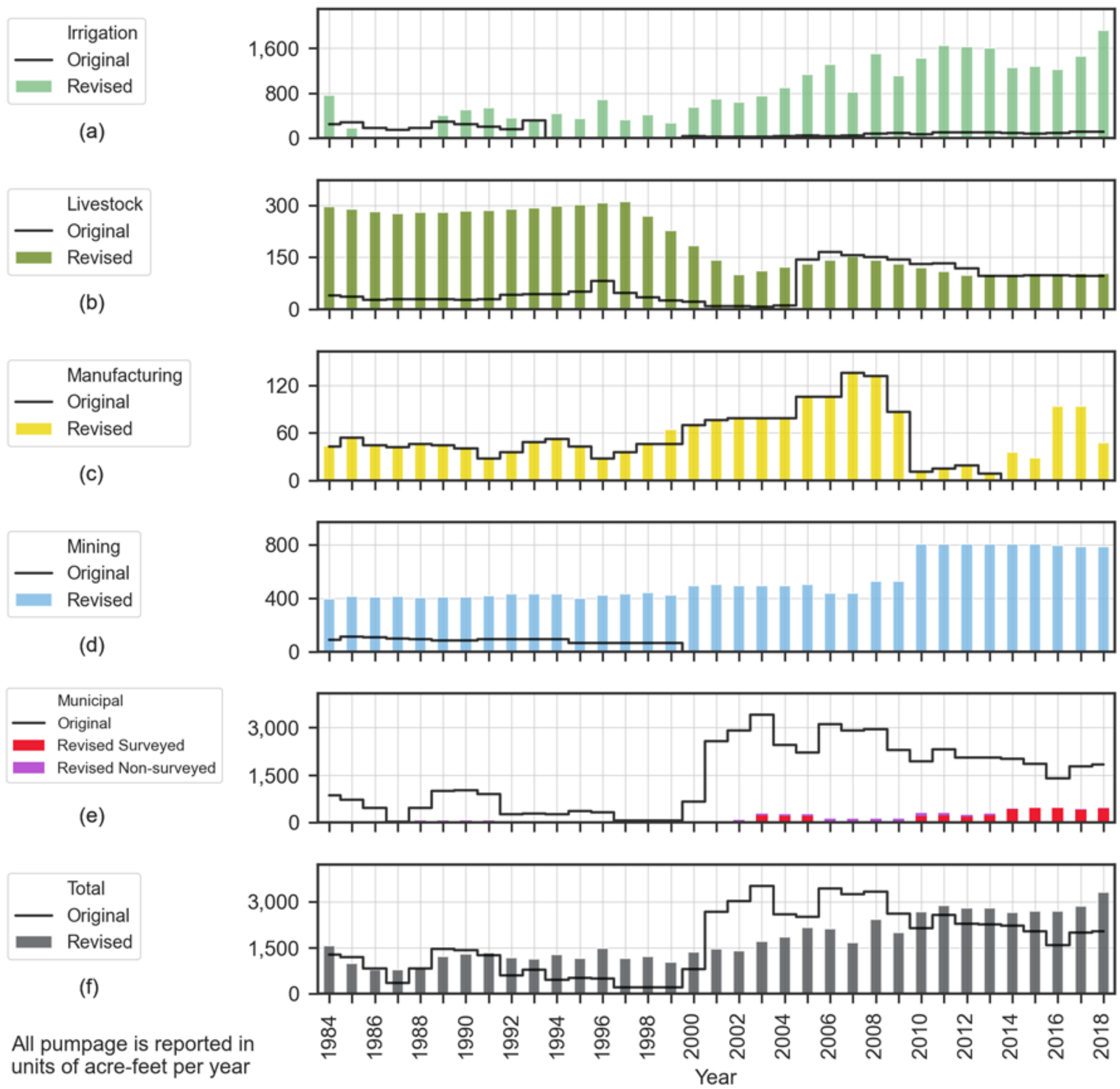


Figure 577. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Nolan County from 1984 through 2018.

Surveyed Municipal

Figure 577e illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Nolan County during the study period. We reassigned the groundwater pumpage by Bitter Creek WSC and Nolan County FWSD from, “Other Aquifer” to the Edwards-Trinity (Plateau) Aquifer for this use. We also reassigned groundwater pumped by the City of Sweetwater from the Edwards-Trinity (Plateau)

Aquifer to the Dockum Aquifer, resulting in the reduction in pumpage. This reassignment of pumpage to the Dockum Aquifer is consistent with the Brazos G 2021 regional water plan and the groundwater availability model used to assess modeled available groundwater for the region.

Non-Surveyed Municipal

Figure 578 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Nolan County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

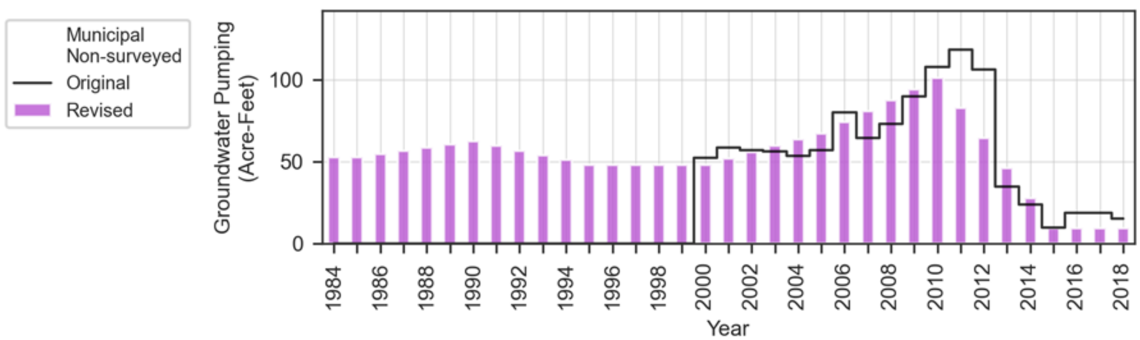


Figure 578. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Nolan County from 1984 through 2018.

Irrigation

Nolan County is underlain by the Edwards-Trinity (Plateau) Aquifer for much of the southern half of the county footprint. The Dockum Aquifer is present along the western county boundary with Mitchell County. All wells identified within the footprint of the Edwards-Trinity (Plateau) Aquifer within Nolan County are also likely screened in the aquifer.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Nolan County range between zero acre-feet per year to 320 acre-feet per year, with the greatest usage occurring prior to 1994 (Figure 579). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Nolan County ranged from slightly over 400 acre-feet per year (in 1985) to over 2,000 acre-feet per year (in 2018). Surface water was partially used to meet this irrigation demand, and its usage eliminated the need for groundwater pumpage for irrigation in 1986 and 1987. Groundwater pumpage for irrigation ranged from zero acre-feet per year up to approximately 1,900 acre-feet per year, with a general increase evident since 2000.

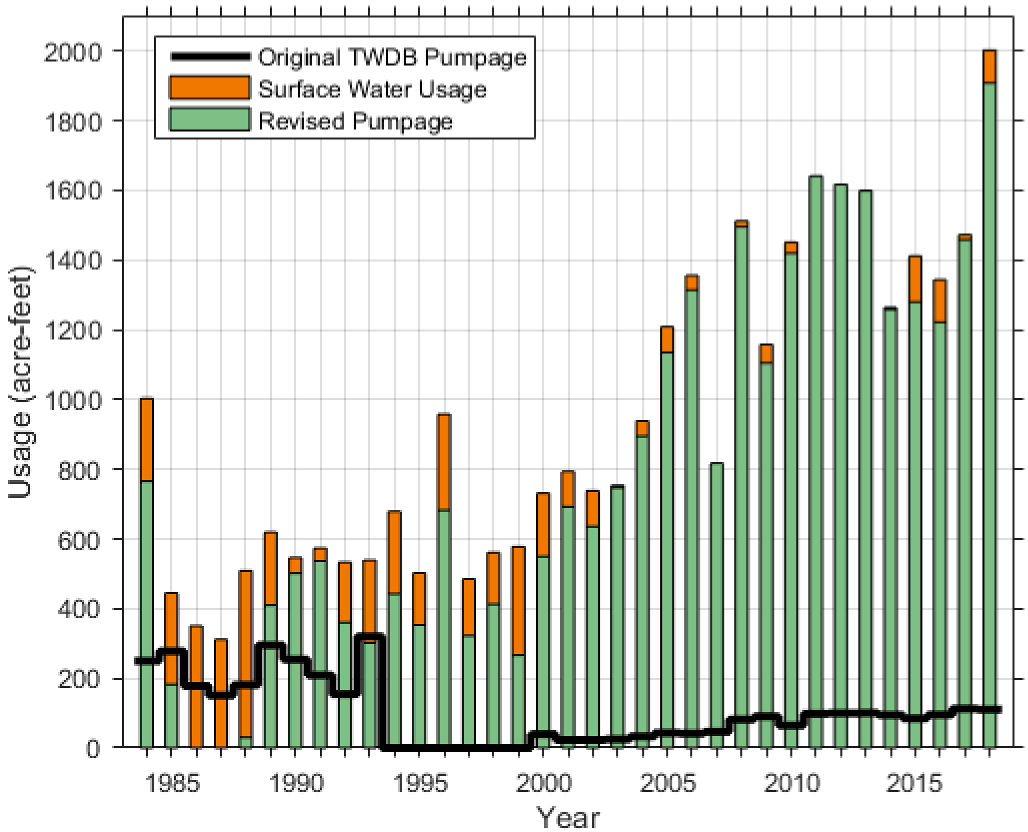


Figure 579. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Nolan County

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Nolan County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Nolan County.

Mining

Figure 577d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Nolan County during the study period. The number of active enhanced oil recovery wells in Nolan was 122 in 1980 which increased up to 287 wells in 2020. No Water Use Survey data was available for Nolan County, and therefore, we compared the estimates obtained from the Bureau of Economic Geology and the U.S. Geological Survey methodologies to fill in the data gaps. The data compare well and are within a factor of two until the year 2004 after which the estimates from the Bureau of Economic Geology methodology start diverging and surpass those from the U.S. Geological Survey. The estimates from the Bureau of Economic Geology methodology end up exceeding the estimates from the U.S. Geological Survey methodology by an order magnitude by the end of the study period. However, in our opinion the higher pumping values are still valid since they remain comparable from the highest to the lowest estimated value overall. We estimate the entirety of groundwater pumping for mining use in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 577c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Nolan County during the study period. The revision reflects a revision to the aquifer designation for the "Lone Star Industries Inc – Maryneal Plant" data for year 2014 and following. The wells associated with the plant are classified as being completed in the Edwards-Trinity (Plateau) Aquifer but the aquifer designation for recent years was Dockum.

Livestock

Figure 577b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Nolan County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Nolan County.

Pecos County

In Figure 580 and Figure 581 we illustrate our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Pecos County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

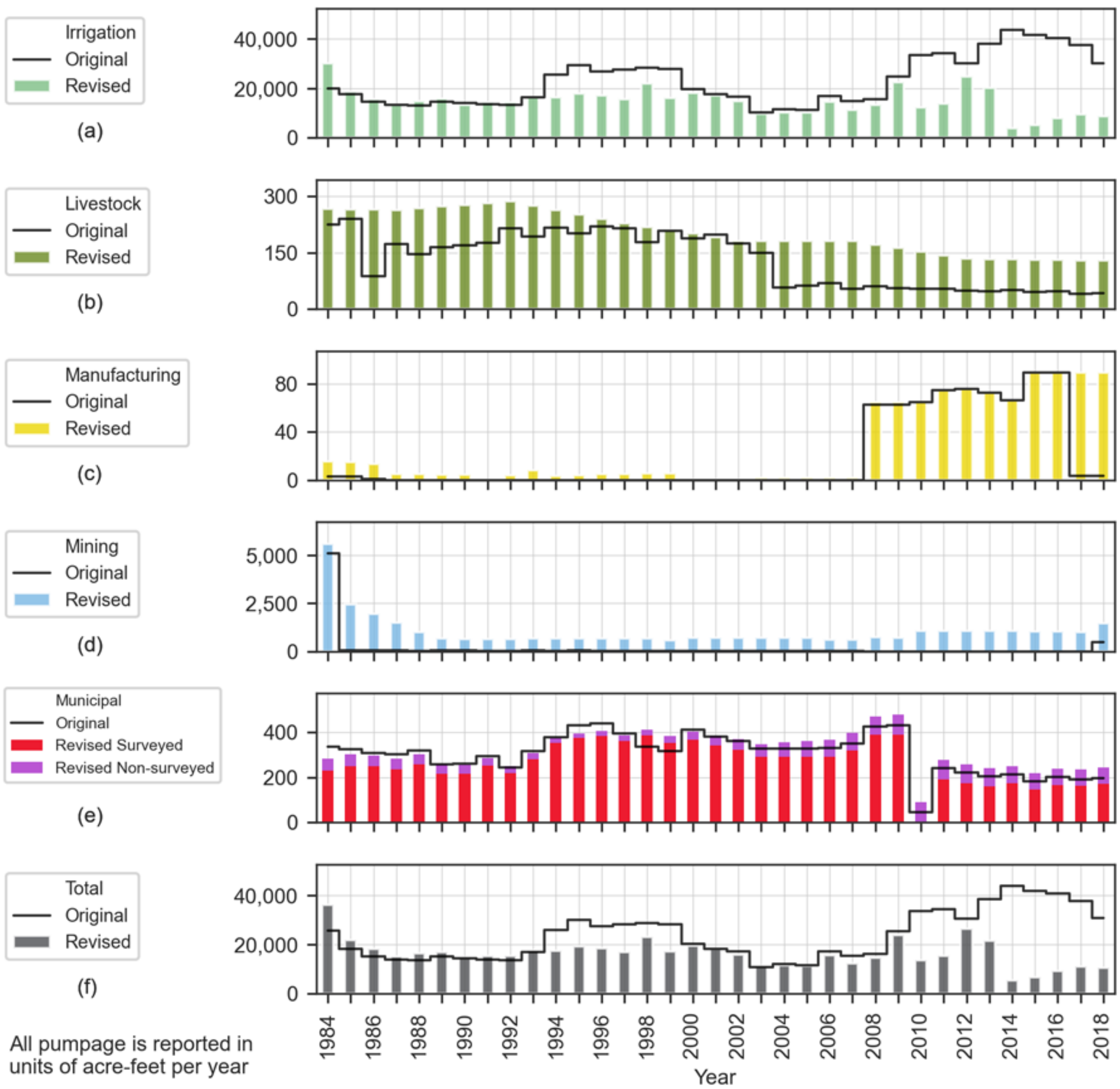


Figure 580. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Pecos County from 1984 through 2018.

Figure 581. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County from 1984 through 2018.

Surveyed Municipal

Figure 580e and Figure 581e illustrate the changes in groundwater pumping associated with surveyed municipal use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Pecos County during the study period. Revisions to reported municipal pumpage from the Pecos Valley Aquifer in Pecos County were not required, as the original dataset did not contain data gaps or any pumpage that needed to be reassigned to a different aquifer or county. The resulting dataset, however, is conspicuous in its content, specifically in that no entity reported pumpage in 2010, when usage before and after this time is relatively stable. Usage decreased after 2009 as Pecos County WCID 1 stopped reporting any pumpage. At that time, Pecos County WCID 1 switched pumpage to wells screened within the Edwards Trinity (Plateau) Aquifer. This increase in pumpage is noticeable within records of pumpage from the Edwards Trinity (Plateau) Aquifer, yet is partially offset by pumpage reductions by other entities.

Non-Surveyed Municipal

Figure 582 and Figure 583 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Pecos County during the study period. Our estimates of pumping for non-surveyed municipal use appear to follow similar trends as the TWDB Water Use Survey data until 2015. While our estimates are about two times higher than the Water Use Survey data for the Pecos Valley Aquifer, they are in general agreement with the Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer.

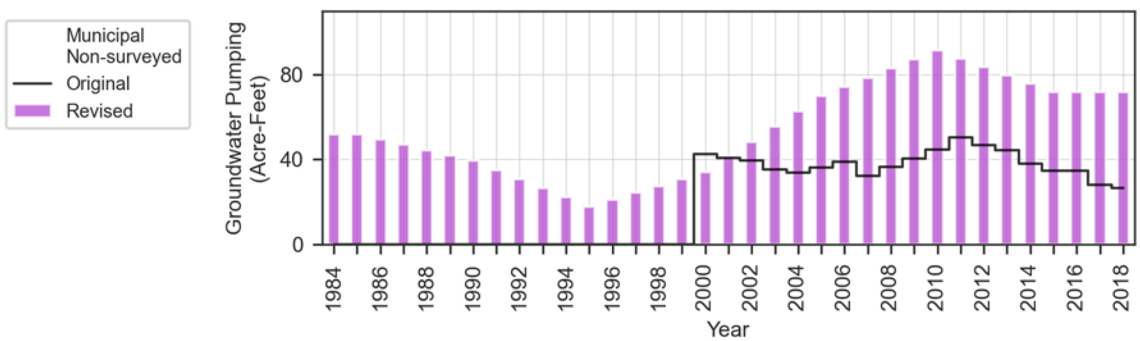


Figure 582. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Pecos County from 1984 through 2018.

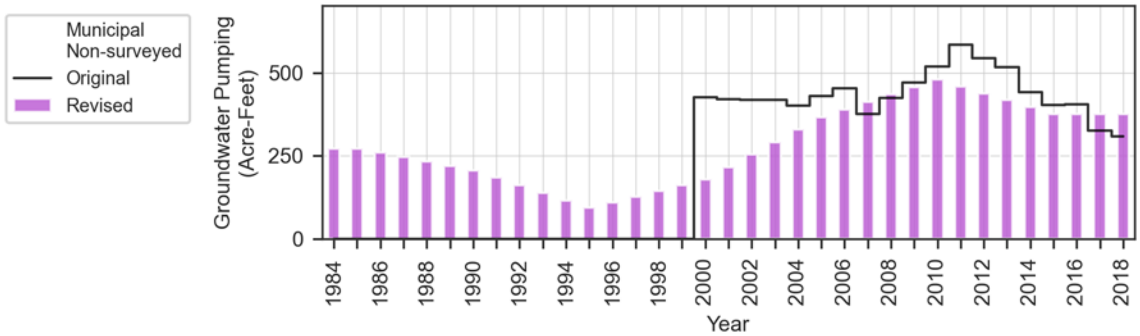


Figure 583. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Pecos County from 1984 through 2018.

Irrigation

Pecos County is underlain by the Pecos Valley Aquifer in the northern corner of the county and along much of the borders with Ward, Crane, and Crockett counties. The Edwards-Trinity (Plateau) Aquifer also underlies much of the area of Pecos County, south of the extent underlain by the Pecos Valley Aquifer. Other aquifers within the county include the Dockum Aquifer, the Rustler Aquifer, and the Capitan Reef Complex; all of these aquifers are located below the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer. For estimating irrigation pumpage within Pecos County, it was assumed that pumpage would occur from the shallowest available aquifer at any given location. This assumption is generally supported by the distribution of wells within the county and by analysis of the TWDB groundwater data viewer.

The original TWDB Water Use Survey data indicated that between 22,500 acre-feet per year and 95,200 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation purposes within Pecos County (Figure 584). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer within the county were lower than the original TWDB estimates, ranging from approximately 12,500 acre-feet per year to 37,000 acre-feet per year over this study period. Surface water was used to meet some of the irrigation demand in most years and was sufficient to entirely eliminate estimate pumpage demands in 2011. As included within the TWDB water use survey dataset, Pecos County used 55,000 acre-feet of surface water for irrigation within 2011. This quantity is anomalous to all other reported annual surface water usage estimates for irrigation, and is approximately ten times larger than other annual estimates. We suspect this usage in 2011 was incorrectly reported within the TWDB Water Use Survey dataset, but we could not discover evidence to support this claim. As such we used this high surface water usage estimate in our calculations, resulting in zero groundwater pumpage computed for 2011. Groundwater pumpage for irrigation above the footprint of the Edwards-Trinity (Plateau) Aquifer in Pecos County peaked at 37,000 acre-feet per year in 1984, and then ranged from between 10,400 acre-feet per year and 25,300 acre-feet per year between 1985 and 2018.

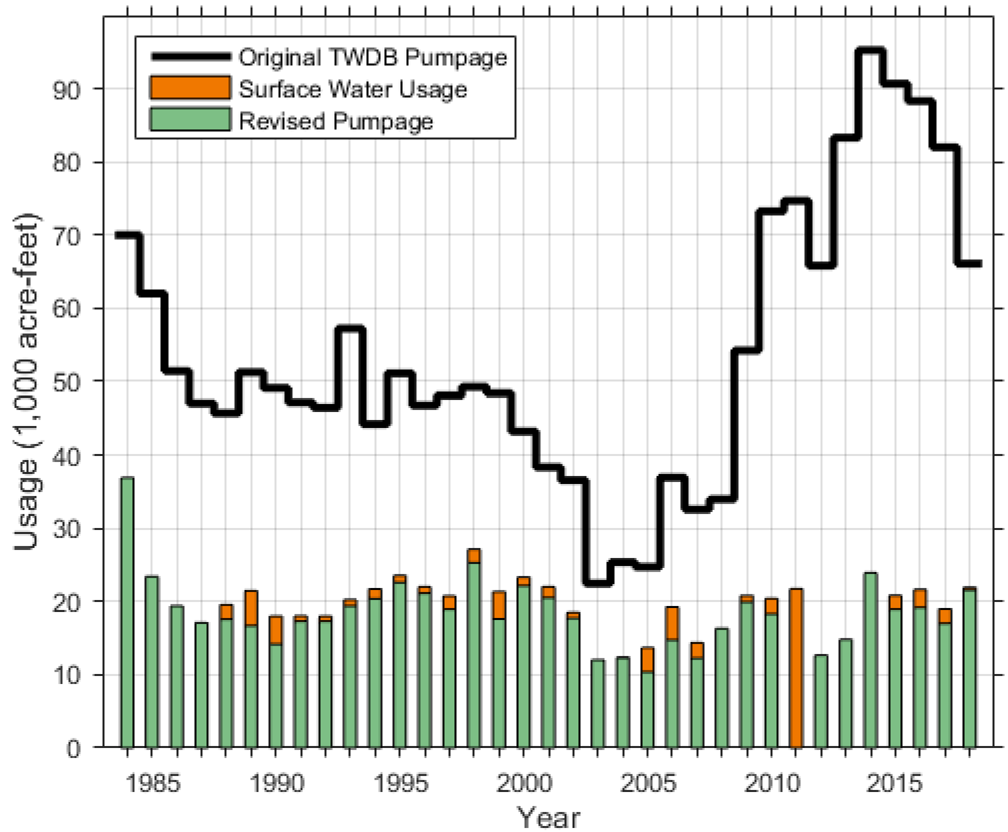


Figure 584. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Pecos County.

Results presented in Figure 584 differ substantially from those presented as our "test case" example (Section 4.2) when we initially developed the irrigation pumpage refinement methodology (See Figure 379). The methodology used to generate the "test case" pumpage estimates for Pecos County irrigation from the Edwards-Trinity (Plateau) Aquifer involved 1) estimating the acreage planted of varying crops, and 2) multiplying that acreage by a water use rate provided by the Middle Pecos Groundwater Conservation District. This method may be applicable within Pecos County, yet other counties within the study area do not have sufficient information regarding the water use rate by crop to make this method universally applicable for all counties. It is also notable that the estimated irrigation water need based on evapotranspiration estimates (Figure 376) ranges from 40,000 acre-feet per year to 65,000 acre-feet per year, which is larger than the irrigation demands shown in Figure 584. This is due, in part, from the example irrigation needs being computed for the entire calendar year (Figure 376) rather than the 214-day irrigation season from March 15 through October 15 (used in generating revised pumpage estimates shown in Figure 584). TWDB has noted that "proposed irrigation estimate data should be in agreement with the local groundwater conservation district data in order to be defensible and accepted" (See Comment #49, in Appendix). We suggest that TWDB decide whether to use locally-provided data in favor of that computed using the methodology presented in this report.

The revised pumpage results and original TWDB Water Use Survey estimates shown in Figure 584 do not agree either in magnitude or in temporal trends. The revised estimates are often over 50 percent lower than the original TWDB Water Use Survey estimates. The original TWDB Water Use Survey estimates also indicate a substantial increase in pumpage after 2013. This increase is not evident within the revised pumpage estimates, or the estimated irrigation needs based on evapotranspiration (Figure 376). The increase is evident, however, within the "test case" estimated pumpage for Pecos County based on crop acreage and water use rates (Figure 379). It is therefore likely that water usage estimates within the TWDB Water Use Survey were based on acreage and water use rates by crop as computed and provided by the Middle Pecos Groundwater Conservation District.

The methodology used to estimate pumpage as reported in this section is based on the computed need for water by the crop. The methodology assumes agricultural producers are not going to use more water than necessary to grow their crops, and accounts for inefficiencies in delivering the water to the crop for uptake into the plant. We have chosen to report the results of this estimation method for irrigation needs for Pecos County from the Edwards-Trinity (Plateau) Aquifer, as the method has produced reasonably similar irrigation estimates with the TWDB original Water Use Survey estimates for other counties and aquifers. We also favor this method in that it is based on reasonable representations of local climactic conditions and is not based on potentially uncertain water use rates by crop. It is our understanding that much of the irrigation pumpage within the Middle Pecos Groundwater Conservation District is not metered and is therefore estimated by other means. Uncertainties in these estimates, as well as uncertainties in the water usage rates by crop, tend to make the results presented in Figure 379 less defensible than those in the revised dataset (Figure 584). We recommend a detailed discussion of these results with TWDB staff and staff from the Middle Pecos Groundwater Conservation District.

The original TWDB Water Use Survey data indicated that between 10,300 acre-feet per year and 43,600 acre-feet per year was historically pumped from the Pecos Valley Aquifer for irrigation purposes within Pecos County (Figure 585). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Pecos Valley Aquifer within the county were lower than the original TWDB estimates, ranging from approximately 4,000 acre-feet per year to 30,000 acre-feet per year over this study period. Surface water was used to meet some of the irrigation demand in most years, yet was not sufficient to entirely eliminate pumpage demands in any given year. It is notable that a large discrepancy exists within the estimated pumpage for the period from 2014 to 2018 between the original TWDB Water Use Survey dataset and the revised dataset described herein. The cause for this discrepancy is unknown, but the general agreement between datasets for prior portions of the study period suggests comparable estimation methods were used. It is possible that inaccuracies in the CropScape data (USDA-NASS, 2008-2019) for Pecos County for the period from 2014 to 2018 has led to an underestimation of pumpage over that time. The accuracy of the CropScape data was not investigated as part of this study.

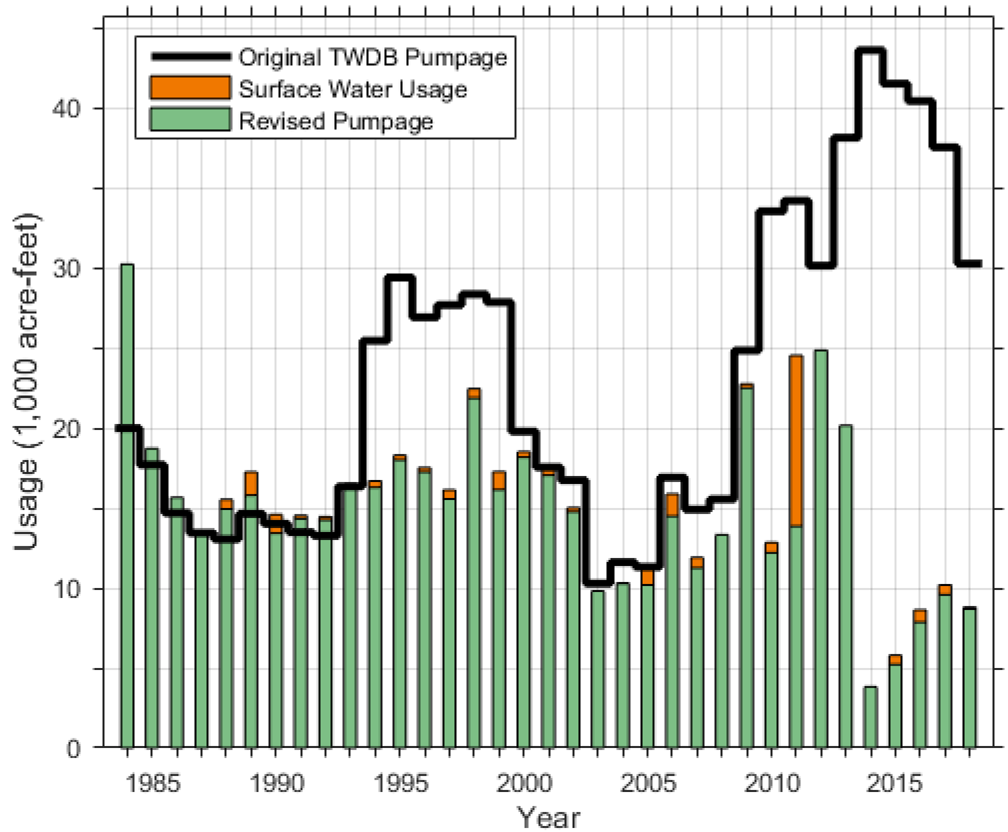


Figure 585. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Pecos County.

The results shown in Figure 585 for the Pecos Valley Aquifer are similar and different than those shown in Figure 584 for the Edwards-Trinity (Plateau) Aquifer. For both aquifers, original TWDB Water Use Survey estimates for the 2010 through 2018 period were larger than the revised estimates based on evapotranspiration needs not met by rainfall. However, there are many periods over which there is excellent agreement between the original TWDB Water Use Survey pumpage and the revised pumpage for the Pecos Valley Aquifer. Specifically, agreement is good from 1985 to 1993 and from 2000 to 2009 (Figure 585). It is unknown whether this agreement is purely coincidental, or whether TWDB estimate for those times were made using a similar methodology. It is also unknown whether the TWDB estimates for the periods of 1994 to 1999 and 2010 to 2018 were made using a different methodology. We believe the revised methodology is superior as it is more directly linked to crop needs and climate patterns, and because it is universally applicable across the study area and the rest of Texas.

Further analysis of the original TWDB Water Use Survey estimates for Pecos County demonstrates trends in how estimated pumpage was assigned to each aquifer within the county footprint. As shown in Figure 584 and Figure 585, total pumpage estimates for the county varied year to year. However, per the original TWBD Water Use Survey estimates, the percentage of the total pumpage assigned to each aquifer was held constant, although altered twice over the study period (Figure 586). From 1984 to 1994, original pumping from the Edwards-Trinity (Plateau) Aquifer was allocated as 77.78 percent of the total pumping in Pecos County. This percentage was reduced to 63.49 percent from 1995 to 2000, and then increased to 68.59 percent through 2018. In contrast, revised pumpage estimates show fairly stable, yet annually variable pumpage distributions amongst aquifers from 1984 to 2008. From 2008 to 2018, the revised pumpage distribution between the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer fluctuates to a larger degree. This analysis suggests that spatial and temporal trends in crop acreage and climate patterns may not have been as significant prior to 2009 as they appear to be after this year. The revised pumpage dataset also suggests that the original TWDB method for allocating pumpage to various aquifers within a given county may have been reasonably appropriate for most of the study period.

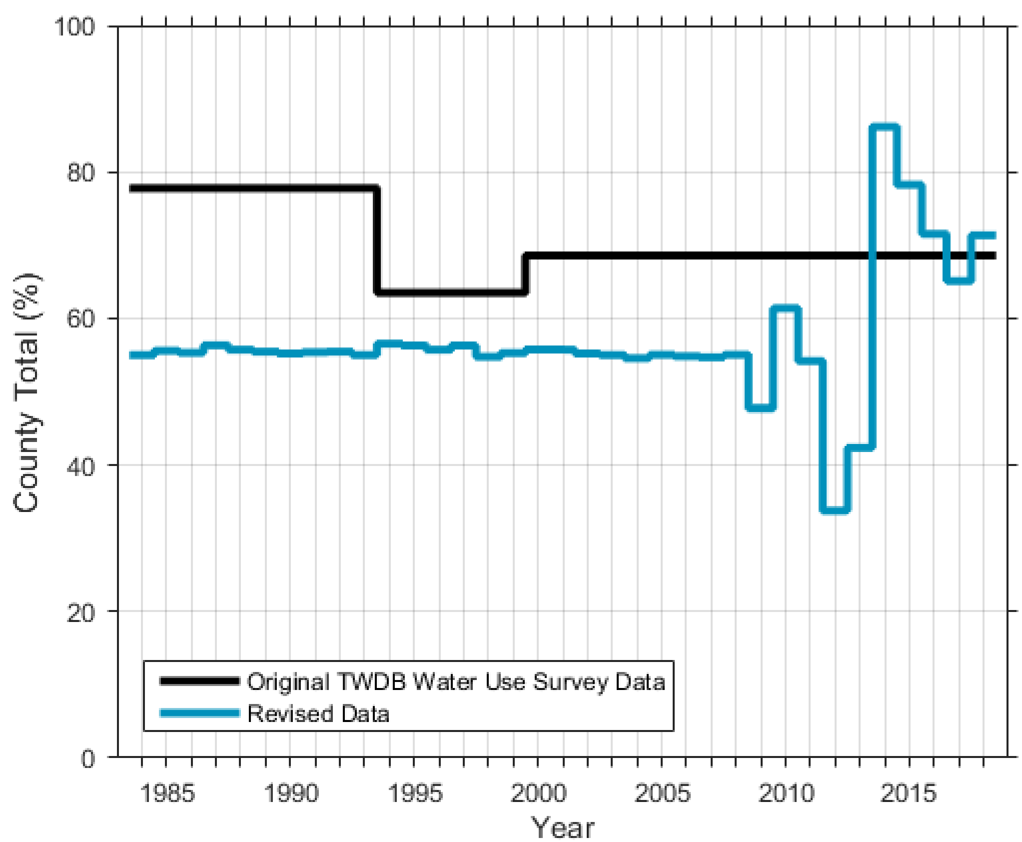


Figure 586. Comparison of irrigation estimates from the Edwards-Trinity (Plateau) Aquifer as a percentage of total irrigation estimates from Pecos County.

Power

As reported in Section 3.3.36 and illustrated on Figure 587, pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County for power use generally ranged between 500 and 2,400 acre-feet per year between 1984 and 2003, with an exception occurring in 1998 when pumpage was not reported. In 2004, pumping for power use was negligible and no more pumpage for power generation was reported from 2005 onwards. We identified several anomalies in the data based on our manual review, a year-to-year change, and a standard deviation analyses.

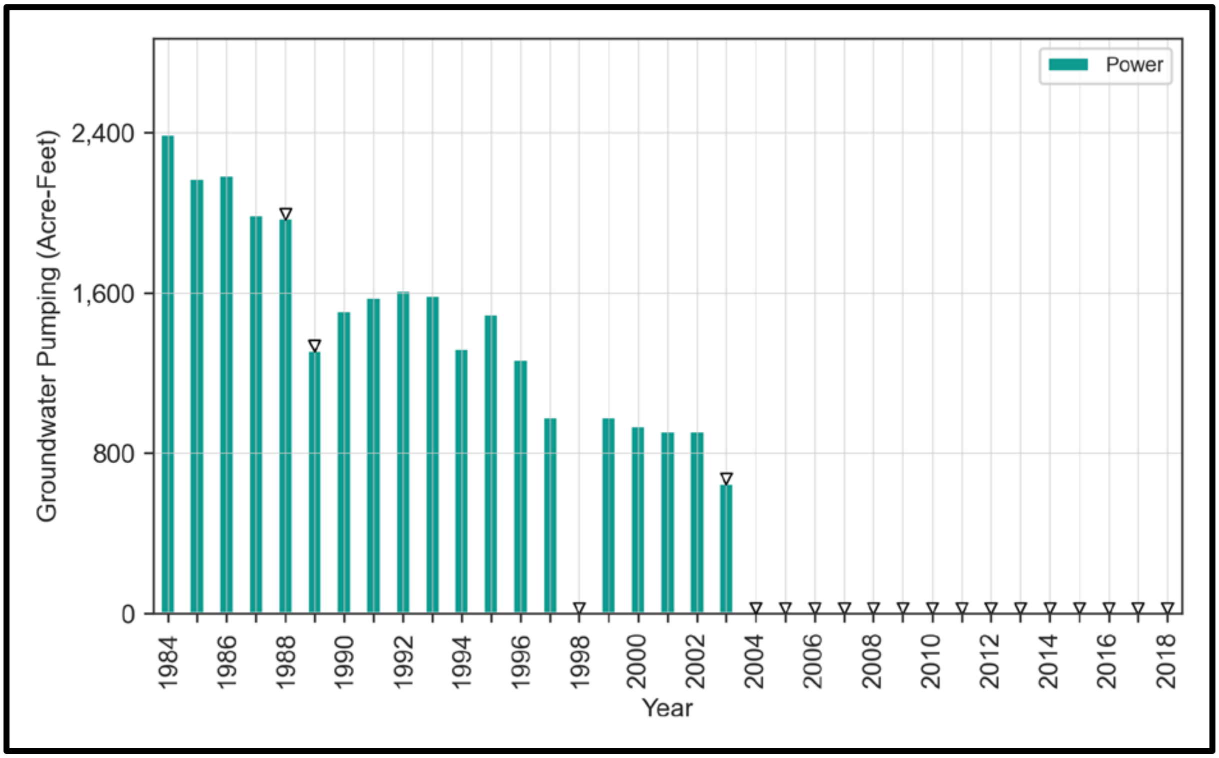


Figure 587. Edwards-Trinity (Plateau) Aquifer groundwater pumping for power use in Pecos County as reported in the original TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Edwards-Trinity (Plateau) Aquifer pumping for power use per entity in Pecos County, we determined there were two surveyed entities reporting groundwater production for use supporting power generation. The reporting entities were AEP Texas North Company – Fort Stockton Station (hereafter referred to as "Fort Stockton Power Plant") and Eagle Supply & Manufacturing LP – Rio Pecos Plant (hereafter referred to as "Rio Pecos Power Plant"). Upon further research, a reported pumpage value was determined pertaining to the Rio Pecos Power Plant for the year 1998 corresponding to a pumpage volume of 996 acre-feet.

Rio Pecos Power Plant was assigned to Pecos County in the TWDB Water Use Survey data but no specific well location was reported. After online research and verification using Google Earth, it was determined that the Rio Pecos Power Plant was in Crockett County near the county border with Pecos County and Crane County. The Rio Pecos Power Plant is discussed under the Crockett County section. The location for the Fort Stockton Power Plant is within Pecos County and is shown in Figure 588. Table 75 presents the timeline of operation events as provided on form EIA-860 for the Fort Stockton Power Plant in Pecos County.

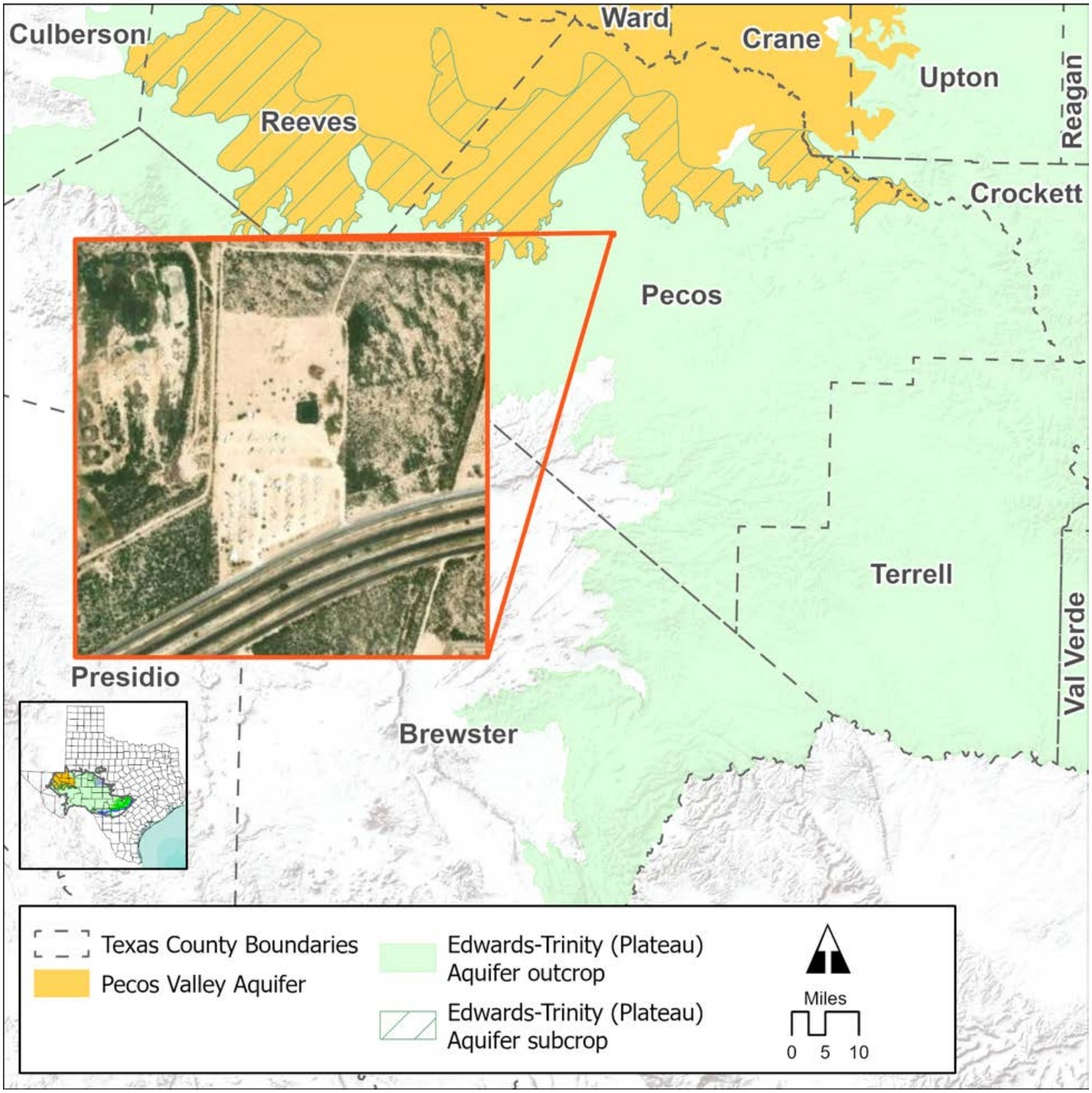


Figure 588. Location of the Fort Stockton Power Plant in Pecos County.

Table 75. Fort Stockton Power Plant timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type	Cooling System
1958	GT	Began Operation	Gas Turbine	Fossil fuels		
2004	GT	Stand by	Gas Turbine	Fossil fuels		

Gas turbines, such as the Fort Stockton Power Plant unit GT, have much lower cooling requirements than steam turbines. Form EIA-860 did not specify if the gas turbine used a wet or dry nitrogen oxide control. Given that the gas turbines started operating in 1958 (EIA, 2020a), we can assume that the turbines used wet nitrogen oxides control. Based on our assumption, we assigned the years with gas turbine operation an average water use value of 0.05 gallons per kilowatt-hour.

Figure 589 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Fort Stockton Power Plant. Figure 589c illustrates the pumpage based on the Water Use Survey. Given the low net power generation values and low corresponding volumes of water extracted at this particular power plant, we did not make any revisions to the original TWDB Water Use Survey reported pumpage volumes.

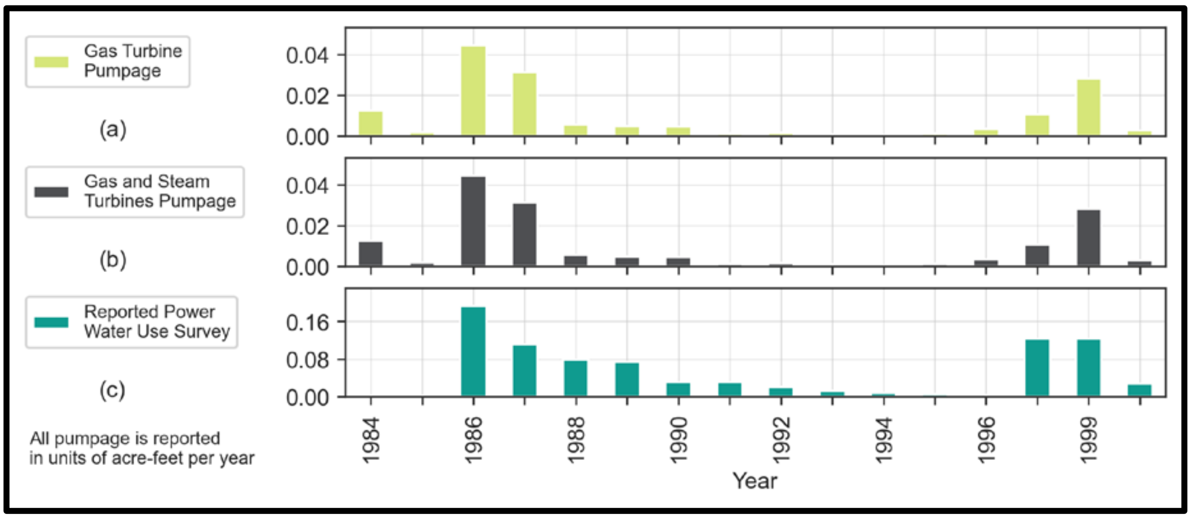


Figure 589. Fort Stockton Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated groundwater pumping associated with gas and steam turbine power generation, (c) Reported groundwater pumping by the Water Use Survey.

As the only entity using groundwater from the Edwards-Trinity (Plateau) to produce power within Pecos County, only reported pumpage from the Fort Stockton Power Plant is included in the revised pumpage dataset.

Mining

Figure 580d and Figure 581d illustrate the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Pecos County during the study period. The number of active enhanced oil recovery wells in Pecos increased from 666 wells in 1980 to 1,257 wells in 2020. The Water Use Survey data has gaps for which estimates from the Bureau of Economic Geology and the U.S. Geological Survey methodologies were compared. The estimates for 1984 based on the U.S. Geological Survey data are almost an order of magnitude higher than the estimates based on the Bureau of Economic Geology methodology, but are an order or magnitude lower by the end of the study period. However, the range of the data stays consistent and therefore, we have confidence in the revised estimated mining use for Pecos County. Revised mining estimates indicate that 27 percent of mining use is pumped out from the Pecos Valley Aquifer and the remaining is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

In Figure 580c and Figure 581c we illustrate the changes in groundwater pumping associated with manufacturing use from the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer, respectively, in Pecos County during the study period. There are several entities for which we applied changes. Table 76 summarizes our revisions to the original estimates.

Table 76. Summary of revisions to groundwater pumping from the Pecos Valley Aquifer and Edwards-Trinity (Plateau) Aquifer for manufacturing use in Pecos County from 1984 through 2018.

Aquifer	Standardized Name	Alternate Water Use Survey Names	Notes
Pecos Valley Aquifer	Energy Transfer Co – Gomez Plant	Hoover Energy Texas LLC – Gomez Plant; Regency Field Service, LLC – Gomez Plant	Changed mining use designation from 1984 through 2009 to manufacturing use to be consistent with designation from 2010 through present
	Navitas Midstream Midland Basin, LLC-Sprayberry Plant	DCP Midstream – Sprayberry Plant	No data after 2016; assumed 2016 pumping for 2017 and 2018
Edwards-Trinity (Plateau) Aquifer	ETC Field Services	Regency Energy Partners – Waha Plant	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present
	Farmland Industries Inc	None	Reduced 1984 pumping to 1985 value
	Firestone Test Center	None	No data after 2012, but business still in operation; assumed 2012 volume for year 2013 and following. “Other Aquifer” designation in 2004 and 2005 revised to Edwards-Trinity (Plateau) Aquifer. No pumping reported from 1995 through 1997; assumed year 2000 volume.
	Kinder Morgan Yates Gas Plant	Kinder Morgan	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present
	Southern Union Gas Service – Grey Ranch Plant Pecos County	Sid Richardson Carbon & Energy Company – Grey Ranch Pecos County (2001-2009)	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2001 through present. Year 2000 value missing; used 1999 volume as estimate

Livestock

In Figure 580b and Figure 581b illustrate the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Pecos County during the study period. Our estimate is greater than the TWDB Water Use Survey data from 1986 through 1998 and 2004 onwards for the Pecos Valley Aquifer. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County.

5.2.36 Reagan County

Figure 590 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Reagan County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

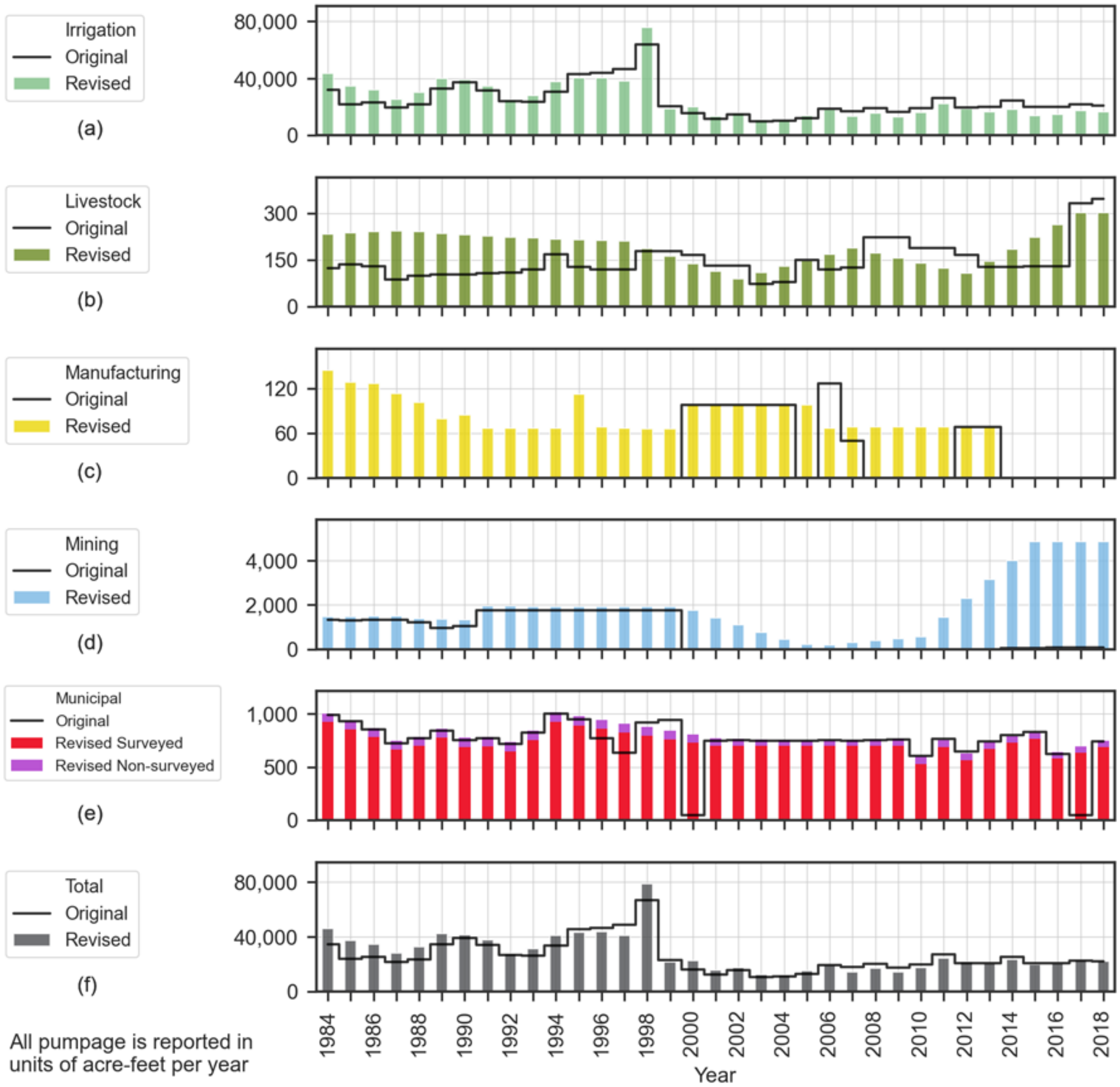


Figure 590. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Reagan County from 1984 through 2018.

Surveyed Municipal

Revisions to the original TWDB Water Use Survey dataset for reported municipal pumping from the Edwards Trinity (Plateau) Aquifer in Reagan County included data interpolation to fill in occasional years of missing data. It is unclear why the original pumpage from 2010-2017 was low, as data was reported for this period for the county's largest water consumer, City of Big Lake. After 2016, it is likely that the City of Big Lake transferred responsibility for providing water services to a new entity, the Reagan County WSD. This entity reported pumpage in 2018, but did not report usage in 2017. We interpolated usage for 2017 based on the 2016 usage by the City of Big Lake and the 2018 usage by Reagan County WSD; both of these usages were of similar magnitude. This is an example of how tracking water provider histories within the TWDB Water Use Survey Dataset may provide insight as to whether pumpage data is being under-reported. Reagan County WSD took on debt in 2016 (according to the Better Business Bureau) in order to finance commencement of its water operations within the region. This supports the idea that it assumed pumpage responsibilities from the City of Big Lake, and that reporting pumpage in 2017 was not performed possibly due to new management oversight. Similar patterns are evident throughout the TWDB municipal surveyed dataset.

Non-Surveyed Municipal

Figure 591 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Reagan County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

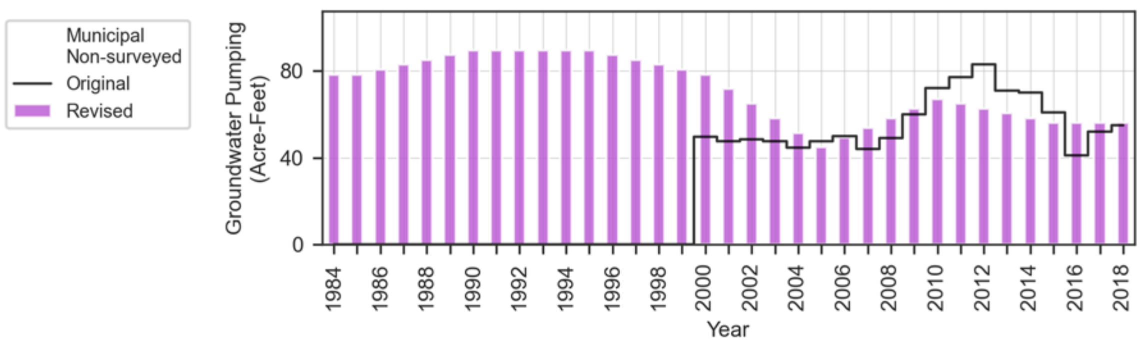


Figure 591. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Reagan County from 1984 through 2018.

Irrigation

Reagan County is entirely underlain by the Edwards-Trinity (Plateau) Aquifer, yet for much of the southeastern portion of the county is also underlain by the Dockum Aquifer. Wells identified within the county appear to be screened in both the Edwards-Trinity (Plateau) Aquifer and Dockum Aquifer within the Dockum Aquifer footprint, without any form of geographic separation. However, based on review of the TWDB groundwater data viewer, the vast majority of wells within the Dockum footprint are screened within the Edwards-Trinity (Plateau) Aquifer. As such, it is assumed that all irrigation withdrawals are coming from wells within the Edwards-Trinity (Plateau) Aquifer and not from the Dockum Aquifer.

The original TWDB Water Use Survey data indicated that between 9,900 acre-feet per year and 63,800 acre-feet per year was historically pumped from the Edwards-Trinity (Plateau) Aquifer for irrigation purposes within Reagan County (Figure 592). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater needs for irrigation of land above the footprint of the Edwards-Trinity (Plateau) Aquifer within the county were very similar to the original TWDB estimates, ranging from approximately 10,000 acre-feet per year to 75,500 acre-feet per year over this study period. Year-to-year variations were similar within each dataset, although revised pumpage estimates are lower for the period from 2007-2018. Surface water was not used to meet irrigation demands in any year within the study period.

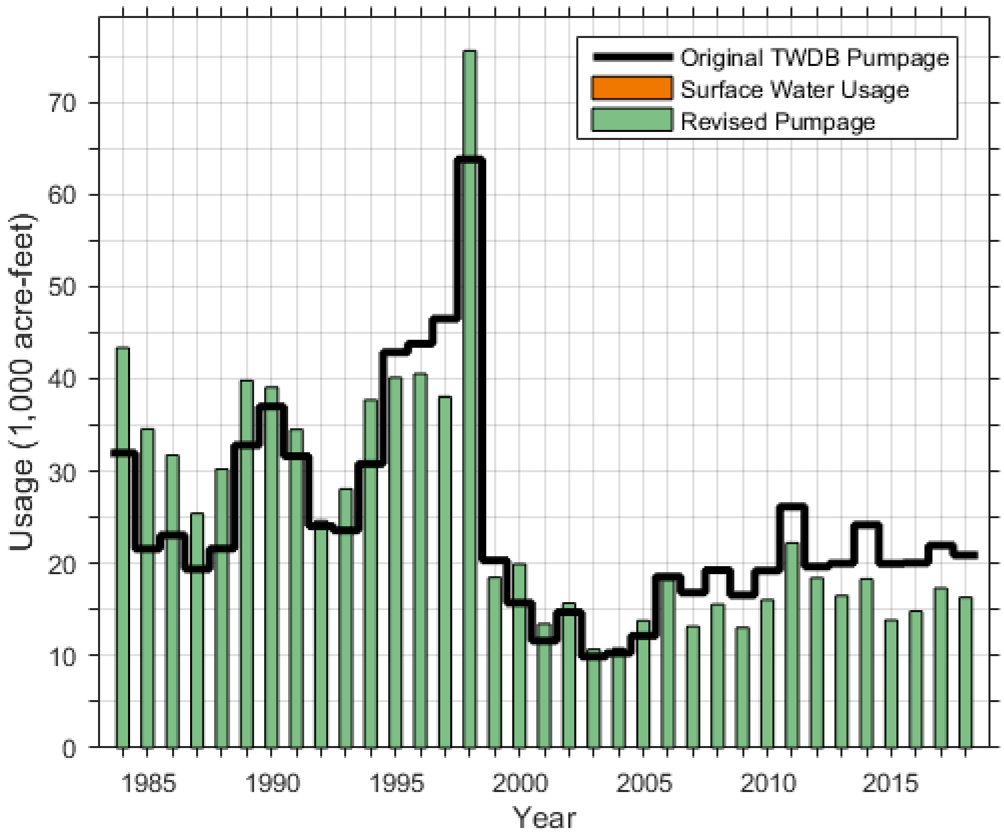


Figure 592. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Reagan County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Reagan County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Reagan County.

Mining

Figure 590d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Reagan County during the study period. The number of active enhanced oil recovery wells in Reagan County increased from 52 wells in 1980 to 116 wells in 2020. Like other counties, the Water Use Survey data has gaps for which estimates from the Bureau of Economic Geology and the U.S. Geological Survey methodologies were compared. The estimates based on the U.S. Geological Survey data were consistently higher but within an order of magnitude of the estimates from the Bureau of Economic Geology methodology. However, there are a few years after the year 2000 where these estimates come close to each other (within a factor of two to three) which provides us with confidence in the results. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 590c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Reagan County during the study period. The revision reflects a revision to the use designation from mining to manufacturing for the "Atlas Pipeline-Benedum Plant" (also reported under "Western Gas Resources Inc-Benedum Plant") data from 1984 through 1999. In addition, we reassigned data for "Western Gas Resources Inc-Midkiff Plant" in years 2006 and 2007 to Upton County where the other survey years are reported.

Livestock

Figure 590b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Reagan County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data.

5.2.37 Real County

Figure 593 and Figure 594 illustrate our revisions to the estimated in groundwater pumping from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Real County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

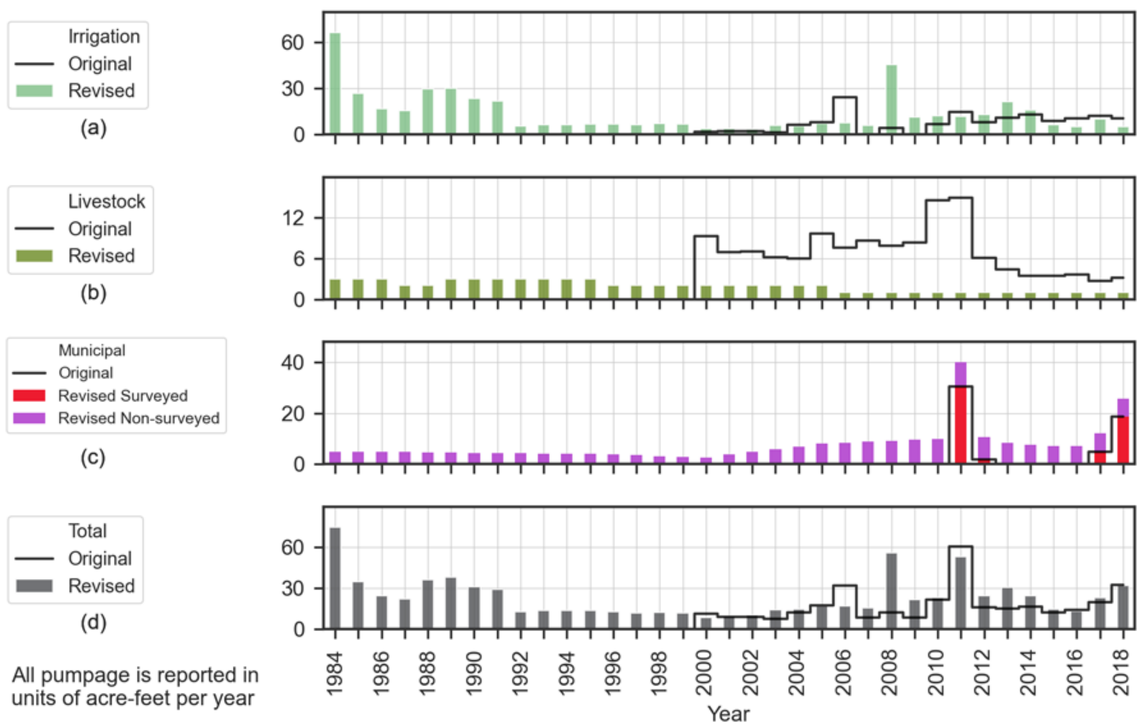


Figure 593. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Real County from 1984 through 2018.

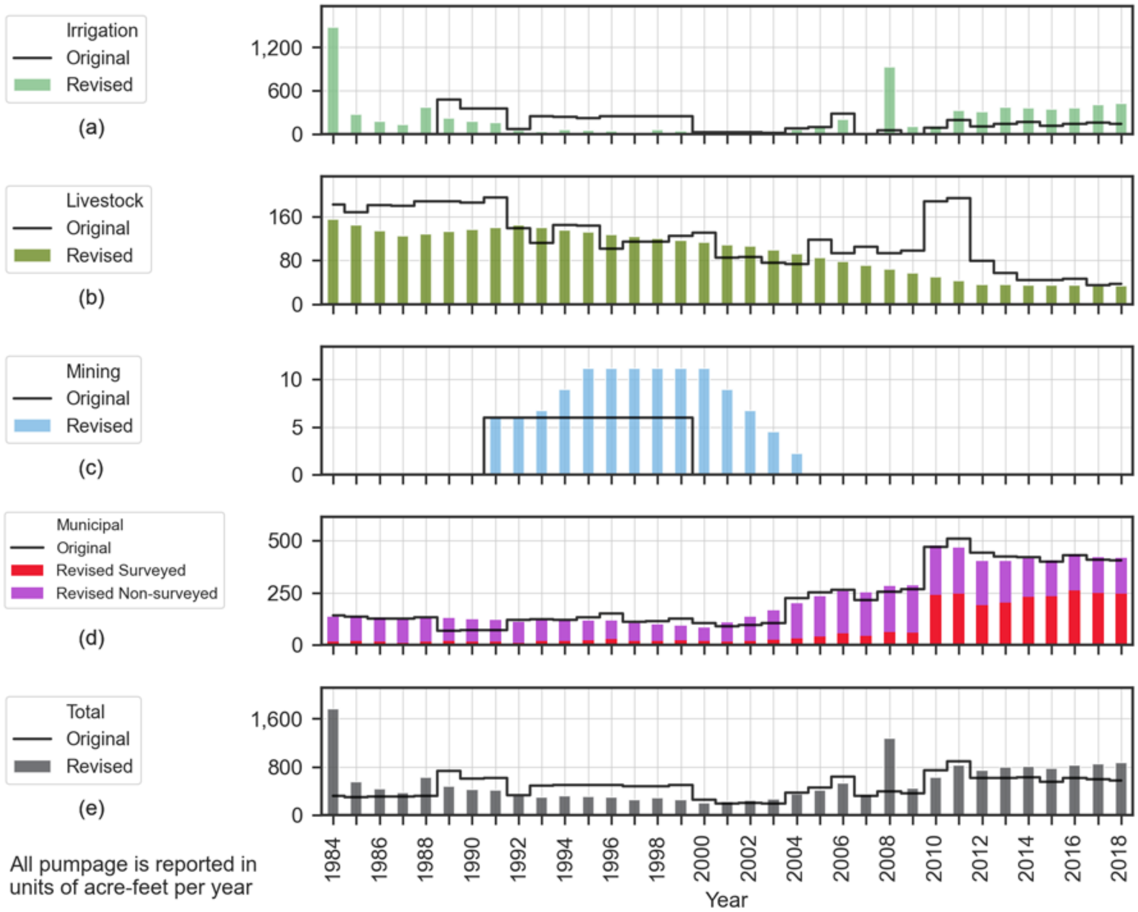


Figure 594. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Real County from 1984 through 2018.

Surveyed Municipal

Reported municipal pumpage from the Trinity (Hill Country) Aquifer within Real County includes pumpage from Crown Mountain WSC (2017-2018), Frio Canon Water (2018) and Real WSC (2011-2012). The locations of groundwater wells for each of these entities was not identifiable, and as such we assumed the reported aquifer designation to be correct. This is despite our suspicion that all pumpage within the county should be actually allocated to the Edwards Trinity (Plateau) Aquifer as this aquifer underlies the majority of the county.

Real WSC also reported pumpage from an “Other Aquifer” from 2010-2018, which we assumed to be the Edwards Trinity (Plateau) Aquifer Real WSC also reported pumpage from the Edwards Trinity (Plateau) Aquifer for 2003-2009. Similarly, the City of Leakey reported pumpage from and “Other Aquifer” from 1955 to 2009, and the reported Edwards Trinity (Plateau) Aquifer pumpage through 2018.

Non-Surveyed Municipal

Figure 595 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Real County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

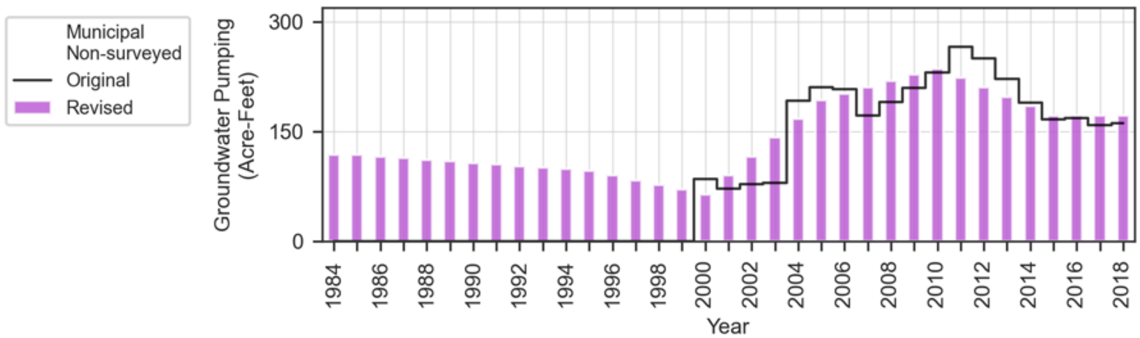


Figure 595. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Real County from 1984 through 2018.

Irrigation

Real County is nearly completely underlain by the Edwards-Trinity (Plateau) Aquifer, except for a small portion of the southeast corner of the county (along the border with Bandera County) where it is underlain by the Trinity (Hill Country) Aquifer. The only wells identified within the county were within the Edwards-Trinity (Plateau) Aquifer footprint and were also all screened within the aquifer.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Real County from the Edwards-Trinity (Plateau) Aquifer amounted to between zero acre-feet per year and 475 acre-feet per year (Figure 596), with usage fairly stable from 1993 to 1999 and then again from 2010 to 2018. Prior to 1989, usage data was either missing or pumpage for irrigation was simply zero acre-feet per year. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Real County ranged from slightly over 100 acre-feet per year (in 2000) to 1,780 acre-feet per year (in 1984). Surface water was partially used to meet this irrigation demand, and its usage eliminated the need for groundwater pumpage for irrigation from 2000 to 2003. Groundwater pumpage for irrigation ranged from zero acre-feet per year up to 1,475 acre-feet per year. There appears to have been a steady increase in irrigation pumpage between 2011 and 2018.

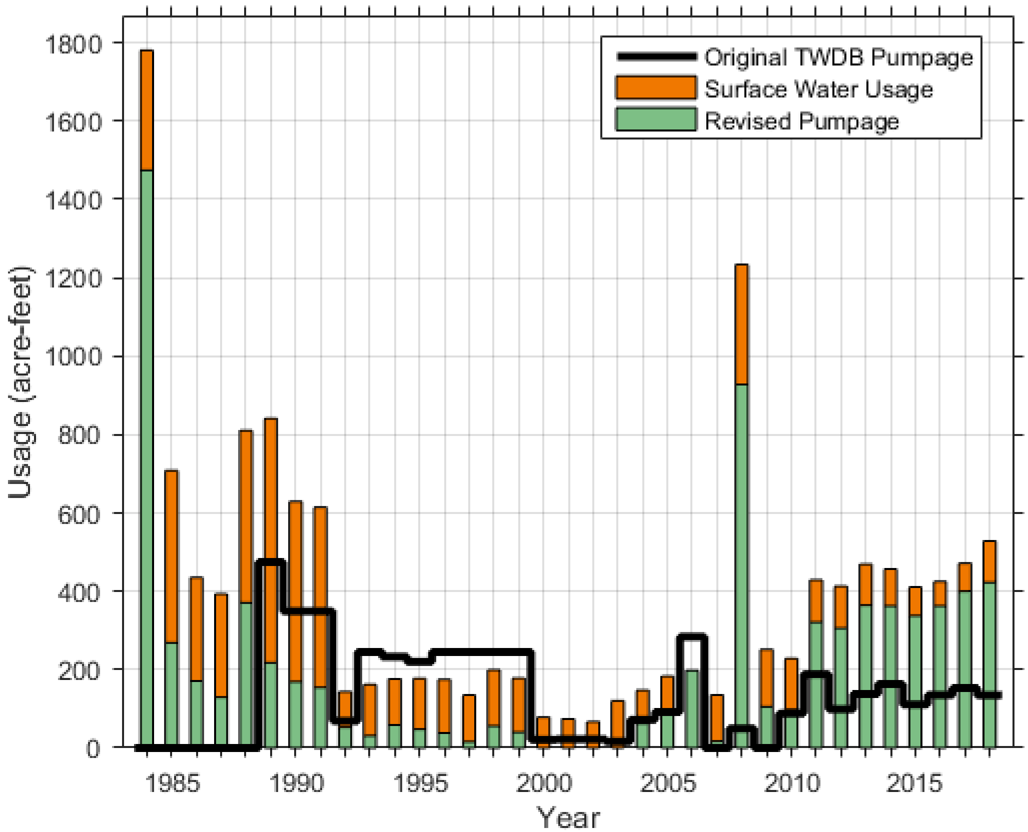


Figure 596. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Real County.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Real County from the Trinity (Hill Country) Aquifer amounted to range between zero acre-feet per year and 24 acre-feet per year (Figure 597), with usage data reported only from 2000 to 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Trinity (Hill Country) Aquifer in Real County ranged from slightly over three acre-feet per year to 66 acre-feet per year. Surface water was not used to meet irrigation demands within the Trinity (Hill Country) Aquifer footprint.

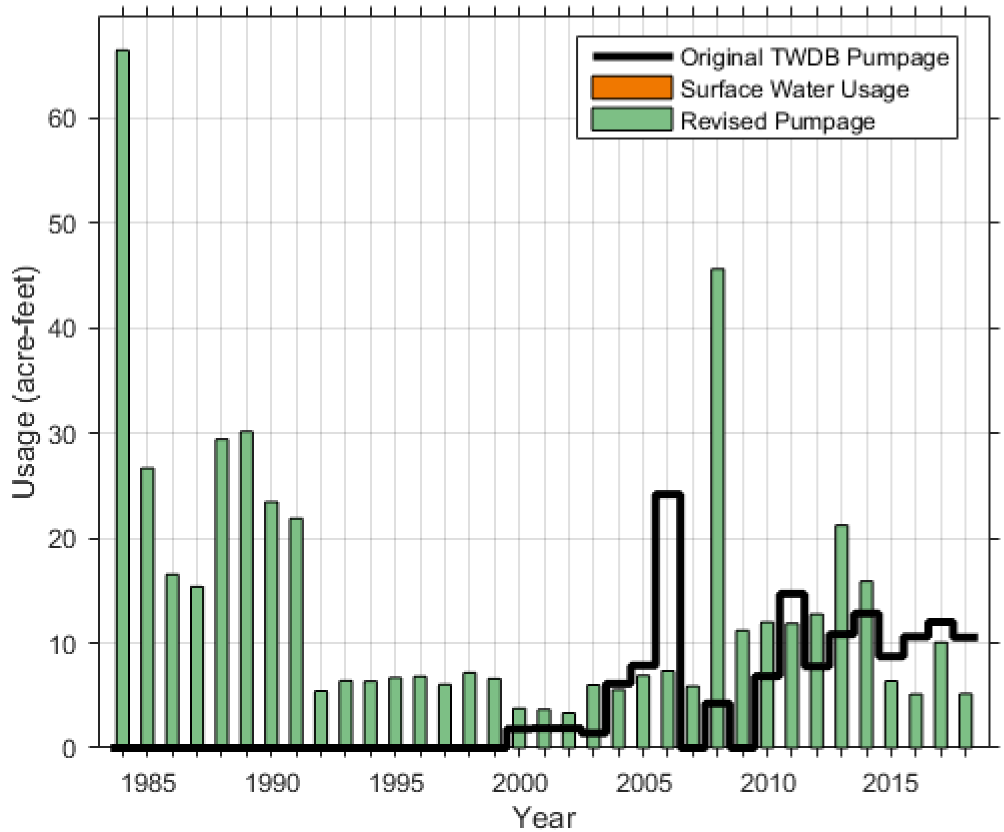


Figure 597. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Real County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Real County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Real County.

Mining

Figure 594c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Real County during the study period. No enhanced oil recovery wells or Water Use Survey data were available, therefore, the revised mining estimates were obtained using the U.S. Geological Survey data. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Real County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Real County.

Livestock

Figure 593b and Figure 594b illustrate the changes in groundwater pumping associated with livestock use from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Real County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Real County except for the years 2010 and 2011, with our estimate being approximately half of that estimated by the TWDB Water Use Survey. Groundwater pumping estimated by the TWDB Water Use Survey data was zero prior to 1999 from the Trinity (Hill Country) while our revised estimate determined groundwater pumping was consistent during the entire study period in Real County.

5.2.38 Reeves County

In Figure 598 and Figure 599 we illustrate our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Reeves County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

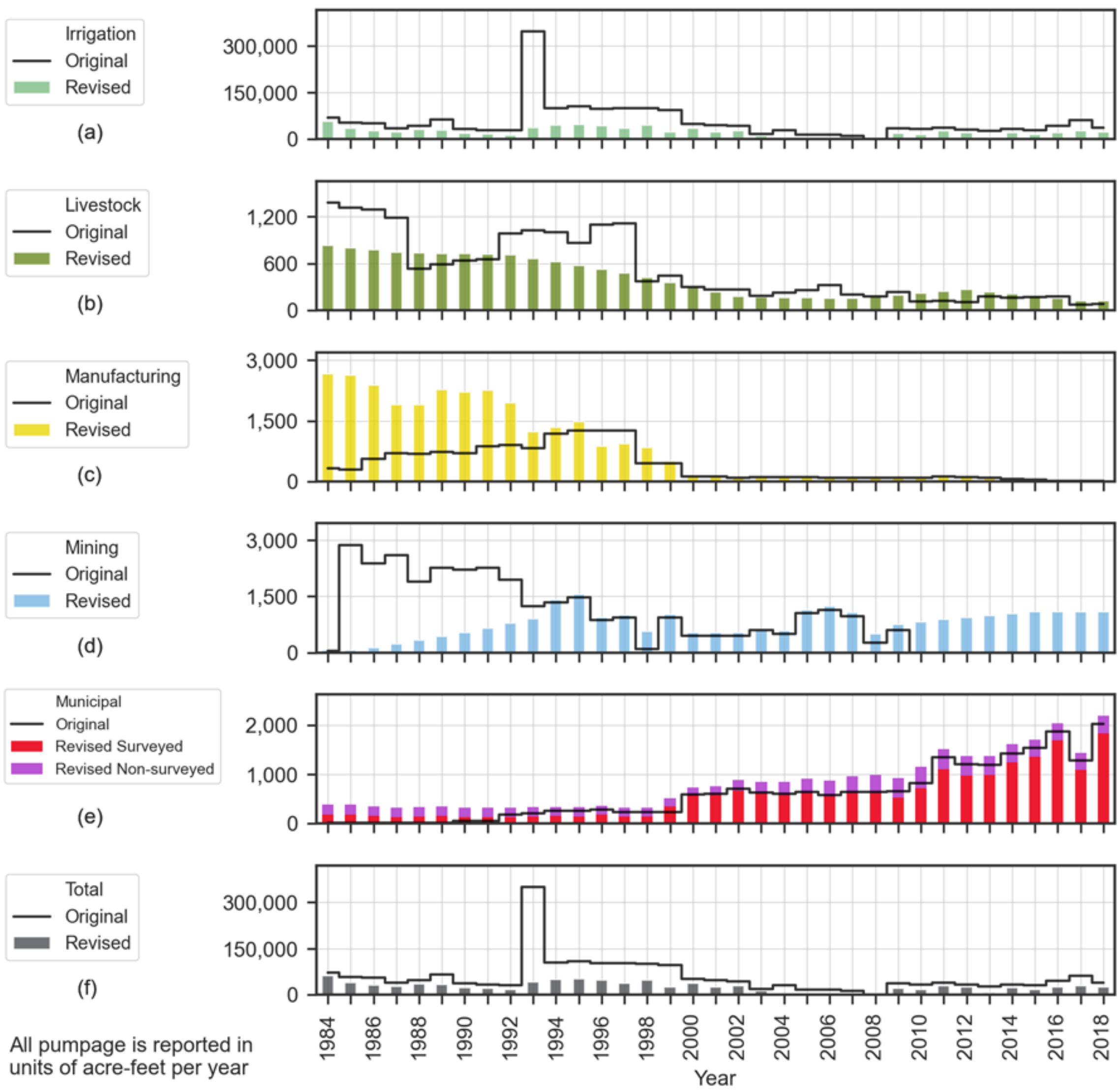


Figure 598. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Reeves County from 1984 through 2018.

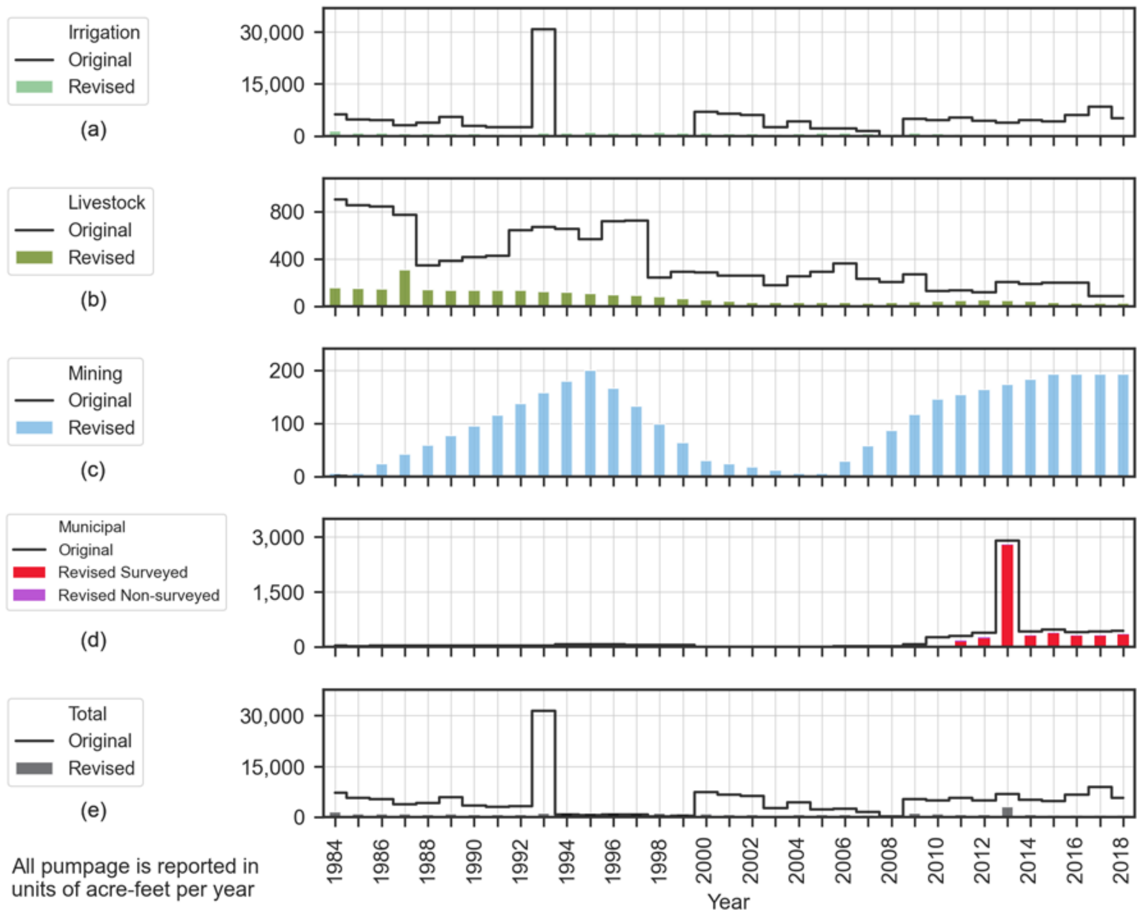


Figure 599. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Reeves County from 1984 through 2018.

Surveyed Municipal

Reported municipal pumping from the Pecos Valley Aquifer in Reeves County did not require revision from the original TWDB Water Use Survey dataset. Reported pumpage was fairly stable between 1984 and 1999, and then increased by nearly 100% in 2000. Pumpage increased further in 2010 when Capitol Aggregates, Inc. began reporting usage from its Hoban Plant. This increased usage was partially offset by a reduction in usage reported by Madera Valley WSC.

Water usage for municipal purposes from the Edwards Trinity (Plateau) Aquifer was not reported until 2011, when Madera Valley WSC began pumping. It appears that they reduced their reliance on the Pecos Valley Aquifer by increasing pumping from the Edwards Trinity (Plateau) Aquifer, with the combined annual total pumpage approximately equal before and after 2010. Pumpage peaked in 2013 when 2,478 acre-feet/year was reportedly used by the City of Pecos, as the only time this entity reported pumpage from Reeves County.

Non-Surveyed Municipal

Figure 600 and Figure 601 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Reeves County during the study period. While our estimates are about two times higher than the Water Use Survey data for the Pecos Valley Aquifer, they are several times less than the Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer.

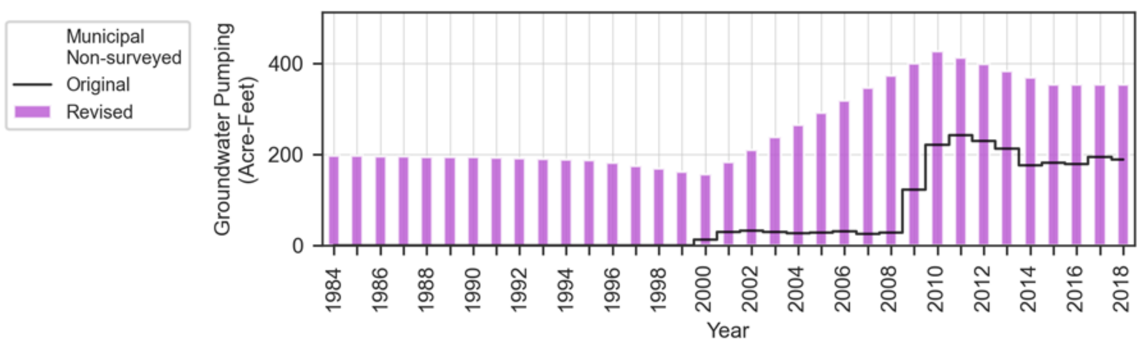


Figure 600. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Reeves County from 1984 through 2018.

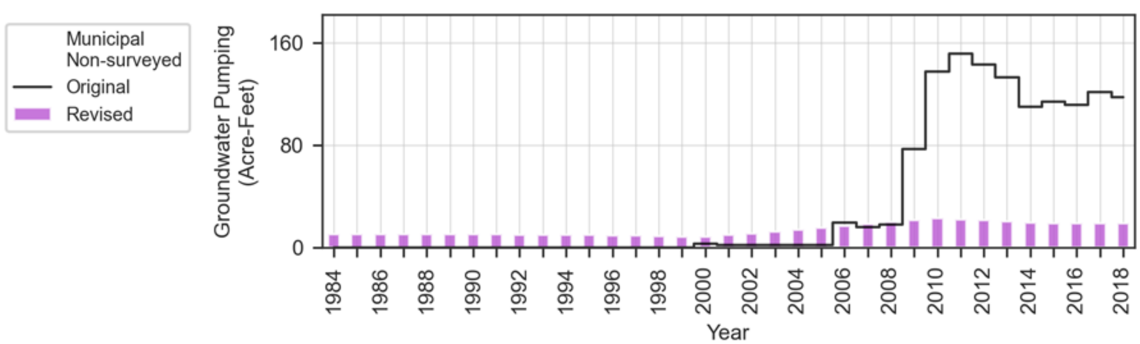


Figure 601. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Reeves County from 1984 through 2018.

Irrigation

Reeves County is predominantly underlain by the Pecos Valley Aquifer, yet is also underlain by the Edwards-Trinity (Plateau) Aquifer along the county's southern and western borders. The Dockum Aquifer is also within eastern portion of the county, and the Rustler Aquifer underlies the Pecos Valley Aquifer over most of the county. Wells identified within the footprint of the Dockum Aquifer appear to be screened in either the Dockum Aquifer or the Pecos Valley Aquifer, without any discernible geographic distribution for either screened interval. Wells screened in the Rustler Aquifer appear geographically clustered within the northern corner of the county, slightly overlapping with the footprint of the Pecos Valley Aquifer. For this analysis, it was assumed that pumpage for irrigation would be preferentially withdrawn from shallower aquifers only, excluding the Dockum and Rustler Aquifers. All pumpage was assumed to be derived from wells screened within the Pecos Valley Aquifer or the Edwards-Trinity (Plateau) Aquifer.

The original TWDB Water Use Survey data indicated that between zero acre-feet per year and 340,000 acre-feet per year was historically pumped from the Pecos Valley Aquifer for irrigation purposes within Reeves County (Figure 602). Pumpage was generally less than 75,000 acre-feet per year, except for the period from 1993 to 1999 when pumpage was estimated to be averaging 100,000 acre-feet per year excluding the anomalously high 340,000 acre-feet per year estimate for 1993. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water needs for irrigation of land above the footprint of the Pecos Valley Aquifer within the Reeves County ranged from approximately 20,000 acre-feet per year to 70,000 acre-feet per year over this study period. Surface water was used to meet some of the irrigation demand in all years and was sufficient to entirely eliminate pumpage demands from 2004 to 2008. In comparing the original TWDB Water Use Survey estimates and the revised estimates, it is notable that there is good agreement between the two datasets excluding the time period between 1993 and 1999 when TWDB Water Use Survey estimates are larger.

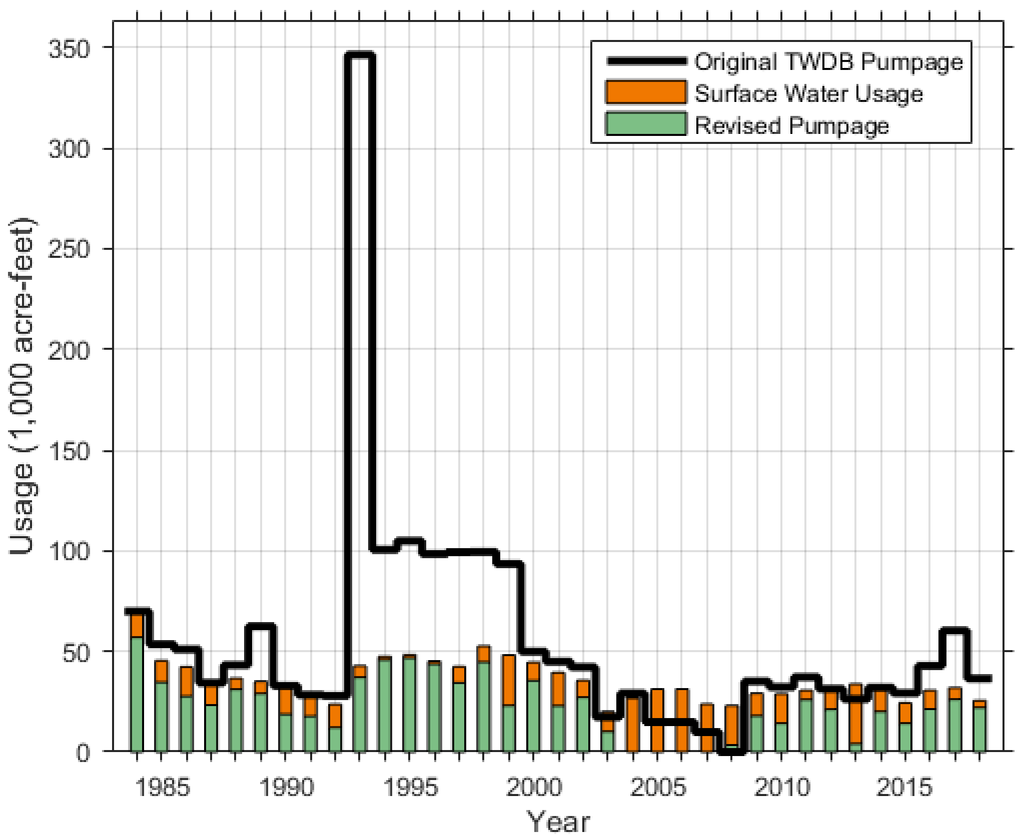


Figure 602. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Reeves County.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Reeves County from the Edwards-Trinity (Plateau) Aquifer amounted to between zero acre-feet per year and 31,000 acre-feet per year (Figure 603), with most annual estimates below 7,000 acre-feet per year. As with the TWDB water use estimate for 1993 from the Pecos Valley Aquifer, the 1993 estimate from the Edwards-Trinity (Plateau) Aquifer is an extreme outlier within the dataset. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Reeves County ranged from 550 acre-feet per year to 1,000 acre-feet per year. Surface water was not used meet this irrigation demand, as the footprint of the Edwards-Trinity (Plateau) Aquifer is distant from the Pecos River, which is the likely source of the surface water.

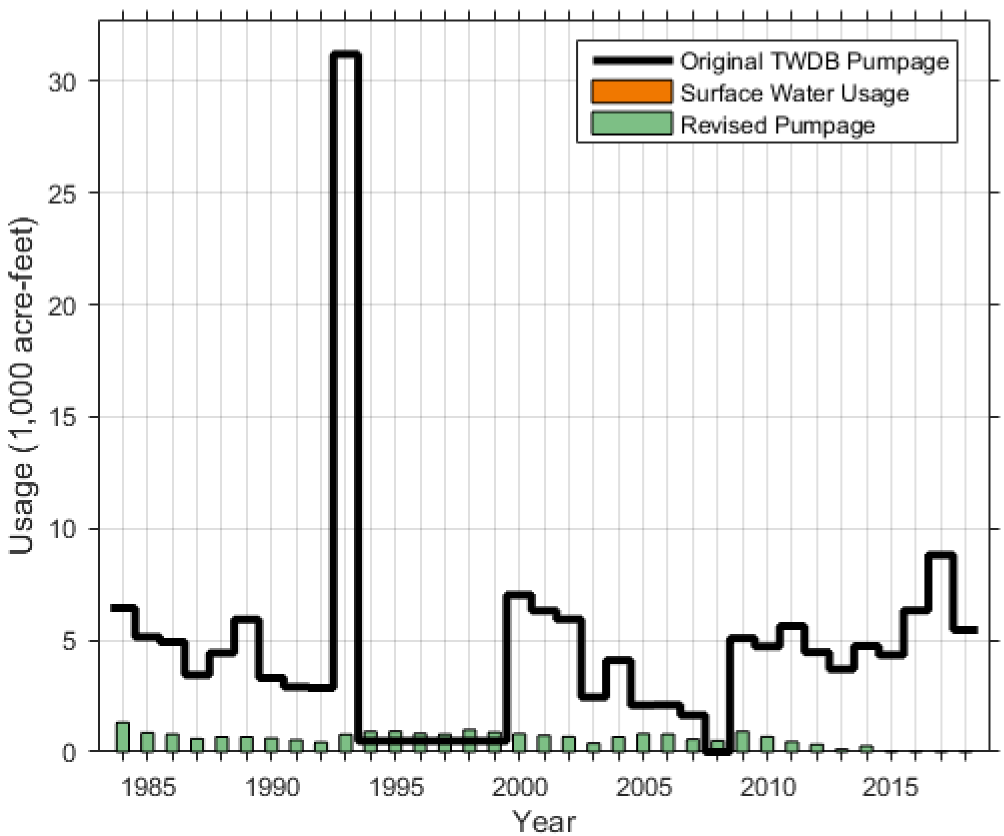


Figure 603. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Reeves County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Reeves County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Reeves County.

Mining

Figure 598c and Figure 599c illustrate the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Reeves County during the study period. There appears to be significant pumping related to oil and gas activities based on the modified Bureau of Economic Geology methodology. The Water Use Survey data, where available, appeared to be generally within the same order of magnitude and within a factor of three of the U.S. Geological Survey estimated pumping values. The revised mining use estimates show that 88 percent of water is pumped from the Pecos Valley Aquifer and the rest is from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 598c illustrates the changes in groundwater pumping associated with manufacturing use from the Pecos Valley Aquifer in Reeves County during the study period. The revision reflects a decrease in pumping associated with "Freeport McMoran Sulphur Inc" reported pumping from 1984 through 1999. We did not identify any necessary revisions to groundwater pumping associated with manufacturing use from the Pecos Valley Aquifer in Reeves County for years following 1999.

Livestock

Figure 598b and Figure 599b illustrate the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Reeves County during the study period. Our estimate is consistently less than the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Pecos Valley Aquifer. There is general agreement with the TWDB Water Use Survey data of decreasing trends of groundwater pumping from both aquifers during the study period in Reeves County.

5.2.39 Runnels County

Figure 604 illustrates our revisions to the estimated in groundwater pumping from the Lipan Aquifer in Runnels County during the study period. The original TWDB Water Use Survey database contained a small amount of pumpage in Runnels County allocated to the Edwards-Trinity (Plateau) Aquifer for municipal and livestock purposes. We allocated this pumpage to the Lipan Aquifer, as the Edwards-Trinity (Plateau) Aquifer does not exist within the county footprint. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

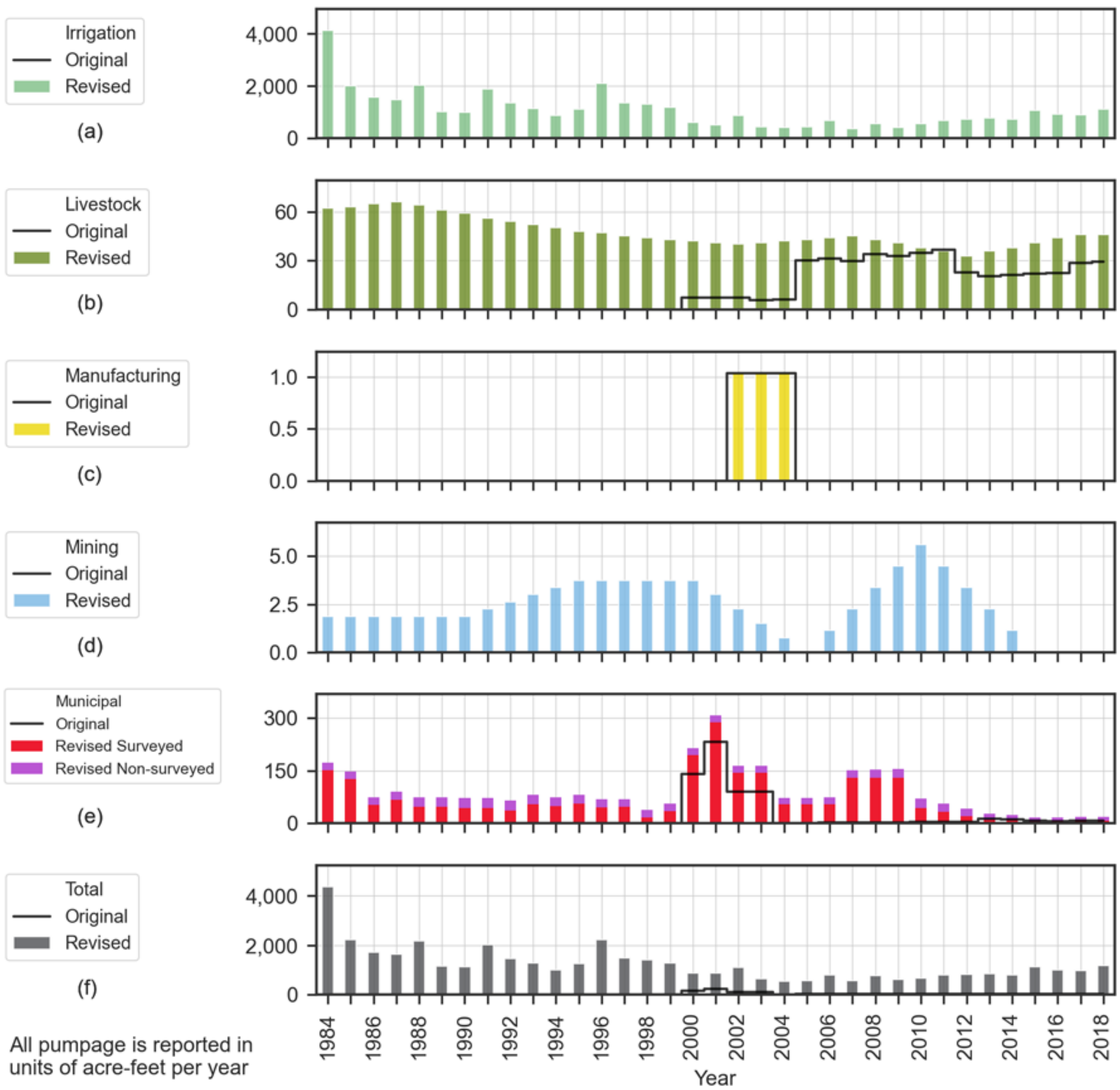


Figure 604. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Runnels County from 1984 through 2018.

Surveyed Municipal

The original TWDB Water Use Survey database contained pumpage from the City of Ballinger that utilized the Lipan Aquifer from 2000-2003. The other reported pumpage was from the City of Miles, which reported usage from 1955-2018 as being from an "Other Aquifer." We assigned this pumpage to the Lipan Aquifer based on the location of the City of Miles within the aquifer footprint. Data interpolation was needed to fill in missing reported pumpage from 1999 and 2010-2012.

Non-Surveyed Municipal

Figure 605 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Lipan Aquifer in Runnels County during the study period. Our estimates are about several times higher than the Water Use Survey data. Our review of the available data suggested the pumping for this use is more than previous estimates suggest. While the TWDB Water Use Survey data includes up to about five acre-feet of pumping from the Edwards-Trinity (Plateau) Aquifer, our estimates do not include any non-surveyed municipal use pumping from this aquifer in Runnels County.

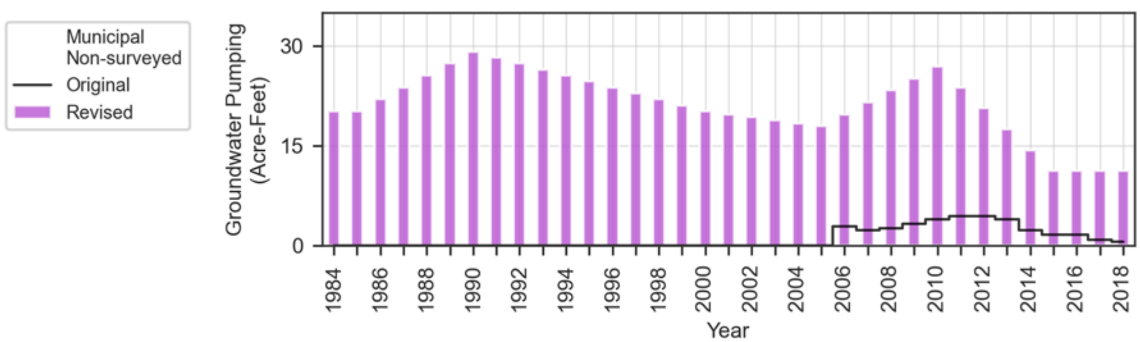


Figure 605. Original and revised estimates of groundwater pumping from the Lipan Aquifer for non-surveyed municipal use in Runnels County from 1984 through 2018.

Irrigation

The southwest corner of Runnels County is underlain with the Lipan Aquifer, and all wells within this aquifer footprint appear to be screened within the Lipan Aquifer. The original TWDB Water Use Survey dataset did not include irrigation pumpage from the Lipan Aquifer for Runnels County, but did quantify usage from "Other Aquifer" as ranging from 480 acre-feet per year to 3,840 acre-feet per year. It is unknown how much of this "Other Aquifer" pumpage was estimated to be from the Lipan Aquifer.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater pumpage for land above the footprint of the Lipan Aquifer in Runnels County ranged from 375 acre-feet per year to 4,130 acre-feet per year (Figure 606). Groundwater pumpage was highest for the years prior to 2000, and remained fairly low and uniform between 2000 and 2009. For the period from 2010 to 2018, groundwater usage for irrigation generally increased.

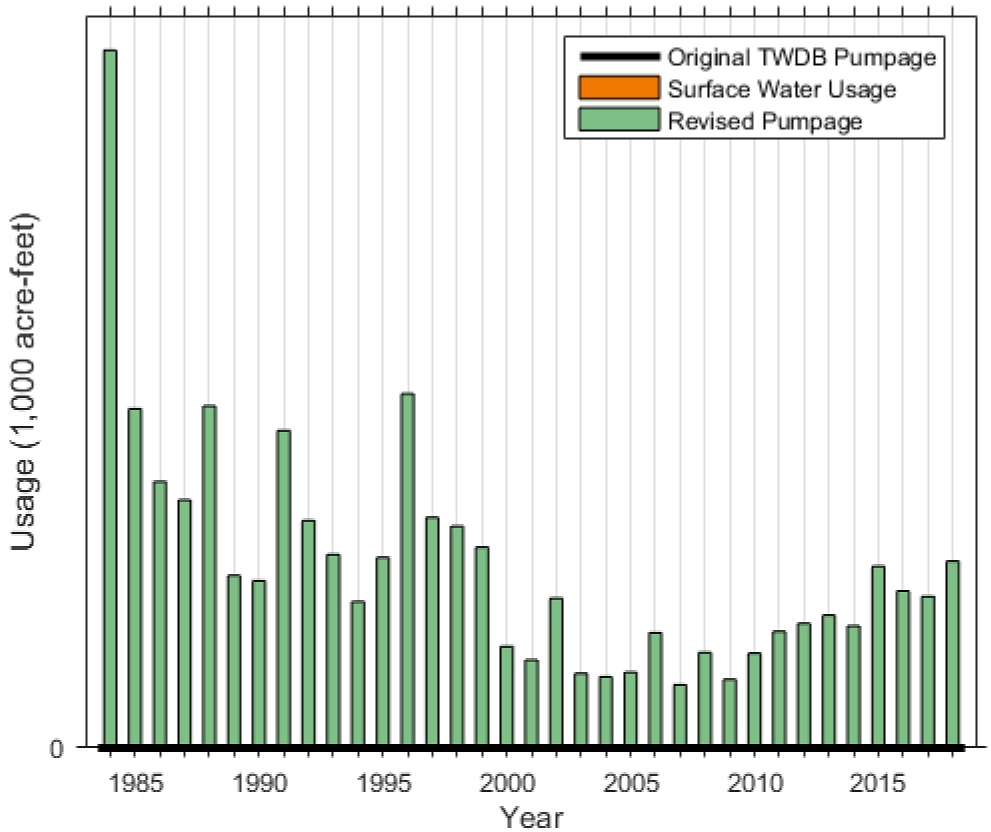


Figure 606. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Runnels County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Runnels County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Runnels County.

Mining

Figure 604d illustrates the changes in groundwater pumping associated with mining use from the Lipan Aquifer in Runnels County during the study period. Since no available enhanced oil recovery or Water Use Survey data were available, we have used the U.S. Geological Survey data to obtain the revised mining use values. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Lipan Aquifer.

Manufacturing

Figure 604c illustrates the groundwater pumping associated with manufacturing use from the Lipan Aquifer in Runnels County during the study period. We identified no changes for this use.

Livestock

Figure 604b illustrate the changes in groundwater pumping associated with livestock use from the Lipan Aquifer in Runnels County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from Lipan Aquifer in Runnels County. Prior to year 2000, the TWDB Water Use Survey data does not contain estimates of groundwater pumping from the Lipan Aquifer for livestock use in Runnels County and our revisions add estimated pumping for this period.

5.2.40 Schleicher County

Figure 607 and Figure 608 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Lipan Aquifer, respectively, in Schleicher County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

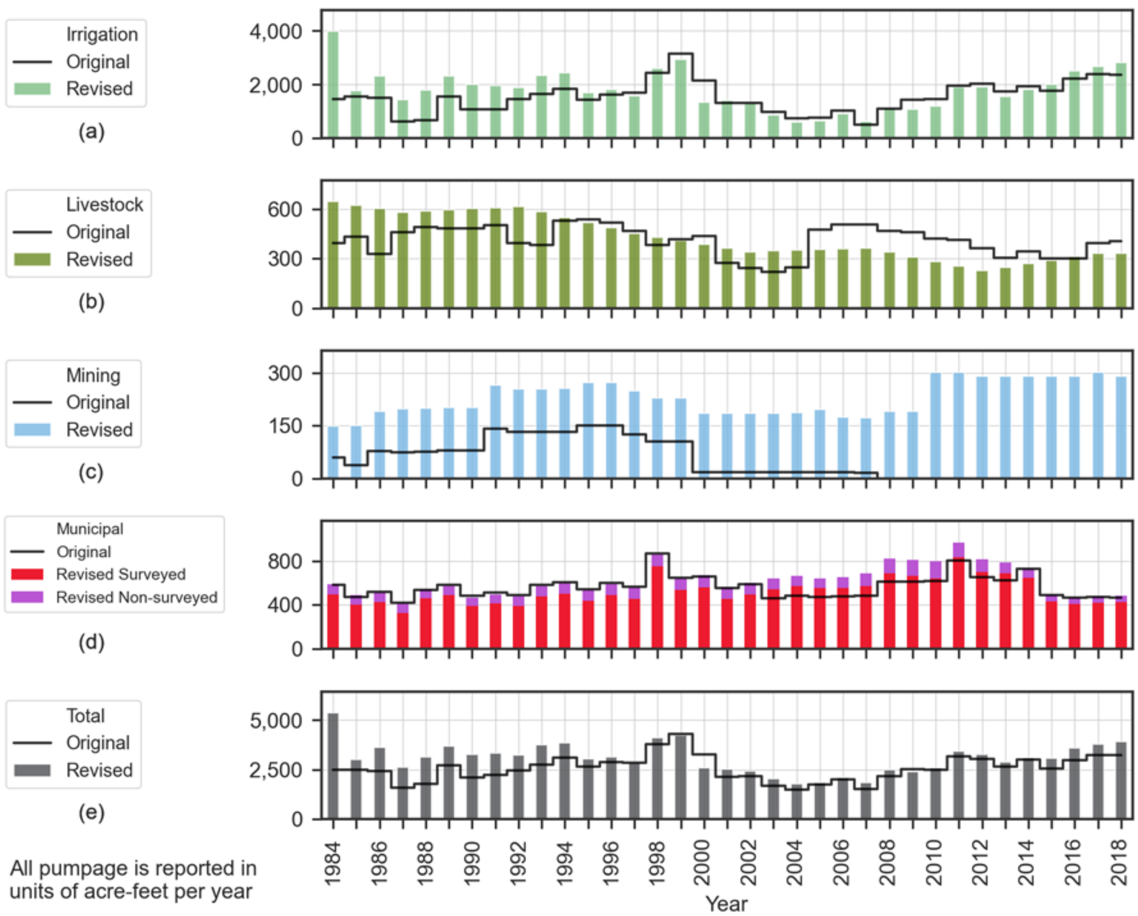


Figure 607. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Schleicher County from 1984 through 2018.

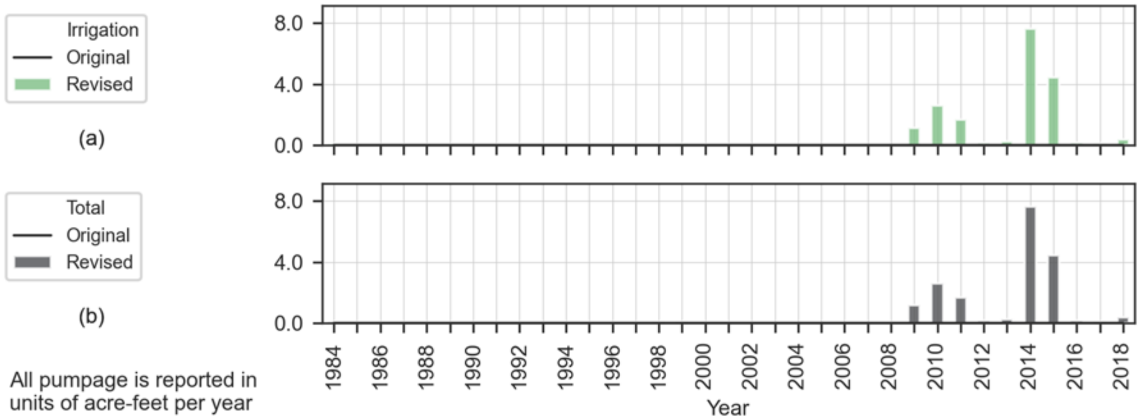


Figure 608. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Schleicher County from 1984 through 2018.

Surveyed Municipal

Reported municipal usage from the Edwards-Trinity (Plateau) Aquifer in Schleicher County was from the City of Eldorado, which reported fluctuating usage from 1955 to 2018. In 2014, usage of 176.31 acre-feet was reported by the entity "YFZ Land Water System." This water system was created to support operations of the Yearning for Zion Ranch which operated in the county between 2003 and 2014, supporting up to 300 people in a self-contained community. Based on newspaper articles describing the Yearning for Zion Ranch, we considered it likely that the ranch consumed equal amounts of water annually from 2004-2013 as it reported used in 2014. The revised dataset reflects this additional expected unreported usage within Schleicher County.

Non-Surveyed Municipal

Figure 609 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Schleicher County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

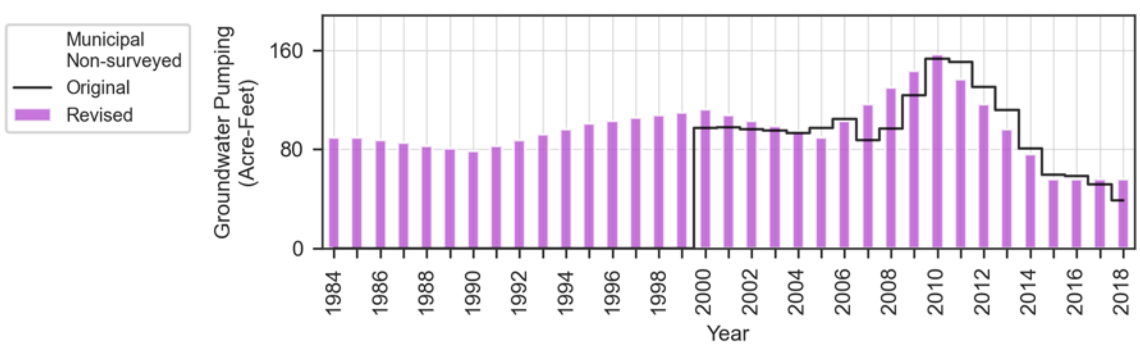


Figure 609. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Schleicher County from 1984 through 2018.

Irrigation

Schleicher County is entirely underlain by the Edwards-Trinity (Plateau) Aquifer, yet also has a narrow portion of land along its northern board with Tom Green County that is also underlain by the Lipan Aquifer. Wells identified within Schleicher County all appear to be screened within the Edwards-Trinity (Plateau) Aquifer, including wells located within the footprint of the subcrop of the Lipan Aquifer. Given the small size of the Lipan Aquifer footprint within Schleicher County, our analysis included all computed irrigation demands as being demands to be met from the Edwards-Trinity (Plateau) Aquifer.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Schleicher County from the Edwards-Trinity (Plateau) Aquifer amounted to between 500 acre-feet per year and 3,130 acre-feet per year (Figure 610), with usage peaking in 1999 followed by a decline until 2007 and then a generally steady increase through 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Schleicher County ranged from 580 acre-feet per year (in 2003) to 3,972 acre-feet per year (in 1984). Surface water was used in 1985 to partially meet demands. The revised groundwater pumpage trends generally matched those evident within the original TWDB Water Use Survey dataset, except for the highest pumpage computed for 1984. Within the revised dataset, usage was generally higher from 1984 to 1999, and 1999 pumpage is a local peak, followed by a general decline in pumpage through 2007. After 2007, groundwater pumpage increased fairly steadily, with computed 2018 pumpage nearly equaling the pumpage peak in 1999. Computed pumpage for the portion of Schleicher County within the footprint of the Lipan Aquifer ranged from zero acre-feet per year to just under eight acre-feet per year.

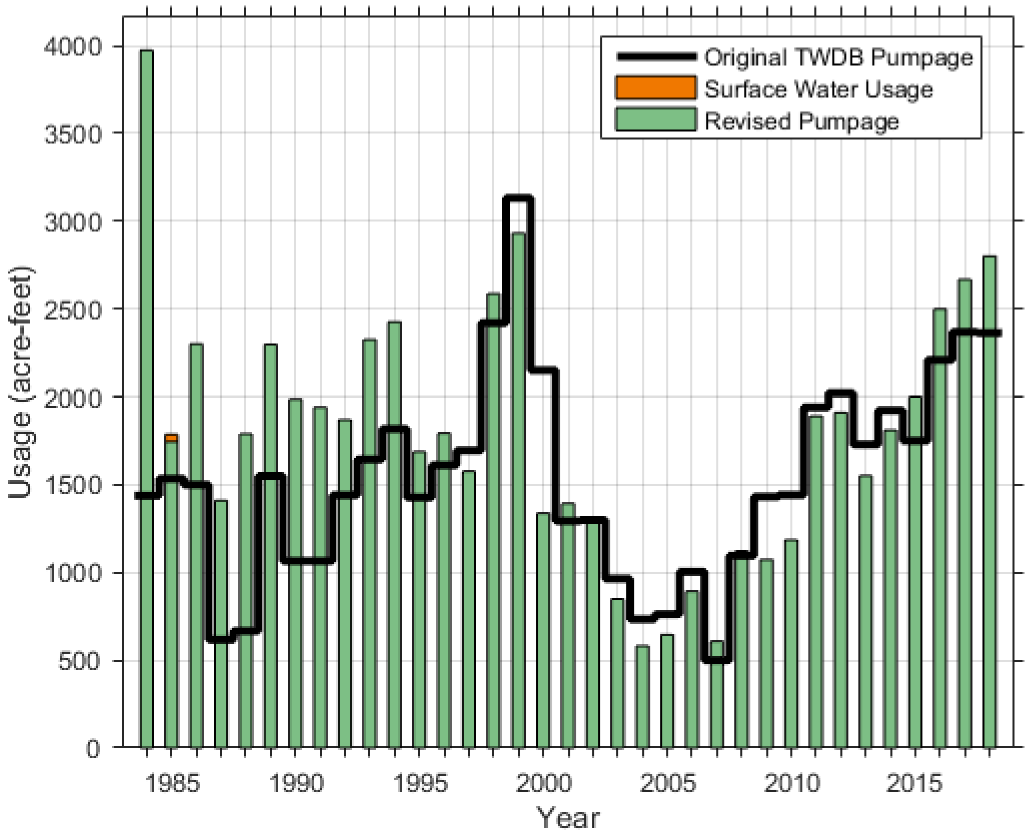


Figure 610. **Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Schleicher County.**

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Schleicher County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Schleicher County.

Mining

Figure 607c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Schleicher County during the study period. The number of active enhanced oil recovery wells in Schleicher County increased from 35 in 1980 to 102 wells in 2020. Although, there was limited Water Use Survey data available, estimates from the Bureau of Economic Geology and the U. S. Geological Survey methodologies were within the same order of magnitude and generally within a factor of five of each other. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Schleicher County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Schleicher County.

Livestock

Figure 607b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Schleicher County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Schleicher County.

5.2.41 Sterling County

Figure 611 and Figure 612 illustrate our revisions to the estimated in groundwater pumping from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Sterling County during the study period. The Water Use Survey data designates pumping from the Pecos Valley Aquifer in Sterling County; however, it appears the pumping designated as Pecos Valley Aquifer is from the Lipan Aquifer. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

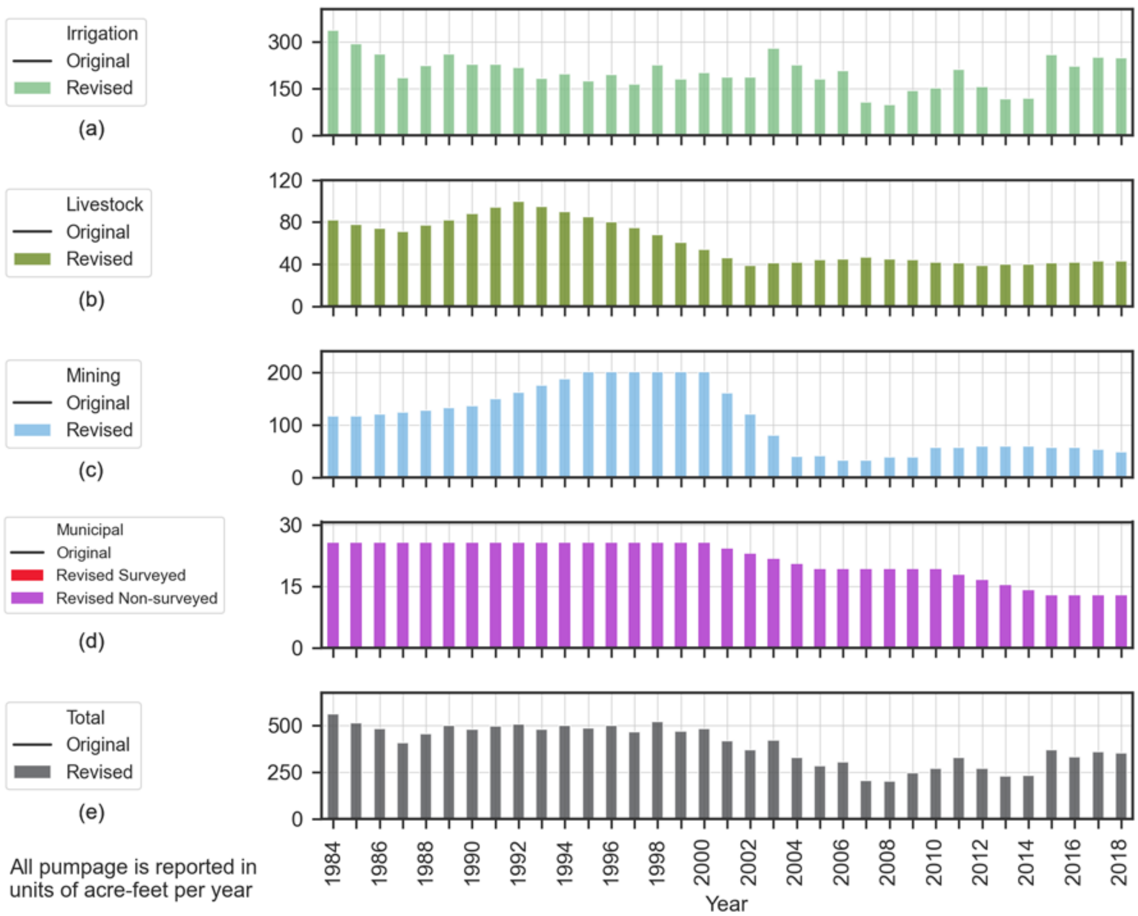


Figure 611. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Sterling County from 1984 through 2018.

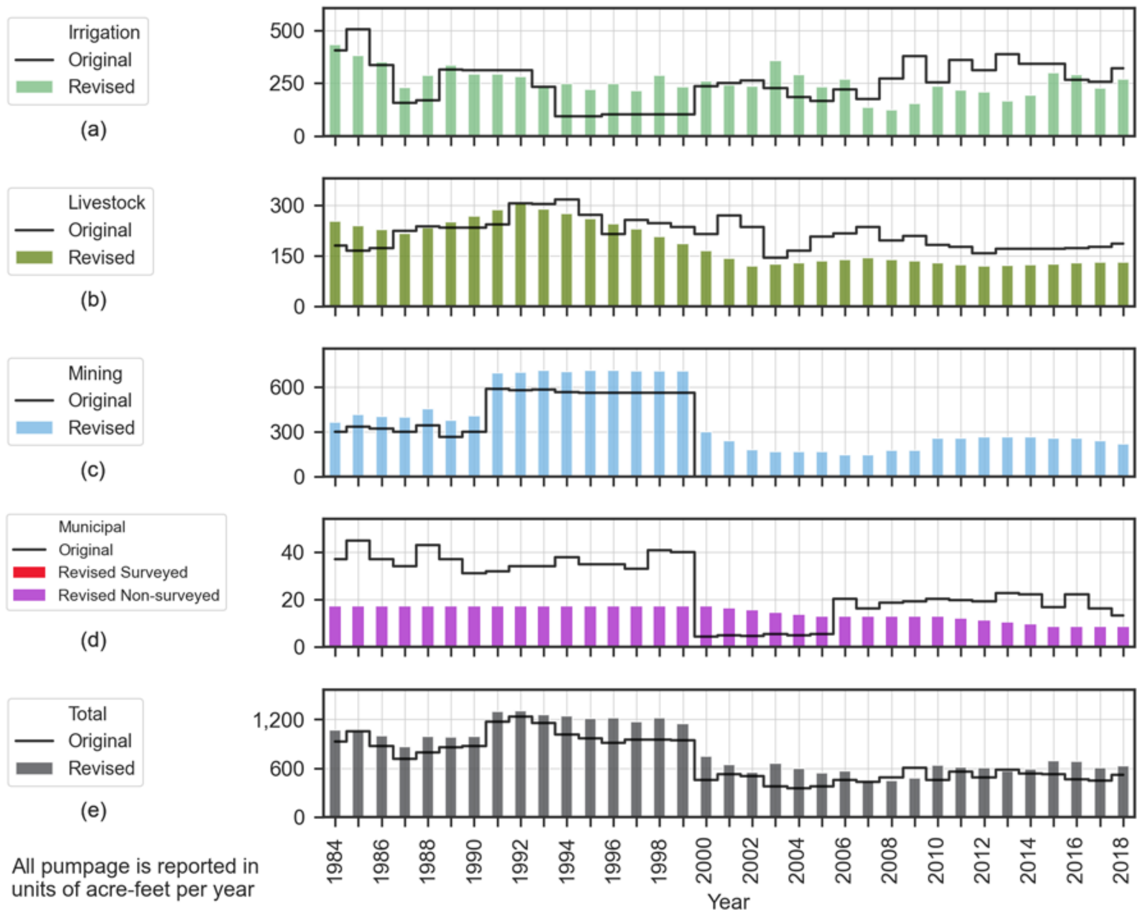


Figure 612. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Sterling County from 1984 through 2018.

Surveyed Municipal

Reported municipal pumping from within in Sterling County was attributed to the Dockum Aquifer from 2010 to 2018 and to an “Other Aquifer” from 1955 to 2009. Wells screened in the Dockum and Lipan Aquifers exist in close proximity to Sterling City (which reported the usage). Based upon the age of the wells identified within the TWDB groundwater data viewer, we believe all municipal pumping for Sterling County to be derived from the Dockum Aquifer.

Non-Surveyed Municipal

Figure 611d illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Lipan Aquifer in Sterling County during the study period. Our estimates range from 27 acre-feet per year to 13 acre-feet per year. The original TWDB Water Use Survey database did not include non-surveyed municipal pumpage from the Lipan Aquifer within Sterling County.

Figure 612d illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Sterling County during the study period. The original TWDB Water Use Survey dataset did not contain non-surveyed municipal water pumpage from the Edwards-Trinity (Plateau) Aquifer prior to 2006. Our revised dataset fills in this missing data, and slightly reduced original pumpage estimates for the 2006-2018 period. The original TWDB Water Use Survey dataset includes up to about three acre-feet of pumping from the Pecos Valley Aquifer. Yet we excluded this pumpage from our revised estimates, as the Pecos Valley Aquifer does not extend to within the Sterling County geographic footprint.

Irrigation

The majority of Sterling County is underlain by the Edwards-Trinity (Plateau) Aquifer, which extends completely across the county in the East-West direction and covers all but the area along the northern county boundary with Mitchell County. The Lipan Aquifer underlays the central portion of the county, separating the Edwards-Trinity (Plateau) Aquifer footprint along a northwest to southeast trending line representing the North Concho River). The Dockum Aquifer also underlies nearly all of the county, yet is physically underneath the Edwards-Trinity (Plateau) and Lipan Aquifers. Wells identified within the county show that Dockum Aquifer wells are located throughout the county, including within the footprints of the Edwards-Trinity (Plateau) Aquifer and Lipan Aquifer. Review of data from the TWDB groundwater data viewer supports the general theory that irrigation wells tend to be shallower wells, withdrawing water from the closest viable aquifer to the land surface. As such, for this analysis it is assumed that wells screened within the Dockum Aquifer are not used to meet irrigation demands within Sterling County.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Sterling County from the Edwards-Trinity (Plateau) Aquifer amounted to between 93 acre-feet per year and 505 acre-feet per year (Figure 613), with usage peaking in 1985 followed by a decline until 2007 and then a generally steady increase through 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater demands for irrigation for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Sterling County ranged from 125 acre-feet per year to 431 acre-feet per year. Surface water was never used to reduce demands for groundwater pumpage to support irrigation activities.

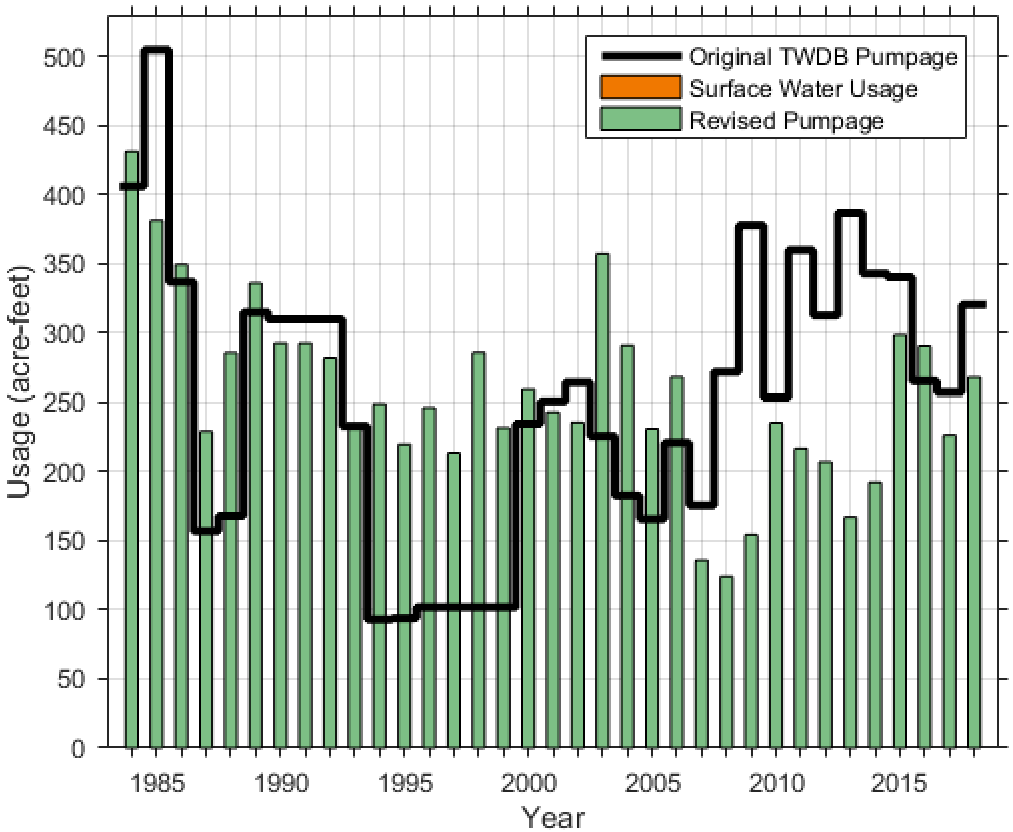


Figure 613. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Sterling County.

The original TWDB Water Use Survey data did not indicate that irrigation needs within Sterling County were met using pumpage from the Lipan Aquifer. It did include, however, estimates for pumpage from the "Pecos Aquifer" and from "Other Aquifer" Estimates of groundwater withdrawals from the "Other Aquifer" for irrigation ranged from 274 acre-feet per year to 580 acre-feet per year between 2000 and 2018. Estimates of pumpage from the "Pecos Aquifer" ranged from 35 acre-feet per year to 83 acre-feet per year. It is likely that the Pecos Aquifer estimates are simply an error as the Pecos Valley Aquifer does not exist within Sterling County. The pumpage from "Other Aquifer" could be from the Dockum Aquifer or the Lipan Aquifer, or a combination of both aquifers.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater pumpage for irrigation of land above the footprint of the Lipan Aquifer in Sterling County ranged from approximately 100 acre-feet per year to over 300 acre-feet per year over the study period (Figure 614). Surface water was not used to meet any of the irrigation needs within the county. This pumpage is generally smaller than that reported for "Other Aquifer" within the TWDB original Water Use Survey dataset, thus supporting the notion that the "Other Aquifer" pumpage may have been a combined estimate of pumpage from the Dockum Aquifer and the Lipan Aquifer.

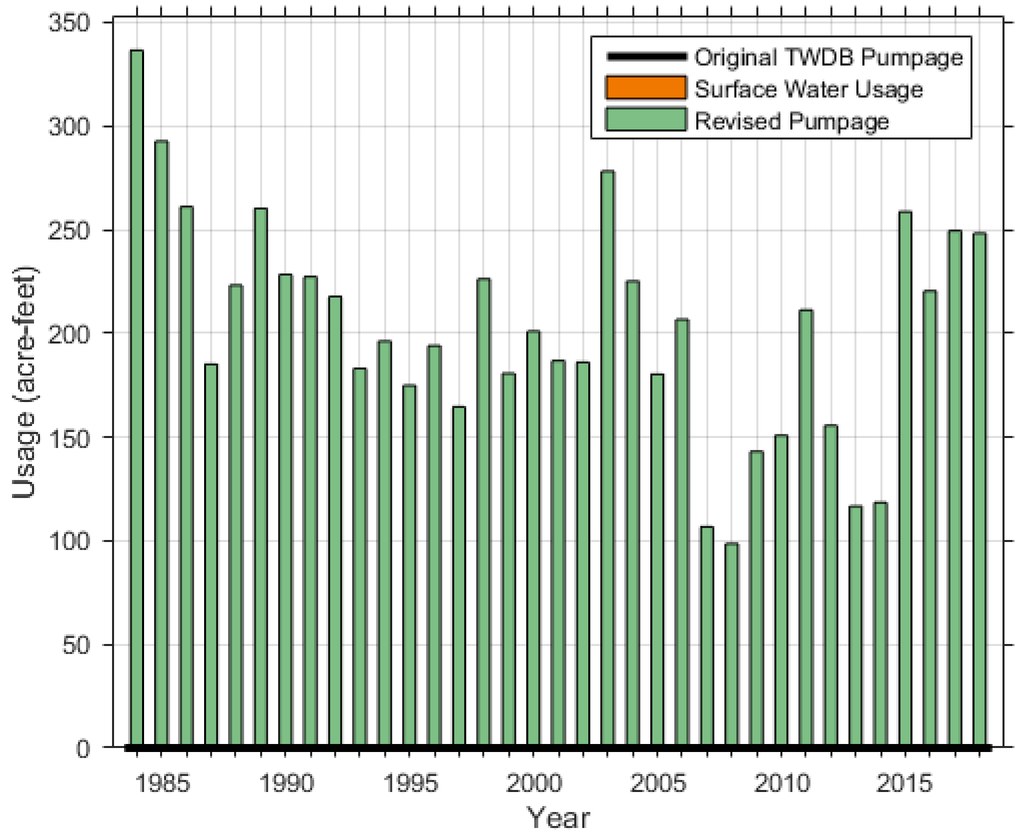


Figure 614. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Sterling County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Sterling County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Sterling County.

Mining

Figure 611c and Figure 612c illustrate the changes in groundwater pumping associated with mining use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Sterling County during the study period. The number of active enhanced oil recovery wells in this county have increased from 10 to 94 between the years 1980 to 2020. Although no Water Use Survey data was available, estimates from the Bureau of Economic Geology and the U.S. Geological Survey methodologies were compared. The estimated mining use from both the Bureau of Economic Geology and the U.S. Geological Survey methodologies were within the same order of magnitude and generally within a few factors of each other until after 2010 when the estimates based on the U.S. Geological Survey data sharply dropped. Final mining use estimates indicate that about two-thirds of water pumped for mining use is sourced from the Edwards-Trinity (Plateau) Aquifer and the rest from is from the Lipan Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Sterling County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Sterling County.

Livestock

Figure 611b and Figure 612b illustrate the changes in groundwater pumping associated with livestock use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Sterling County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Sterling County. The TWDB Water Use Survey data contain estimates of groundwater pumping from mis-assigned to the Pecos Valley Aquifer that do not surpass 20 acre-feet. Our revised estimates of pumpage from the Lipan aquifer range from 40 to 100 acre-feet.

5.2.42 Sutton County

Figure 615 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Sutton County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

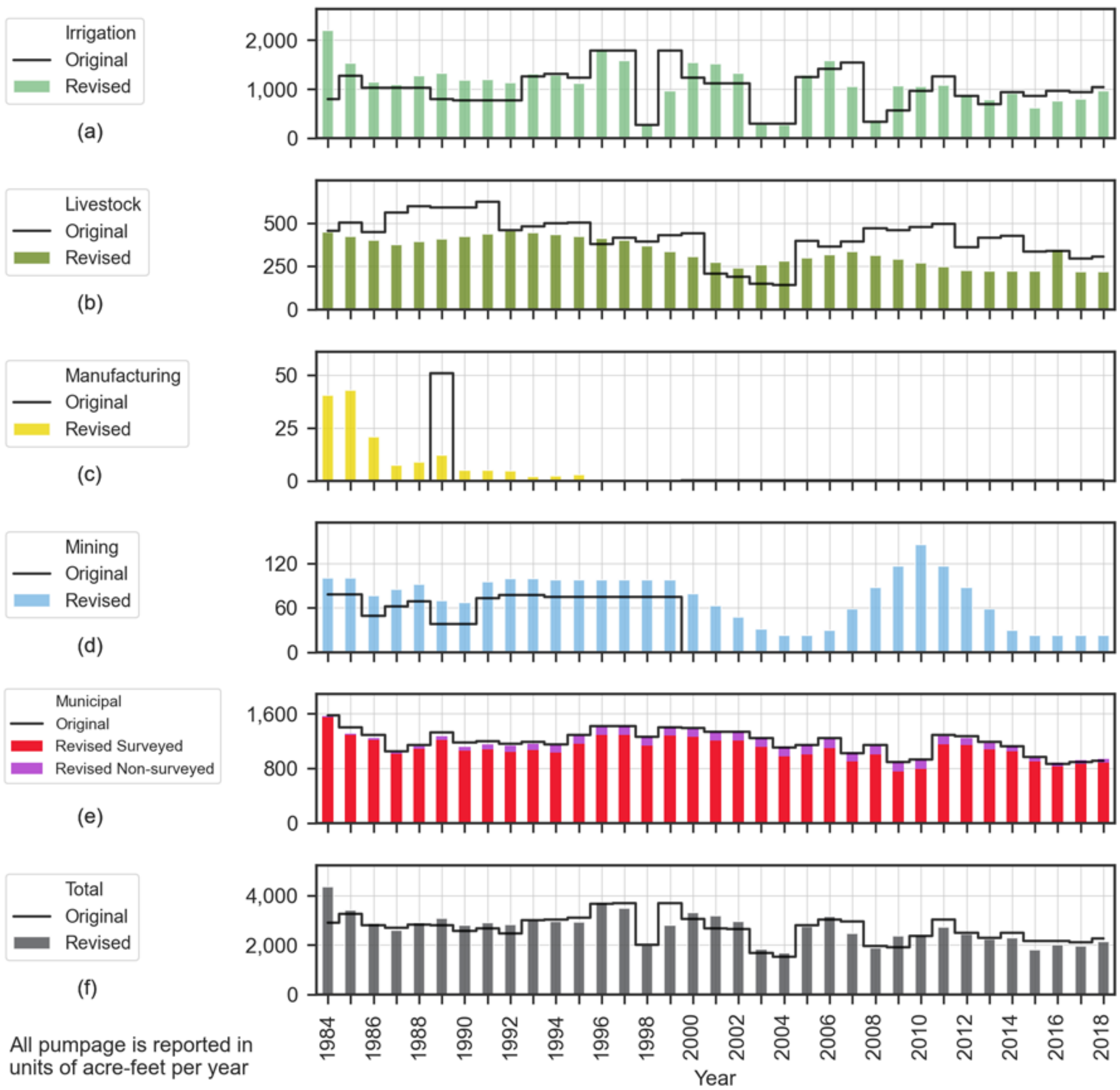


Figure 615. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Sutton County from 1984 through 2018.

Surveyed Municipal

Reported municipal pumpage from the Edwards-Trinity (Plateau) Aquifer in Sutton County during the study period were mostly attributable to the City of Sonora. Over the study period, the City of Sonora pumpage fluctuated from year to year yet did not exhibit an increasing or decreasing overall trend. No revision was needed of the original TWDB Water Use Survey data.

Non-Surveyed Municipal

Figure 616 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Sutton County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

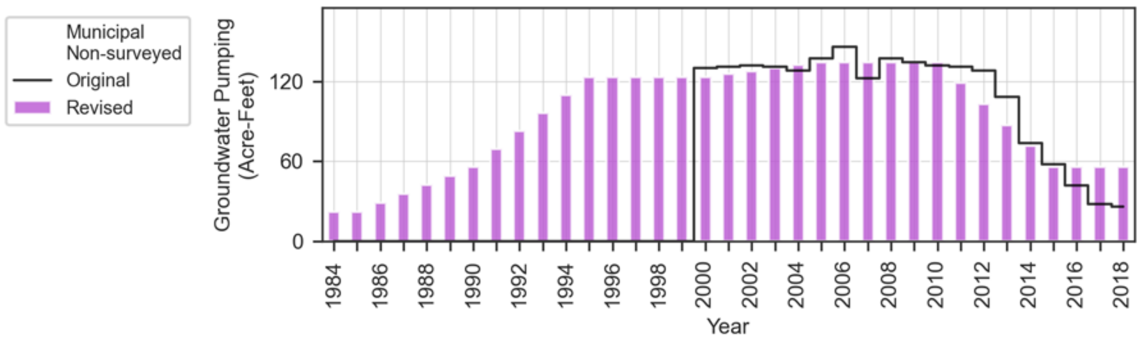


Figure 616. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Sutton County from 1984 through 2018.

Irrigation

Sutton County is entirely underlain by the Edwards-Trinity (Plateau) Aquifer, and all wells identified in the county are screened within the aquifer. The original TWDB Water Use Survey dataset suggested that irrigation needs for Sutton County from the Edwards-Trinity (Plateau) Aquifer amounted to between 270 acre-feet per year and 1,785 acre-feet per year (Figure 617). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Sutton County ranged from 270 acre-feet per year to 2,312 acre-feet per year. Surface water was used to partially meet irrigation demands from 1984 through 1999. Revised groundwater pumpage ranged from 270 acre-feet per year (2003) to 2,187 acre-feet per year (1984). There is generally excellent agreement between the revised pumpage and the original TWDB water usage survey data, especially with respect to the timing of changes in pumpage values. For example, both datasets computed low pumpage amounts in 1998, 2003 to 2004, and 2008.

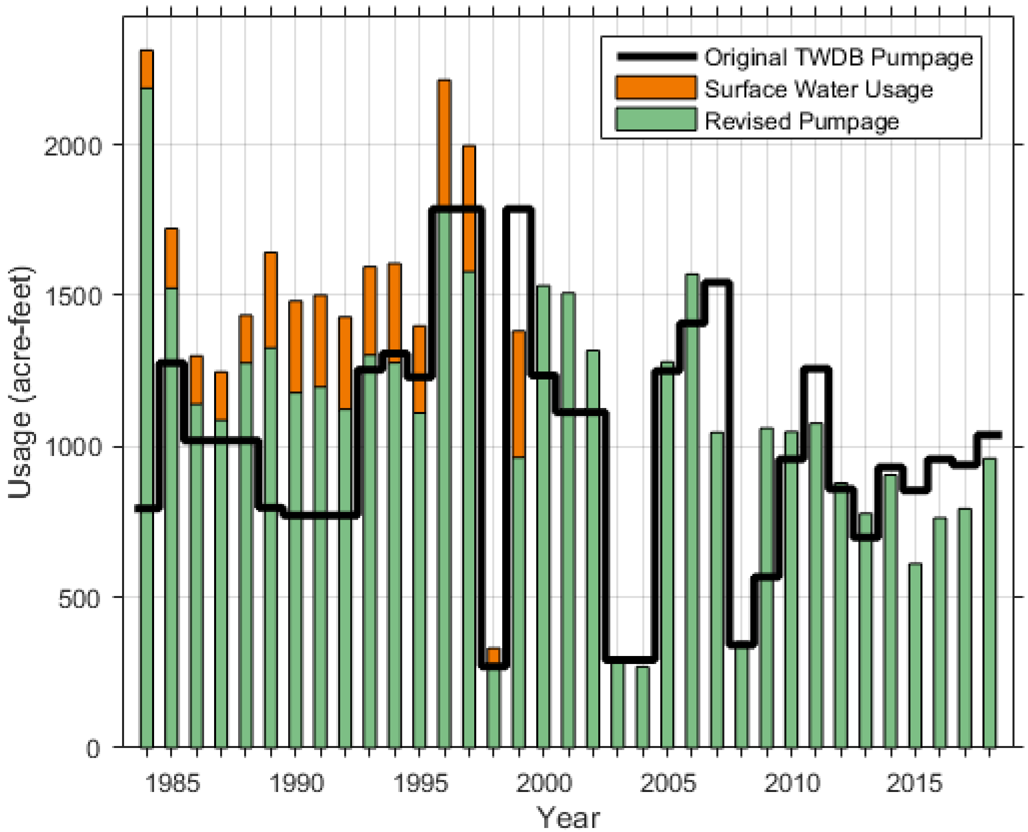


Figure 617. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Sutton County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Sutton County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Sutton County.

Mining

Figure 615d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Sutton County during the study period. The number of active enhanced oil recovery wells in Sutton County were only eight in 1980, increased slightly to nine after a few years and dropped again to eight in 2020. No Water Use Survey data was available, however, estimates from the Bureau of Economic Geology and the U.S. Geological Survey methodologies were compared and were within the same order of magnitude and mostly only a few factors of each other. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 615c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Sutton County during the study period. The revision reflects data in the Water Use Survey. We reduced the high pumping in 1989 associated with “Shurley Enterprises Industies [sic] Park” to the average of previous years.

Livestock

Figure 615b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Sutton County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Sutton County.

5.2.43 Taylor County

Figure 618 and Figure 619 illustrate our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Taylor County during the study period. The Water Use Survey data designated pumping from the Trinity (Hill Country) Aquifer in Taylor County; however, it appears the pumping designated as Trinity (Hill Country) Aquifer is from the Edwards-Trinity (Plateau) Aquifer. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

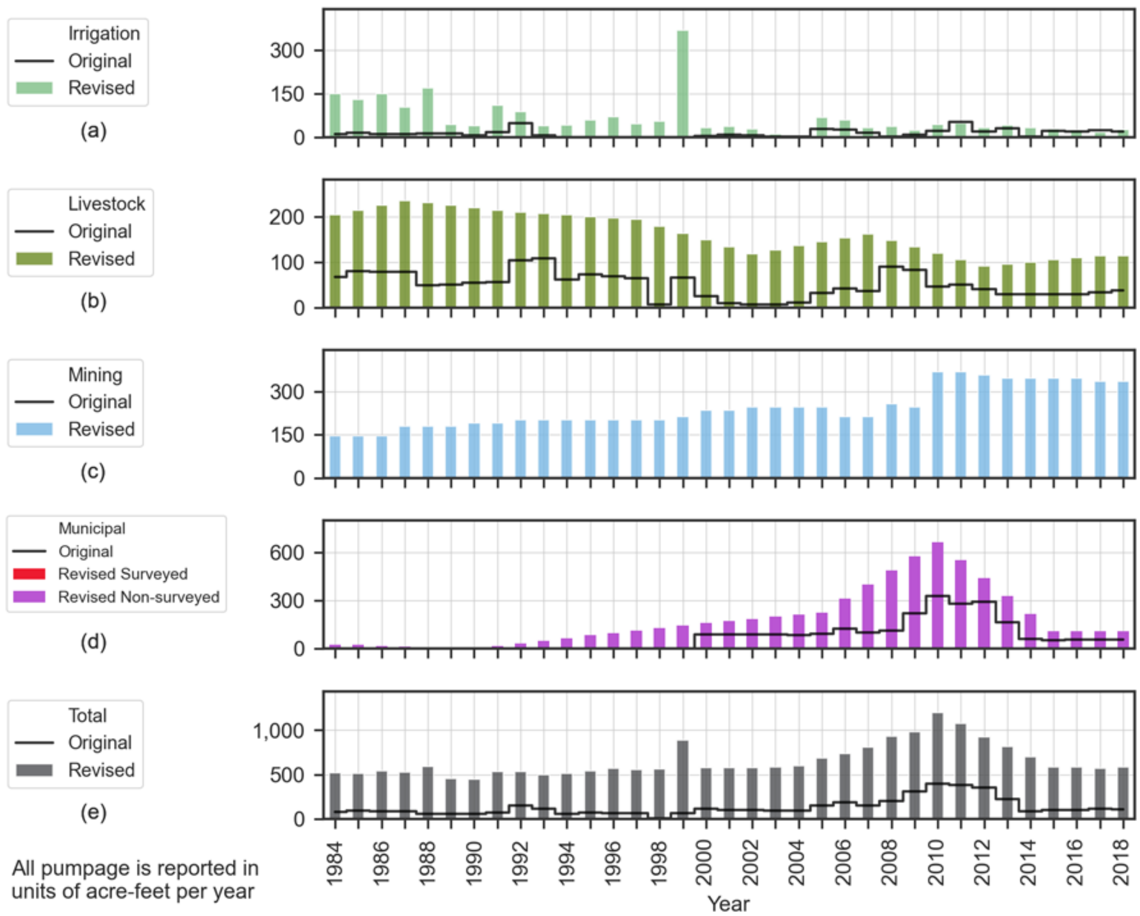


Figure 618. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Taylor County from 1984 through 2018.

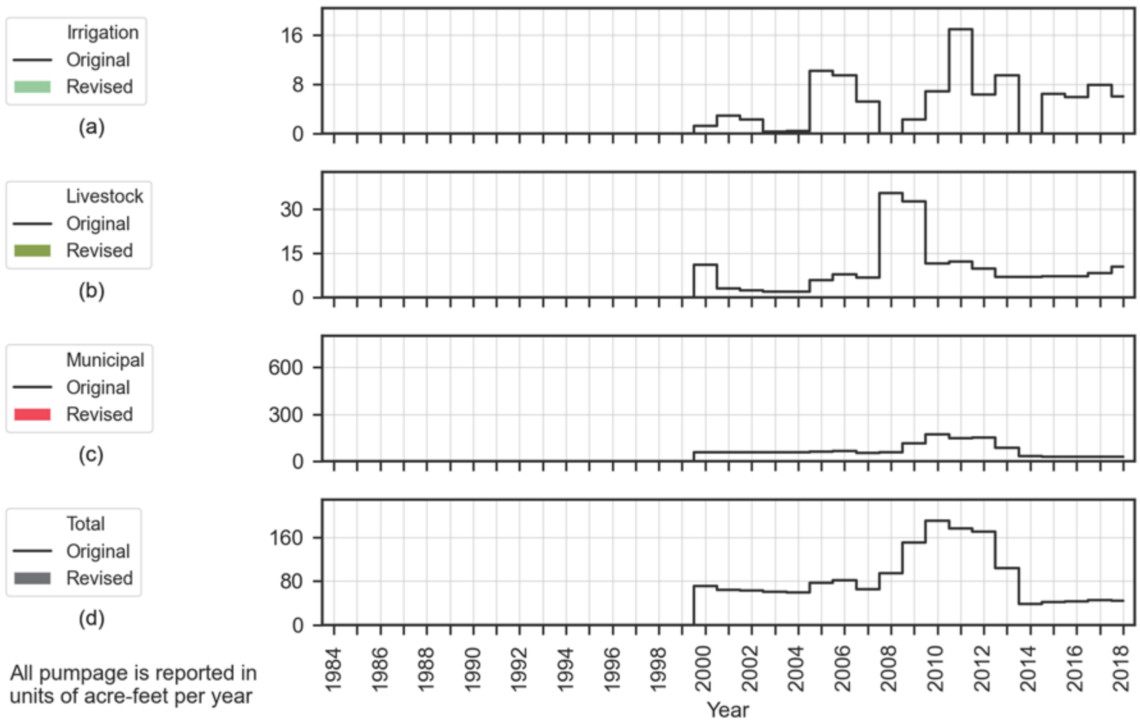


Figure 619. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Taylor County from 1984 through 2018.

Surveyed Municipal

Figure 618d illustrates the changes in groundwater pumping associated with surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Taylor County during the study period. All of the entities within Taylor County reporting municipal usage attributed that usage to aquifers other than the Edwards Trinity (Plateau) Aquifer. Our review of the likely locations of these reporting entities confirms that the usage likely occurs outside of the Edwards Trinity (Plateau) Aquifer footprint within the county. As such, our revised dataset does not contain municipal pumpage for Taylor County.

Non-Surveyed Municipal

Figure 620 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Taylor County during the study period. Our estimates are about two times higher than the TWDB Water Use Survey data. While the Water Use Survey data contains groundwater pumping for non-surveyed municipal use from the Trinity (Hill Country) Aquifer up to 180 acre-feet, our estimate does not.

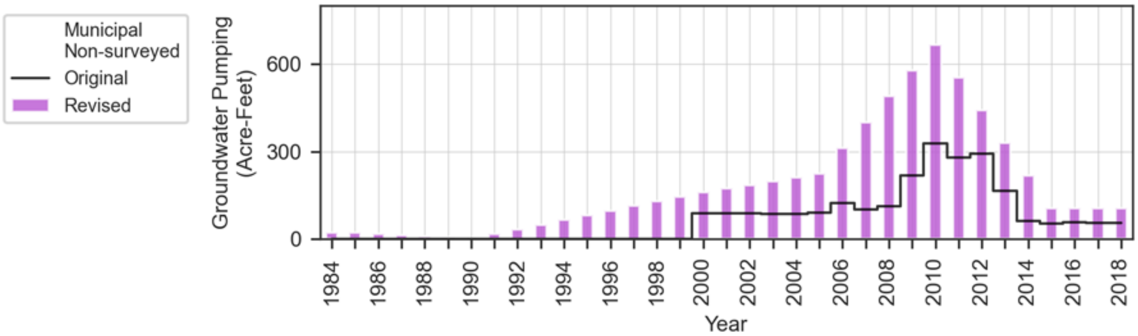


Figure 620. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Taylor County from 1984 through 2018.

Irrigation

Taylor County is underlain by the Edwards-Trinity (Plateau) Aquifer within a portion of the southwest quadrant of the county. Wells identified within this aquifer footprint all are also screened within the aquifer. The original TWDB Water Use Survey dataset suggested that irrigation needs for Taylor County from the Edwards-Trinity (Plateau) Aquifer amounted to between zero acre-feet per year and 52 acre-feet per year. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Taylor County ranged from four acre-feet per year to 368 acre-feet per year (Figure 621). In general, pumpage was greater prior to 2004, and exhibited a declining trend from 1984 to 2004. After 2004, pumpage increased back to mid-1990's levels, and then declined through 2018. The peak pumpage year (1999) is anomalous and is due to the reported irrigation of 8,500 acres of wheat in that year. Reported acreage of wheat in 1998 and 2000 was 500 acres and 190 acres, respectively.

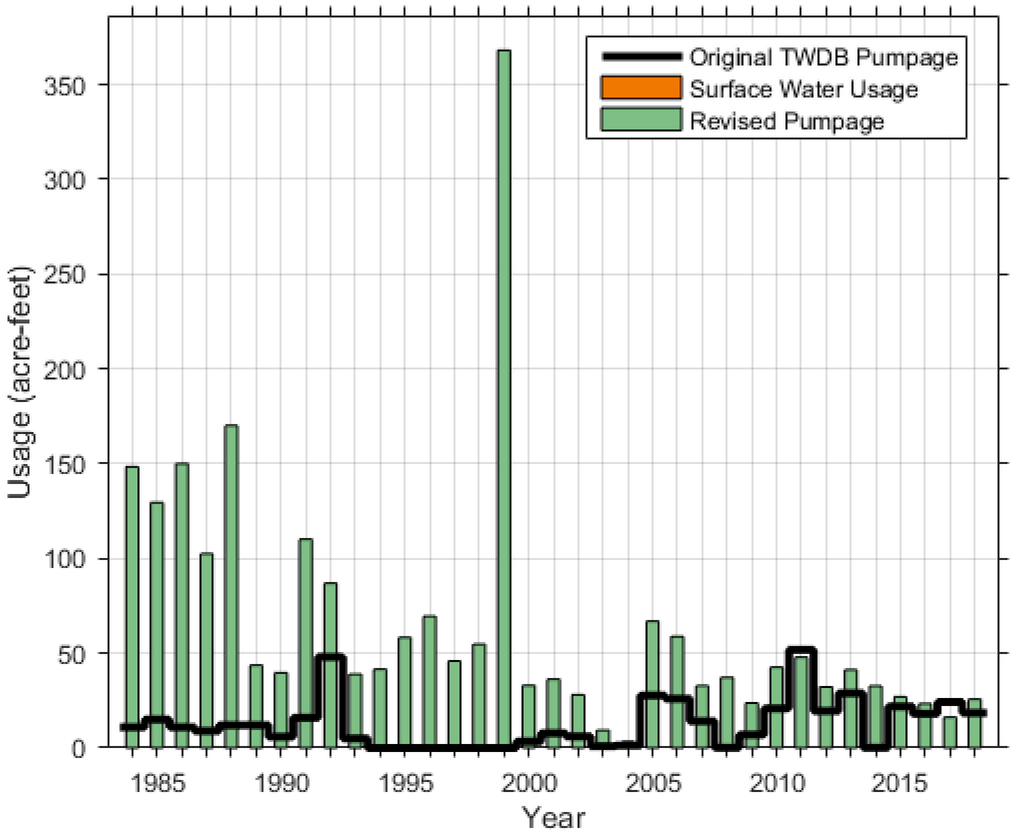


Figure 621. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Taylor County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Taylor County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Taylor County.

Mining

Figure 618c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Taylor County during the study period. The number of active enhanced oil recovery wells in Taylor County increased from 67 in 1980 to 122 wells in 2020. No Water Use Survey data was available, however, estimates from the Bureau of Economic Geology and the U.S. Geological Survey methodologies were compared and were within the same order of magnitude and mostly only a factor of five of each other. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

For the study period and the study area aquifers, there is no groundwater pumping associated with manufacturing use in Taylor County. Also, there is no indication unreported groundwater pumping associated with manufacturing use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for manufacturing use in Taylor County.

Livestock

Figure 618b and Figure 619b illustrate the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer and the Trinity (Hill Country) in Taylor County during the study period. Our estimate is generally greater than the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Taylor County. Our review of groundwater pumping from the Trinity (Hill Country) does not indicate groundwater pumpage for this use within Taylor County.

5.2.44 Terrell County

Figure 622 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Terrell County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

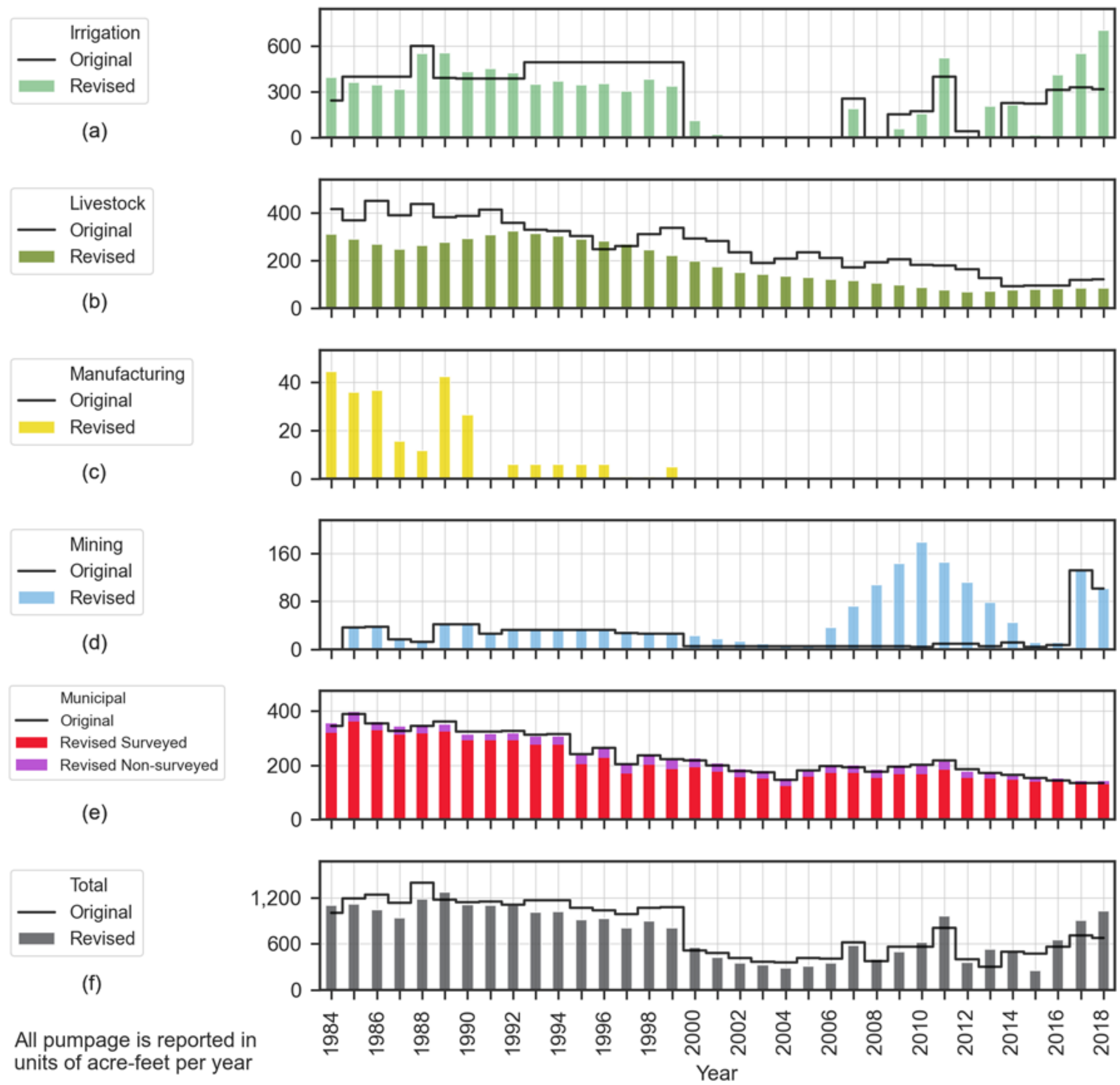


Figure 622. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Terrell County from 1984 through 2018.

Surveyed Municipal

Of the two entities reporting municipal water usage in Terrell County, the Terrell County WCID 1 has reported continuously since 1955 and the City of Dryden reported between 0.5 and 4.5 acre-feet of usage per year until 2000. U.S. Census Bureau records indicate that the City of Dryden is still populated, yet not sufficiently to require reportable water usage as a municipality.

Pumpage for Terrell County WCID 1 fluctuates has ranged between 75 acre-feet per year and 307 acre-feet/year, but has recently fluctuated at levels close to 150 acre-feet/year.

Non-Surveyed Municipal

Figure 623 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Terrell County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

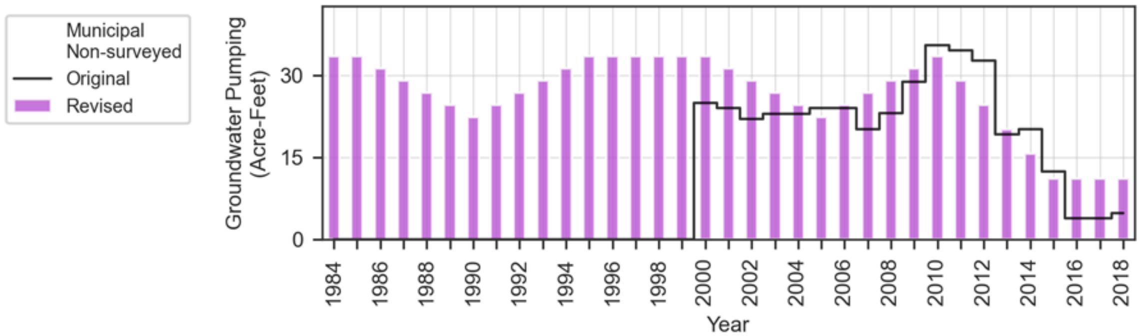


Figure 623. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Terrell County from 1984 through 2018.

Irrigation

Terrell County is entirely underlain by the Edwards-Trinity (Plateau) Aquifer, and all wells identified within the county were determined to be screened within the aquifer. The original TWDB Water Use Survey dataset suggested that irrigation needs for Terrell County from the Edwards-Trinity (Plateau) Aquifer amounted to between zero acre-feet per year and 600 acre-feet per year, although it is unknown if the zero acre-feet per year values were realistic pumpage estimates or reflected missing data.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Terrell County ranged from 88 acre-feet per year to 883 acre-feet per year (Figure 624). Surface water was used to meet irrigation demands from 2000 to 2017, and for 2003 to 2006, 2008, and 2012 was sufficiently available to reduce required groundwater pumpage to zero. Revised groundwater pumpage estimates for irrigation from the Edwards-Trinity (Plateau) Aquifer within Terrell County range from zero acre-feet per year to 700 acre-feet per year. Irrigation demand from 2003 to 2018 is generally higher than demands from 1984 to 1999, although there are large demand fluctuations from year to year. Demands were smallest from 2000 to 2003 and in 2005, when less acres of hay were reported as having been grown.

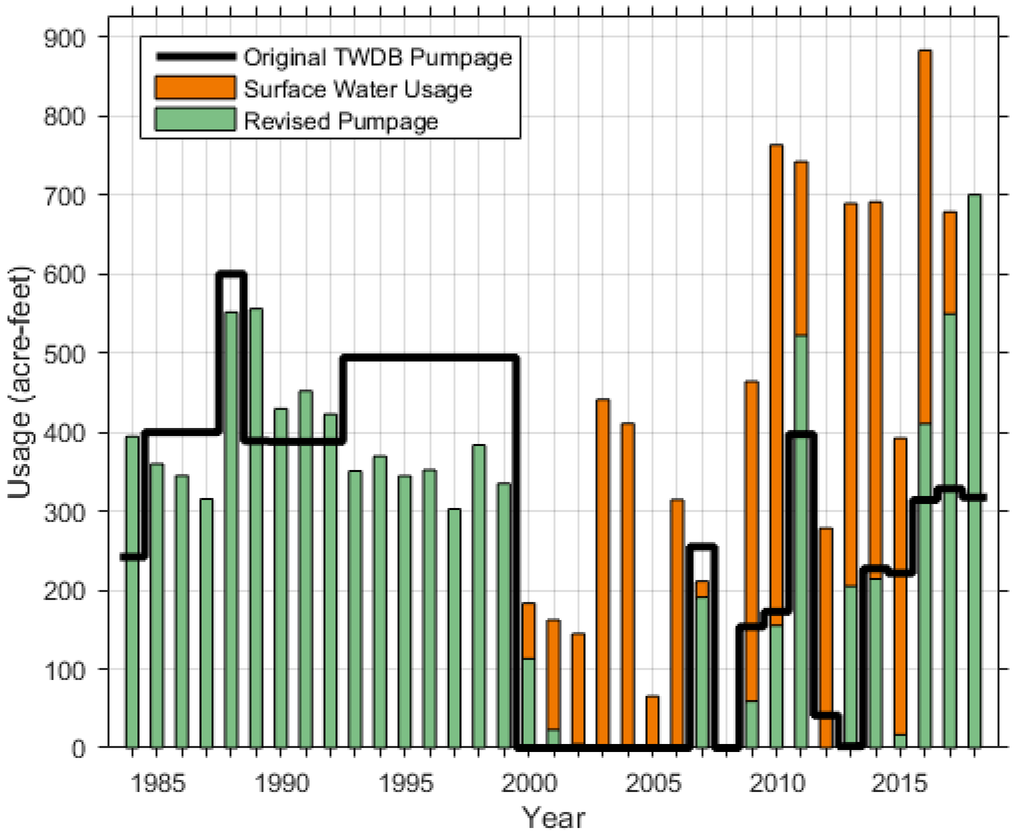


Figure 624. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Terrell County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Terrell County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Terrell County.

Mining

Figure 622d illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Terrell County during the study period. No enhanced oil recovery wells were reported in Terrell County. Therefore, estimates based on the Water Use Survey and the U.S. Geological Survey methodology were compared. Estimates made using the U.S. Geological Survey data were generally much higher until the last couple of years (2017 and 2018) when the Water Use Survey estimates suddenly spiked up to the ranges of the U. S. Geological Survey estimates from the previous year. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 622c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Terrell County during the study period. Most of the manufacturing occurred prior to the year 2000 and was limited to less than 50 acre-feet per year.

Livestock

Figure 622b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Terrell County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for livestock use in Terrell County.

5.2.45 Tom Green County

Figure 625 and Figure 626 illustrate our revisions to the estimated in groundwater pumping from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Tom Green County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

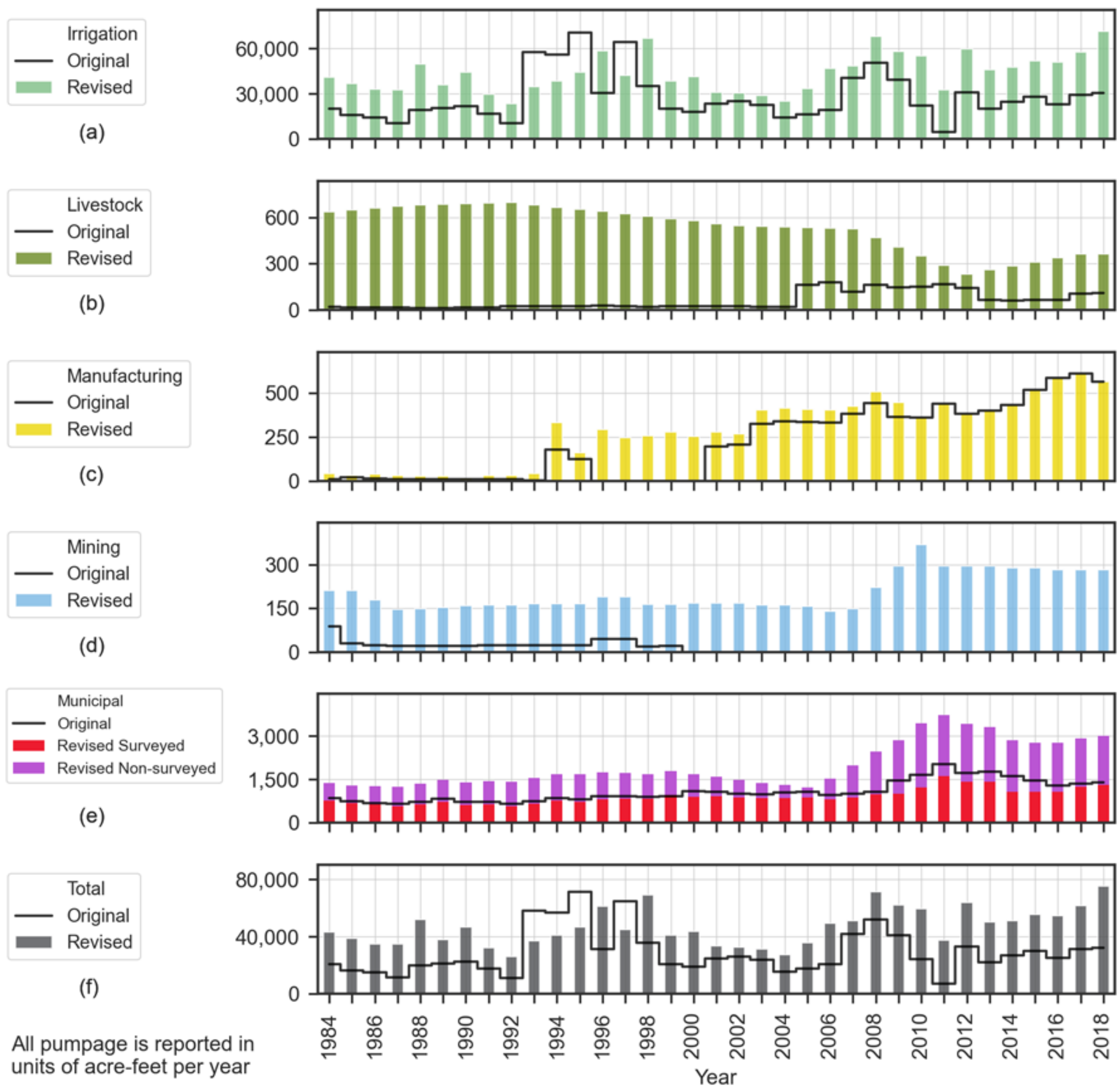


Figure 625. Original and revised estimates of groundwater pumping from the Lipan Aquifer in Tom Green County from 1984 through 2018.

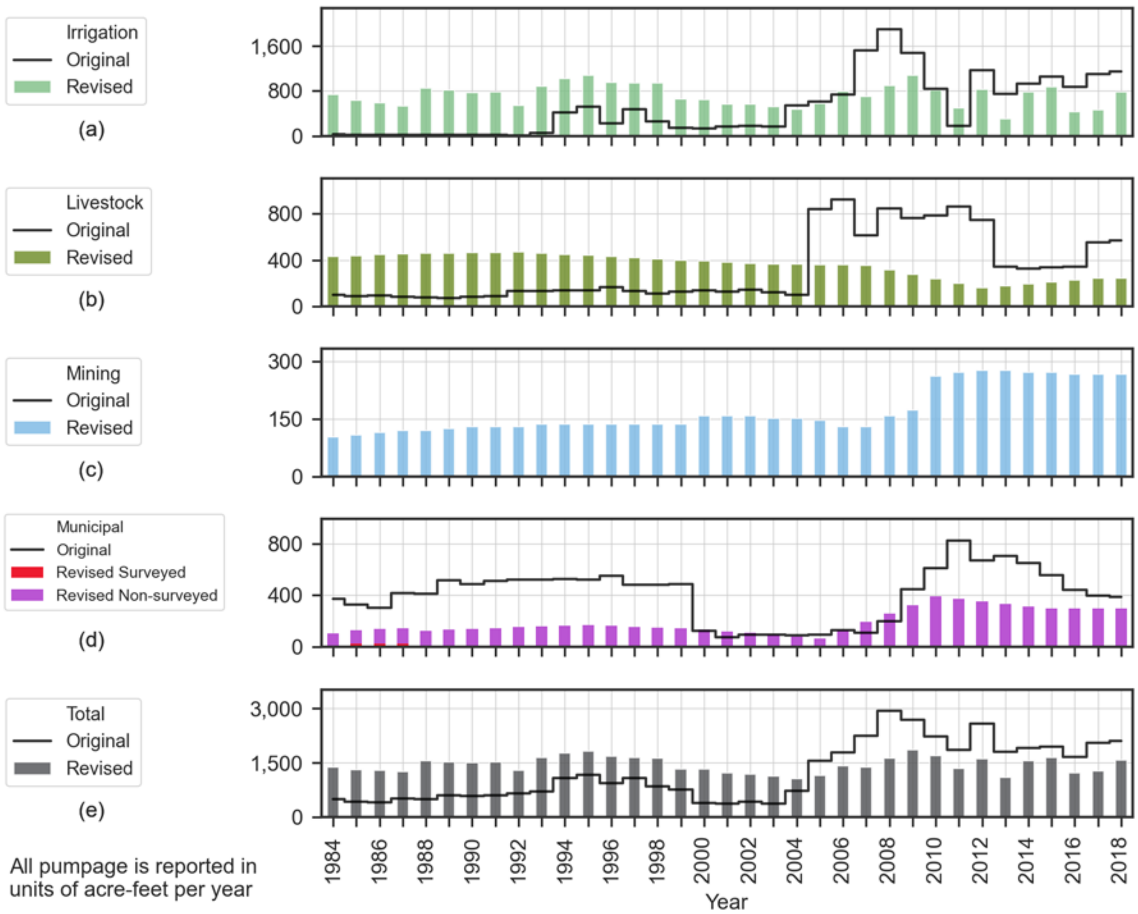


Figure 626. **Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Tom Green County from 1984 through 2018.**

Surveyed Municipal

Figure 625e and Figure 626d illustrate the changes in groundwater pumping associated with surveyed municipal use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Tom Green County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data. Four entities (West Texas Boys Ranch, Goodyear Tire and Rubber Company – Goodyear Proving Grounds, Angelo State University, and Texas Department of MHMR) were reassigned from, "Other Aquifer" to the Lipan Aquifer based on their locations. Municipal pumpage was not reported from the Edwards Trinity (Plateau) Aquifer within Tom Green County.

Non-Surveyed Municipal

Figure 627 and Figure 628 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Tom Green County during the study period. Our estimates appear to have similar trends to the TWDB Water Use Survey data for pumping for non-surveyed municipal use. While our estimates are more than the Water Use Survey data for the Lipan Aquifer, they are less for the Edwards-Trinity (Plateau) Aquifer.

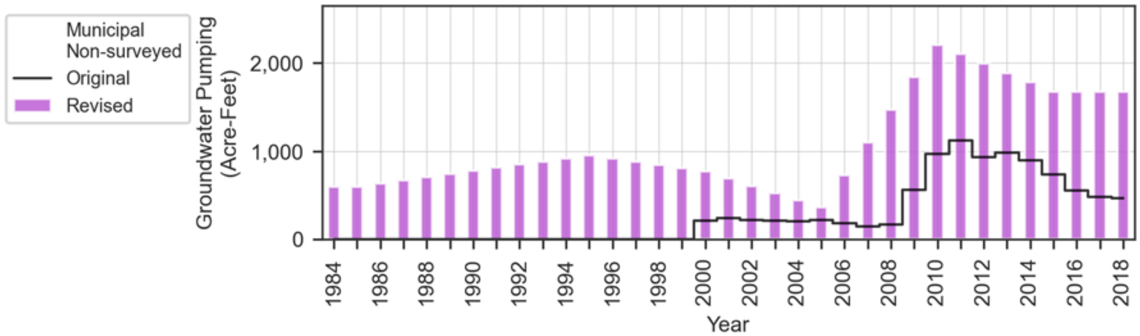


Figure 627. Original and revised estimates of groundwater pumping from the Lipan Aquifer for non-surveyed municipal use in Tom Green County from 1984 through 2018.

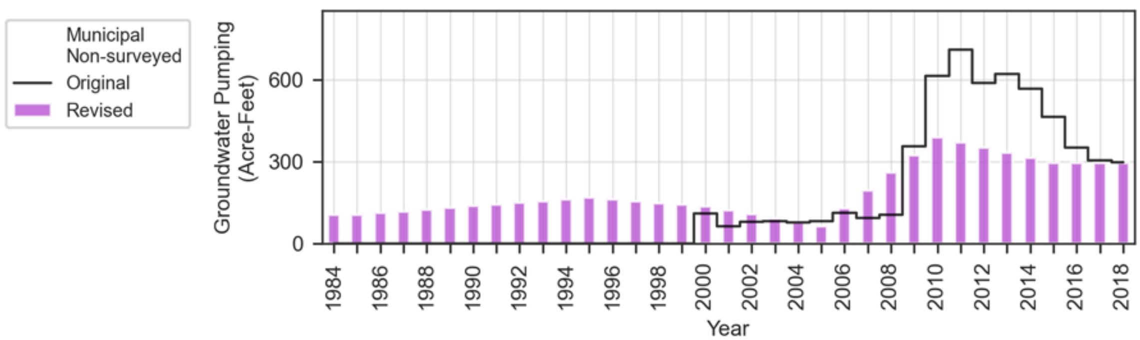


Figure 628. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Tom Green County from 1984 through 2018.

Irrigation

Tom Green County is predominantly underlain by the Lipan Aquifer, which generally makes up the alluvial system adjacent to the Concho River and its tributaries. Within the southern portion of the county, the Lipan Aquifer subcrop is located below the Edwards-Trinity (Plateau) Aquifer outcrop. The Edwards-Trinity (Plateau) Aquifer also underlies the remainder of Tom Green County not covered by the Lipan Aquifer footprint. The Dockum Aquifer also underlies portions of the western extent of the county, including much of the county panhandle separating Irion County and Sterling County. Wells identified within the county are predominantly screened within the Lipan Aquifer or within the Edwards-Trinity (Plateau) Aquifer, and are geographically clustered consistently with the aquifer footprints. Wells screened within the Dockum Aquifer do exist within the county (per the TWDB groundwater data viewer), yet these wells appear unlikely to contribute pumpage for irrigation. For this analysis, it was assumed that pumpage for irrigation was derived from the shallowest aquifer within the county, including from the Edwards-Trinity (Plateau) Aquifer where it is located above the Lipan Aquifer subcrop.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Tom Green County from the Edwards-Trinity (Plateau) Aquifer amounted to between 10 acre-feet per year and 1,900 acre-feet per year (Figure 629), with usage remaining low from 1984 to 1993, then generally increasing through the remainder of the study period with some year-to-year fluctuations and an anomalous peak usage in 2008. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, groundwater demands for irrigation for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Tom Green County ranged from 300 acre-feet per year to 1,100 acre-feet per year. Surface water was never used to reduce demands for groundwater pumpage to support irrigation activities. The revised pumpage dataset is more uniform across the entire study period than the original TWDB Water Use Survey dataset, and does not include a period of low pumpage prior to 1994. The revised dataset also does not contain an anomalous pumpage spike from 2007 to 2009, although it does show a slight increase in pumpage across this timeframe.

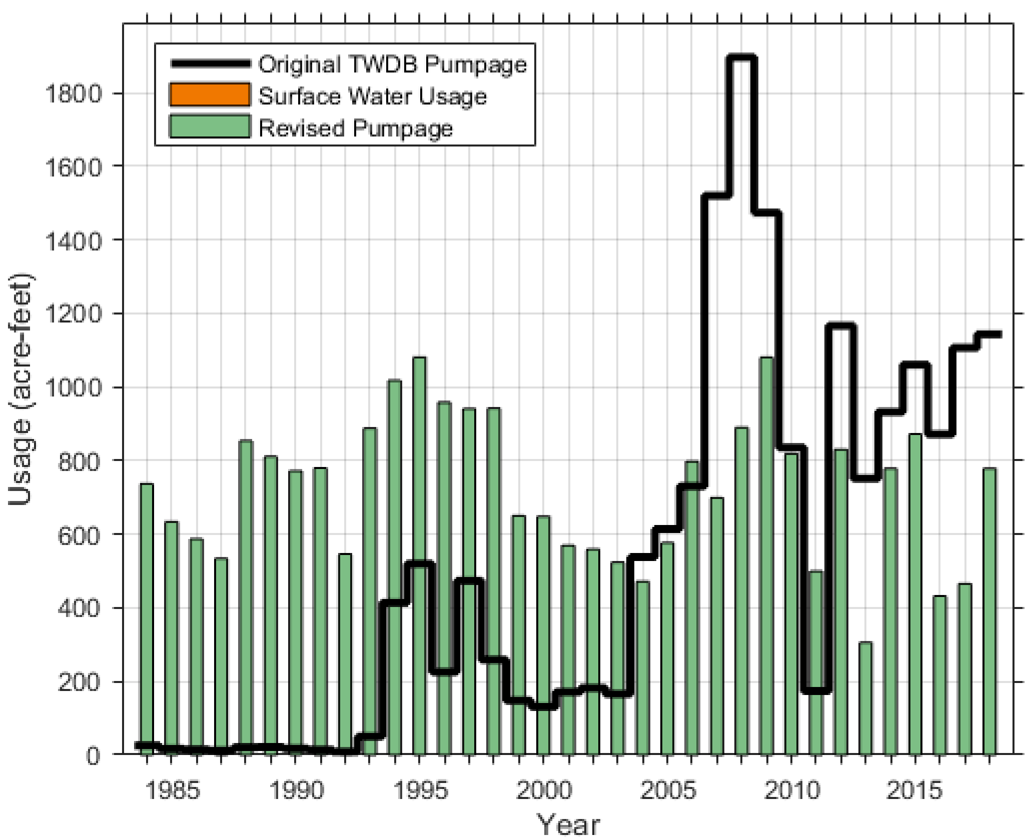


Figure 629. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Tom Green County.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Tom Green County from the Lipan Aquifer amounted to between 4,500 acre-feet per year and 70,000 acre-feet per year (Figure 630), with usage peaking over the 1994 to 1997 period and again over the 2007 to 2009 period. Outside of these peak periods, pumpage was generally lower, ranging between 10,000 acre-feet per year and 30,000 acre-feet per year. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, water demands for irrigation for land above the footprint of the Lipan Aquifer (outcrop) in Tom Green County ranged from 35,000 acre-feet per year to 83,000 acre-feet per year. Every revised annual demand was greater than the corresponding annual demand from the original TWDB Water Use Survey dataset. Surface water was used in all but one year to reduce demands for groundwater pumpage to support irrigation activities. The revised pumpage dataset shows year-to-year fluctuations similar in pattern and magnitude to those implicit within the TWDB Water Use Survey dataset, indicating that previously identified data anomalies are likely caused by climatic variation and/or changes in crop production. Groundwater pumpage for irrigation within the Lipan Aquifer (outcrop) footprint in Tom Green County ranged from 23,500 acre-feet per year to 71,100 acre-feet per year, with the greatest pumpage occurring in 2018.

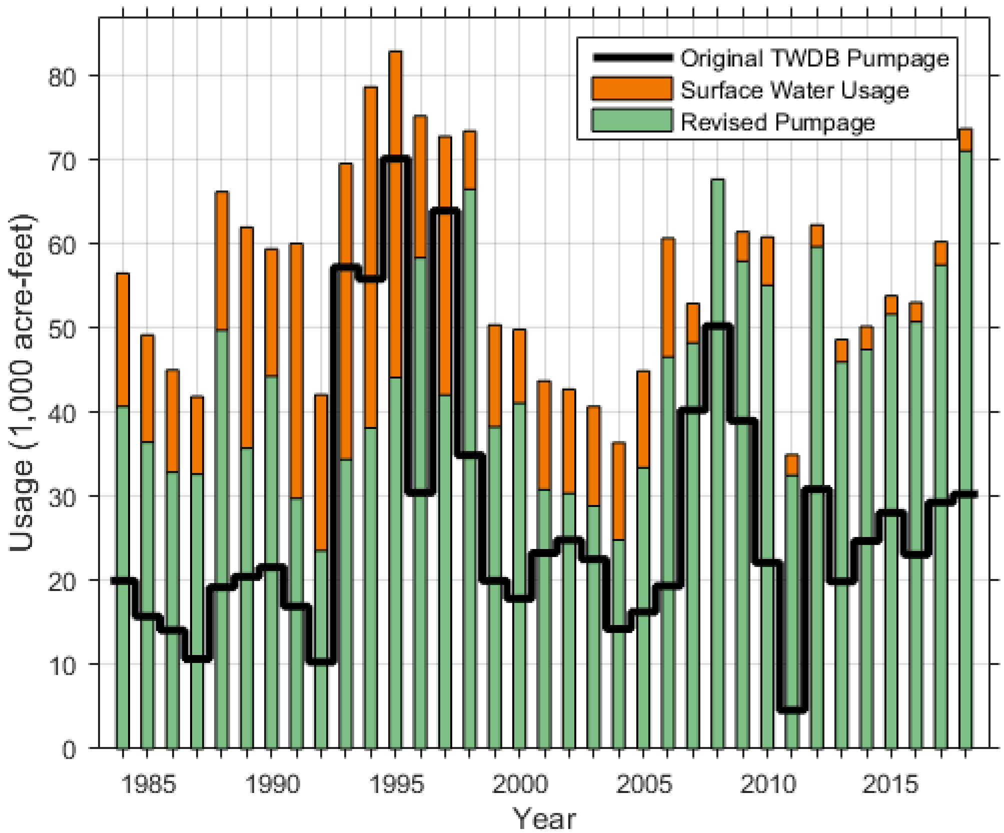


Figure 630. Revised groundwater pumpage for irrigation from the Lipan Aquifer within Tom Green County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Tom Green County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Tom Green County.

Mining

Figure 625d and Figure 626c illustrate the changes in groundwater pumping associated with mining use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Tom Green County during the study period. The number of active enhanced oil recovery wells in Tom Green County increased from 24 in 1980 to 191 in 2020. No Water Use Survey data was available, however, estimates from Bureau of Economic Geology and U.S. Geological Survey methodologies were compared and were within the same order of magnitude and mostly only a factor of two from each other. In Tom Green County, we observe that approximately 45 percent of water for mining use is pumped from Edwards-Trinity (Plateau) Aquifer and the remaining is from the Lipan Aquifer.

Manufacturing

Figure 625c illustrates the changes in groundwater pumping associated with manufacturing use from the Lipan Aquifer in Tom Green County during the study period. There are several entities for which we applied changes. Table 77 summarizes our revisions to the original estimates.

Table 77. Summary of revisions to groundwater pumping from the Lipan Aquifer for manufacturing use in Tom Green County from 1984 through 2018.

Standardized Name	Notes
Ethicon Inc	Changed aquifer designation to Lipan. Missing data from 1995 through 1997; used average from previous years as estimate. Reduced pumping in 1998 and 1999 to average from previous three years.
Goodyear Tire & Rubber Company – Goodyear Proving Grounds	Changed aquifer designation to Lipan. Pumping from this entity is designated in both the surveyed municipal and manufacturing categories
Lone Star Beef Processors LP	Missing data from 1996 through 2000; used linear interpolation between values in 1995 and 2001 to estimate use.
Ranchers Lamb of Texas Inc	Changed aquifer designation to Lipan.
San Angelo By Products	Missing volumes for 1986, 1987, and 2010; used 0.5 acre-feet as estimate for each missing year.
San Angelo Electric Service Company	Changed aquifer designation to Lipan. Missing data from 1992 through 1995; used average of previous years to estimate use.

With respect to the Goodyear Tire & Rubber Company – Goodyear Proving Grounds, we determined that this entity reported pumpage in both the municipal and manufacturing categories. The numbers provided for each category are distinct and not related based on a standard ratio. However municipal data were reported for 2010-2018, yet manufacturing data were reported for 2000-2018. The reported manufacturing pumpage during each year of the 2010-2018 period (when municipal data were also reported) was reported as 82.04781 acre-feet/year. As it is unlikely this entity used the exact same pumpage every year, we believe that the pumping was reported in error. It is our assumption that manufacturing pumpage was reported accurately for 2000-2009, and then mis-reported from 2010-2018. We also assume that the municipal reported pumpage from 2010-2018 was mis-categorized, and should have been reported as a manufacturing use. Our attempts to discuss our interpretation of this data directly with Goodyear Tire & Rubber Company were continuously unsuccessful. As such, we kept the data as originally reported within the TWDB Water Use Survey dataset.

Livestock

Figure 625b and Figure 626b illustrate the changes in groundwater pumping associated with livestock use from the Lipan Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Tom Green County during the study period. Our estimate is significantly higher than the TWDB Water Use Survey data for groundwater pumping from the Lipan Aquifer. The TWDB Water Use Survey data suggests a sharp increase in pumpage in 2005 whereas our revised estimates show a gradual decreasing trend for both aquifers in Tom Green County based on a decreasing animal count. Our estimate is higher than the TWDB Water Use Survey data prior to 2005 and less than the TWDB Water Use Survey data from 2005 onwards for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer.

5.2.46 Travis County

Figure 631 and Figure 632 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Travis County during the study period. Note that our analysis is limited to the portion of Travis County south of the Colorado River. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

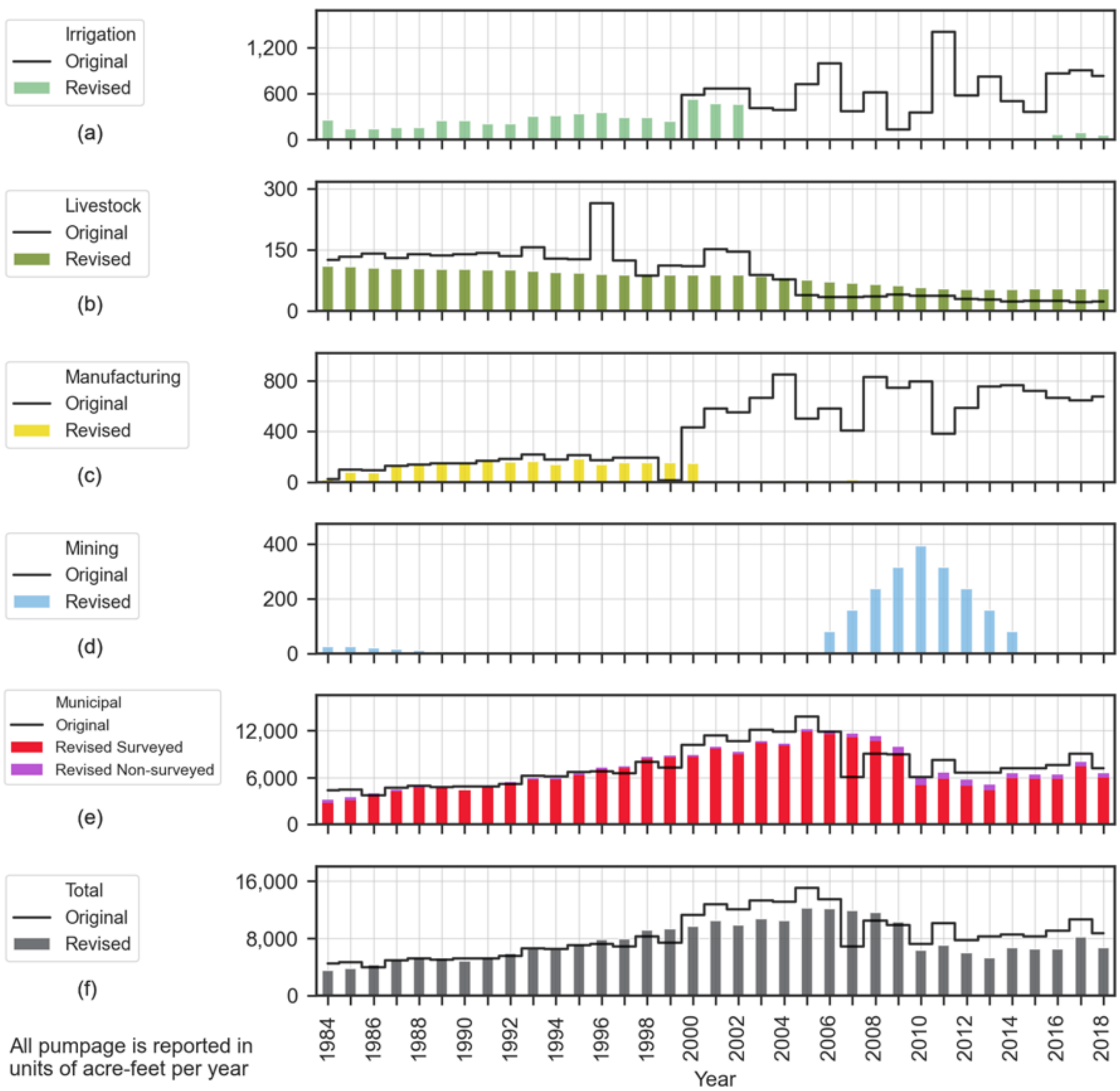


Figure 631. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Travis County from 1984 through 2018.

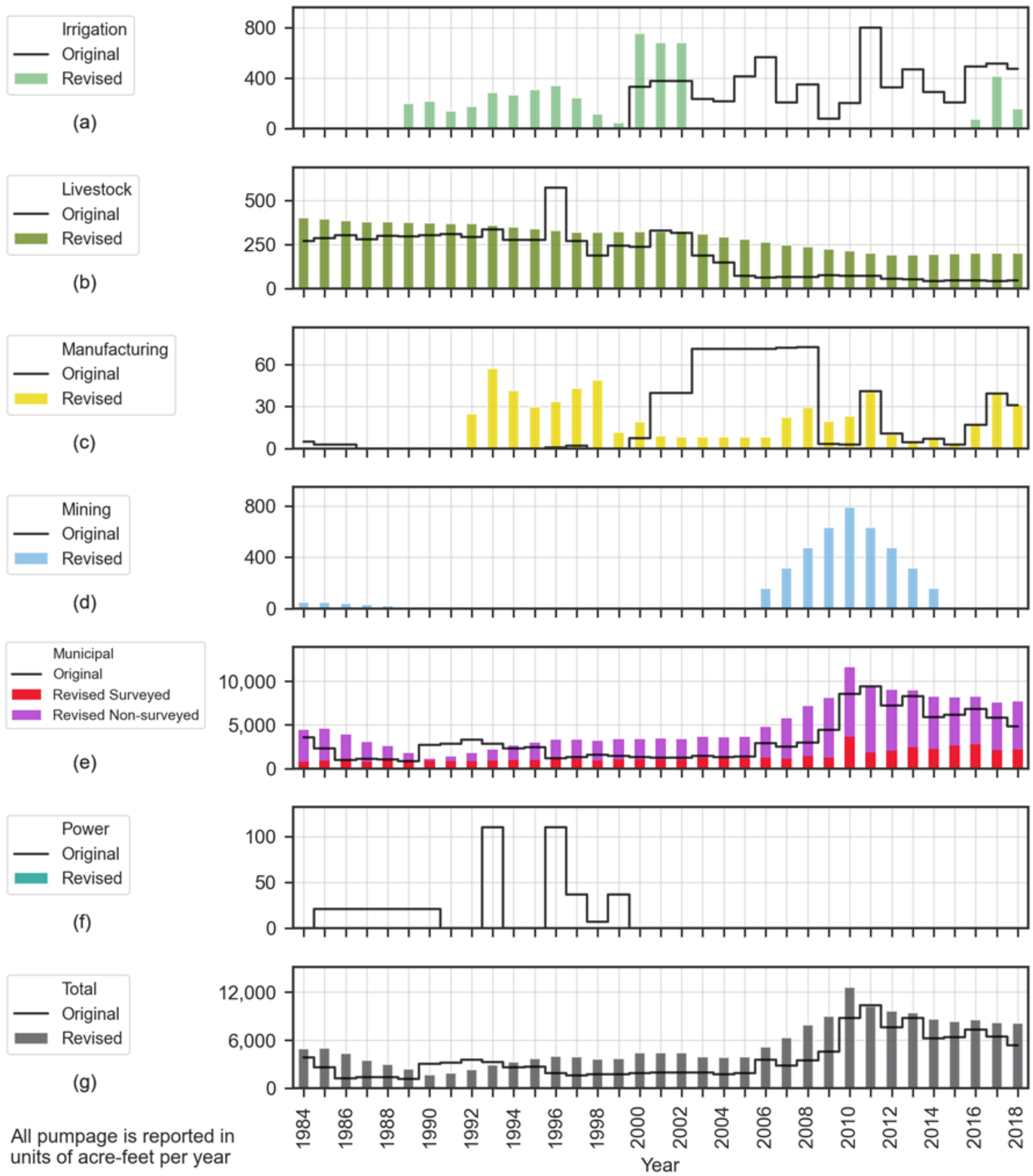


Figure 632. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Travis County from 1984 through 2018.

Surveyed Municipal

Revisions to the original TWDB Water Use Survey dataset for Travis County municipal reported use include interpolating data gaps and re-assigning pumpage to alternate aquifers. Specifically we assigned pumpage from Aqua Texas Inc. – Barton Creek Lakeside and Aqua Texas Inc – Lakecliff on Lake Travis to the Trinity (Hill Country) Aquifer rather than to the Edwards (Balcones Fault Zone) Aquifer. We also re-assigned some entities initially with the "Other Aquifer" designation to designations based on their location within the aquifer footprints in the county.

Non-Surveyed Municipal

Figure 633 and Figure 634 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Travis County during the study period. Our estimates are several times lower than the Water Use Survey data for the Edwards (Balcones Fault Zone) Aquifer. Our estimates of pumping for non-surveyed municipal use from the Trinity (Hill Country) Aquifer appear to agree with the TWDB Water Use Survey data.

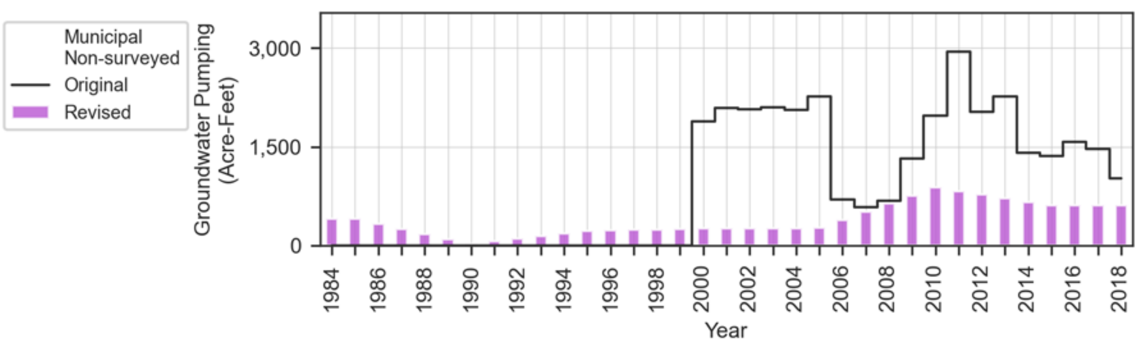


Figure 633. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Travis County from 1984 through 2018.

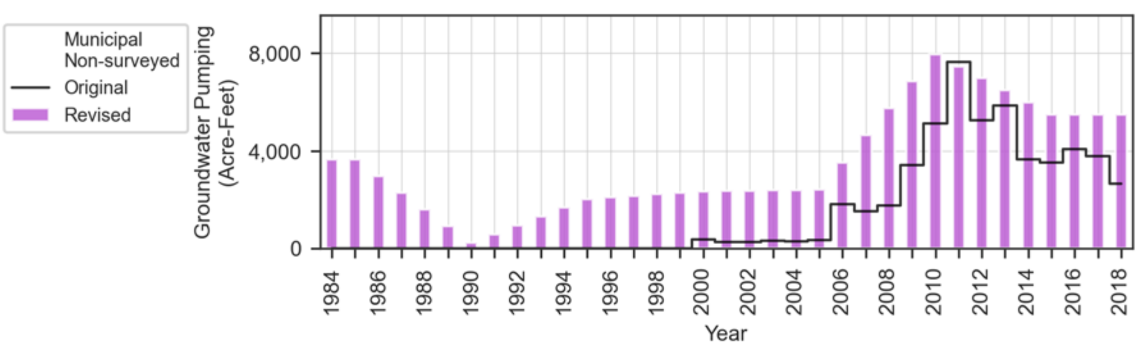


Figure 634. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Travis County from 1984 through 2018.

Irrigation

Travis County is underlain by the Trinity (Hill Country) Aquifer, the Edwards (Balcones Fault Zone) Aquifer, and the Carrizo Aquifer. The Trinity (Hill Country) Aquifer underlies the Edwards (Balcones Fault Zone) Aquifer (Figure 635). Wells identified within Travis County demonstrate a geographic separation between those screened in the Trinity (Hill Country) Aquifer and those screened within the Edwards (Balcones Fault Zone) Aquifer. Due to this geographic separation, the footprint of the Edwards (Balcones Fault Zone) Aquifer is used to assess irrigation needs. The revised irrigation demands reported for Travis County are also limited to the footprint of the county located south of the Colorado River. Due to this limitation, it is not possible to compare the revised irrigation demands to the original pumpage totals included within the TWDB Water Use Survey dataset as the Water Use Survey dataset reports data for the entire Travis County area.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards (Balcones Fault Zone) Aquifer in Travis County ranged from 140 acre-feet per year to 1,960 acre-feet per year (Figure 636). Surface water was used to meet irrigation demands in all years within the study period, and surface water usage was sufficient to meet all irrigation needs from 2003 to 2015. Groundwater pumpage estimates for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Travis County range from zero acre-feet per year to 530 acre-feet per year. Irrigation demands from 2003 to 2015 were generally higher than demands from 1984 to 2002, and demand from 2016 to 2018 dropped significantly as rainfall increased over the county during this period.

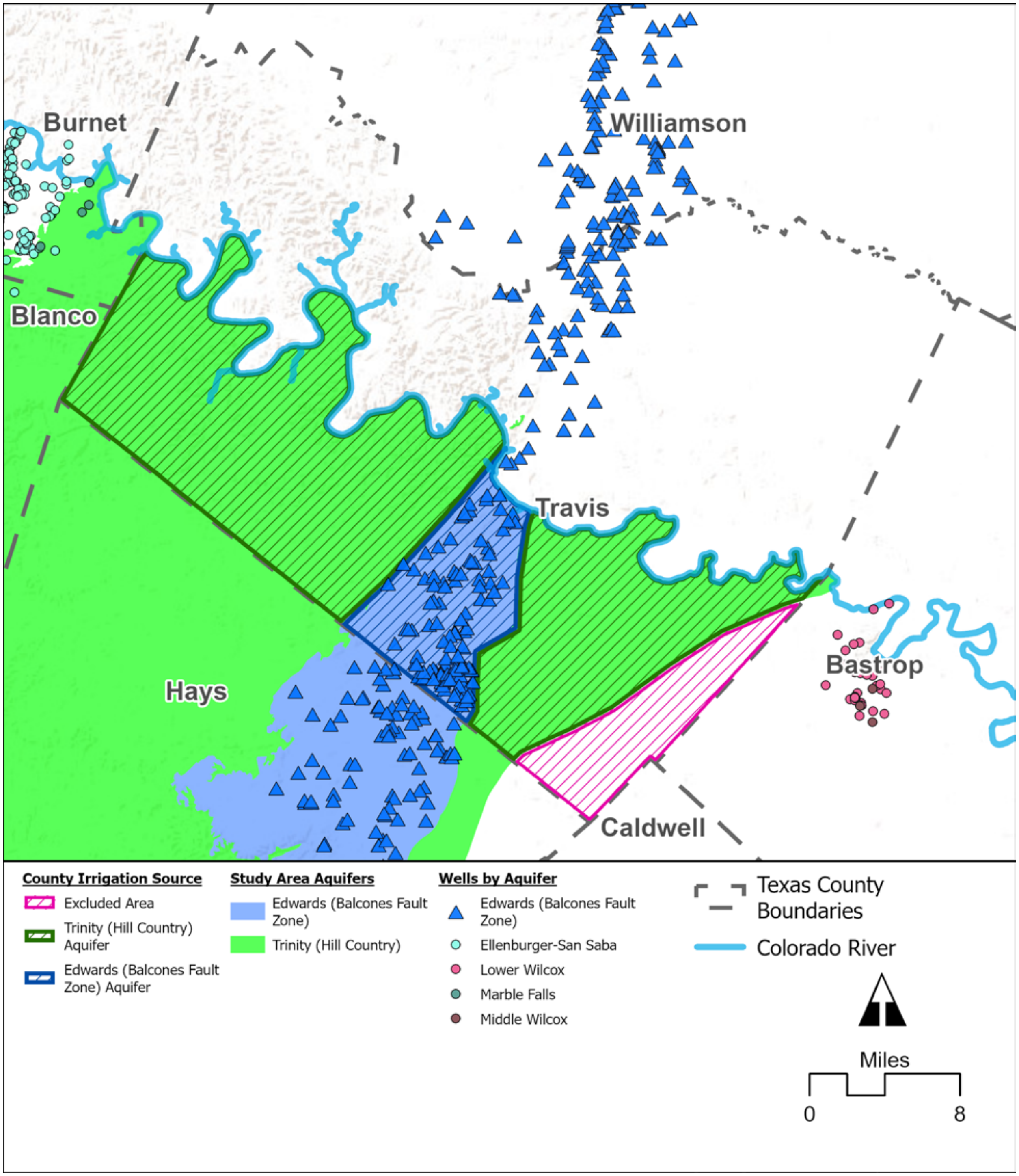


Figure 635. Travis County map showing aquifers and wells used in assessing irrigation pumpage.

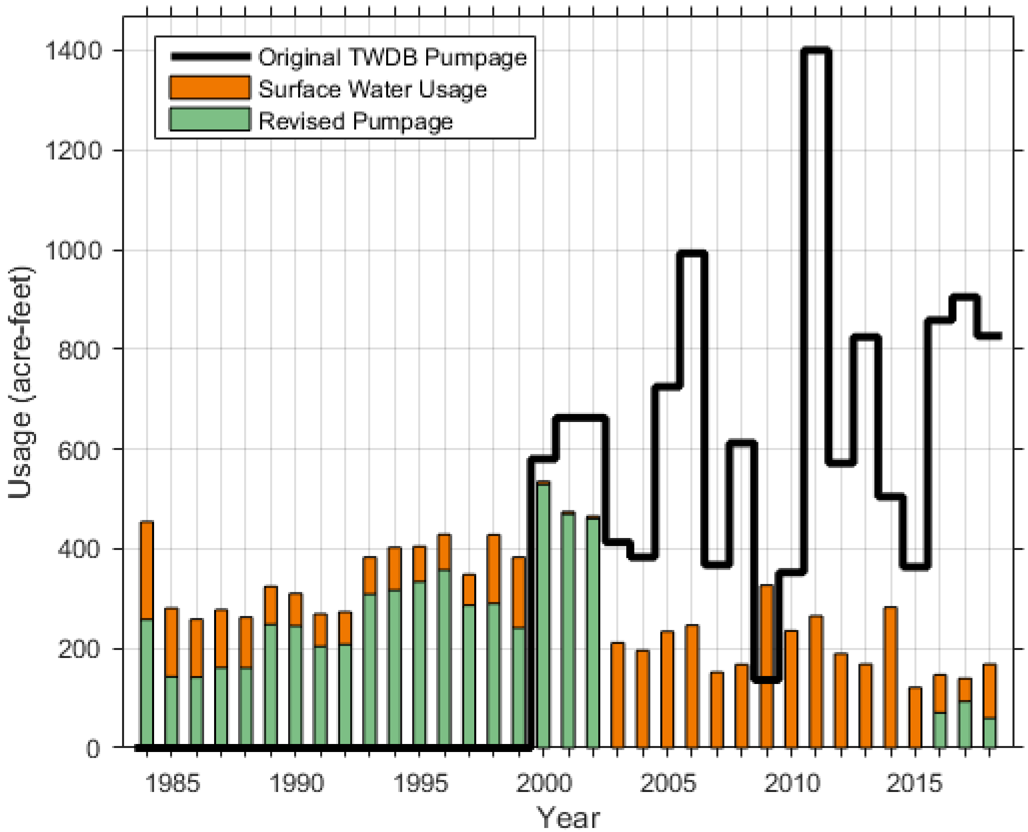


Figure 636. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Travis County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Trinity (Hill Country) Aquifer in Travis County ranged from 350 acre-feet per year to 6,980 acre-feet per year. Surface water was used to meet irrigation demands in all years within the study period, and surface water usage was sufficient to meet all irrigation needs from 1984 to 1988 and from 2003 to 2015. Groundwater pumpage estimates for irrigation from the Trinity (Hill Country) Aquifer within Travis County range from zero acre-feet per year to 750 acre-feet per year. Irrigation demands from 2003 to 2015 were generally higher than demands from 1984 to 2002, and demand from 2016 to 2018 dropped significantly as rainfall increased over the county during this period.

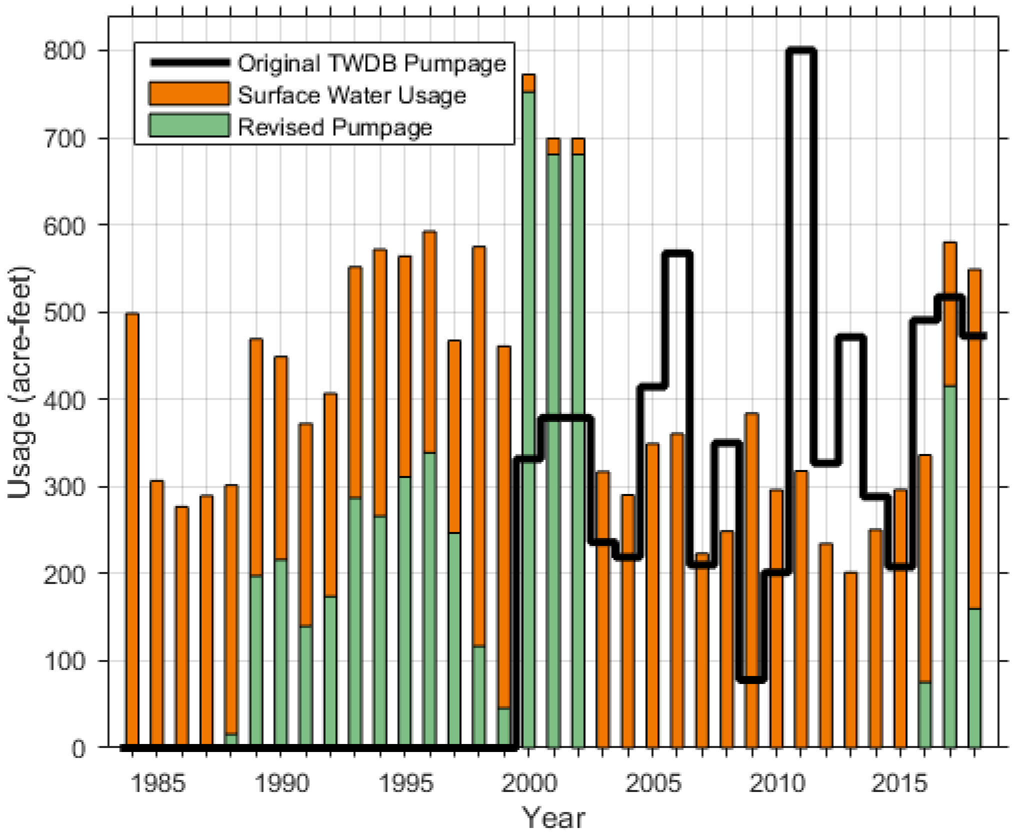


Figure 637. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Travis County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Travis County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Travis County.

Mining

Figure 631d and Figure 632d illustrate the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Travis County during the study period. Only the U.S. Geological Survey data was available to estimate the mining use within Travis County. Based on the revised estimates, 67 percent of the pumped water for mining use is sourced from the Trinity (Hill Country) Aquifer and the remaining is from the Edwards (Balcones Fault Zone) Aquifer.

Manufacturing

Figure 631c and Figure 632c illustrate the changes in groundwater pumping associated with manufacturing use from the Edwards (Balcones Fault Zone) Aquifer and Trinity (Hill Country)

Aquifer, respectively, in Travis County during the study period. Revised data is only applicable to the portion of Travis County within the study area.

Livestock

Figure 631b and Figure 632b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone) Aquifer and the Trinity (Hill Country) Aquifer, respectively, in Travis County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from both aquifers. There is a peak in the TWDB Water Use Survey data for both aquifers in 1996 that is not present in our estimates.

5.2.47 *Upton County*

Figure 638 and Figure 639 illustrate our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Upton County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

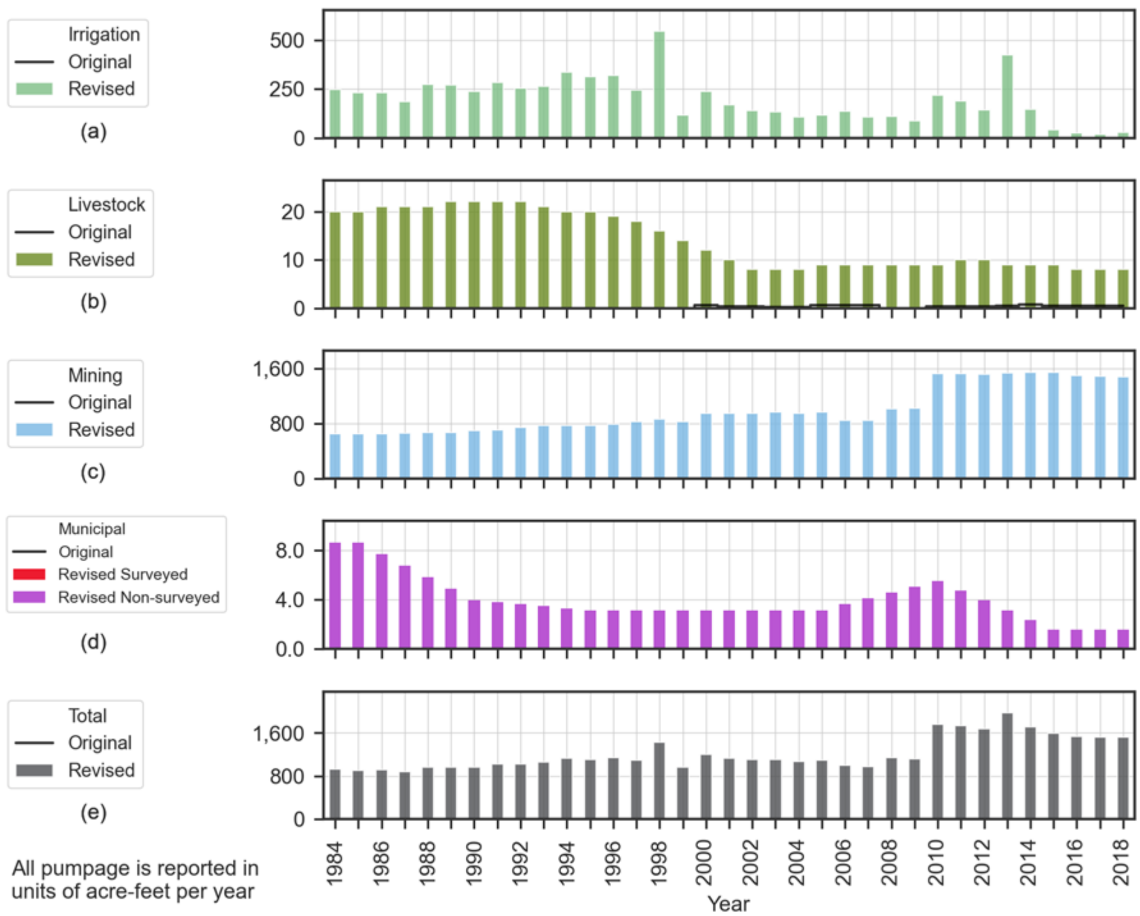


Figure 638. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Upton County from 1984 through 2018.

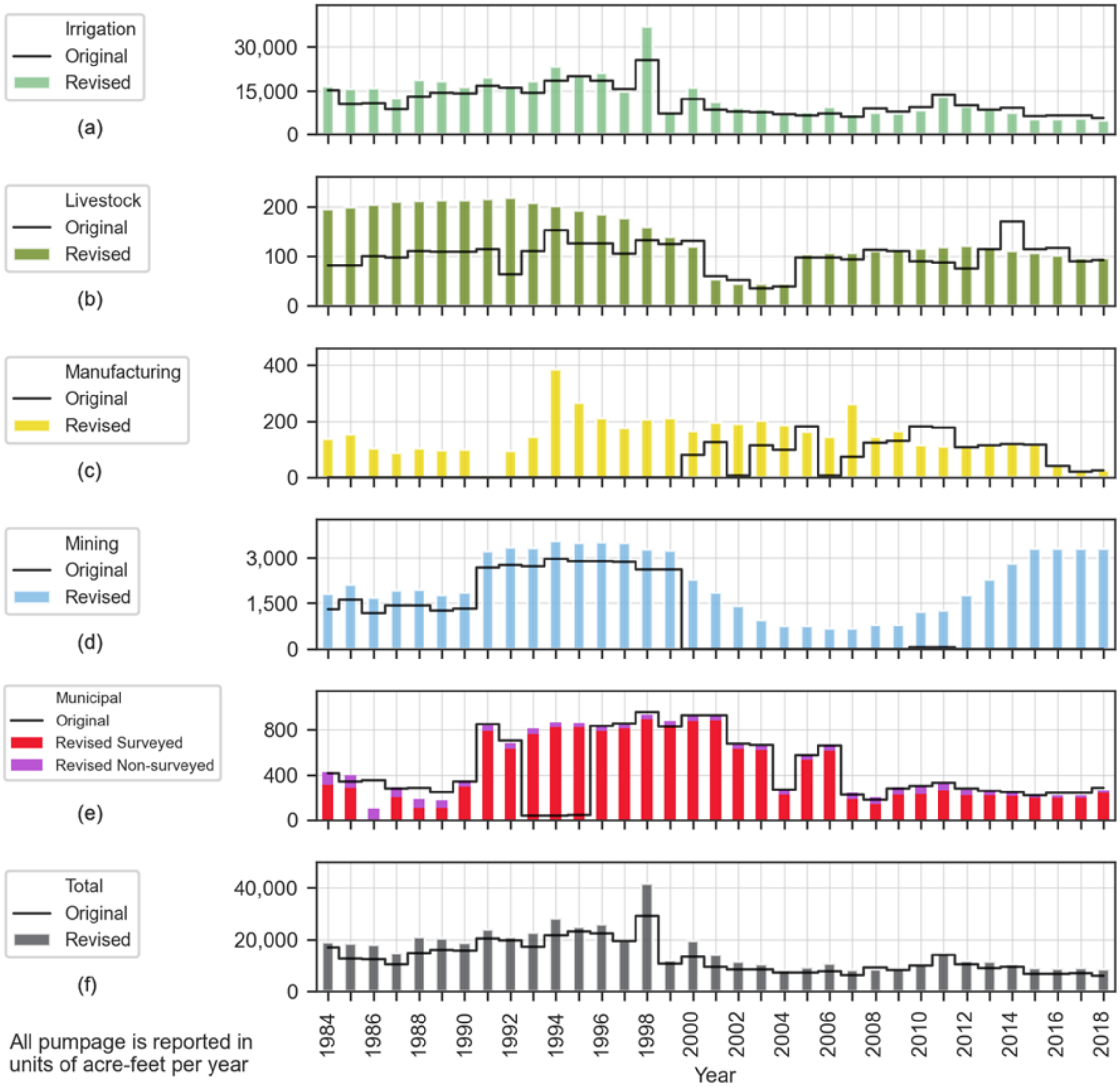


Figure 639. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Upton County from 1984 through 2018.

Surveyed Municipal

Municipal pumpage from the Pecos Valley Aquifer within Upton County is not included in the TWDB Water Use Survey database. Pumpage reported from the Edwards Trinity (Plateau) Aquifer was variable from year to year, with the greatest pumpage reported between 1990 and 2006 when multiple entities contributed reports. These entities include the Upton County Water Department, Upton County WCID 1, the City of Rankin, and the City of McCamey. All these entities reported for only relatively short portion of the study period, perhaps indicating that reports are missing for other years in which these seemingly stable local governmental agencies would be operating.

Non-Surveyed Municipal

Figure 640 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Upton County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data. Our estimates agree with the TWDB Water Use Survey data which does not include pumping from the Pecos Valley Aquifer in Upton County during the study period.

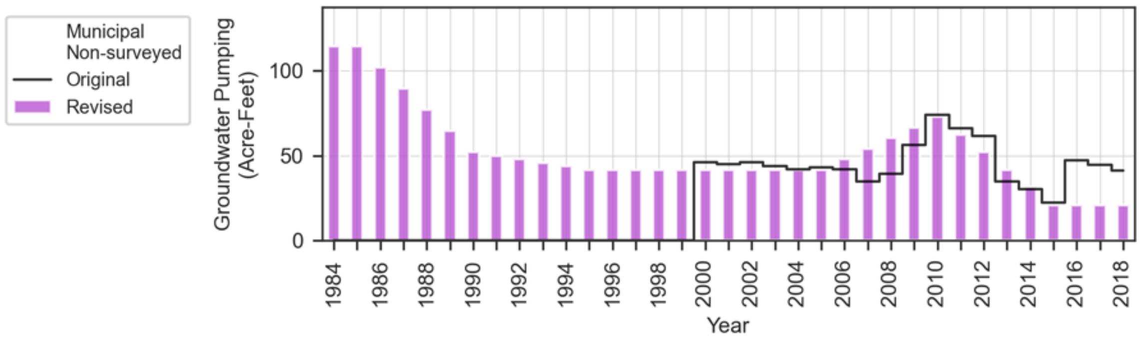


Figure 640. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Upton County from 1984 through 2018.

Irrigation

Upton County is underlain by the Edwards-Trinity (Plateau) Aquifer for a majority of the county area and is underlain by a portion of the Pecos Valley Aquifer along the central portion of the western county border with Crane County. The Dockum Aquifer underlies the Edwards-Trinity (Plateau) Aquifer in the southern portion of the county along the border with Crockett County. Wells identified within the county are screened within the Edwards-Trinity (Plateau) Aquifer, and those located within the southwestern corner of the county are preferentially screened within the Dockum Aquifer. As such, in revising the irrigation demands for the county, the southwest corner of the county was assumed to be irrigated using wells screened in the Dockum Aquifer and not in the Edwards-Trinity (Plateau) Aquifer. Although no wells were identified as being screened within the Pecos Valley Aquifer, review of the TWDB groundwater data viewer indicated that such wells exist within the footprint of the aquifer identified in Figure 641.

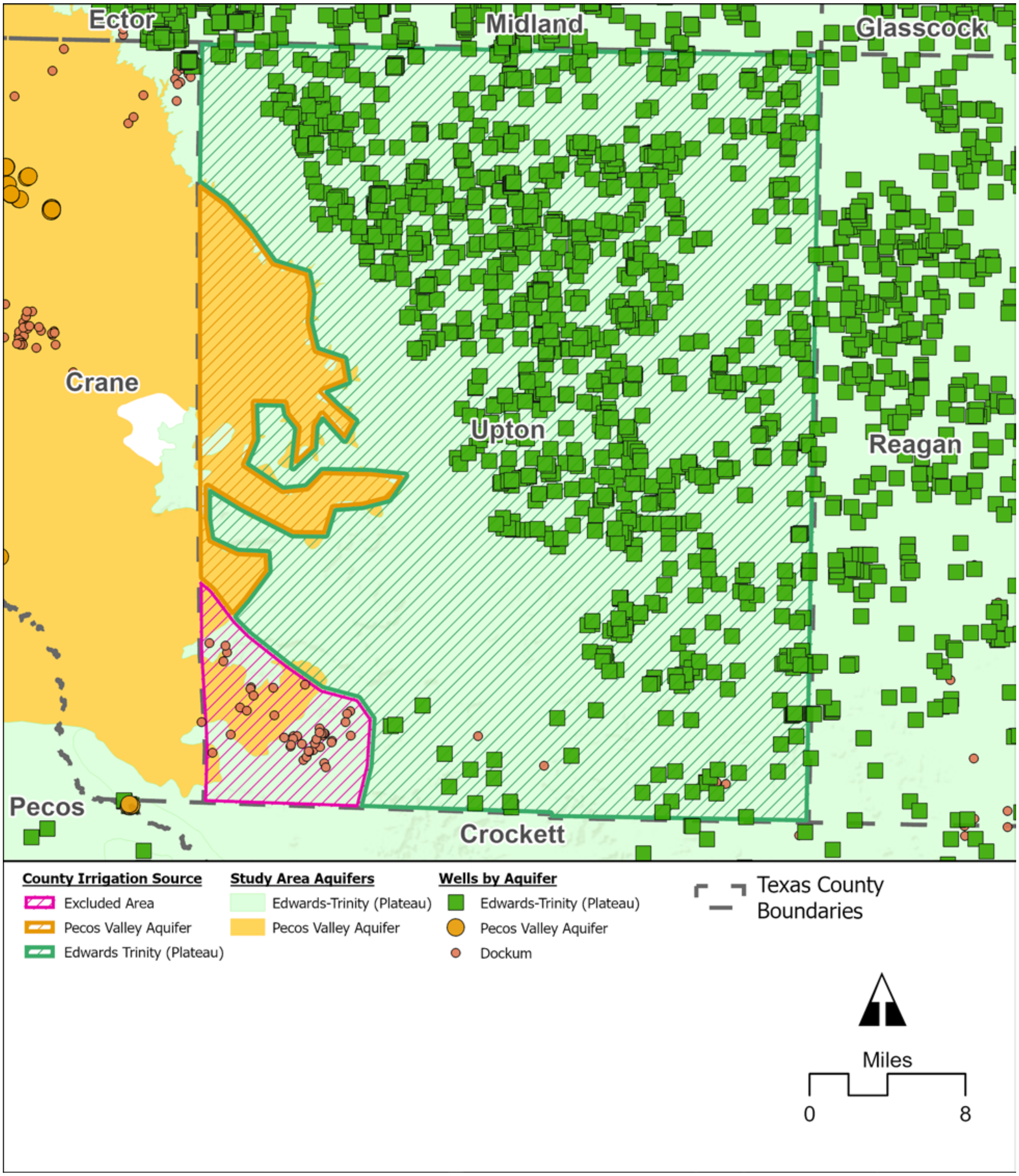


Figure 641. Upton County map showing aquifers and wells used in assessing irrigation pumpage.

The original TWDB Water Use Survey dataset suggested that irrigation needs for Upton County were met from diversions from the Edwards-Trinity (Plateau) Aquifer and from the Ogallala Aquifer. As the Ogallala Aquifer does not exist within Upton County, it is expected that pumping previously attributed to the Ogallala Aquifer was actually pumpage from either the

Dockum Aquifer or from the Pecos Valley Aquifer. Pumpage from the Edwards-Trinity (Plateau) Aquifer ranged from 5,680 acre-feet per year to 25,425 acre-feet per year (Figure 642). The revised pumpage dataset based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates within the modified footprint of the Edwards-Trinity (Plateau) Aquifer within Upton County largely agrees with the magnitude and trends in pumpage from the original TWDB Water Use Survey estimates. Revised pumpage ranged from 4,850 acre-feet per year to 36,895 acre-feet per year, with the maximum and minimum pumpage occurring 1998 and 2018, respectively within both the revised and original datasets.

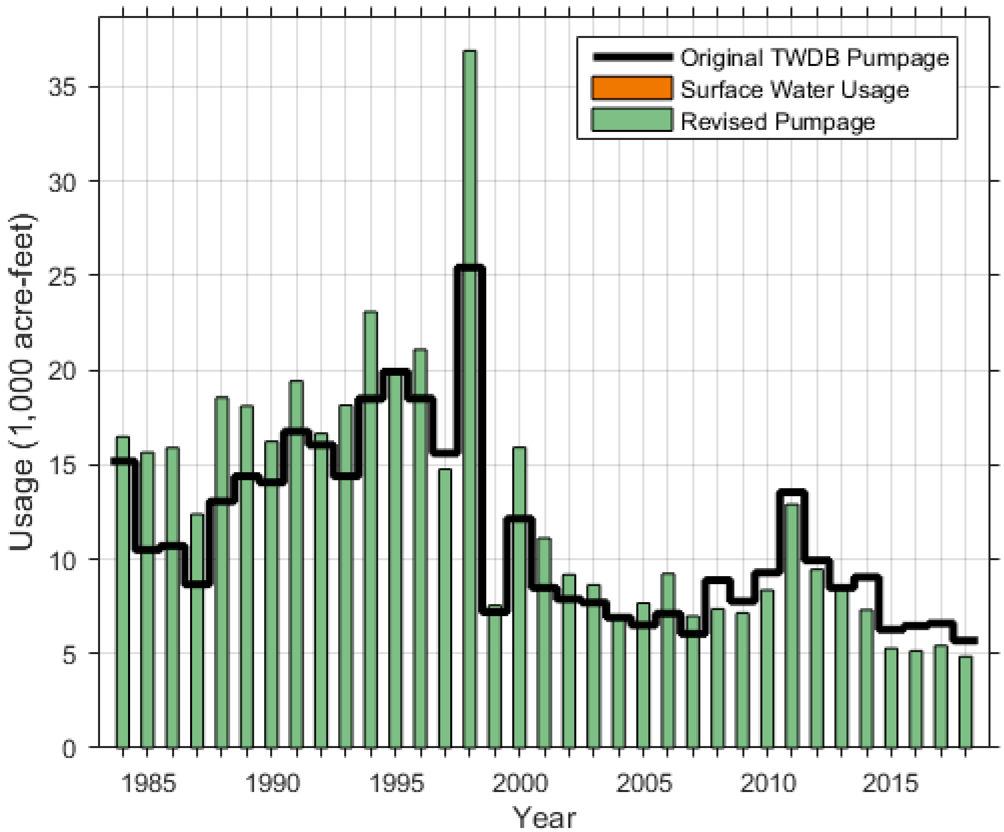


Figure 642. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Upton County.

The revised pumpage values based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates within the modified footprint of the Pecos Valley Aquifer within Upton County ranged from 20 acre-feet per year to 545 acre-feet per year (Figure 643). The pumpage data follows a similar pattern as the data from the Edwards-Trinity (Plateau) Aquifer, with an anomalous peak in 1998 and the lowest pumpage values computed for the 2015 to 2018 period.

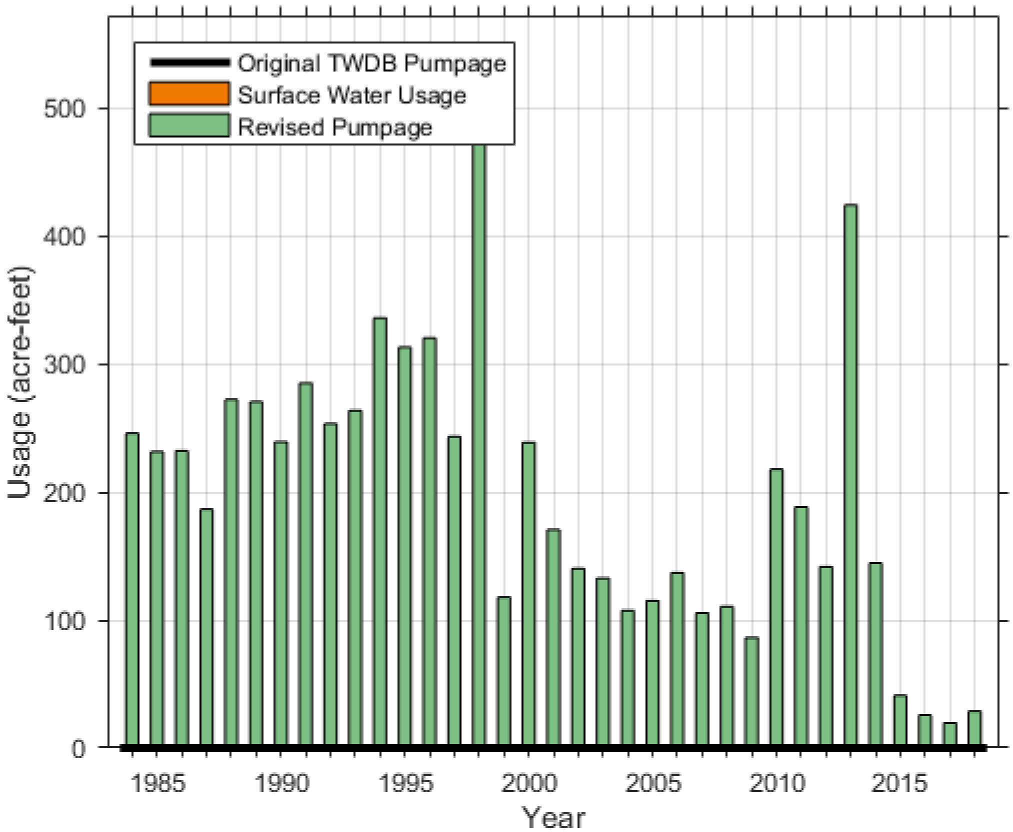


Figure 643. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Upton County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Upton County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Upton County.

Mining

Figure 638c and Figure 639d illustrate the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Upton County during the study period. The number of active enhanced oil recovery wells in Upton County increased from 465 in 1980 to 963 in 2020. Little Water Use Survey data are available for Upton County and the data available is orders of magnitude less than that estimated by the Bureau of Economic Geology and U.S. Geological Survey methodologies. In general, the estimates from the U.S. Geological Survey and the Bureau of Economic Geology methodologies are comparable to each other, in the same order of magnitude, and within a factor of two from each other. The revised mining estimates indicate that one-third of the water pumped for mining use is sourced from the Pecos Valley Aquifer and the remaining is from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 639c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Upton County during the study period. There are several entities for which we applied changes. Table 78 summarizes our revisions to the original estimates.

Table 78. Summary of revisions to groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for manufacturing use in Upton County from 1984 through 2018.

Standardized Name	Alternate Water Use Survey Names	Notes
Atlas Pipeline – Benedum Plant	Western Gas Resources Inc – Benedum Plant	Some years reported in Reagan County. Assigned all pumping to Reagan County for consistency
Navitas Midstream Partners – Crane Gas Plant	BP America Production Company – Crane Gas Plant; Navitas Midstream Midland Basin, LLC – Crane Gas Plant	Changed mining use designation from 1984 through 1999 to manufacturing use to be consistent with designation from 2000 through present. Missing value for 1990; assumed one acre-foot
Western Gas Resources Inc – Midkiff Plant	None	No data after 2009. Missing data for 2002; used previous year value as estimate. Changed mining use designation from 1993 through 1999 to manufacturing use to be consistent with designation from 2000 through 2009.

Livestock

Figure 638b and Figure 639b illustrate the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Upton County during the study period. Our estimate is greater than the TWDB Water Use Survey data for groundwater pumping from the Pecos Valley Aquifer. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) after 2000. Prior to 2000, our review indicates pumpage is more than what had been previously estimated.

5.2.48 Uvalde County

Figure 644, Figure 645, and Figure 646 illustrate our revisions to the estimated in groundwater pumping from the Edwards (Balcones Fault Zone), the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Uvalde County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

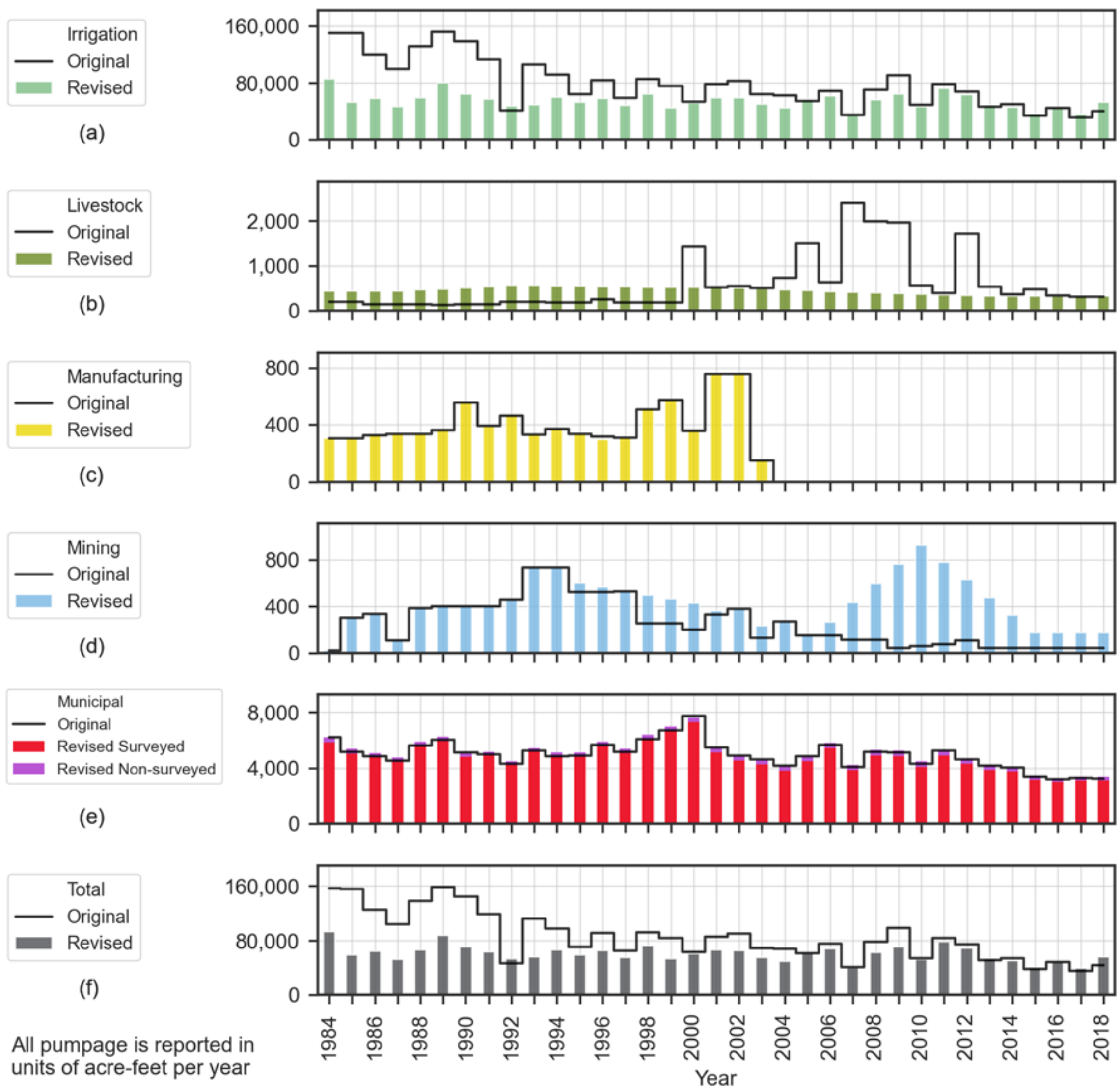


Figure 644. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer in Uvalde County from 1984 through 2018.

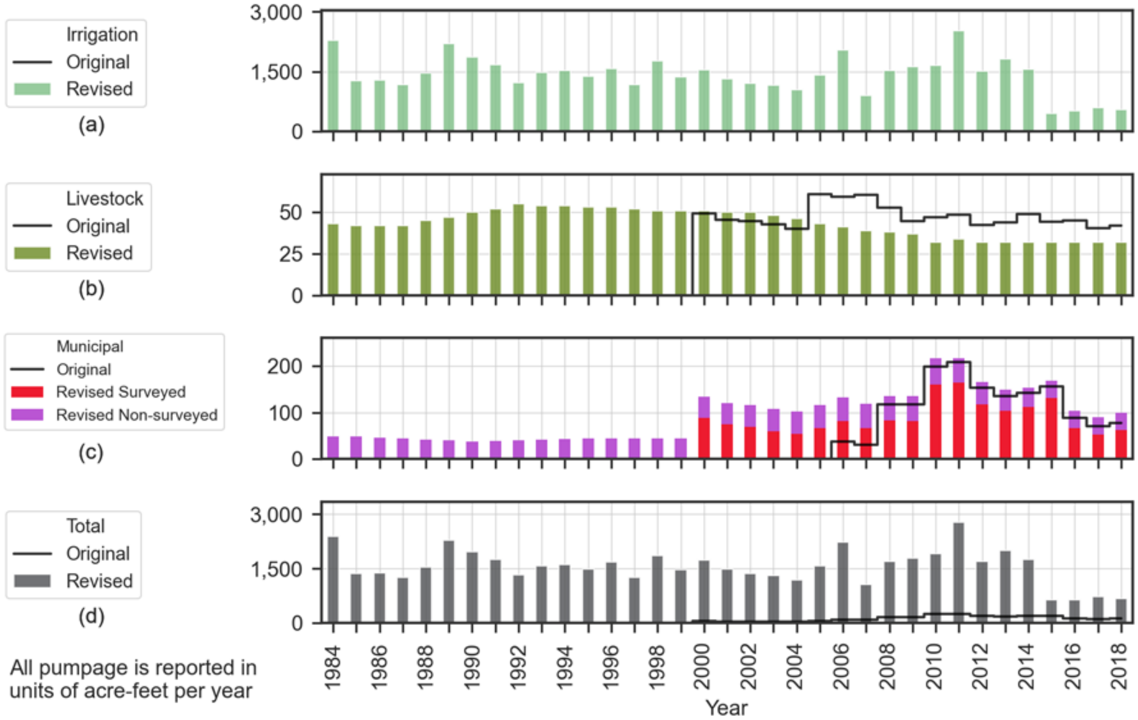


Figure 645. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer in Uvalde County from 1984 through 2018.

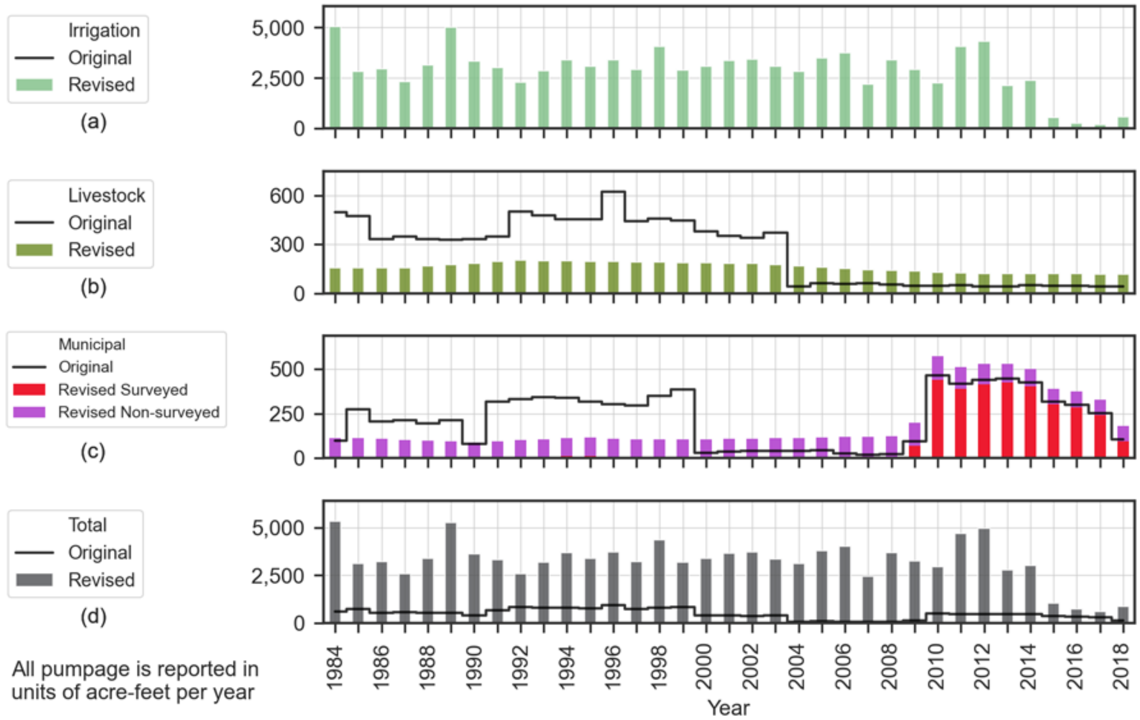


Figure 646. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Uvalde County from 1984 through 2018.

Surveyed Municipal

Revisions to the original TWDB Water Use Survey data for surveyed municipal pumpage in Uvalde County included the reassignment of source aquifers based on the entity location within the county. This included assigning pumpage to support Garner State Park to the Edwards (Balcones Fault Zone) Aquifer based on the park location.

Non-Surveyed Municipal

Figure 647, Figure 648, and Figure 649 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards (Balcones Fault Zone), the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Uvalde County during the study period. Our estimate is less than the TWDB Water Use Survey data for groundwater pumping from the Edwards (Balcones Fault Zone) prior to 2006. Our estimate is higher than TWDB Water Use Survey data for groundwater pumping from the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer.

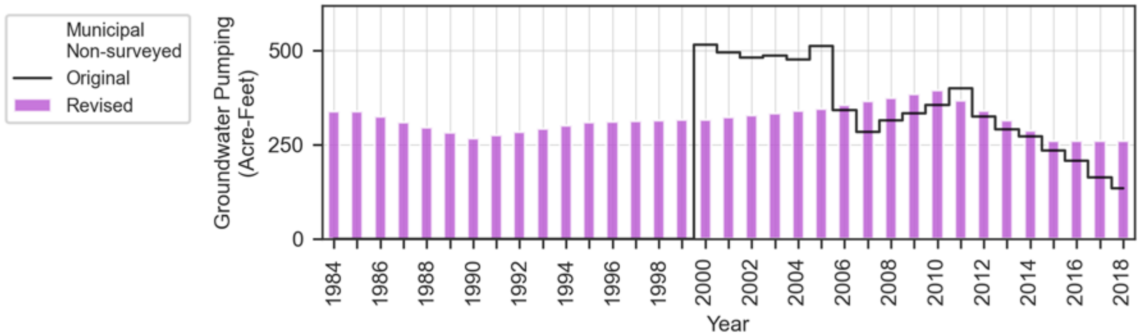


Figure 647. Original and revised estimates of groundwater pumping from the Edwards (Balcones Fault Zone) Aquifer for non-surveyed municipal use in Uvalde County from 1984 through 2018.

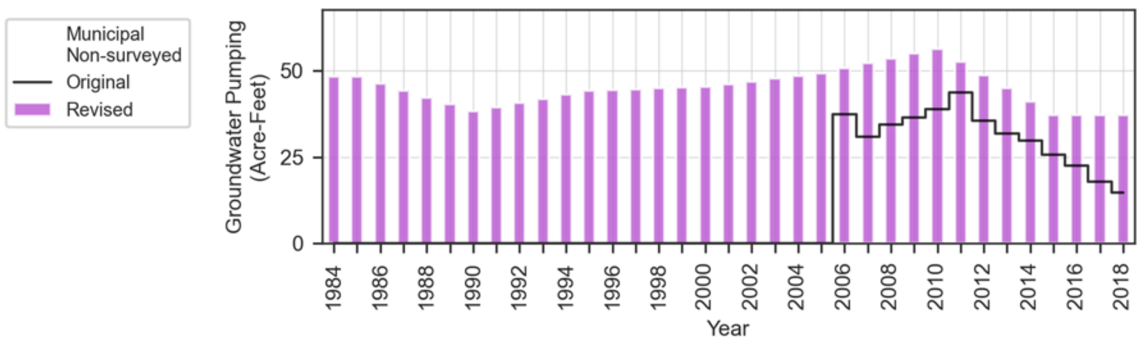


Figure 648. Original and revised estimates of groundwater pumping from the Trinity (Hill Country) Aquifer for non-surveyed municipal use in Uvalde County from 1984 through 2018.

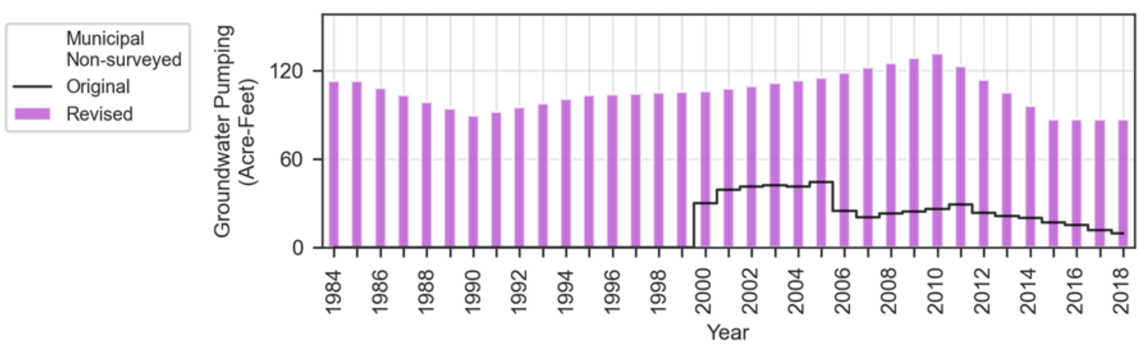


Figure 649. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Uvalde County from 1984 through 2018.

Irrigation

Uvalde County is underlain by the Edwards-Trinity (Plateau) Aquifer along the majority of the northern county border with Edwards County and Real County (Figure 650). The Trinity (Hill Country) Aquifer underlies much of the eastern extent of the county along the border with Medina County. The Edwards (Balcones Fault Zone) Aquifer underlies a majority of the central portion of the county. The southern portion of the county is underlain by the Carrizo Aquifer (which is not a subject aquifer in this study). Wells within Uvalde County are geographically distinct, and wells within the region of overlap between the Trinity (Hill Country) Aquifer and the Edwards (Balcones Fault Zone) Aquifer are all screened within the Edwards (Balcones Fault Zone) Aquifer. As such, for assessing irrigation pumpage, aquifer footprints across Uvalde County were defined such that the Edwards (Balcones Fault Zone) Aquifer took precedence over the Trinity (Hill Country) Aquifer, relegating the latter to a smaller footprint covering the northeast corner of the county.

The original TWDB Water Use Survey dataset suggested irrigation pumpage from the Edwards (Balcones Fault Zone) Aquifer ranged from approximately 150,000 acre-feet per year early in the study period to approximately 31,000 acre-feet per year by the end of the study period (Figure 651). Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, revised irrigation demands for land above the footprint of the Edwards (Balcones Fault Zone) Aquifer in Uvalde County were more uniform over the study period, ranging from 35,000 acre-feet per year to 86,500 acre-feet per year. Surface water was used to partially meet irrigation demands in some years, but never in sufficient quantities to significantly reduce groundwater pumpage needs. Fluctuations within the revised dataset are temporally consistent with fluctuations within the TWDB original Water Use Survey dataset.

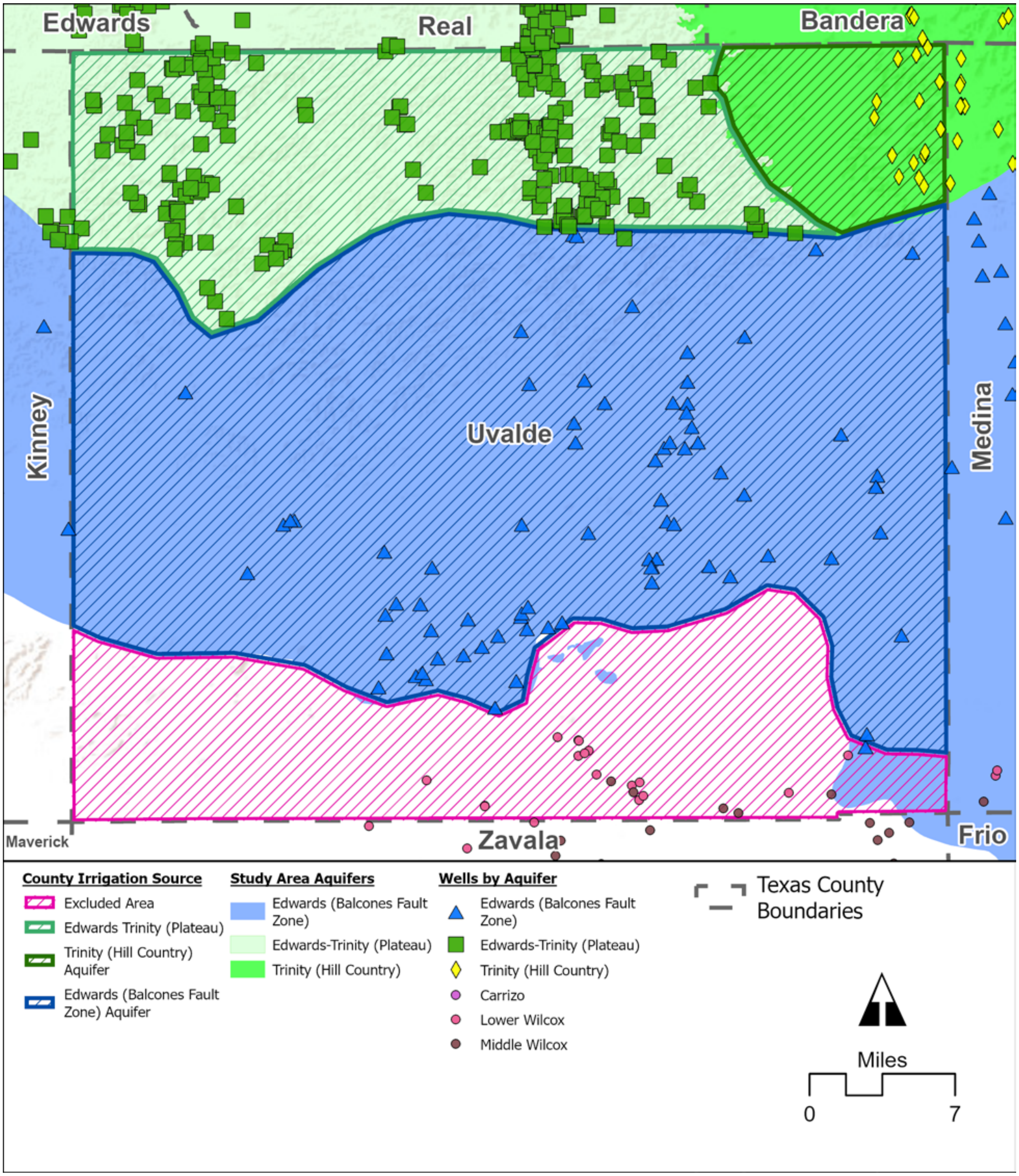


Figure 650. Uvalde County map showing aquifers and wells used in assessing irrigation pumpage.

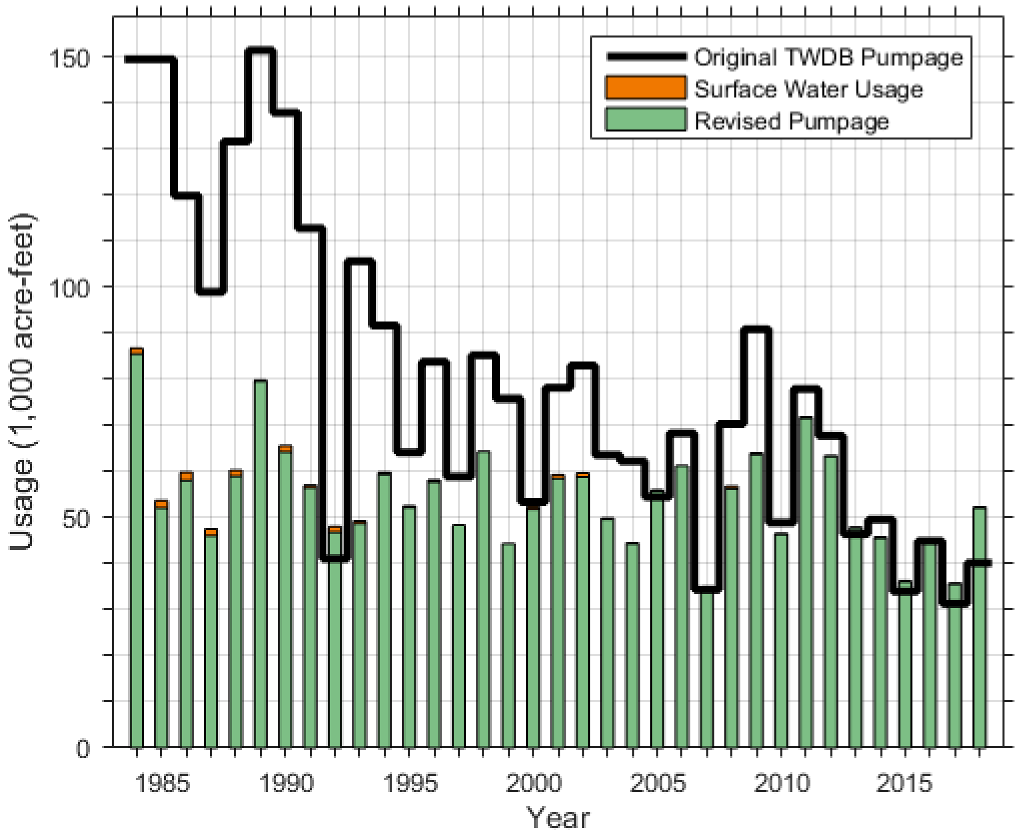


Figure 651. Revised groundwater pumpage for irrigation from the Edwards (Balcones Fault Zone) Aquifer within Uvalde County.

The original TWDB Water Use Survey dataset does not specify irrigation pumpage from Uvalde County from either the Trinity (Hill Country) Aquifer, the Edwards-Trinity (Plateau) Aquifer, or the Carrizo Aquifer. It does contain data for "Other Aquifer" with reported pumpage ranging from 3,063 acre-feet per year to 5,992 acre-feet per year between 2000 and 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, revised irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in ranged from 5,500 acre-feet per year in 1984 to 250 acre-feet per year in 2017 (Figure 652), with most of the drop in pumpage occurring between 2014 and 2015. Surface water was used to meet some of the demands for irrigation water, with generally less surface water usage later within the study period.

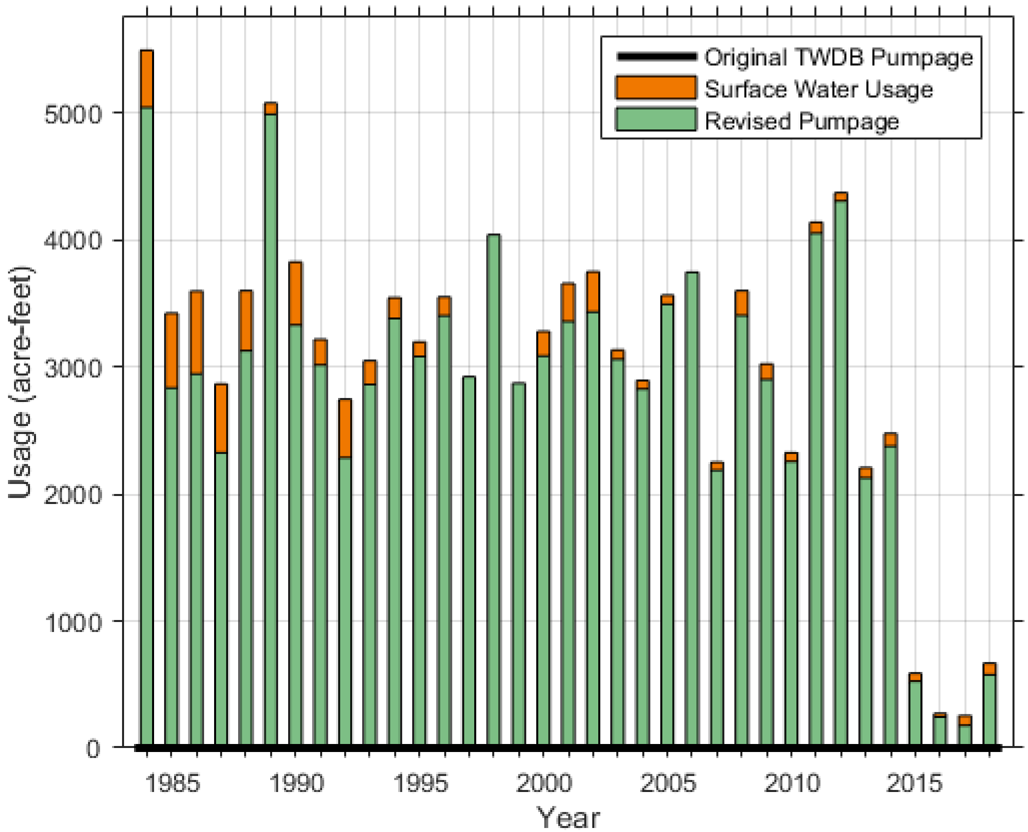


Figure 652. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Uvalde County.

Revised irrigation pumpage for the Trinity (Hill Country) Aquifer in Uvalde County ranged from 460 acre-feet per year in 2015 to 2,560 acre-feet per year in 2011 (Figure 653). Similar patterns in the temporal fluctuation of pumpage from each aquifer indicate that demands were likely driven largely by fluctuating climate, rather than local fluctuations in crop acreage or crop type.

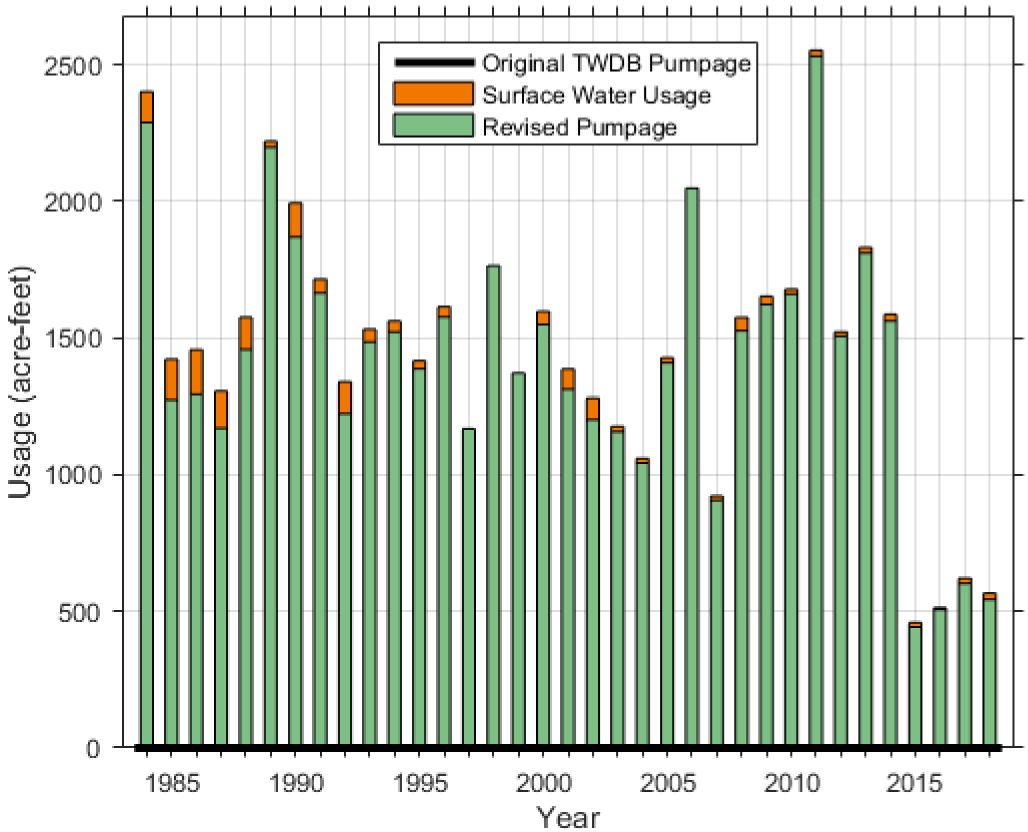


Figure 653. Revised groundwater pumpage for irrigation from the Trinity (Hill Country) Aquifer within Uvalde County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Uvalde County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Uvalde County.

Mining

Figure 644d, Figure 645b, and Figure 646b illustrate the changes in groundwater pumping associated with mining use from the Edwards (Balcones Fault Zone), the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Uvalde County during the study period. No enhanced oil recovery wells were reported within the county. Therefore, we compared the estimates obtained from the U.S. Geological Survey to those obtained from the Bureau of Economic Geology methodology. In general, the two methods provided estimates within the same order of magnitude with the U.S. Geological Survey estimates being greater than the Bureau of Economic Geology estimates. However, there were a few years when the trends reversed. Overall, the pumping trends remained smooth throughout the study time period even though individually the two estimates may have suffered data gaps. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards (Balcones Fault Zone) Aquifer.

Manufacturing

Figure 644c illustrates the groundwater pumping associated with manufacturing use from the Edwards (Balcones Fault Zone) Aquifer in Uvalde County during the study period. We identified no changes for this use.

Livestock

Figure 644b, Figure 645b, and Figure 646b illustrate the changes in groundwater pumping associated with livestock use from the Edwards (Balcones Fault Zone), the Trinity (Hill Country) Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Uvalde County during the study period. Our estimate does not include the groundwater pumping peaks present in the TWDB Water Use Survey data has for the years 2000, 2005, 2007 to 2009 and 2012 for the Edwards (Balcones Fault Zone) Aquifer. Our estimate is several times less than the TWDB Water Use Survey data for groundwater pumping from the Edwards (Balcones Fault Zone). Our estimate is in general agreement with the TWDB Water Use Survey data for the Trinity (Hill Country) Aquifer and includes data prior to year 2000 whereas the TWDB Water Use Survey data does not. Finally, our estimate is less than the TWDB Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer prior to 2004 and more than the Water Survey data after 2004.

5.2.49 Val Verde County

Figure 654 illustrates our revisions to the estimated in groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Val Verde County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

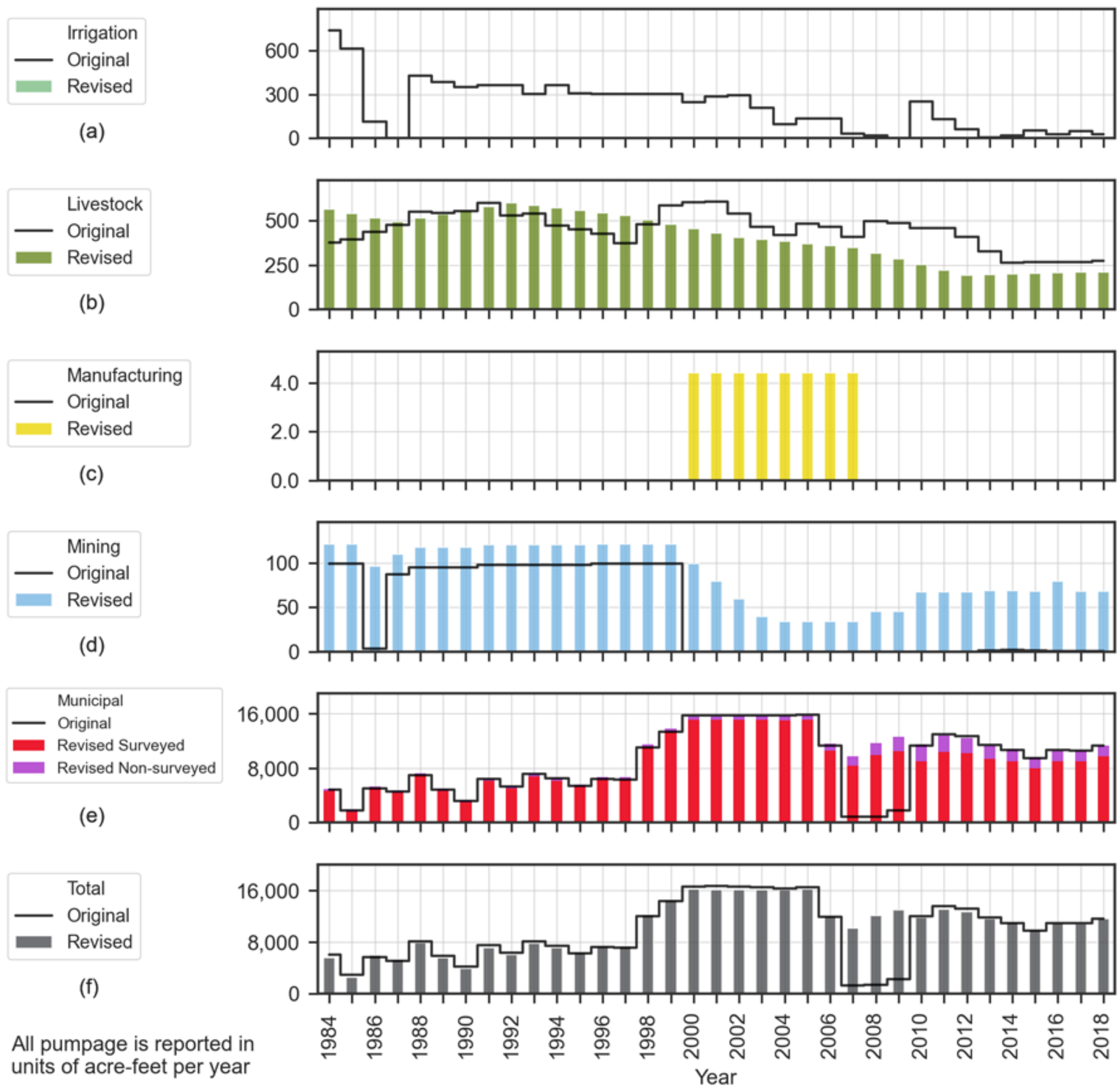


Figure 654. **Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Val Verde County from 1984 through 2018.**

Surveyed Municipal

Figure 654e illustrates the changes in groundwater pumping associated with surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Val Verde County during the study period. Changes included interpolation of missing data from 2007 to 2009, which resulted in an increase in total pumpage over the study period.

Non-Surveyed Municipal

Figure 655 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Edwards-Trinity (Plateau) Aquifer in Val Verde County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

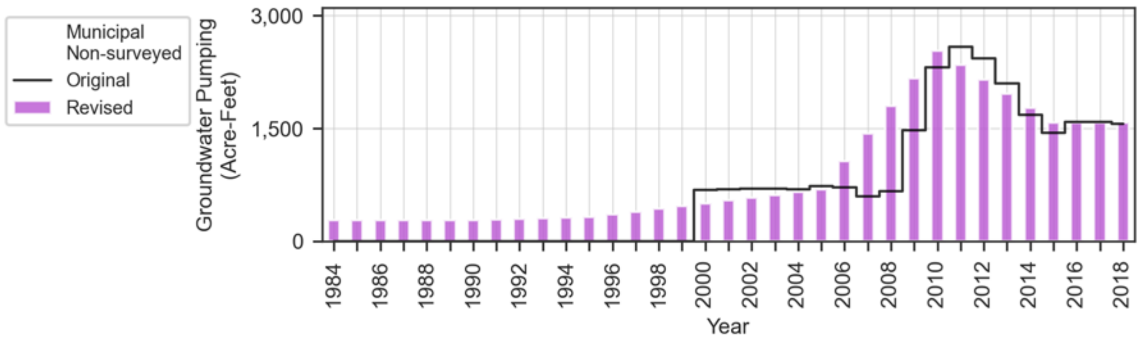


Figure 655. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Val Verde County from 1984 through 2018.

Irrigation

Val Verde County is almost entirely underlain by the Edwards-Trinity (Plateau) Aquifer, and all wells identified within the aquifer footprint are also considered to be screened within the aquifer. The original TWDB Water Use Survey pumpage estimates for the Edwards-Trinity (Plateau) Aquifer in Val Verde County ranged from zero acre-feet per year to approximately 750 acre-feet per year with pumpage generally declining over the study period (Figure 656).

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Edwards-Trinity (Plateau) Aquifer in Val Verde County ranged from 900 acre-feet per year to 3,450 acre-feet per year. Surface water was used to meet 100 percent of all irrigation demands in all years within the study period. As such, revised groundwater pumpage estimates for irrigation within Val Verde County are set to zero acre-feet per year during the entire study period.

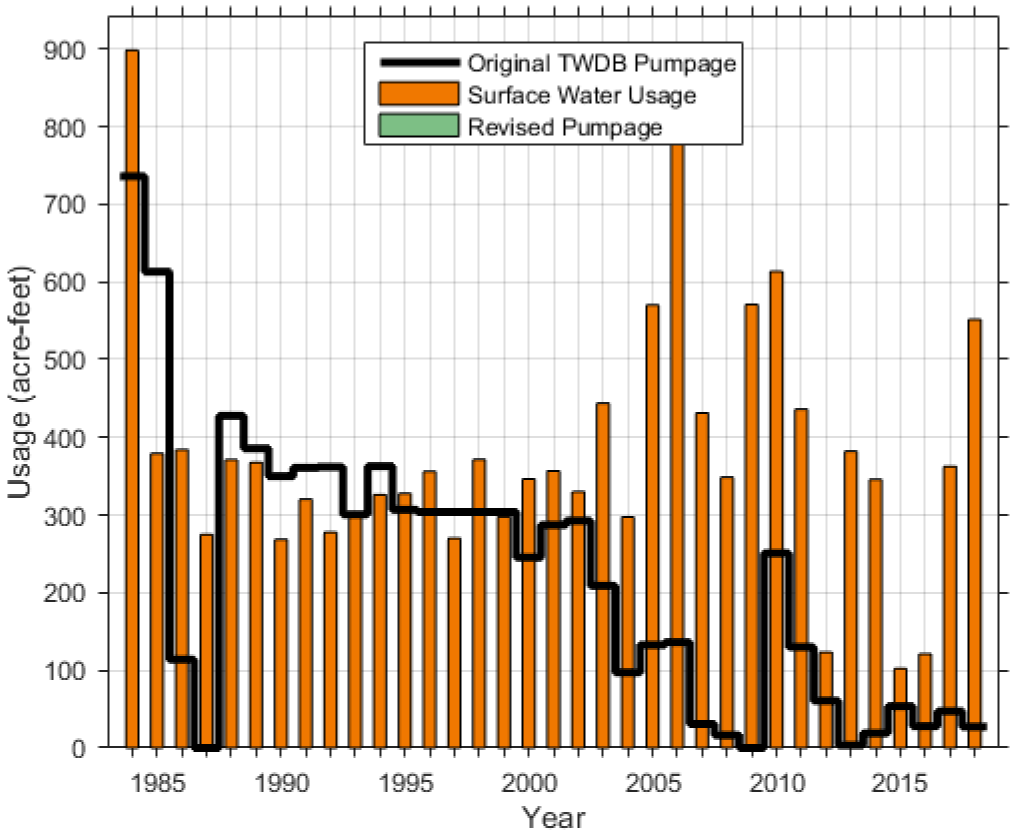


Figure 656. Revised groundwater pumpage for irrigation from the Edwards-Trinity (Plateau) Aquifer within Val Verde County.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Val Verde County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Val Verde County.

Mining

Figure 654c illustrates the changes in groundwater pumping associated with mining use from the Edwards-Trinity (Plateau) Aquifer in Val Verde County during the study period. The number of active enhanced oil recovery wells in Val Verde County increased from seven in 1980 to 23 wells in 2020. Limited Water Use Survey data is available within Val Verde County, but it is orders of magnitude lower than that estimated by the Bureau of Economic Geology and the U.S. Geological Survey methodologies. Generally, estimates from the U.S. Geological Survey methodology are greater than those from the Bureau of Economic Geology in the initial years but then the trend reverses in the later year (mid-2000's). The resulting revised mining pumping estimates provide a smooth trend over the study time-period. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Edwards-Trinity (Plateau) Aquifer.

Manufacturing

Figure 654c illustrates the changes in groundwater pumping associated with manufacturing use from the Edwards-Trinity (Plateau) Aquifer in Val Verde County during the study period. We reduced groundwater pumping associated with manufacturing use in Val Verde County during the study period to zero for all years. The revision is associated with reported data for "Kinder Morgan" where the use designated was mining for most years. Our revision involved associating the "Kinder Morgan" pumping with mining use.

Livestock

Figure 654b illustrates the changes in groundwater pumping associated with livestock use from the Edwards-Trinity (Plateau) Aquifer in Val Verde County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Val Verde County.

5.2.50 Ward County

Figure 657 illustrates our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer in Ward County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

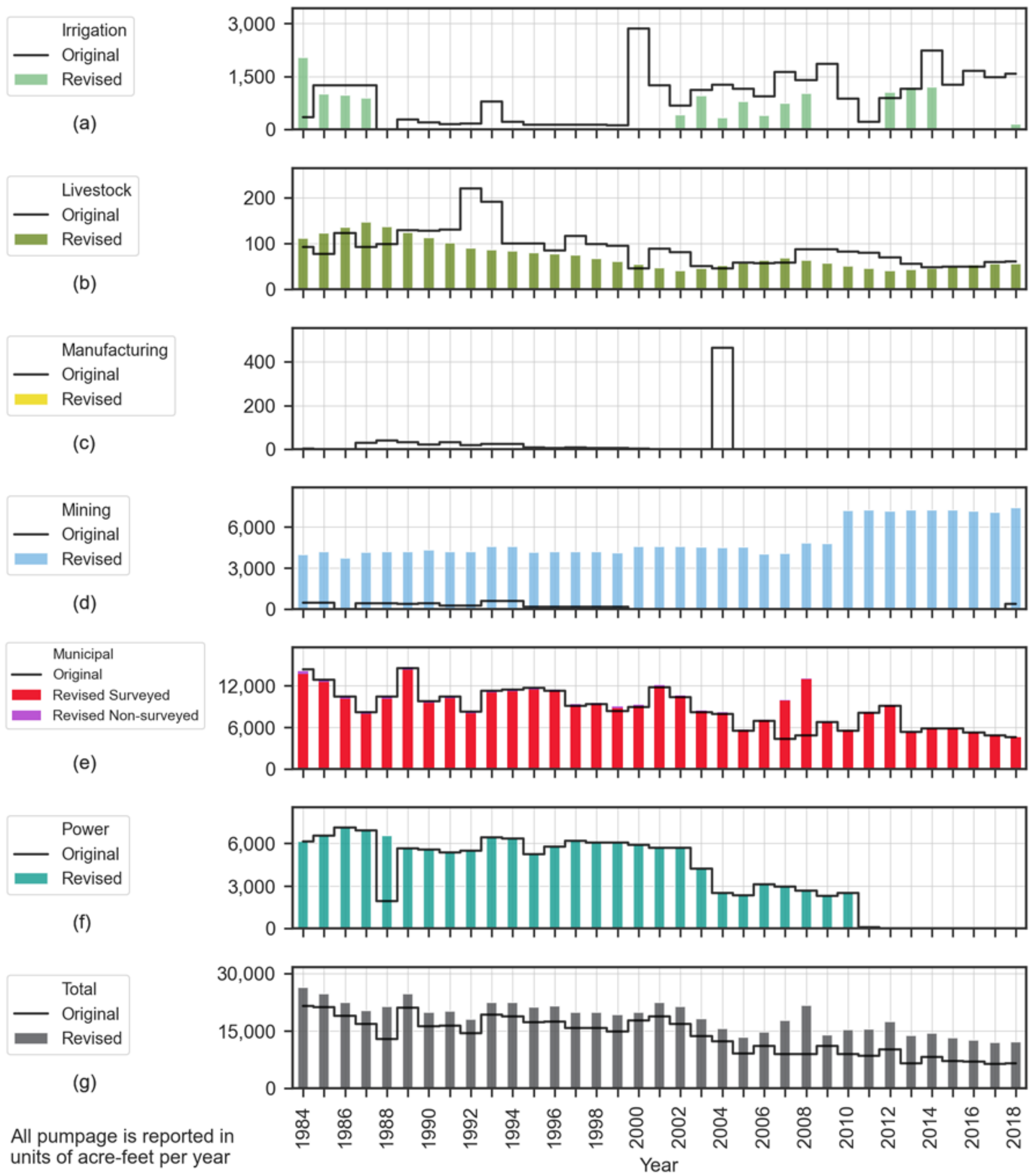


Figure 657. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Ward County from 1984 through 2018.

Surveyed Municipal

Figure 657e illustrates the changes in groundwater pumping associated with surveyed municipal use from the Pecos Valley Aquifer in Ward County during the study period. Groundwater pumping data associated with the City of Grand Falls were interpolated for missing years. Our estimates are generally consistent with the TWDB Water Use Survey data.

Non-Surveyed Municipal

Figure 658 illustrates the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer in Ward County during the study period. Our estimates are generally consistent with the TWDB Water Use Survey data.

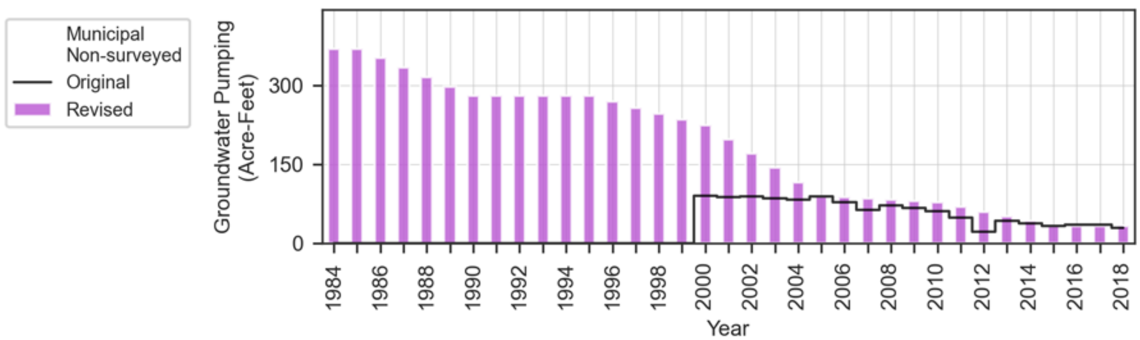


Figure 658. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Ward County from 1984 through 2018.

Irrigation

Ward County is completely underlain by the Pecos Valley Aquifer, and is also partially underlain by the Dockum Aquifer, the Rustler Aquifer, and the Capitan Reef Complex. Wells identified within the county were primarily screened within the Pecos Valley Aquifer, yet wells were identified as being screened within the Dockum Aquifer and the Capitan Reef Complex as well. Upon review of data within the TWDB groundwater data viewer, it is likely that pumpage for irrigation was derived primarily from wells screened within the Pecos Valley Aquifer. As such, for this effort it as assumed that all groundwater pumpage for irrigation within Ward County was derived from wells screened within the Pecos Valley Aquifer.

The original TWDB Water Use Survey dataset suggested that irrigation pumpage for Ward County from the Pecos Valley Aquifer ranged from zero acre-feet per year to 2,850 acre-feet per year (Figure 659). Usage was generally lowest between 1988 and 1999, and showed an average increase over time between 2000 and 2018. Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, revised irrigation demands for Ward County above the footprint of the Pecos Valley Aquifer in ranged from 750 acre-feet per year to 7,100 acre-feet per year, with year-to-year demand fluctuations commonly occurring. Surface water was used to meet some of the demands for irrigation water and was sufficiently available to eliminate pumpage needs in 1988 to 2001, from 2009 to 2011, and from 2015 to 2017.

Groundwater pumpage for irrigation within Ward County ranged from zero acre-feet per year to 2,025 acre-feet per year.

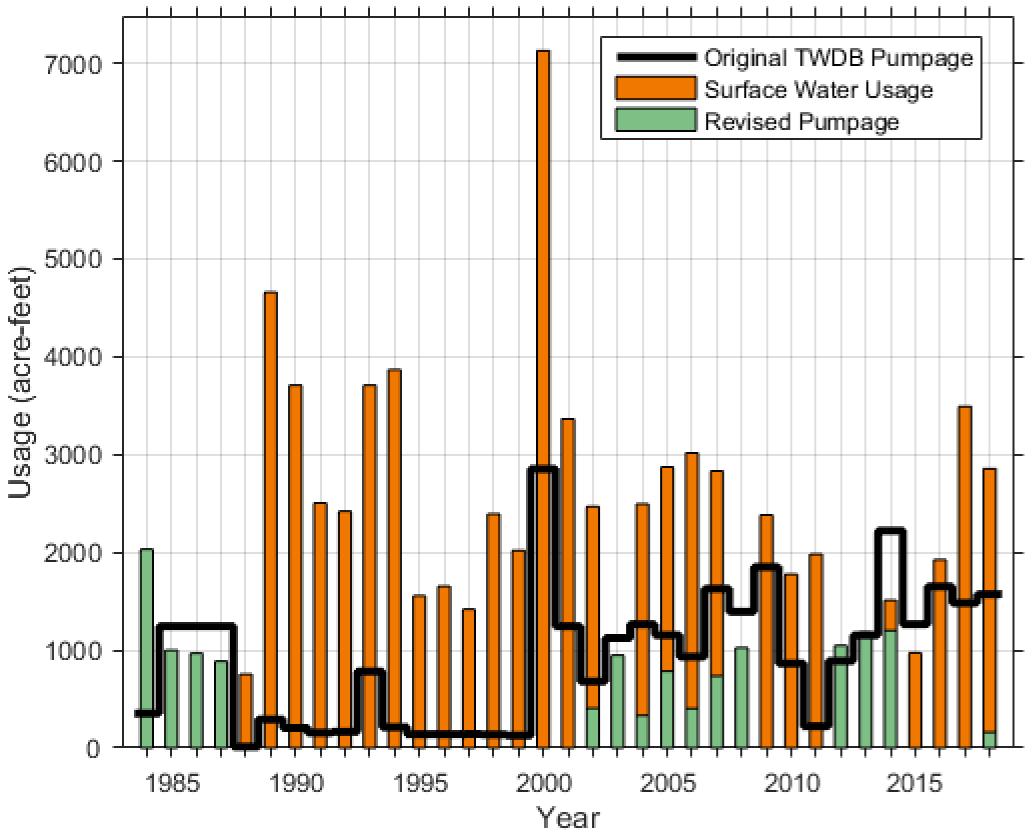


Figure 659. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Ward County.

Power

As reported in Section 3.3.51 and illustrated on Figure 660, pumping from the Pecos Valley Aquifer in Ward County for power use generally ranged between 4,000 and 6,000 acre-feet between 1984 and 2003. The lone exception during this period occurred in 1988 when pumping decreased abruptly to less than 2,000 acre-feet. From 2003 through 2010, pumping for power use remained close to 2,500 acre-feet per year with annual fluctuations above and below this level. Pumping decreased to near zero levels in 2011, and the TWDB Water Use Survey database does not contain data for power usage this time. We identified several anomalies in the original TWDB Water Use Survey data based on our manual review, year-to-year change, and a standard deviation analyses.

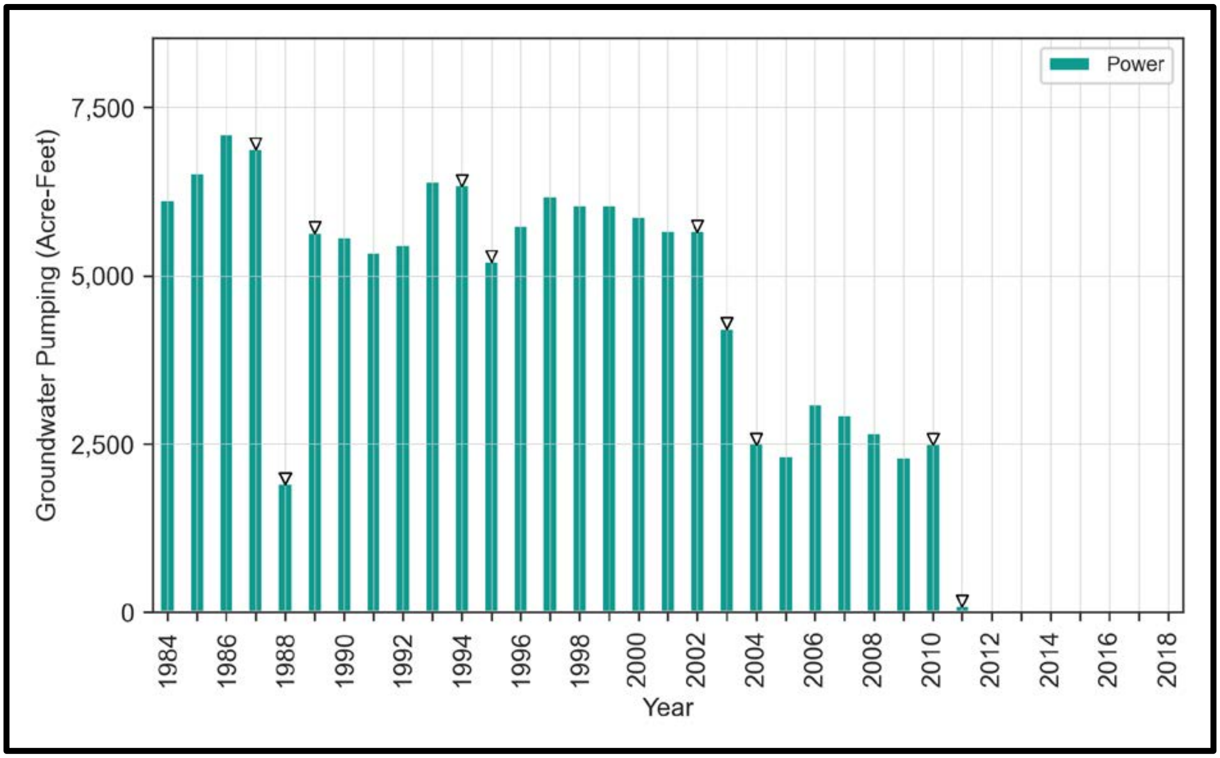


Figure 660. Pecos Valley Aquifer groundwater pumping for power use in Ward County as reported in the TWDB Water Use Survey data. Triangles mark years identified as having anomalous data.

Upon review of the reported Pecos Valley Aquifer pumping for power use in Ward County, we determined there was only one surveyed entity reporting groundwater production. The sole reporting entity was Luminant Generation Company LLC - Permian Basin Steam Electric Station (hereafter referred to as "Luminant Power Plant"). The location of the Luminant Power Plant is shown in Figure 661.

The Luminant Power Plant has a 325-megawatt operating capacity. It is a gas-fired facility with five combustion turbines, one mothballed steam unit, and one retired steam unit (Luminant, 2015).

Table 79 presents the timeline of operation events as provided on form EIA-860, published by the U.S. Energy Information Administration.

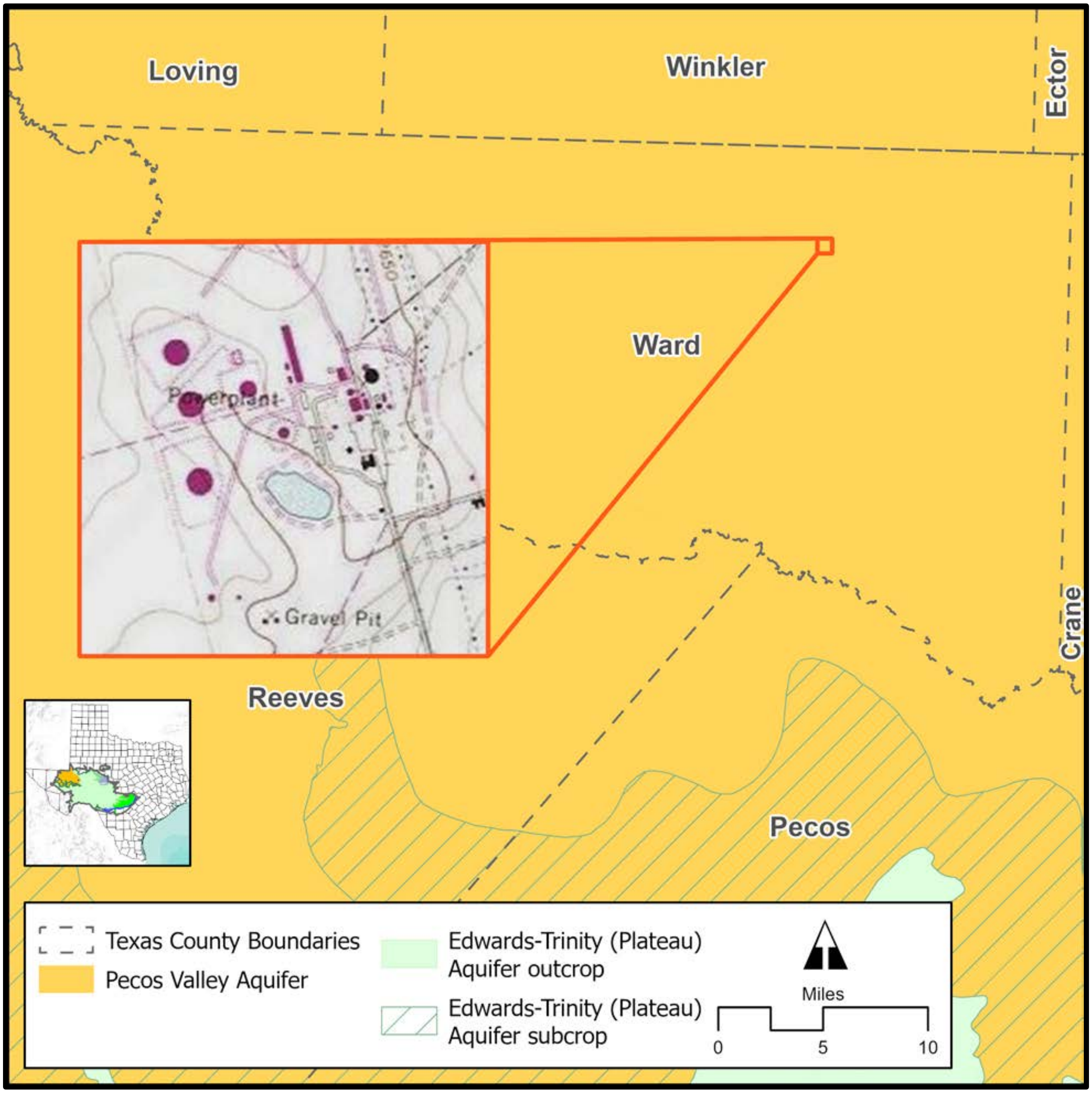


Figure 661. Location of the Luminant Power Plant in Ward County.

Table 79. Luminant Power Plant Operational Timeline.

Year	Unit	Event	Primary Mover	Fuel Type	Cooling Tower Type
1958	ST 5	Began operation	Steam Turbine	Fossil fuels	Mechanical draft, wet process
1973	ST 6	Began operation	Steam Turbine	Fossil fuels	Mechanical draft, wet process
1988	CTs 1, 2, 3	Began operation	Gas Turbine	Fossil fuels	Not Applicable
1990	CTs 4, 5	Began operation	Gas Turbine	Fossil fuels	Not Applicable
2011-2015	ST 5	Out of Service	Steam Turbine	Fossil fuels	Mechanical draft, wet process
2012	ST 6	Out of Service	Steam Turbine	Fossil fuels	Mechanical draft, wet process
2012-2015	ST 6	Standby	Steam Turbine	Fossil fuels	Mechanical draft, wet process
2016	STs 5, 6	Retired	Steam Turbine	Fossil fuels	Mechanical draft, wet process

Steam turbines and boilers, such as Luminant Power Plant units ST 5 and ST 6, heat water and subsequently condense the steam. These types of turbine have cooling requirements much greater than combustion or gas turbines. Using information gathered from EIA-860 (Table 79), we determined that the Luminant Power Plant steam turbines used a wet-type cooling tower. The Luminant Power Plant would fall under the classification of a large power plant but given that the power plant began operation in 1958 we can assume that it is not as efficient as a modern power plant. We therefore assigned it an average water use value of 0.75 gallons per kilowatt-hour (see Figure 380).

Gas turbines have relatively small cooling systems in comparison to steam turbines since water is used only to control emissions of nitrogen oxides (Sledge and others, 2003). Form EIA-860 did not specify if the gas turbine used a wet or dry nitrogen oxide control. Given that the gas turbines started operating in 1988 (EIA, 2020a), we can assume that the turbines used wet nitrogen oxides control. Based on this assumption, we assigned the years with gas turbine operation (1988-2018) a water use value of 0.05 gallons per kilowatt-hour.

Using the net power generation values from form EIA-923 (EIA, 2020b), we were able to estimate water use and address the identified anomalies in the original TWDB Water Use Survey data. Figure 662 illustrates the groundwater pumping estimates associated with each turbine type used for power generation at the Luminant Power Plant. Figure 662e illustrates the complete estimated pumping dataset incorporating the Water Use Survey data with the pumping estimates based on the turbine type to correct for the pumpage anomaly in 1988. All other anomalies identified in Figure 660 are considered to be accurate, per the revised power usage estimates. Our revised estimates include only gas turbine usage after 2010, resulting in much smaller, but non-zero, annual pumpage values. We applied these revised estimates of pumping for power use from the Pecos Valley Aquifer in Ward County based on the location of the power plant (Figure 661) and any associated wells.

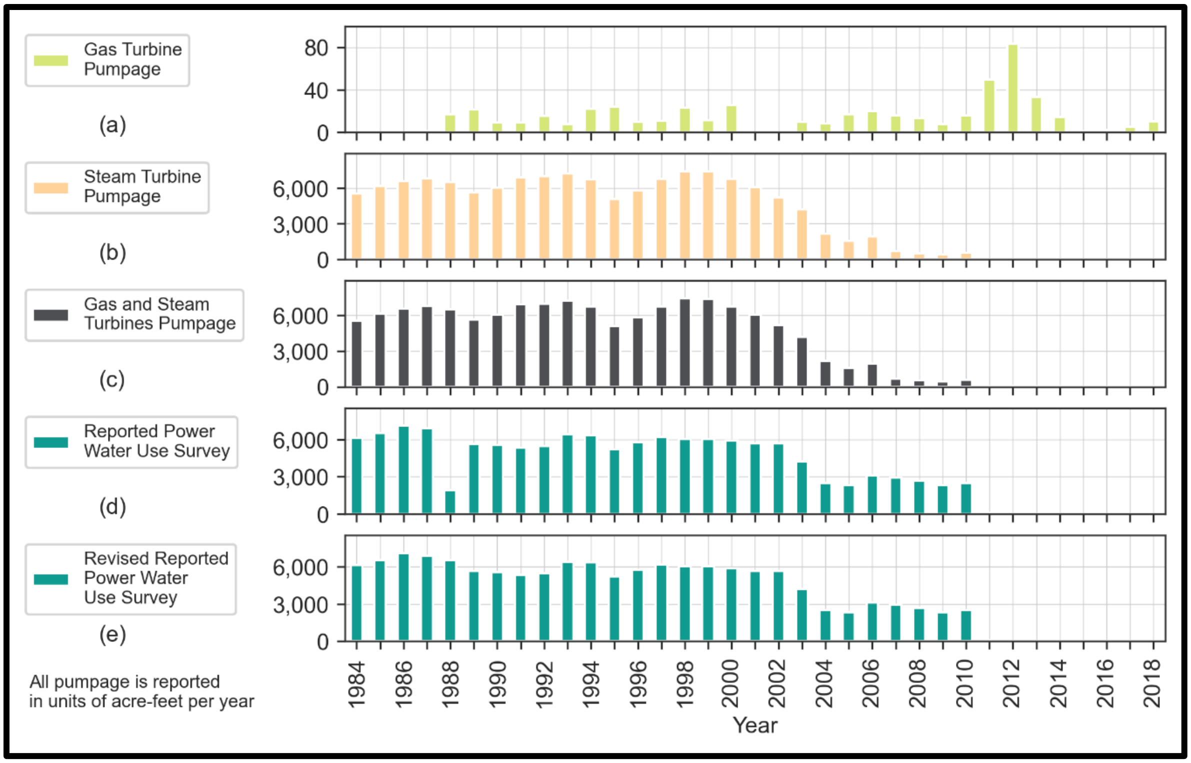


Figure 662. Luminant Power Plant (a) Estimated groundwater pumping associated with gas turbine power generation, (b) Estimated groundwater pumping associated with steam turbine power generation, (c) Estimated combined groundwater pumping by both steam and gas turbines (d), Reported groundwater pumping by the Water Use Survey, and (e) Revised groundwater pumping.

Mining

Figure 657d illustrates the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer in Ward County during the study period. The number of active enhanced oil recovery wells in Ward has increased from 1,372 in 1980 to 2,562 wells in 2020. Limited Water Use Survey data is available for Ward County with available data being orders of magnitude lower than that estimated by the Bureau of Economic Geology and U.S. Geological Survey methodologies. Generally, estimates from the Bureau of Economic Geology methodology are greater by a factor of five or more than those obtained from U.S. Geological Survey data. However, due to the large number of enhanced oil recovery wells, we are confident that the estimates from the Bureau of Economic Geology are closer to reality. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Pecos Valley Aquifer.

Manufacturing

Figure 657c illustrates the changes in groundwater pumping associated with manufacturing use from the Pecos Valley Aquifer in Ward County during the study period. The revision is primarily associated with “Targa Premain LP – Monahans Plant 162” data. High pumping in 2004 appeared to be a typographical error. We also designated the pumping to be from Crane County for consistency with other reported data.

Livestock

Figure 657b illustrates the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer in Ward County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey contains estimates of groundwater pumping. While the TWDB Water Use Survey data includes a groundwater pumping peak in 1992 and 1993, our review suggests there is no groundwater pumping peak during those two years from the Pecos Valley Aquifer for livestock use in Ward County.

5.2.51 Winkler County

Figure 663 and Figure 664 illustrate our revisions to the estimated in groundwater pumping from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Reeves County during the study period. Following is a brief description of the changes in estimated groundwater pumping associated with each use category.

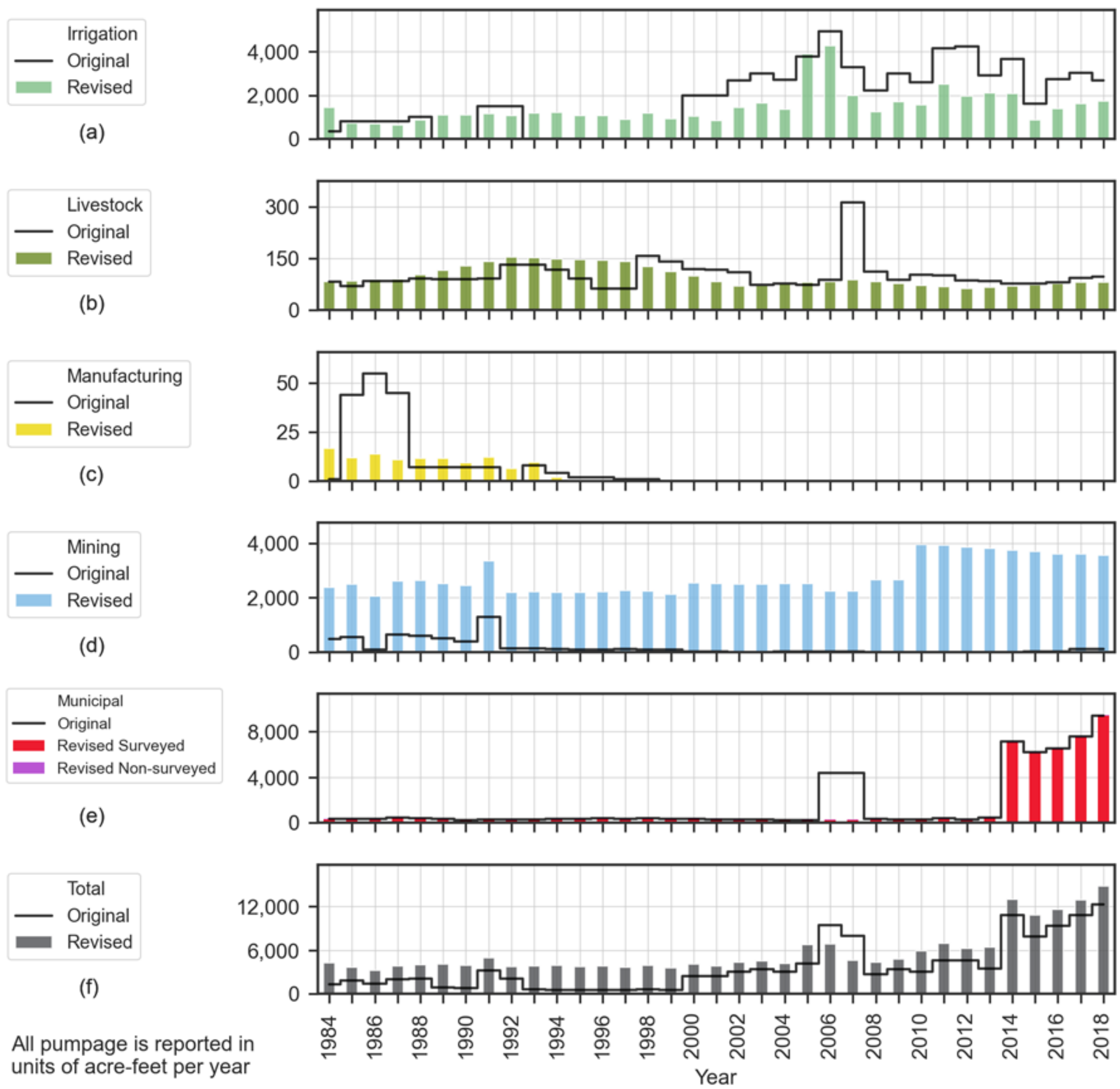


Figure 663. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer in Winkler County from 1984 through 2018.

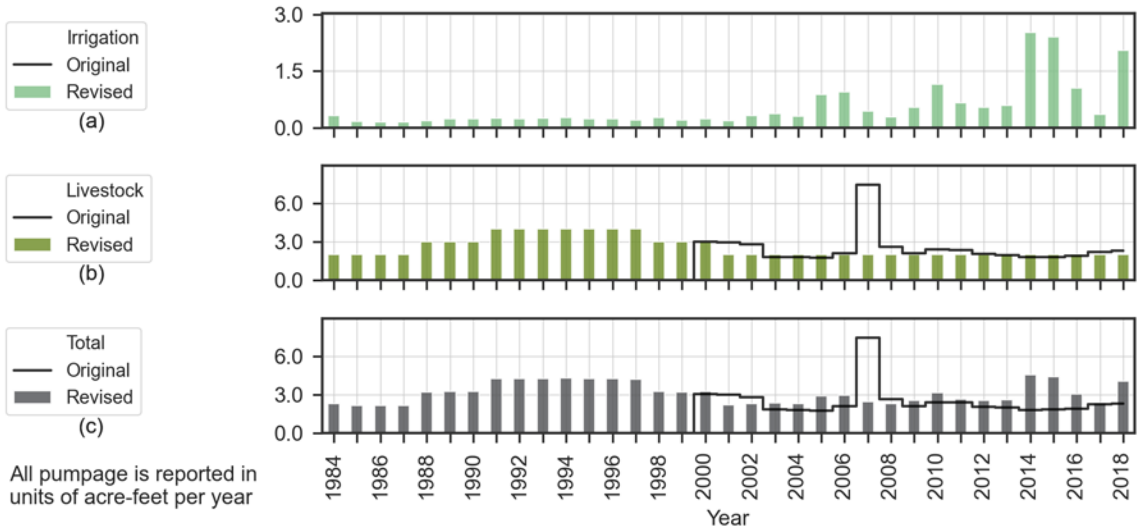


Figure 664. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer in Winkler County from 1984 through 2018.

Surveyed Municipal

Figure 663e illustrates the changes in groundwater pumping associated with surveyed municipal use from the Pecos Valley Aquifer in Winkler County during the study period. These changes include the pumpage of over 6,000 acre-feet/year from 2016-2018 under a water transfer agreement with the City of Midland.

Non-Surveyed Municipal

Figure 665 and Figure 666 illustrate the changes in groundwater pumping associated with non-surveyed municipal use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Winkler County during the study period. While our estimates are higher than the Water Use Survey data for the Pecos Valley Aquifer, they are several times less than the Water Use Survey data for the Edwards-Trinity (Plateau) Aquifer.

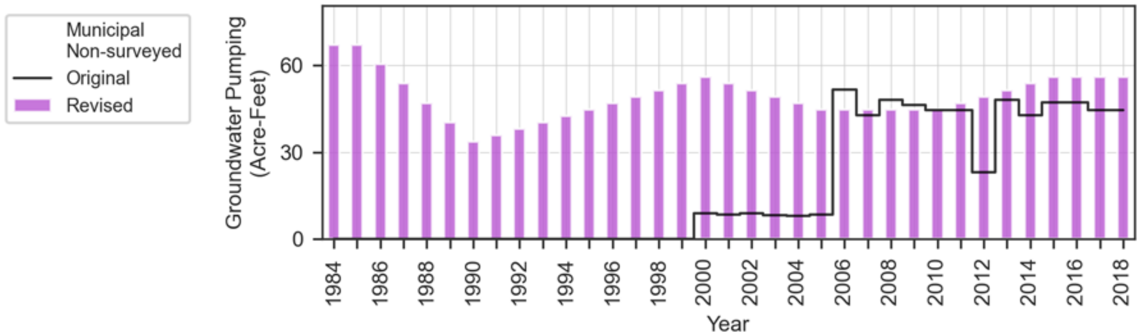


Figure 665. Original and revised estimates of groundwater pumping from the Pecos Valley Aquifer for non-surveyed municipal use in Winkler County from 1984 through 2018.

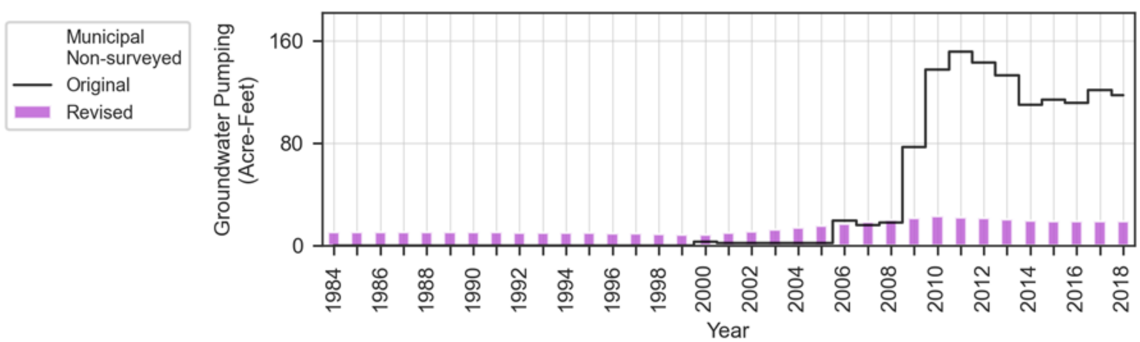


Figure 666. Original and revised estimates of groundwater pumping from the Edwards-Trinity (Plateau) Aquifer for non-surveyed municipal use in Winkler County from 1984 through 2018.

Irrigation

Winkler County is nearly entirely underlain by the Pecos Valley Aquifer. There is a small portion of along the northeastern border of the county with Ector County where the Edwards-Trinity (Plateau) Aquifer is present. The Ogallala Aquifer is also present along the northern part of the eastern county boundary. The Dockum Aquifer also underlies the majority of the county footprint, and it is located below the other aquifers that are present. Wells within the county appear to be screened within the Pecos Valley Aquifer and the Dockum Aquifer, without any geographic separation. Upon inspection of the wells displayed on the TWDB groundwater data viewer, it was determined that the vast majority of wells within Winkler County are screened within the Pecos Valley Aquifer. Wells screened in the Dockum Aquifer do exist, and often near wells screened within the Pecos Valley Aquifer. However, amongst the submitted drillers reports, wells identified as being used for irrigation were nearly uniformly screened within the Pecos Valley Aquifer. As such, it was determined that irrigation within Winkler County was likely supplied from the Pecos Valley Aquifer, as well as from the relatively small footprint of the Edwards-Trinity (Plateau) Aquifer. This finding was consistent with the TWDB Water Use

Survey dataset, which reports irrigation pumpage in Winkler County as only being from the Pecos Valley Aquifer.

The original TWDB Water Use Survey pumpage estimates for the Pecos Valley Aquifer in Winkler County ranged from zero acre-feet per year (in multiple years) to 4,912 acre-feet per year (in 2005). Pumpage generally increased from 2000 to 2018 with fluctuations likely due to seasonal rainfall patterns. The multiple years of reported zero acre-feet per year pumpage are likely dataset errors or omissions (Figure 667).

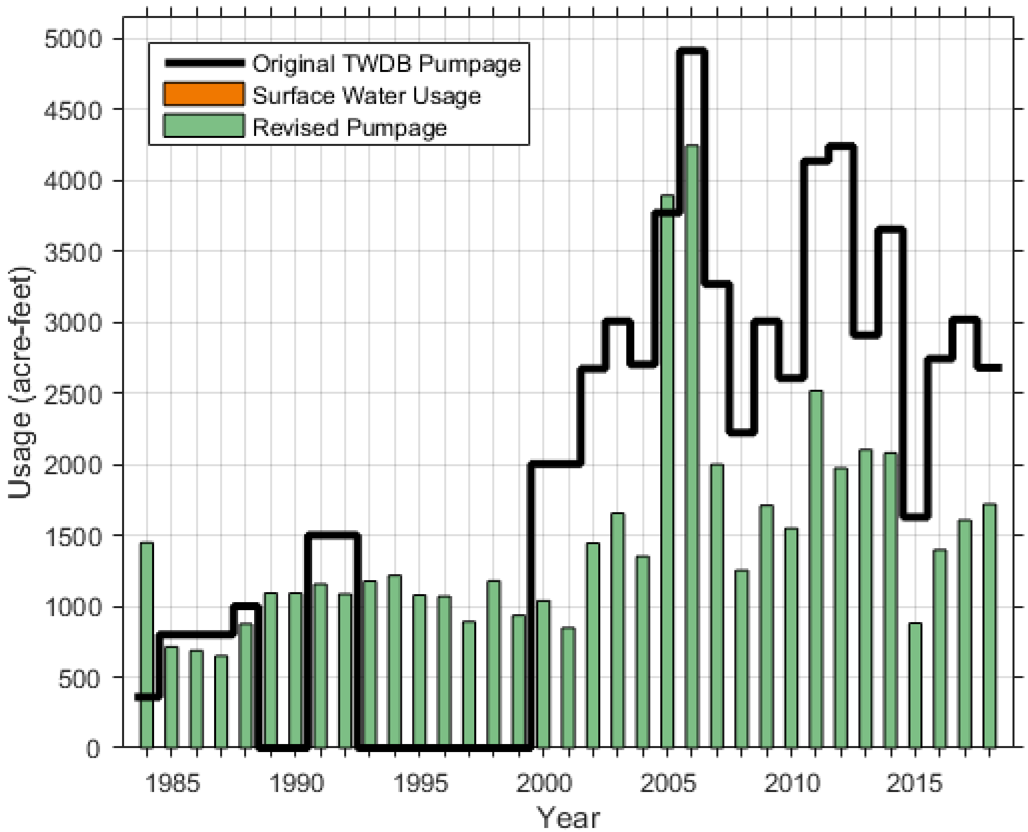


Figure 667. Revised groundwater pumpage for irrigation from the Pecos Valley Aquifer within Winkler County.

Based on crop spatial distribution data, rainfall patterns, and computed evapotranspiration rates, irrigation demands for land above the footprint of the Pecos Valley Aquifer in Winkler County ranged from 650 acre-feet per year to 4,250 acre-feet per year. Surface water was not used to meet irrigation demands in Winkler County over the study period. In general, pumpage was relatively stable from 1984 to 2001, and then increased on average after 2001 with fluctuations in year-to-year pumpage. The revised pumpage data contains year-to-year fluctuations following a similar pattern to those from the original TWDB Water Use Survey dataset, suggesting consistent means for pumpage estimation.

While the original TWDB Water Use Survey pumpage estimates did not include pumping from the Edwards-Trinity (Plateau) Aquifer in Winkler County, the revised dataset suggests minimal pumpage over the study period. Irrigation pumpage from the Edwards-Trinity (Plateau) Aquifer in Winkler County ranged from 0.25 acre-feet per year to 2.5 acre-feet per year, quantities which are largely insignificant given the county pumpage from the Pecos Valley Aquifer.

Power

For the study period and the study area aquifers, there is no groundwater pumping associated with power use in Winkler County. Also, there is no indication unreported groundwater pumping associated with power use is occurring. We made no changes to the estimated groundwater pumping from the study area aquifers during the study period for power use in Winkler County.

Mining

Figure 663d illustrates the changes in groundwater pumping associated with mining use from the Pecos Valley Aquifer in Winkler County during the study period. The number of active enhanced oil recovery wells has almost doubled from 741 wells in 1980 to 1,250 wells in 2020. Like Ward County, very limited Water Use Survey data is available for Winkler County, and it is orders of magnitude lower than that estimated pumpage by the Bureau of Economic Geology and the U.S. Geological Survey methodologies. Generally, estimates from the Bureau of Economic Geology methodology are greater by a factor of three to ten than those obtained from U.S. Geological Survey data. However, due to the large number of enhanced oil recovery wells, we are confident that the conservatively greater estimates from the Bureau of Economic Geology are closer to reality. We estimate the entirety of groundwater pumping for mining in this area is sourced from the Pecos Valley Aquifer.

Manufacturing

Figure 663c illustrates the changes in groundwater pumping associated with manufacturing use from the Pecos Valley Aquifer in Winkler County during the study period. The revision reflects data in the Water Use Survey.

Livestock

Figure 663b and Figure 664b illustrate the changes in groundwater pumping associated with livestock use from the Pecos Valley Aquifer and the Edwards-Trinity (Plateau) Aquifer, respectively, in Winkler County during the study period. Our estimate is in general agreement with the TWDB Water Use Survey data for groundwater pumping from both aquifers. There is a peak in the TWDB Water Use Survey data for both aquifers in 2007 that is not present in our estimates. Additionally, our estimate includes groundwater pumping for livestock use prior to 2000 from the Edwards-Trinity (Plateau) which is not present in previous estimates.

6 Summary and Conclusions

This project involved developing estimates of the volume, location, and timing of groundwater pumpage over a large area of Texas for the Pecos Valley Aquifer, Edwards-Trinity (Plateau) Aquifer, Trinity (Hill Country) Aquifer, Lipan Aquifer, and Edwards (Balcones Fault Zone) Aquifer (located south of the Colorado River). These aquifers are found within 56 Texas counties, and collectively span over 34 million acres. This amounts to nearly 20 percent of the State of Texas and exceeds the land area of ten U.S. states.

Our work was completed in three phases: 1) collecting data and evaluating the TWDB Water Use Survey data, 2) developing a methodology for systematically revising the water use survey data, and 3) implementing the plan, revising the survey data, and developing this report. We also created a group of ArcGIS tools which will translate the revised pumpage data into formats suitable for direct inclusion into MODFLOW numerical groundwater flow models. This report serves as one deliverable from the project, providing a written and graphical description of the original TWDB Water Use Survey data, our revision methodology, and the revision results. An electronic deliverable accompanying this report contains the original and revised data, data used in performing the revisions, and the ArcGIS toolbox created during this project.

During this first project phase (Section 3), our evaluation of the TWDB Water Use Survey data involved detecting anomalies using three methods:

- Manual review and professional judgement
- Year-to-year change analysis
- Statistical analysis using a standard deviation criterion

In general, each method identified anomalies as abrupt changes in pumping amount, recognizing that gradual changes are less likely to be indicative of potentially erroneous data. We found each of the methods suitable for detecting some, but not all, potentially erroneous data. During this first project phase, along with the anomalies we identified four counties as not having any pumping associated with the study area aquifers despite have a portion of a defined study area aquifer footprint within the county. For the remaining 52 counties, identified data anomalies were subject to additional review and scrutiny, potentially leading to data revision based on the methods we developed within the second project phase (Section 4).

Each water use category required application of different methods for addressing the identified anomalies. For the surveyed use categories (municipal, manufacturing, power, and some mining) we used the entity survey records as a first step in identifying the source of an anomaly. However, for non-surveyed uses we relied on other datasets (such as remote sensing or census data) to develop estimates of water use. In addition, some of the anomalies appeared to simply be reporting errors (such as pumping from an aquifer that does not exist in the county) which addressed through reassignment of the pumping to the correct aquifer.

We ultimately refined the methods through application to all 52 counties with pumping from the study area aquifers within the study area. Through application, we adjusted methods based on data availability as well as the properties of the individual county and aquifer. We applied consistent methods across each aquifer and county within the study area, as well as for each year within the study period. We believe the resulting revised dataset is a robust and reasonable estimation of historical pumpage within the study area.

The original TWDB water use survey dataset and revised dataset show marked agreement for many counties, aquifers, and water use classifications. There are also instances, however, where revisions are significantly different than the original data. For example, irrigation pumpage from the Edwards Trinity (Plateau) Aquifer in Pecos County where revised values are often less than half the original values and are also low compared to estimates generated by the Middle Pecos Groundwater Conservation District. We believe in the validity of the method for estimating irrigation pumpage in a uniform and repeatable manner with available data and were surprised by the resulting discrepancy between the revised values and those obtained using methods developed by the Middle Pecos Groundwater Conservation District. It is our expectation that this effort will generate a detailed discussion and review of both methodologies and their appropriateness as applied to Pecos County. We encourage TWDB to develop a policy regarding how to best utilize local knowledge/estimates of irrigation water usage within its Water Use Survey dataset.

The true historical pumpage (totals, spatial distribution, and temporal distribution) cannot be known. As such, it is difficult to assert that one set of pumpage estimates is inherently better than other. The uniformity of the revised estimation methods, applied in time and across the study area, provides a consistent, defensible, and repeatable approach for aquifers across Texas. TWDB staff have devoted many years of effort to developing estimates of water use and the groundwater production associated with that use. The TWDB Water Use Survey dataset is a beneficial dataset for understanding historical water use and groundwater pumpage. While beneficial, this project highlights anomalies in the Water Use Survey data and provides a means for investigating and addressing those anomalies. Through our revision approach, we strove to increase the accuracy of pumpage data which could then increase the accuracy of our groundwater availability models. These accuracy increases can only lead to improving groundwater availability modeling and management of Texas' groundwater resources.

7 References

Alexander Jr., W.H. and Pattman, J.H., 1969, Ground-Water Resources of Kimble County, Texas: Texas Water Development Board Report No. 95, 93 p.

Alexander, Jr., W.H. and White, D.E., 1966, Ground-Water Resources of Atascosa and Frio Counties, Texas: Texas Water Development Board Report 32, 200 p.

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M., 1998, Crop Evapotranspiration (guidelines for computing crop water requirements): FAO Irrigation and Drainage Paper No. 56, 300 p.

Awal, R., Habibi, H., Fares, A., and Deb, S., 2020, Estimating reference crop evapotranspiration under limited climate data in West Texas: Journal of Hydrology: Regional Studies, v. 28, no. 100677, p. 1-19.

Bakker, M., Post, V., Langevin, C.D., Hughes, J.D., White, J.T., Starn, J.J., and Fienen, M.N., 2016, Scripting MODFLOW Model Development Using Python and FloPy: Groundwater, v. 54, p. 733-739.

Barnett, V. and Lewis, T., 1994, Outliers in Statistical Data: (3rd) West Sussex, John Wiley & Sons Ltd., 584 p.

Billingsley, B., 2019, Administrative Procedures for the Water Use Survey Program: Texas Water Development Board Internal Procedure, 65 p.

Black, C.W., 1988, Hydrogeology of the Hickory Sandstone Aquifer, Upper Cambrian, Riley Formation, Mason and McCulloch Counties, Texas: Masters Thesis, 194 p.

Brouwer, C., 1989, Irrigation Water Management: Irrigation Scheduling: FAO Training manual no. 4, 66 p.

Chauvenet, W., 1863, Method of least squares. Appendix to Manual of Spherical and Practical Astronomy: Vol 2, Philadelphia, Lippincott, 469-566 p.

Deines, J.M., Kendall, A.D., Crowley, M.A., Rapp, J., Cardille, J.A., and Hyndman, D.W., 2019, Mapping three decades of annual irrigation across the US High Plains Aquifer using Landsat and Google Earth Engine: Remote Sensing of Environment, v. 223, no. 111400, p. 1-18.

Delgado, A., 2018, Irrigation Estimates: Texas Water Development Board Internal Procedure, 21 p.

EcoKai Environmental, Inc., 2014, Val Verde County / City of Del Rio Hydrogeological Study: Final Draft Report, 66 p.

Evans, J., 1996, Straightforward Statistics for the Behavioral Sciences: Pacific Grove , Brooks/Cole Publishing Company, 600 p.

FracFocus, 2021, FracFocus Chemical Disclosure Registry, https://fracfocus.org/, accessed January 2021.

Furnans, J., Keester, M., Colvin, D., Bauer, J., Barber, J., Gin, G., Danielson, V., Erickson, L., Ryan, R., Khorzad, K., Worsley, A., and Snyder, G., 2018, Final Report: Identification of the Vulnerability of the Major and Minor Aquifers of Texas to Subsidence with Regard to Groundwater Pumping: Texas Water Development Board Contract Report No, 1648302062, 434 p.

Google, LLC, 2020, Google Earth Engine FAQ, https://earthengine.google.com/faq/, accessed October 2020.

Harden, B., Beach, J., and Thornhill, M.R., 2011, Hydrogeologic, geochemical and groundwater modeling evaluation of the Leon-Belding Area in Pecos County: Contract report prepared for Fort Stockton Holdings, L.P., Various p.

Hickory Underground Water Conservation District No. 1, 2019, Groundwater Management Plan: District Management Plan, 21 p.

Hutson, S.S., Barber, N.L., Kenny, J.F., Linsey, K.S., Lumia, D.S., and Maupin, M.A., 2004, Estimated Use of Water in the United States in 2000: U.S. Geological Survey Circular 1268, 46 p.

Jain, P.C., 1984, Table for monthly average daily extraterrestrial irradiation on horizontal surface and the maximum possible sunshine duration: International Centre for Theoretical Physics Report Number IC--84/7, 14 p.

Kelley, V.A., Ewing, J., Jones, T.L., Young, S.C., Deeds, N., and Hamlin, S., eds., 2014, Updated Groundwater Availability Model of the Northern Trinity and Woodbine Aquifers: Vol 1, Austin, Texas, Intera, 990 p.

Kluge, K., 2014, August 12, WUS history: Email to Cindy Ridgeway and Bill Billingsley.

Lovelace, J.K., 2009a, Method for Estimating Water Withdrawals for Livestock in the United States, 2005: U.S. Geological Survey Scientific Investigations Report 2009–5041, 7 p.

Lovelace, J.K., 2009b, Methods for Estimating Water Withdrawals for Mining in the United States, 2005: U.S. Geological Survey Scientific Investigations Report 2009–5053, 7 p.

Luminant, 2015, Permian Basin Power Plant, https://www.luminant.com/wp-content/uploads/2015/02/Permian-Basin-2015.pdf, accessed January 2021.

Lurry, D.L. and Pavlicek, D.J., 1991, Withdrawals from the Edwards-Trinity aquifer system and contiguous hydraulically connected units, west-central Texas, December 1974 through March 1977: U.S. Geological Survey Water Resources Investigation 91-4021, 1 p.

Mace, R.E., Leurig, S., Seely, H., and Wierman, D.A., 2020, Bringing Back Comanche Springs: An Analysis of the History, Hydrogeology, Policy, and Economics: Texas Water Trade Report 2020-08, 153 p.

Nicot, J.P., Hebel, A.K., Ritter, S.M., Walden, S., Baier, R., Galusky, P., Beach, J., Kyle, R., Symank, L., and Breton, C., 2011, Current and Projected Water Use in the Texas Mining and Oil and Gas Industry: prepared for the Texas Water Development Board, 381 p.

Nicot, J.P., Reedy, R.C., Costley, R.A., and Huang, Y., 2012, Oil & Gas Water Use in Texas: Update to the 2011 Mining Water Use Report: prepared for the Texas Water Development Board, 97 p.

PRISM Climate Group, Oregon State University, 2020, http://prism.oregonstate.edu/, accessed September 2020.

Railroad Commission of Texas, 2021a, Data Sets Available for Download, https://www.rrc.state.tx.us/resource-center/research/data-sets-available-for-download/, accessed September 2021.

Railroad Commission of Texas, 2021b, Surface Mining and Reclamation, https://www.rrc.texas.gov/surface-mining, accessed October 2021.

Railroad Commission of Texas, 2021c, Surface Coal Mine County Information, https://www.rrc.texas.gov/surface-mining/permits/surface-coal-mine-county-information/, accessed October 2021.

Railroad Commission of Texas, 2021d, Permitted coal mines locations, https://www.rrc.texas.gov/media/homltpim/coal-mine-map-07-2021.pdf, accessed October 2021.

Railroad Commission of Texas, 2021e, Texas Uranium Exploration Permits, https://www.rrc.texas.gov/surface-mining/programs/uranium-exploration/texas-uranium-exploration-permits/, accessed October 2021.

Ridgeway, C., 2014, August 12, FW: WUS history for Llano Uplift Report: Email to Jerry Shi.

Ridgeway, C., 2020, Pumped Up About Pumping: Texas Water Development Board Groundwater Availability Modeling Program Internal Training Document, 24 p.

Shafer, G.H., 1966, Ground-Water Resouces of Guadalupe County, Texas: Texas Water Development Board Report No. 19, 93 p.

Sledge, B.L., Carter, W.G., Bisset, C.A., Simecek, J., Whelan, K.M., Zweiacker, P., and Fluharty, J., 2003, Power Generation Water Use in Texas for the Years 2000 through 2060: Contract Report Number 2001483396 - Prepared by Representative of Investor-Owned Utility Companies of Texas for the Texas Water Development Board, 35 p.

Sohl, T., Reker, R., Bouchard, M., Sayler, K., Dornbierer, J., Wika, S., Quenzer, R., and Friesz, A., 2016, Modeled historical land use and land cover for the conterminous United States: Journal of Land Use Science, v. 11, no. 4, p. 476-499.

Sohl, T.L., Sayler, K.L., Bouchard, M.A., Reker, R.R., Friesz, A.M., Bennett, S.L., Sleeter, B.M., Sleeter, R.R., Wilson, T., Soulard, C., Knuppe, M., and Van Hofwegen, T., 2014, Spatially explicit modeling of 1992–2100 land cover and forest stand age for the conterminous United States: Ecological Applications, v. 24, no. 5, p. 1115-1136.

Texas Alliance of Groundwater Districts, 2020, What We Do - Texas Alliance of Groundwater Districts, https://texasgroundwater.org/what-we-do/, accessed October 2020.

Texas Commission on Environmental Quality, 2020, Well, https://gis-tceq.opendata.arcgis.com/datasets/well, accessed September 2020.

Texas Commission on Environmental Quality, 2021, Texas Drinking Water Watch, https://dww2.tceq.texas.gov/DWW/, accessed January 2021.

Texas Water Conservation Association, 2020, About Us: Texas Water Conservation Association, https://www.twca.org/Public/About_Us/About_TWCA/Public/About.aspx, accessed October 2020.

Texas Water Development Board, 2001, Surveys of Irrigation in Texas: 1958, 1964, 1969, 1974, 1979, 1984, 1989, 1994 and 2000: Texas Water Development Board Report 347, 102 p.

Texas Water Development Board, 2020a, Frequently Asked Questions for Water Use Survey, https://www.twdb.texas.gov/waterplanning/waterusesurvey/faq.asp, accessed September 2020.

Texas Water Development Board, 2020b, Groundwater Database Reports, http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp, accessed September 2020.

Texas Water Development Board, 2020c, Historical Pumpage, http://www.twdb.texas.gov/waterplanning/waterusesurvey/historical-pumpage.asp, accessed September 2020.

Texas Water Development Board, 2020d, Irrigation Water Use Estimates, https://www.twdb.texas.gov/conservation/agriculture/irrigation/index.asp, accessed September 2020.

Texas Water Development Board, 2020e, Irrigation Water Use Methodologies: 1994-2007: Unpublished Microsoft Word document provided by Cindy Ridgeway via email on August 3, 2020, 3 p.

Texas Water Development Board, 2020f, Submitted Drillers Reports Database Download, http://www.twdb.state.tx.us/groundwater/data/drillersdb.asp, accessed September 2020.

Texas Water Development Board, 2020g, TWDB Reports Index, http://www.twdb.texas.gov/publications/reports/index.asp, accessed September 2020.

Texas Water Development Board, 2021, Groundwater Availability Model (GAM) and Geodatabase Downloads, http://www.twdb.texas.gov/groundwater/models/download.asp, accessed October 2021.

Thornhill, M.R., Peckham, D.S., and Keester, M.R., 2008, Edwards-Trinity Aquifer Study, Leon Belding Area: Prepared for Clayton Williams Farms, Inc., 80 p.

Turner, C., 2015, Irrigaiton Water Use Estimates, https://www.twdb.texas.gov/conservation/agriculture/irrigation/doc/Estimates_Process_2015_0817.pdf, accessed September 2020.

Turner, C., 2020, October 15, Discussion regarding TWDB Agricultural Conservation Program and the development of irrigation water use estimates: Meeting with TWDB staff.

TWDB Staff, 2021, TWDB Contract 2048302456, Deliverable received October 30, 2020 - Review of Draft Report and Data Deliverables for: “Task 1: Development of pumping volumes, locations, and aquifers for selected study areas”: Comments on draft report, 11 p.

U.S. Geological Survey, 2018, Water Use in the United States, https://water.usgs.gov/watuse/data/, accessed January 2021.

U.S. Geological Survey, 2018, Water Use in the United States, https://water.usgs.gov/watuse/data/, accessed January 2021.

U.S. Geological Survey, 2020a, USGS Publications Warehouse, https://pubs.er.usgs.gov/, accessed September 2020.

U.S. Geological Survey, 2020b, Land Use Land Cover Modeling, https://www.usgs.gov/core-science-systems/eros/lulc, accessed September 2020.

U.S. Geological Survey, 2021, Water-Use Terminology, https://www.usgs.gov/mission-areas/water-resources/science/water-use-terminology?qt-science_center_objects=0#qt-science_center_objects, accessed January 2021.

United States Department of Agriculture - National Agricultural Statistics Service, 2008-2019, CropScape and Cropland Data Layer, https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php, accessed January 2021.

United States Department of Agriculture, 2019, 2017 Census of Agriculture, https://www.nass.usda.gov/AgCensus/index.php.

United States Department of Agriculture, 2020a, National Agricultural Statistics Service Quick Stats, https://quickstats.nass.usda.gov/, accessed September 2020.

United States Department of Agriculture, 2020b, Census of Agriculture Historical Archive, http://agcensus.mannlib.cornell.edu/AgCensus/homepage.do, accessed September 2020.

United States Energy Information Administration, 2020a, Form EIA-860 detailed data with previous form data (EIA-860A/860B), https://www.eia.gov/electricity/data/eia860/, accessed January 2021.

United States Energy Information Administration, 2020b, Form EIA-923 detailed data with previous form data (EIA-906/920), https://www.eia.gov/electricity/data/eia923/.

Weinberg, A., French, L.N., and Perez, J.B., 2018, Overview of Groundwater Conditions in Val Verde County, Texas: TWDB Special Projects Report, 116 p.

Appendix 1 – Geodatabase Description

On September 29, 2020 Dr. Ian Jones provided us a copy of groundwater availability model file geodatabase version 4.3.1 for use in this project. During this first phase of the project, we did not remove any unused feature datasets or raster catalogs. However, we have added data used as part of our evaluations to the geodatabase. Figure GDB-1 is a screenshot of the draft project file geodatabase highlighting the modified or added tables, feature datasets, and raster catalogs.

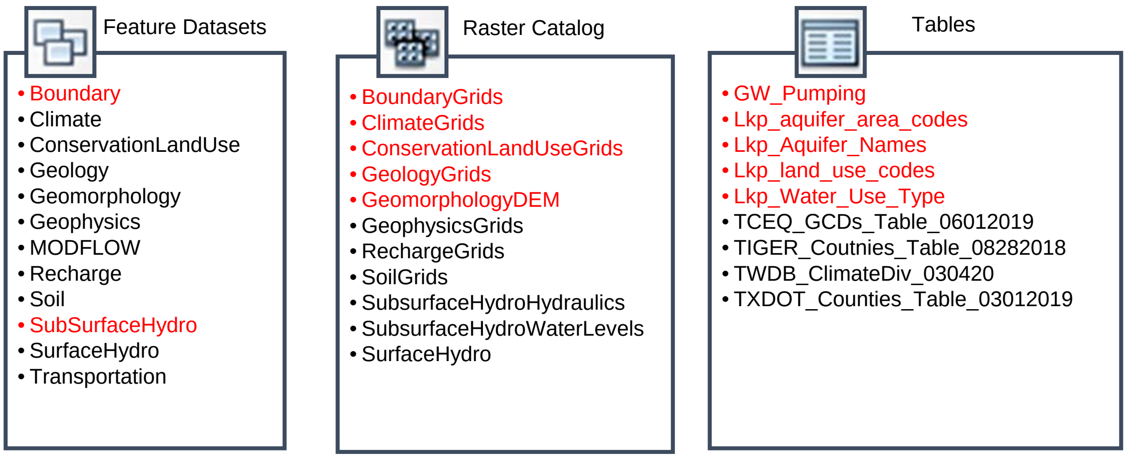


Figure GDB-1. Summary of modifications to the draft groundwater availability model file geodatabase. Files in red identify datasets added to or modified in the draft geodatabase during the first phase of the project.

The following provides a brief description of the data added to the draft groundwater availability model file geodatabase during this project phase.

- Within the "Boundary" feature dataset we added two features:
  - Study_Area – polygon feature outlining the study area aquifers,
  - Study_Area_Aquifers – polygon feature extracted from the TWDB_MajorAquifers_07032019 and TWDB_MinorAquifers_07032019 features then merged and clipped to illustrate the aquifers included in the project study area.
- Within the "SubsurfaceHydro" feature dataset we added four features:
  - Study_Area_Wells – merged dataset of wells from other sources as described in Section 2.2.
  - TCEQ_PWS_Wells – Public water supply wells located within the study area from the Texas Commission on Environmental Quality (TCEQ, 2020).
  - TWDB_GWDB_Wells – Wells located within the study area from the TWDB groundwater database (TWDB, 2020b).
  - TWDB_SDRDB_Wells – Wells located within the study area from the submitted drillers report database (TWDB, 2020f)

- We added the “BoundaryGrids” raster catalog to store gridded representations of the aquifer areas (aq_areas.asc) and the counties (tx_counties.asc) included in the project study area.
- Within the “ClimateGrids” raster catalog we imported the PRISM (2020) precipitation data discussed in Section 2.3 and used in our analyses.
- Within the “ConservationLandUseGrids” raster catalog we imported the land use data discussed in Section 2.4 and used in our analyses.
- Within the “GeologyGrids” raster catalog we imported the groundwater availability model structure data discussed in Section 2.1.3 and used in our analyses.
- Within the “GeomorphologyDEM” raster catalog we imported a digital elevation model of the Texas land surface.
- We also added five tables to the draft groundwater availability model file geodatabase:
  - GW_Pumping – Includes the data from the TWDB Water Use Survey discussed in Section 2.1.4 and historical data as discussed in Section 2.1.1
  - Lkp_aquifer_area_codes – lookup table providing integer codes used in “aq_areas.asc” raster to define the aquifer areas
  - Lkp_Aquifer_Names – lookup table correlating study area aquifer names and aliases found in various datasets
  - Lkp_land_use_codes– lookup table providing integer codes used in the land use rasters stored in the “ConservationLandUseGrids” raster catalog to define the land use type
  - Lkp_Water_Use_Type – lookup table correlating water use types and aliases found in various datasets

We developed our analysis scripts using Python 2.7 for compatibility with ArcGIS 10.8.1. Currently, these scripts are stand-alone files executed outside of the ArcGIS environment to create the report figures. As the project continues, we will incorporate the draft scripts into the ArcGIS platform through ESRI’s Model Builder or within a project Toolbox. In addition, we will continue to update metadata within the compiled datasets.

Appendix 2 – Documentation of ArcGIS Pro Well File Toolbox

Toolbox Introduction & Overview

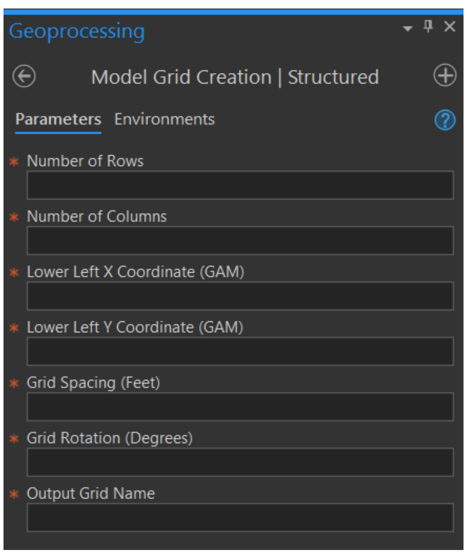
The primary purpose of the functions contained in this toolbox are as follows:

- Create custom structured groundwater availability model grids.
- Intersect attributed point and areal pumping data with both structured and unstructured groundwater availability model grids.
- Convert intersected point and areal pumping datasets into Well files usable in USGS MODFLOW-2005, MODFLOW 6, and MODFLOW USG software.

The toolbox was developed in ArcGIS Pro which relies on Python 3 for geoprocessing. We used this version because the MODFLOW scripting tools developed by the USGS (that is, FloPy) also use Python 3. These existing scripting tools allowed us to develop the well file tools within the current ArcGIS environment. ArcGIS version 10 uses Python 2.7 for geoprocessing. Python 2.7 is a deprecated version of the language and is not compatible with FloPy.

ArcGIS Pro Toolbox Models

Model Grid Creation | Structured



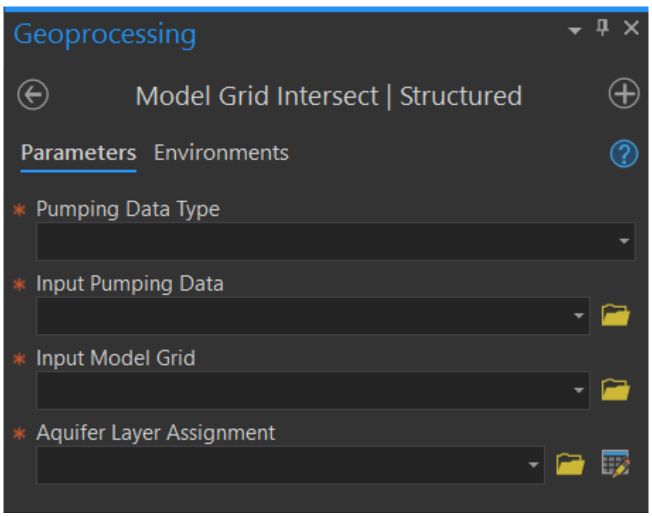
Function: Create a new model grid based on user-input parameters. Created model grids can be intersected with Point and/or Areal pumping datasets using additional models in the toolbox.

Output: Custom model grid (as shapefile) based on user-input parameters. Out files are in the GAM coordinate system by default.

Required User Inputs:

* **Number of Rows:** Number of rows in output grid
* **Number of Columns:** Number of columns in output grid
* **Lower Left X Coordinate:** Lower left X coordinate (GAM coordinate system)
* **Lower Left Y Coordinate:** Lower left Y coordinate (GAM coordinate system)
* **Grid Spacing (Feet):** Spacing of output grid cells in feet
* **Grid Rotation (Degrees):** Grid rotation in degrees from lower left corner.
* **Output Grid Name:** Output file name assigned to the grid. Note that the output file directory defaults to the following location: *\APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\01_Toolbox_Output\Output Grid Name\Output*

Model Grid Intersect | Structured



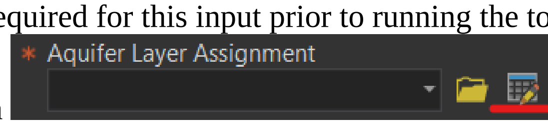
Function: Intersects Point or Areal pumping data with a structured grid by performing a spatial join, and allows the user to assign a unique layer number per aquifer code.

Output: Point or Areal pumping data as a feature class, populated with model grid attribution and layer assignment.

Required User Inputs:

* **Pumping Data Type:** The type of data being intersected (Point or Areal)
* **Input Pumping Data:** Point or Areal pumping data to be intersected
* **Input Model Grid:** User selected model grid, structured data format
* **Aquifer Layer Assignment:** Required layer # assignment to Aquifer

The following workflow is required for this input prior to running the tool.

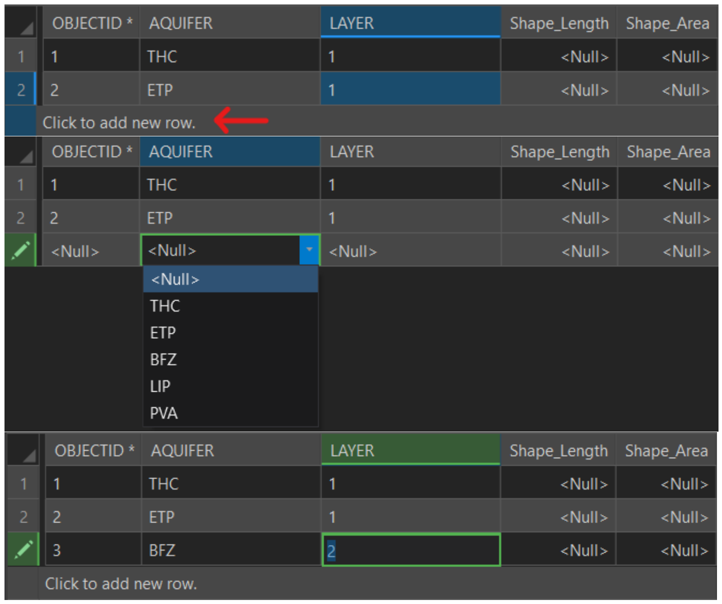
1. Click the 'Create Table' icon 

2. A new table will automatically be added to the contents pane as a standalone table (please allow 10-20 seconds for table to load). Once the table has been added to the contents pane, right click and open the attribute table.

3. A new record will need to be created for each aquifer in question, in addition to the associated layer that the user would like assigned.

a. Use the drop-down menu to assign the associated aquifer code. For information on adding additional aquifer codes to the list, please see *Adding Additional Aquifers* in the ArcGIS Pro Toolbox Models - Adding Additional Attributes section.

b. Click the 'LAYER' record to assign an associated number manually.



4. Once all of the records have been added to the table, ensure that the edits are saved. 

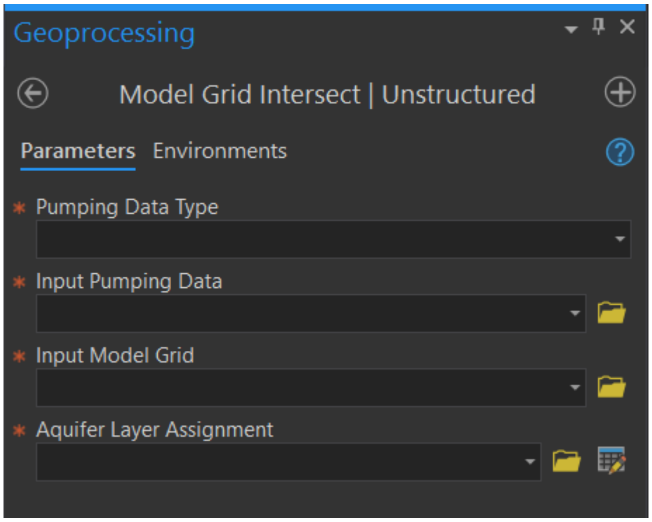
5. Once the edits to the table have been saved, the tool can be **run**. The new intersected feature class will be automatically added to the contents pane.

Additional Aquifer Codes can be added as options using the Adding Additional Aquifers section.

Note that the output feature class directory defaults to the following location: *\APRX_TWDB_Pumping_Toolbox\Scratch.gdb*

Note that the output csv directory defaults to the following location: *\APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\01_Toolbox_Output*

Model Grid Intersect | Unstructured



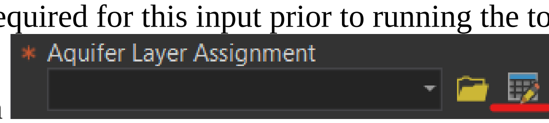
Function: Intersects Point or Areal pumping data with an unstructured grid by performing a spatial join, and allows the user to assign a unique layer number per aquifer code.

Output: Point or Areal pumping data as a feature class, populated with model grid attribution and layer assignment.

Required User Inputs:

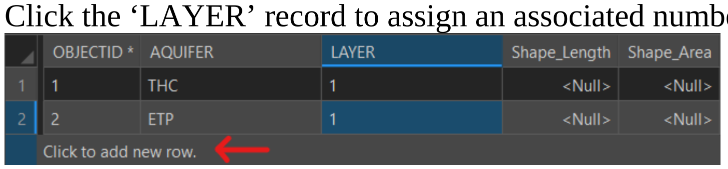
- * **Pumping Data Type:** The type of data being intersected (Point or Areal)
- * **Input Pumping Data:** Point or Areal pumping data to be intersected
- * **Input Model Grid:** User selected model grid, <u>unstructured</u> data format
- * **Aquifer Layer Assignment:** Required layer # assignment to Aquifer

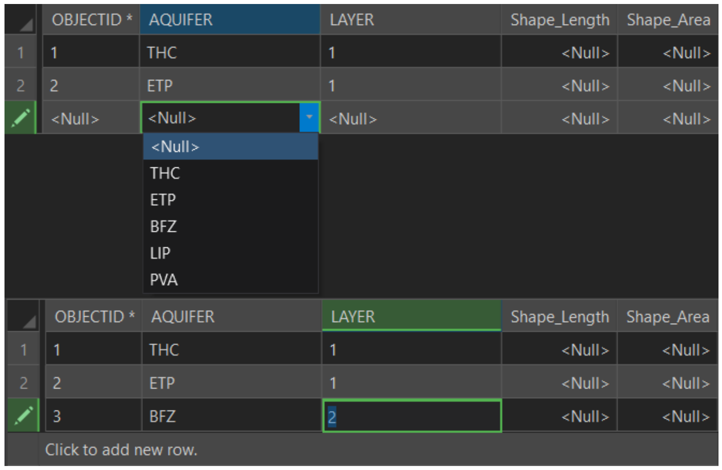
The following workflow is required for this input prior to running the tool:

1. Click the 'Create Table' icon 

2. A new table will automatically be added to the contents pane as a standalone table (please allow 10-20 seconds for table to load). Once the table has been added to the contents pane, right click and open the attribute table.

3. A new record will need to be created for each aquifer in question, in addition to the associated layer that the user would like assigned.
   a. Use the drop-down menu to assign the associated aquifer code.
   b. Click the 'LAYER' record to assign an associated number manually.





4. Once all of the records have been added to the table, ensure that the edits are saved. 

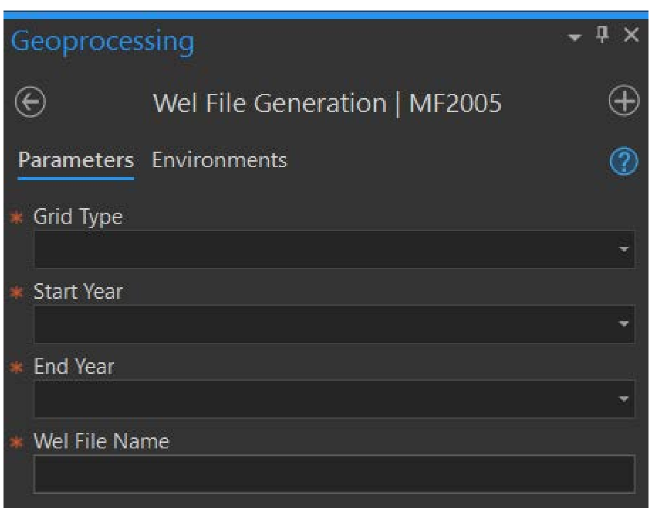
5. Once the edits to the table have been saved, the tool can be **run**. The new intersected feature class will be automatically added to the contents pane.

6. Additional Aquifer Codes can be added as options using the Adding Additional Aquifers section.

Note that the output feature class directory defaults to the following location:
\APRX_TWDB_Pumping_Toolbox\Scratch.gdb

Note that the output csv directory defaults to the following location:
\APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\01_Toolbox_Output

Wel File Generation | MF2005



Function: Creates a MODFLOW-2005 Wel file based on user input parameters. Note that either intersected Point or Areal data outputs from the Model Grid Intersect tool are required prior to running this tool.

Output: {Wel File Name}_MF2005.wel

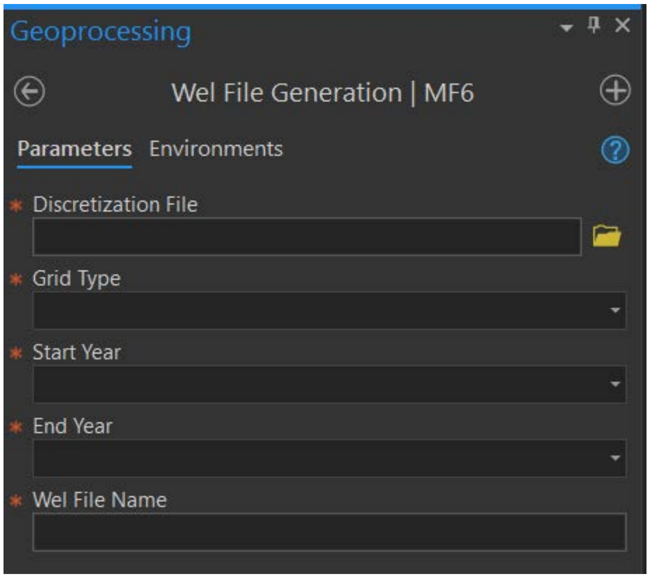
Required User Inputs:

* **Grid Type:** The grid type associated with the initial pumping data intersect. Either Structured or Unstructured options are available from the dropdown list.
* **Start Year:** The starting year to be defined in the output Wel file (1984-2018).
* **End Year:** The ending year to be defined in the output Wel file (1984-2018).
* **Wel File Name:** The file name for the output Wel file.

Additional years can be added to the model by following Adding Additional Years / Stress Periods section.

Note that the output files are placed in a new folder with the same name as the specified 'Wel File Name' in the following directory: *\APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\01_Toolbox_Output*

Wel File Generation | MF6



Function: Creates a MODFLOW 6 Wel file based on user input parameters. Note that either intersected Point or Areal data outputs from the Model Grid Intersect tool are required prior to running this tool.

Output: {Wel File Name}_MF6.wel

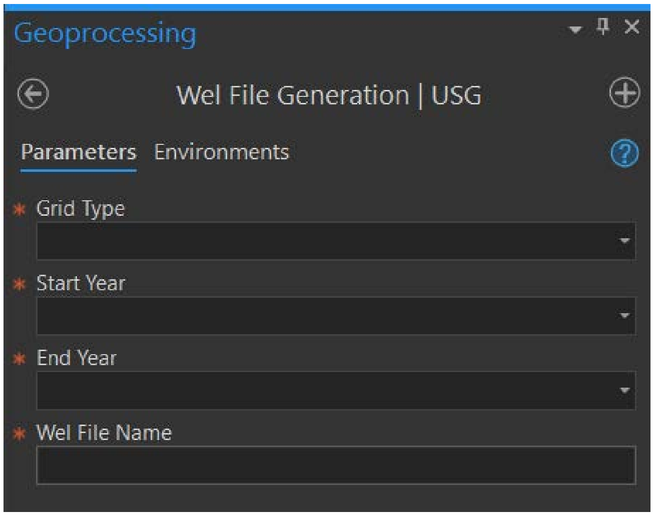
Required User Inputs:

* **Discretization File:** The associated .dis file required for the associated output.
* **Grid Type:** The grid type associated with the initial pumping data intersect. Either Structured or Unstructured options are available from the dropdown list.
* **Start Year:** The starting year to be defined in the output Wel file (1984-2018).
* **End Year:** The ending year to be defined in the output Wel file (1984-2018).
* **Wel File Name:** The file name for the output Wel file.

Additional years can be added to the model by following Adding Additional Years / Stress Periods section.

Note that the output files are placed in a new folder with the same name as the specified 'Wel File Name' in the following directory:
APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\01_Toolbox_Output

Wel File Generation | USG



Function: Creates a MODFLOW USG Wel file based on user input parameters. Note that either intersected Point or Areal data outputs from the Model Grid Intersect tool are required prior to running this tool. This tool only accepts an unstructured grid with the column "nodenumber" to output a wel file. If the user would like to use a structured grid, the user can use the Wel File Generation | MF2005 tool to output the Wel file which will work with the MODFLOW USG code.

Output: {Wel File Name}_MFUSG.wel

Required User Inputs:

*** Grid Type:** The grid type associated with the initial pumping data intersect. Either Structured or Unstructured options are available from the dropdown list.
*** Start Year:** The starting year to be defined in the output Wel file (1984-2018).
*** End Year:** The ending year to be defined in the output Wel file (1984-2018).
*** Wel File Name:** The file name for the output Wel file.

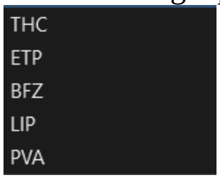
Additional years can be added to the model by following Adding Additional Years / Stress Periods section.

Note that the output files are placed in a new folder with the same name as the specified 'Wel File Name' in the following directory:
APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\01_Toolbox_Output

ArcGIS Pro Toolbox Models - Adding Additional Attributes

Adding Additional Aquifers

The following aquifer codes have been added as field population options by default:

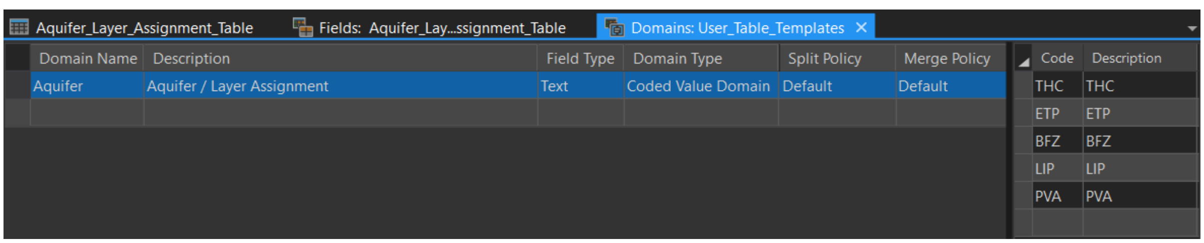


If additional aquifer codes need to be added to the drop-down list, the following steps can be taken:

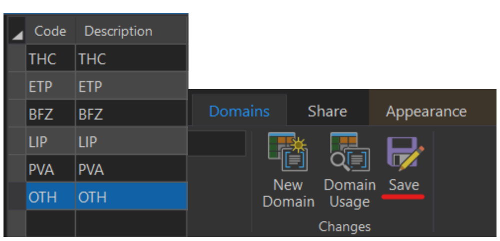
1. Navigate to the following geodatabase within the Catalog view in ArcGIS Pro: \APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\00_Ancilliary\Templates\User_Table_Templates.gdb

Once there, right click on the geodatabase and click 'Domains'

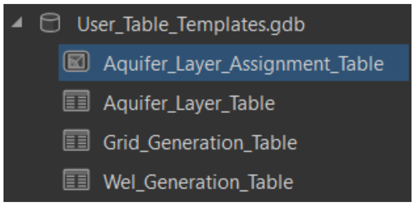
The Domains view will open in a new tab



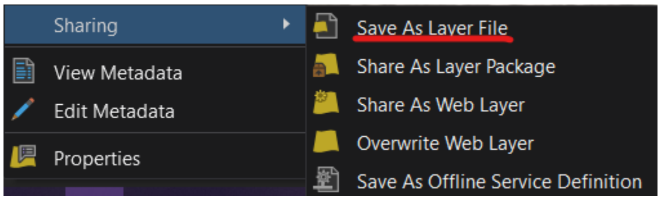
Additional codes can be added to the column on the right-hand side. Both the Code and Description fields should be populated with the same code associated with any pumping data for a successful attribute join in subsequent steps. After any new aquifer codes have been added, all edits should be **saved** within the Domain ribbon.



2. Next, add the 'Aquifer_Layer_Assignment_Table' feature class to the contents pane from the same User_Table_Templates geodatabase:



3. Once the layer has been added to the contents pane, right click on the Aquifer_Layer_Assignment_Table feature class in the contents pane and select Sharing > Save As Layer File

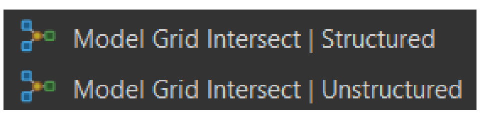


The layer file (.lyrx) in the following location should be overwritten:

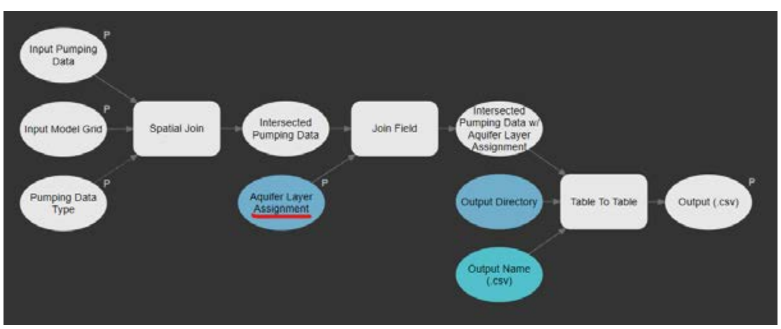
\APRX_TWDB_Pumping_Toolbox\Toolbox_Functions\00_Ancilliary\Templates\Lyrx

File name: Aquifer_Layer_Assignment_Table.lyrx

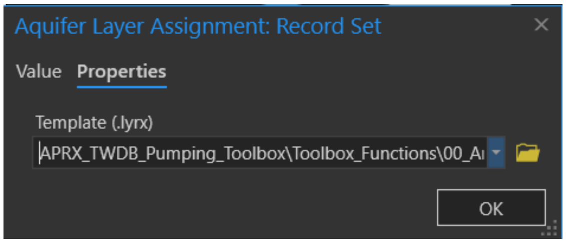
4. Next, navigate to the TWDB_Pumping_Toolbox.tbx in the ArcGIS Pro Catalog view. The following step will need to be completed from both of the following models:

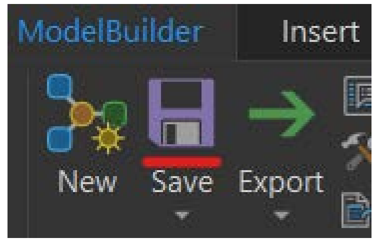


Right click on the model, enter the password (lrewater), and click ‘edit’. The associated model will open in a new tab. Double click the ‘Aquifer Layer Assignment’ variable.

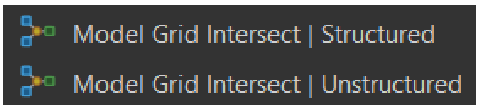


Once open, click on the properties tab, then navigate to the .lyrx file that was saved in step 3. Note that this step needs to be performed even though the file path is likely already associated with the .lyrx file. Once the path has been updated, save the model above.





***** Remember that this step will need to be completed for each of the following models for the newly assigned aquifer codes to appear as options in the Aquifer Assignment Table:

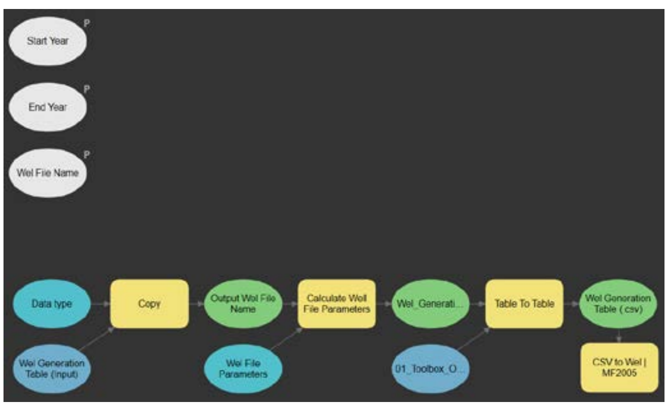


Adding Additional Years / Stress Periods

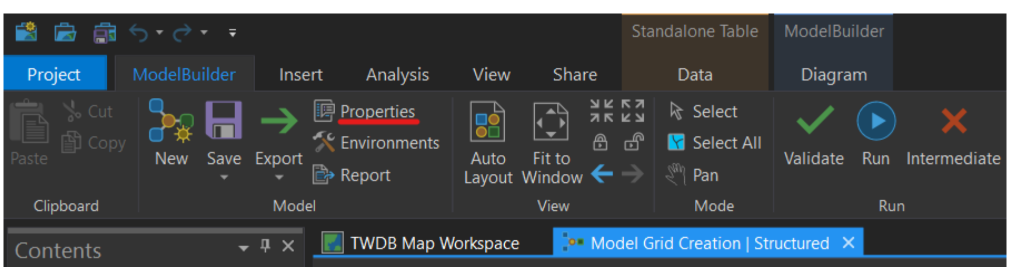
By default, the Wel File Generation models have been populated with a possible Start and End year of 1984 - 2018. Additional years can be added to each model using the following steps:

1. Right click on the Wel File Generation model for which additional years are needed (MF2005/MF6/USG) in the TWDB_Pumping_Toolbox.tbx, enter the password (lrewater), and right click 'edit'.

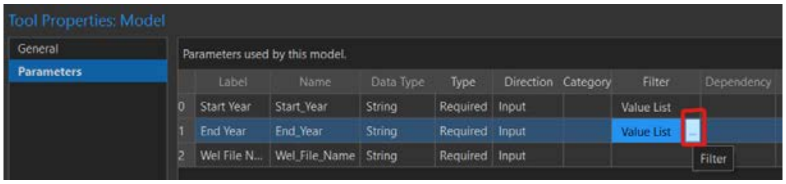
2. The associated model will open on a new tab within ArcGIS Pro



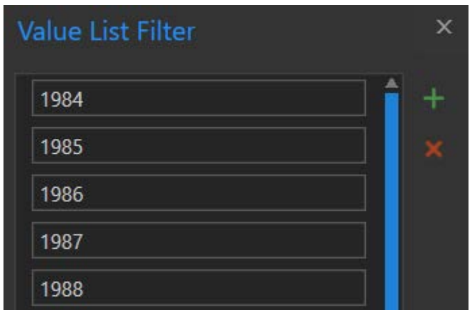
3. Click on the 'properties' button under the Model Builder ribbon



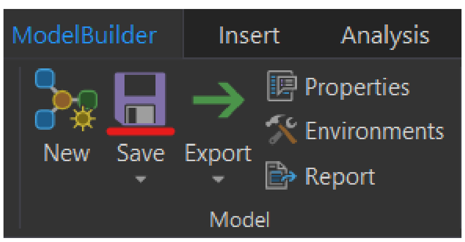
4. In the properties window that opens, select the parameters tab, then click on the ellipses symbol next to the parameter that needs to be adjusted (Start_Year **OR** End_Year)



A value list will appear where new years can be added as inputs



5. After additional years have been added, click okay to close the properties toolbox, then click save under the model builder ribbon. The added years should now be options in the dropdown menu when opening the geoprocessing model.



***** Remember that this step will need to be completed for each model where additional years are required:

Wel File Generation | MF2005, Wel File Generation | MF6, and Wel File Generation | USG.

FloPy Scripting Documentation

The toolbox uses python scripts to create the wel files. The python scripts depend on a package called FloPy to write the wel files. FloPy is a Python package for creating, running, and post-processing MODFLOW-based models (Bakker and others, 2016). Flopy requires Python 3.7 (or higher), and NumPy 1.15.0 (or higher). Documentation on Flopy is available online: https://flopy.readthedocs.io/en/3.3.4/. The python scripts also depend on the following libraries: os, pandas, shutil and datetime.

Modflow 2005

Both the point and areal annual pumpage data corresponding to each layer, row and column in the user-provided grid resulting from the Model Grid Intersect Model are merged into one single dataframe. The pumpage values are converted from acre-feet per year to cubic feet per day using a conversion factor.

An empty modflow model class is initialized using the Mf module. The tool assumes that a stress period corresponds to each year within the user-defined year range. The script organizes the stress period data in the form of a dictionary with lists of boundaries for each stress period, where each list of boundaries itself is a list of boundaries. Indices of the dictionary are the numbers of the stress period and each well within a stress period is defined through the definition of layer, row, column and flux. A negative flux indicates groundwater pumping. The script assumes that all reported volumes in this toolbox are pumpage and automatically assigns a negative sign to the reported fluxes.

A MODFLOWWel class is initialized using the flopy mfwel module with the empty modflow model class and the stress period data contained in the dictionary. To export the wel file, the MODFLOWWel class write_file() function is called and the annual pumpage data is exported as a csv file to allow the user to verify the wel file dataset.

Modflow 6

Both the point and areal annual pumpage data corresponding to each grid cell or node in the user-provided grid resulting from the Model Grid Intersect Model are merged into one single dataframe. The pumpage values are converted from acre-feet per year to cubic feet per day using a conversion factor.

An empty Modflow 6 MFSimulation class is initialized using the mf6 module. A temporal discretization package (TDIS) is generated and associated to the simulation assuming each year within the user-defined year range corresponds to a stress period. The following parameters are set in the script:

- Time unit: days
- Number of stress periods (nper): number of years between the user-define year range
- Length of stress period (perlen): 365.25 days
- Number of time steps in a stress period (nstp): 1
- Multiplier for the length of successive time steps (tsmult): 1

Using FloPy's Modflow 6 ModflowGWf module, a groundwater flow model is initialized along with a simple iterative model solver using the Modflow Ims module. The user's discretization file is read to determine the:

- Number of layers (nlay), rows (nrow), and columns (ncol), for a structured grid
- Number of cells per layer (ncpl) and total number of vertex pairs (nvert), for a vertices grid
- Number of nodes (nodes) and the sum of node connections and nodes (nja)

Using the values read from the discretization file, a corresponding ModflowGwfDis class is initialized.

The script organizes the stress period data in the form of a dictionary with lists of boundaries for each stress period, where each list of boundaries itself is a list of boundaries. Indices of the dictionary are the numbers of the stress period and each well within a stress period is defined through the definition of:

- Layer, row, column, and flux for a structured grid
- Layer, CELL2D number and flux for a vertices grid
- Node number for the cell and flux for an unstructured grid

A negative flux indicates groundwater pumping. The script assumes that all reported volumes in this toolbox are pumpage and automatically assigns a negative signs to the reported fluxes. A Modflow 6 ModflowGwfWel class is initialized with the stress period data contained in the dictionary. To export the wel file, the ModflowGwfWel class write() function is called and the annual pumpage data is exported as a csv file to allow the user to verify the wel file dataset.

Modflow USG

Both the point and areal annual pumpage data corresponding to each layer, row and column in the user-provided grid resulting from the Model Grid Intersect Model are merged into one single dataframe. The pumpage values are converted from acre-feet per year to cubic feet per day using a conversion factor.

The tool assumes that a stress period corresponds to each year within the user-defined year range. The script organizes the stress period data in the form of a dictionary with lists of boundaries for each stress period, where each list of boundaries itself is a list of boundaries. Indices of the dictionary are the numbers of the stress period and each well within a stress period is defined through the definition of layer, row, column and flux. A negative flux indicates groundwater pumping. The script assumes that all reported volumes in this toolbox are pumpage and automatically assigns a negative sign to the reported fluxes.

For Modflow USG, there were no flopy functions available in the documentation that could create a well package object for export. However, flopy utilities were used to write the well package to a text file using free format. The script first loops over the stress period data contained in the dictionary to calculate the value for the maximum number of wells in use during any stress period (MXACTW). Using the flopy.utils.flopy.io module’s write_fixed_var() function, the node number and pumpage value is written in a line for each well within a stress period using free format. The well package is written out to a text file and the annual pumpage data is exported as a csv file to allow the user to verify the wel file dataset.

Appendix 3 – Task 1 Draft Report Comments and Responses

The following provides comments from the TWDB on the Task 1 draft report which is included in Section 2 and Section 3 of this final report.

General comments to be addressed

1. Per Exhibit B, Attachment 1: Please review the text to correct spelling and grammatical errors.

   Done

2. It is apparent that in the year-to-year change analyses used to identify anomalies, an anomalous pumping estimate occurring in the first year is never identified but instead the second year pumping estimate is flagged as anomalous even though it may be compatible with the following years. Please discuss this in the text (Section 3.2).

   Noted. Added text identifying that only our manual review is applicable to the first year.

3. Please cite the source of precipitation data used throughout the text and in several figures.

   Done. As noted in Section 2.3, all precipitation data are from PRISM (2020).

4. Please discuss why analysis of irrigation pumping versus land use, number of wells, or precipitation were only conducted for selected counties.

   As discussed in Section 3.2, the analyses were conducted but were not "universally beneficial for our analyses during this phase of the project." As such, we only included discussion where we deemed it meaningful to the analysis.

5. It apparent that the anomaly analysis detects changes inter-annual pumping and thus only identifies the first 1 to 2 years of a change in the data but does not identify longer periods of anomalous data that are apparent using manual methods. Please discuss this apparent weakness in the analyses.

   This weakness of the automated methods is one reason for maintaining manual review in the process. Similarly, the automated methods may identify issues that are not apparent to manual review.

6. The anomaly analysis methodologies seem to be most applicable to pumping categories with relatively small inter-annual variation in pumping. These methodologies seem to be least applicable to irrigation pumping where interannual pumping variation can be relatively large due to large interannual fluctuations of rainfall. In this case, anomaly analysis often tags pumping in years that transition from wet to dry periods or vice versa. Please discuss these issues in the text.

   Our automated methods intentionally look only at the reported pumping data. As such, large changes are anomalous and require a second look. During this second look, the transition from wet to dry periods may be noted as an explanation for the identified anomaly.

7. Since the year-to-year difference is normalized with the range value, it is highly influenced by the range (i.e. maximum-minimum) of pumping value. If the range is significantly high, there is a chance that the analysis will not flag the anomalous data, even when the year-to-year difference shows a significant volume. Please consider providing a supplementary method that is based on the absolute pumping volume.

   As discussed in Section 3.2, we used two trigger percent values based on the range and the magnitude of reported pumping in our year-to-year analysis. To also help mitigate the chance of missing anomalies, we applied three methods to our analysis of the Water Use Survey data.

8. From the year-to-year difference approach, the flag is on the year that experienced significant changes compare to the previous year. We suggest considering the year before the significant change for an anomaly. For example, if the pumping was 100, 100, 100, 100 and 20 for 5 years, the current approach will put the flag on the 5th year. However, it could be gradual decrease if the 4th year pumping was 60. Thus, it is worth checking the year prior to a significant change.

   By applying three methods we strove to mitigate the potential for missing anomalous data.

9. Please provide the units on figures that show the pumpage volumes.

   Done

Specific comments to be addressed

10. Page 51, paragraph 2: Please change “USGS, 2020” to “USGS, 2020b”.

    Done

11. Page 54, paragraph 1: This paragraph states: “We used the data from the TWDB online reports to verify the data provided by TWDB staff. Much of the data matched, although we did identify some minor differences in the data from the online reports compared to the data provided by TWDB staff. Upon investigation, the differences in values were due to the syntax of the database query used to extract the data from the database.” In the original dataset sent by TWDB staff, we had included aquifer parameters in the query for the counties. Once identified, the query was updated, and revised data provided. The revised data then matched the online reports. Please change the text to reflect that the online data and the data provided by TWDB matched in the end.

    Done

12. Page 55, Table 2: Please clarify if Industrial (cooling) could also be Steam-electric/Power and update table as needed.

    Done

13. Page 56, paragraph 3: Please clarify what land use classification would represent livestock, if classifying pasture as possible irrigation.

    Updated

14. Page 56, paragraph 3: Please change “USGS, 2020” to “USGS, 2020a”.

    Done

15. Page 57, paragraph 1: Please change the first occurrence of “USDA, 2020” to “USDA, 2020b” and the second occurrence to “USDA, 2020a”.

    Done

16. Page 57, Figure 6: Please clarify “HerHay” in legend and please update legend as needed.

    Done

17. Page 59, paragraph 2: The term “Other Aquifer” could refer to pumping from stratigraphic units not included in any of the major or minor aquifers recognized by the TWDB, for example, Quaternary alluvium or various Paleozoic stratigraphic units. Please revise the text to reflect this.

    Done

18. Page 59, paragraph 2: Please correct the typo, *“Ror many of the study area…”*.

    Done

19. Page 59, paragraph 2: The reference in the text to Figure 7 on Page 60 is mistakenly mentioned as Figure 1. Please revise the text to refer to the correct figure.

    Done

20. Page 59, paragraph 2: In the discussion regarding Irion County groundwater use, please include that one other possible reason for the increase in pumpage is changes in the methodology of estimating irrigation water use.

    Done

21. Page 60, Figure 7: Please consider using another color or hatching to distinguish between “Other aquifer” and “Unknown”.

    Done

22. Page 61, paragraph 1: In the second to last sentence, please note that the “Water Use Survey” differs from the actual Water Use Survey Program for the approach that Groundwater Availability Modeling staff used to develop estimates of pumping. For example, to distribute annual irrigation estimates from the Water Use Survey into monthly irrigation estimates we used annual crop acreage and evapotranspiration.

    Noted

23. Page 61, paragraph 1; paragraph 2; Tables 3 and 5: Please include the following in the text and appropriate tables. Historically county-other estimates (rural domestic) were derived from the following process. The number of connections reported in the municipal survey were multiplied by a factor (such as 3.5 as an example, to represent the average number of people per household). The result of the calculation was then compared to the total number of people in the county reported by the census. If there was a remainder after this subtraction, then that value was assigned to County-Other. If the value from the connection analysis was greater than the county-wide census information, then the value applied to County-other was zero. For estimating rural domestic pumping for the modeling program, we assumed rural domestic pumping occurred in every county. Therefore, we used census block data for areas outside of cities and assigned the average gallons per capita use for Texas per year.

    Revised and incorporated as requested. Cited these comments as the source for the explanation.

24. Page 61, paragraph 1: Please correct the following references:
    a. Change “National Agricultural Statistics Service” to “National Agricultural Statistics Service”.
    b. Change “Texas Agricultural Experiment Station” to “Texas A&M AgriLife Research”.
    c. Change “Farm Service Administration” to “Farm Service Agency”.

    Changed. Original text used names identified in the source document cited.

25. Page 61, Table 3: Please update the historical livestock and irrigation water use methodologies based on work process document and actual procedures developed by staff responsible for these estimates. For example, the irrigation estimates were only based on potential evapotranspiration for a limited number of years, whereas the current methodology more accurately reflects water availability limitations.

    a. Consult with Antonio Delgado (WSC-CIWT-AWC) for current and historical methodologies for estimating irrigation water use.
    b. Consult with Yun Cho or John Ellis (WSI-WUPP-EDA) for current and historical methodologies for estimating livestock water use.

    Noted. No change needed. Table 3 provides a very brief description of each use category with further discussion and details of the methodology summarized later in the section. Tables with the history of the estimation per TWDB documents are provided in the text.

26. Page 62, Table 4: Please note that annual summaries were developed for each historical State Water Plan. For example, the 1961 State Water Plan used estimates for 1959 (https://www.twdb.texas.gov/waterplanning/swp/index.asp, note there were also summaries produced in 1974 and 1977 for interim “planning” update reports).

    Noted

27. Page 63, paragraph 3: Please change “National Agricultural Statistics Service” (TASS) to “National Agricultural Statistics Service” (NASS). *(TASS reports were developed through a partnership between NASS and the Texas Department of Agriculture, however, that partnership ended sometime in the early 2000’s.)*

    Done

28. Page 64, paragraph 3: Please consult with Yun Cho or John Ellis (WSI-WUPP-EDA) to update the livestock water use methodology, as the entities listed are either no longer in existence or their names have changed and the methodology has changed over the years.

    Updated the names to current entities. The general methodology has not changed significantly from that described by Ridgeway (Ridgeway, 2020)

29. Page 65, paragraph 1: Please revise the text to state that the "irrigation surveys" conducted by USDA-NRCS staff are really just another source of estimates, rather than actual "surveys" of irrigators.

    Revised text

30. Page 68, paragraph 1: Regarding the year-to-year change analysis methodology, please note in the text that the methodology used is very sensitive to change in counties where water use is low. For instance, in Atascosa county the usage dropped 500 ac-ft from 700 ac-ft around 2010. While this is a notable percent drop it is not a notable drop in usage.

    Noted

31. Page 68: Step 3 in the process for determining the threshold value is unclear. Based on the text, the range (228 acre-feet) is greater than 1/2 of average (77 acre-feet) and it should be the threshold should be 15%. But the example used 35%.

    Comment addressed by correcting the threshold value on the figure to be at the 15% level. We also verified that proper thresholds were used when identifying anomalies for all datasets.

32. Page 70, paragraph 3: There is no Figure 10-d. Please revise the text to reference the correct figure.

    Done

33. Page 93, paragraph 4: Please consider listing the pumping categories as shown in Figure 32. In Figure 32 the pumping categories appear in the order irrigation, livestock, manufacturing, mining, and municipal. The text the pumping categories are listed "…livestock, mining, manufacturing, …".

    Done

34. Page 100, Figure 35: The pumpage values in Figure 35 should match those in Figure 32a. Please revise or clarify.

    Done

35. Page 103, paragraph 2: Please list all the graphs in the order in which they appear in Figure 38.

    Done

36. Page 103, paragraph 6: Please discuss whether there is any chance that the irrigation source changed from Edwards (Balcones Fault Zone) Aquifer to Trinity (Hill Country) Aquifer from around 2000. Edwards (Balcones Fault Zone) Aquifer irrigation decreased while Trinity Aquifer irrigation increased from 2000.

    Comment acknowledged and not addressed in this Task 1 report. We will address this topic in Task 3 where we investigate and modify anomalous data.

37. Page 148, Figure 75: Irrigation in Comal County Trinity (Hill Country) Aquifer and Edwards (Balcones Fault Zone) Aquifer (Figure 72) are very similar after year 2000 while other categories are substantially different between two the aquifers. It might be coincidence but please double-check the data.

    Done. We verified that the two graphs do depict different datasets, even though they show similar trends. No changes necessary.

38. Page 166, paragraph 2: Please list all the graphs in the order in which they appear in Figure 92.

    Done

39. Page 166, paragraph 2: The text states "…irrigation use in 1998 and 1998…". Please correct these years.

    Done

40. Page 177, paragraph 1: Please change "Figure 101" to "Figure 100".

    Done

41. Page 177, paragraph 4: Considering that in Figure 104, most data points lie well outside of the 95 percent confidence interval. It seems unlikely that there should be a linear correlation value as high as 0.83. Please recalculate to ensure that the correlation value indicated in the text is correct.

    Checked and verified. The calculation of the linear correlation coefficient ("r") is accurate.

42. Page 177, paragraph 5: Considering that in Figure 106, most data points lie well outside of the 95 percent confidence interval. It seems unlikely that there should be a linear correlation value as high as 0.73. Please recalculate to ensure that the correlation value indicated in the text is correct.

    Checked and verified. The calculation of the linear correlation coefficient ("r") is accurate.

43. Page 181, Figure 103: Please revise the figure caption for clarity.

    Done

44. Page 201, paragraph 2: The text states "…total production in 2011 and 2012…". It seems it is referring to incorrect years. Please correct it.

    Done

45. Page 210, paragraph 2: Please list all the graphs in the order in which they appear in Figure 127.

    Done

46. Page 219, Figure 132: There are no flags on years 2005 and 2008 on the municipal pumpage graph and year 2013 on the manufacturing graph as indicated in Table 26. Please explain this or correct the figure.

    Corrected

47. Page 223, paragraph 2: Please list all the graphs in the order in which they appear in Figure 138.

    Done

48. Page 223, paragraph 5: Please list all the graphs in the order in which they appear in Figure 142.

    Done

49. Page 229, paragraph 3: Please list all the graphs in the order in which they appear in Figure 150.

    Done

50. Page 251, paragraph 4: Please list all the graphs in the order in which they appear in Figure 164.

    Done

51. Page 259, paragraph 2: Please list all the graphs in the order in which they appear in Figure 128.

    Done

52. Page 259, paragraph 4: Please specify the figure number in the sentence that begins "Figure indicates a linear …".

    Done

53. Page 259, paragraph 5: Please list all the graphs in the order in which they appear in Figure 172.

    Done

54. Page 265: Please correct the figure number on this page as well as the figure numbers for all subsequent figures (Figures 172 through 360).

    Done

55. Page 282, paragraph 6: This paragraph references "Kimble County". Please clarify if this should be "Kinney County" and please update text, as needed.

    Done

56. Page 292: Please update the figure caption format.

    Done

57. Page 298, paragraph 1: Please restructure paragraph 1, sentence 1 for clarification and spelling.

    Done

58. Page 298, Paragraph 1: Per TWDB terminology, please change "High Plains Aquifer System" to "Ogallala Aquifer".

    Comment addressed by revising the paragraph to avoid specific references to aquifers not included in this project.

59. Page 298, Paragraph 1: Please change "Martin Coue" to "Martin County".

    Done

60. Page 300, Figure 202: The Hickory Aquifer should be included in this because it is referred to in the text. Please revise the figure to reflect this.

    Comment addressed by revising text to exclude specific reference to aquifers not under investigation in this project.

61. Page 303, paragraph 2: Please list all the graphs in the order in which they appear in Figure 207.

    Done

62. Page 318, paragraph 2: Please list all the graphs in the order in which they appear in Figure 220.

    Done

63. Page 324, Paragraph 1: Per TWDB terminology, please change “High Plains Aquifer System” to “Ogallala Aquifer”.

    Comment addressed by revising text to exclude specific reference to aquifers not under investigation in this project.

64. Page 325, Figure 224: The Ogallala Aquifer should be included in this figure because it is referred to in the text. Please revise the figure to reflect this.

    Comment not addressed as text revisions precluded the need to revise this figure as directed.

65. Page 334, paragraph 2: Please list all the graphs in the order in which they appear in Figure 232.

    Done

66. Page 379, paragraph 1: Please rewrite the first sentence for clarity.

    Done

67. Page 379, paragraph 1: Please change “Figure 107Figure 267” to “Figure 267”.

    Done

68. Page 421, paragraph 1: The text states that an analysis of the correlation between irrigation and annual precipitation was not carried out for the Lipan Aquifer but Figures 304 and 305 reflect analysis for the Edwards-Trinity (Plateau) Aquifer. Please correct the text.

    Done

69. Page 421, paragraph 1: Please add justification for why analysis of the correlation between irrigation and annual precipitation was not carried out for the Lipan Aquifer.

    Comment not addressed. In our methodology (Section 3.2.4) we state that we present correlations only when the linear correlation coefficient (“r”) exceeds 0.4. This was not the case for the computed correlation between irrigation pumpage and annual precipitation for the Lipan Aquifer.

70. Page 430, paragraph 4: There is a typographical error “… from 1984 through 2007total …”. Please correct it.

    Done

71. Page 499, paragraph 1: There are two references for USGS (2020). Please change “2020” to “2020a”.

    Done

72. Page 499, paragraph 2: There are two references for USGS (2020). Please change “2020” to “2020b”.

    Done

73. Page 499, paragraph 4: There are two references for USDA (2020). Please change 2020 to 2020a.

    Done

74. Page 499, paragraph 5: There are two references for USDA (2020). Please change 2020 to 2020b.

    Done

75. Section 5: The following references are not cited in the text and should therefore be deleted:
    a. Anaya and Jones, 2009
    b. Beach and others, 2004
    c. Brakefield and others, 2015
    d. Hutchison and others, 2011a
    e. Hutchison and others, 2011b
    f. Jones and others, 2011
    g. Lindgren and others, 2004
    h. Scanlon and others, 2001

    Done

Draft geodatabase and data deliverables comments:

General comments to be addressed

76. Please add metadata to all new data added to the geodatabase.

    Metadata updated

Specific comments to be addressed

77. None.

Suggestions for the Task 1 report:

78. It would be helpful if the guideline (i.e., absolute value) for the 'relatively low amounts of production' is provided.

    Comment addressed by removing all identified statements using this phrase, and by removing all text asserting that anomaly review efforts would be less for instances in which the pumpage volume was low (compared to volumes for other counties or uses).

79. Please reformat the following sections to make them consistent with the formatting of the rest of the report: sections 3.3.8, 3.3.29, and 3.4.

    Comment addressed as requested. Section 3.3.6 was also reformatted.

80. Section 3.3 County Evaluations: Figures for groundwater pumping and anomalies have different scales on the Y-axis even though the data is the same. For consistency, please adjust scales so they are the same.

    With consistent scales low pumping amounts would not be as noticeable for manual review. To help with anomaly identification we have left the scales variable relative to the total range of volumes being shown on each chart.

81. Page 272, paragraph 2: Please consider using the livestock inventory for the 2017 Census of Agriculture for Kimble County in 2017 (https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Texas/cp48267.pdf) and the top three categories, a rough estimate of annual use is around 550 acre-feet (Assumed the following, 1. may be more gallons/day for hot weather and 2. all animals use groundwater):

    a. 15,000 cow × 40 gallons/day = 450,000 gallons/day,
    b. 24,000 goats × 1.5 gallons/day = 36,000 gallons/day
    c. 9,291 sheep × 2 gallons/day = 18,582 gallons/day

    Sums to 504,582 gallons/day or 1.5 acre-feet × 365 = ~550 acre-feet. This appears lower than Water Use Survey for 2017, regardless of the number of wells.

    Comment not addressed. Additional insight gleaned from the above reference and information contained within the comment were used to address identified anomalies for livestock pumping data as part of Task 3 of this project. We reviewed the above reference as part of Task 2 of this project, where we developed a plan to research and address the identified anomalies.

82. Page 278, Figure 181: Please correct spelling of Kimbl.

    Done

83. Pages 282 to 293: Please consider including additional insight for pumping in Kinney that may be found in the model report and model files (https://www.twdb.texas.gov/groundwater/models/alt/knny/knny.asp). TWDB also received additional data from the Kinney County Groundwater Conservation District.

    Comment not addressed. Additional insight gleaned from the above reference was used to address identified anomalies for Kinney County pumping data as part of Task 3 of this project. We reviewed the above reference as part of Task 2 of this project, where we developed a plan to research and address the identified anomalies.

84. Page 292, Figure 195: Please adjust the caption, "Figure 195Trinity…."

    Done

85. Pages 299 to 307: Please note that the *Conceptual Model Report: Minor Aquifers in the Llano Uplift Region Of Texas* (https://www.twdb.texas.gov/groundwater/models/gam/llano/llano.asp) shows small amounts of pumping from the Cretaceous Aquifer from 1984 to 2003 in Figure 4.6.8.

    Noted. For Task 1, our discussion of Mason County and McCulloch County pumping was limited to only the Edwards-Trinity (Plateau) Aquifer. For a subject county, we do not discuss pumping in the Water Use Survey Dataset attributed to another aquifer UNLESS the specified aquifer is the subject of this project, or the aquifer is specified as "Other" or "Unknown." Pumping attributed to the "Cretaceous Aquifer" will be considered in Task 3.

86. Page 308, paragraph 1: Please consider substituting "underlie" for "underly".

    Done

87. Page 419, paragraph 5: Please add space in the following, "…approximately800…".

    Done

Suggestions for draft geodatabase and data file deliverables:

88. Please change "conservation districts" to "groundwater conservation district".

    Done

Public Comments:

None.

Appendix 4 – Task 2 Draft Report Comments and Responses

The following provides comments from the TWDB on the Task 2 draft report which is included in Section 4 of this final report.

General comments to be addressed

1. Per Exhibit B, Attachment 1: Please review the text to correct spelling and grammatical errors.

   Done

2. Please include page numbers in the report.

   Done

3. Please cite TWDB (2020a through 2020e) in the order in which they appear in the text. For example, TWDB (2020e) appears before TWDB (2020c and 2020d).

4. Please cite Lovelace (2009a and 2009b) in the order in which they appear in the text. For example, Lovelace (2009b) appears before Lovelace (2009a).

Specific comments to be addressed

5. Figure 8: Please use the consistent y-axis title "Groundwater Pumping"

   Done

6. Section 2.2, paragraph 19: Please change the terms "Figure 19 illustrates the difference between **estimated** irrigation pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County (Figure 14) and **irrigation need** (Figure 18). Since 2009, the difference between the **estimates** is …" to "Figure 19 illustrates the difference between **reported** irrigation pumping from the Edwards-Trinity (Plateau) Aquifer in Pecos County (Figure 14) and **estimated irrigation need** (Figure 18). Since 2009, the difference between the **reported and estimated value** is …"

   Done

7. Section 2.2, paragraph 20: Please change the terms "… we expect that many of the irrigation **estimates** prior to 2010 are low." to "… we expect that the **reported** irrigation prior to 2010 is low."

   Done

8. Section 2.3: Please correct the order of Figure 22 and Figure 23 as they appear in the text.

   Done

9. Section 2.3, paragraph 2: Please cite “Figure 22” in this paragraph.

   Corrected the order of the figures. Citation here no longer needed.

10. Figure 22: Please use the correct citation format for “Power Generation Use in Texas” Report or use the data name as in Figure 13.

    Done

11. Section 2.3, paragraph 11: Please use the consistent name for “Luminant Permian Plant”.

    Done

12. Section 2.4: Please remove “TWDB” in front of “Water Use Survey” for consistency with previous chapters.

    No change. We use “Water Use Survey” both with and without “TWDB” throughout the report.

13. Figure 27: Please provide a reference for “Railroad Commission Database”.

    Done

14. Section 2.4, Method #3: The data analysis process in this method should be written in general format instead of as an example.

    The reference is within a test case section. A general description is added to the previous section.

15. Figure 33: This schematic diagram only addresses missing data. Please include some process for addressing anomalously high or low values.

    Done. Also corrected on the Surveyed municipal flow chart

16. Figure 38: Please use the same font size as the other figures.

    Done

17. Section 2.6, paragraph 2: Please change “… Survey Manufacturing Pumping …” to “… Survey Livestock Pumping …”.

    Done

Draft geodatabase and data deliverables comments:

18. None.

Suggestions for the Task 2 report:

Please note that the items listed under “suggestions” are editorial in context and are not contractually required; however, the suggested adjustments noted may improve the readability of the report and/or the usability of the data deliverables.

General suggestions

19. Please do not use abbreviations in the text or figures. For example, please spell out Balcones Fault Zone instead of BFZ in the legend for Figures 2, 3, and 4.

    Corrected

20. Please cite references used for figures. For example, please provide date in the figure legend or caption for groundwater conservation districts and their boundaries in Figure 2 and the groundwater management area boundaries in Figure 3.

    Done

Specific suggestions

21. Section 1, paragraph 3: Please change “Data” to “data”.

    Done

22. Section 2: If not mentioned in the report, it may be important to note the following (from TWDB webpage): "TWDB Historical Groundwater Pumpage Estimates are specific to the location where groundwater is pumped from an aquifer, whereas Historical Water Use Estimates are specific to the location where surface and groundwater is used by end users. The location of pumpage may not necessarily be the same as the location of use due to water transfers or purchases from other geographic areas."

    Noted and added to Section 4 of this report.

23. Table 1: Please change “Reported municipal water use” to "Self-reported municipal water use by active community public water systems."

    Done

24. Section 2.1, paragraph 1: Please change “…active public … system type …” to “…active community public water systems …”

    Done

25. Section 2.1.1, paragraph 1: Please change "respond" to "surveyed". Not all suppliers respond to the survey. Approximate 70-80% annual response rate. If a survey is not submitted and data is available, water use data is rolled over from the most current year that data was reported.

    Sentence revised

26. Section 2.1.1: The straight interpolation method for filling in missing municipal pumping data is ok. One consideration is to seek patterns in surrounding municipal pumping and use this information to factor in the missing pumping or since municipal pumping is usually tied into weather conditions to find a correlation between weather and pumping in the data reported.

    No change. For purposes of this project, the approach was deemed sufficient.

27. Figure 5: Please consider moving Figure 5 to next page for a better readability.

    Figure placement updated.

28. Section 2.1.2: Using population not served by a water system times the statewide per capita water use is fine for rural West Texas but does not work in East Texas. Previous estimates using this method overestimated rural groundwater use for East Texas where precipitation is high, and more people had private stock ponds and tanks. For previous models we used the precent of municipal users with groundwater vs surface water sources and applied this factor to our estimates.

    We understand. Because of the potential variability our approach was to build upon the U.S. Geological Survey estimates for domestic water.

29. Section 2.2: Please discuss how this approach can be used for rotating summer/winter crops such as summer cotton and winter wheat or year-round citrus in the Rio Grande Valley. Also please discuss how to account for dry land farming.

    Noted. Clarification added to Section 4.2.

30. Figure 13: Please consider updating the figure for a better readability. There are unnecessary elbows can be removed by flowchart alignment.

    No change.

31. Section 2.2, paragraph 4: Please add a missing comma, changing “During the project we have…” to “During the project, we have…”

    Revised paragraph.

32. Section 2.3, paragraph 5: Please add comma, changing. "… EIA 860 (EIA, 2020a) and EIA 923 (EIA, 2020b) we are able…" to "… EIA 860 (EIA, 2020a) and EIA 923 (EIA, 2020b)**,** we are able…"

    Done

33. Section 2.3, paragraph 5: Please add period at the end of sentence.

    Done

34. Section 2.4, Method #3: It would be preferable to include the tables, figures, and text from Nicot and others (2012) in this report.

35. Figure 34: Please use same scale on Y-axis of graphs (Groundwater Pumping Acre-Feet).

36. Figure 35: Please use same scale on Y-axis of graphs (Groundwater Pumping Acre-Feet).

37. Section 2.6: Livestock was discussed as being assigned to surface water and adjusted to groundwater. Please provide more information for deciding on groundwater versus surface water sources.

38. Figure 39: Please use same scale on Y-axis of graphs (Groundwater Pumping Acre-Feet).

Appendix 5 – Task 3 Draft Report Comments and Responses

The following provides comments from the TWDB on the Task 3 draft report which was revised into this final report.

General comments to be addressed

1. Per Exhibit B, Attachment 1: Please review the text, including the list of authors to correct several spelling and grammatical errors. (IJ)

Comment has been addressed, and all spelling and grammatical errors have been corrected.

2. Please note that a municipality may draw water from a non-adjacent aquifer. Consequently, the assumption that city boundaries must coincide with aquifer boundaries may not be valid. For example, the cities of Odessa and Midland own wells drawing groundwater from the Pecos Valley Aquifer in Ward or Winkler counties. Please review the report to ensure that cities drawing groundwater from a non-adjacent aquifer are included. (IJ)

Comment addressed in section 4.1.1, and we ensured pumpage was properly assigned and located within the project geodatabase.

3. Please propose an explanation for the sudden increase in livestock pumpage starting in 2005 in several counties, for example, Medina, Nolan and Tom Green counties. (IJ)

Comment addressed for all the county revisions in the report by correcting the livestock pumpage subplot in the figure.

4. The first figure in Section 5.2.36 has no caption. Please renumber this figure and all subsequent figures in the report and revise the text accordingly. (IJ)

The figure in question was a duplicate of Figure 584 and therefore deleted.

5. All abbreviations used in figures should be explained in the legend of the figure, examples include BFZ, GCD, UWCD. (CR)

Explanations for abbreviations have been added to figure captions, as suggested in comment 14.

6. Please double-check the figure numbers in the text and revise as appropriate. Several figure numbers are referencing incorrect figures. (KC)

Comment was addressed throughout the document.

7. Please include all symbology in the legend of each multi-axis chart (pumpage versus number of wells) and add units to all figures consistently. (WSP)

Figures including pumpage versus number of wells in Sections 3.2 and 3.3 have been replaced to include all symbology in the legend and units were added for pumpage.

8. In Section 1, it was stated that "Method change, incorrect geographic allocation, incorrect surface water changes in the methodology for determining annual volume used or from which aquifer the estimated use occurred have likely resulted in inconsistent pumping estimates for this project study area and for other areas within Texas." Please revise the following sections, especially in Section 3, to better describe methods used for each water use category for developing geographic and water source splits for non-surveyed estimates. (WSP)

Comment was addressed by adding descriptions of how water usage was distributed spatially across county/aquifer footprints for non-surveyed estimates (such as livestock and non-surveyed municipal). This was addressed throughout Section 4.

9. Section 3.1: Please specify which TWDB program areas develop water use estimates in each water use category. The Conservation department develops the irrigation estimates. The non-surveyed livestock and non-surveyed mining water use estimates (including fracking) are developed by the Projections and Socioeconomic Analysis department. The program areas enter the information in the Water Use Survey Database. Please see the table below for detailed information on which program area is responsible for providing estimates for each water use category. (WSP)

Water Use Category	**Surveyed?**	**Estimated by TWDB staff? + responsible program area**
Municipal: PWS	**Yes**	
Municipal: non-system (domestic) use		**Yes** – by Water Supply & Infrastructure - Water Supply Planning division - Water Use and Planning Data department
Irrigation		**Yes** – by Water Science & Conservation - Conservation & Innovative Water Technologies division - Conservation department
Livestock	**Yes** (fish hatcheries only)	**Yes** – by Water Supply & Infrastructure - Water Supply Planning division - Projections & Socioeconomic Analysis department
Manufacturing	**Yes**	

Mining	**Yes** (aggregate/surface mining facilities)	**Yes** – by Water Supply & Infrastructure -Water Supply Planning division **-** Projections & Socioeconomic Analysis department (oil and gas only)
Steam-Electric	**Yes**	

Text and table have been added to Section 3.1 as described in comment 9.

10. Please discuss why the analysis of irrigation pumping versus land use, number of wells, or precipitation were only conducted for selected counties. You responded to this comment in the previous report stating that "only included discussion where we deemed it meaningful to the analysis". Please discuss how to determine when to include these additional analyses and provide a clear set of criteria or conditions that trigger this approach. This could be utilized by TWDB staff because this approach will still require manual investigation and judgment in identifying which method to use for each case. (WSP)

Comment was addressed in Section 3.2.4.

11. The anomaly analysis looks at surface water components selectively. Please discuss further when the surface water or total demands should be included in your evaluation. (WSP)

Comment was addressed in Section 4.2

Specific comments to be addressed

12. In Section 1, please include discussion on how other factors could also cause inconsistency or significant fluctuation in pumping data including weather, precipitations, economy (crop, oil prices), etc. (WSP)

Comment was addressed in Section 1.

13. Section 1, page 1, paragraph 2: Please change "One source of pumping…." to "One major source of pumping…" (WSP)

Sentence has been revised as described in comment 13.

14. Figure 2: Please include in legend or caption GCD and UWCD spelled out (CR)

Explanations for abbreviations have been added to figure captions.

15. Section 2.1.1, Page 6: Please use the reference order as it appears in the text. TWDB, 2020g is the first citation for the TWDB, 2020 series. (KC)

Comment was not addressed as citations were continuously re-ordered through document editing, and were automatically assigned references within the Microsoft Word referencing functions.

16. Section 2.1.1, page 7, paragraph 2: Please include a short description of each United States Geological Survey report listed including time frame available. (WSP)

Comment was addressed within Section 2.1.1 by providing an annotated spreadsheet of requested reference data along with the electronic deliverables to this project. The spreadsheet file is named "4014TDB03 – Pumping Data Research.xlsx".

17. Section 2.1.2: Please describe the output of your outreach efforts included in this section. (WSP).

Comment was addressed in Section 2.1.2.

18. Section 2.1.4, Page 10: Please list the references in the order it appears in the text and revise the list of references as appropriate. For example, is cited TWDB, 2020c before TWDB, 2020a on this page. (KC)

Comment was not addressed as citations were continuously re-ordered through document editing, and were automatically assigned references within the Microsoft Word referencing functions.

19. Table 1: Please change *1,000,000,000* to *100,000,000* under "Source Data Base Identification and Modification". (KC)

Table has been revised as described in comment 19.

20. Section 2.2, page 11-12: Please include discussion of when wells were taken out of operation – capped wells. (CR)

Comment has been addressed in Section 2.2.

21. Section 2.2, page 11, Table 2: Please revise the text to indicate that the use category used in this table is not consistent with the TWDB water use survey pumping data. The most current water use survey category indicates the following: commercial is included in municipal not manufacturing; golf courses using self-supplied groundwater is included in irrigation; steam-electric power plants that generate and sell electricity are included in steam-electric power; co-generation plants with manufacturing NAICS associated are included in manufacturing. (WSP)

Comment has been addressed in Section 2.2.

22. Section 3, page 15, paragraph 3, sentence 2; Subsection 'Surveyed and Non-Surveyed Municipal Water Use', page 33, paragraph 1, sentence 1 and paragraph 2, sentence 2: Text refers to Section 0, please update to appropriate section in the report. (CR)

Section numbers have been updated as described in comment 22.

23. Section 3, Page 15: The first paragraph states "56 counties included in our study area". In the third paragraph, 52 counties in Section 3.3 and three counties in Section 3.4 which is 55 counties. Please revise the text for consistency. (KC)

Text in section 3.4 has been revised to include Mitchell County; thus, there are four counties without pumping data, 52 counties with pumping data, for a total of 56 counties.

24. Section 3, page 15: Please change "3. Survey Evaluation" to "3. Water Use Survey Evaluation" (WSP)

The section title has been revised as described in comment 24.

25. Section 3, page 15, paragraph 2: Please add introduction to the water use survey here and why this is important in this study. (WSP)

A paragraph introducing the Water Use Survey was added to the beginning of Section 3.

26. Section 3, page 16: Please change "TWDB staff compile the information received from approximately 7,000 annual surveys, as well as water use estimates for irrigation, livestock, mining, and rural domestic purposes to generate the Water Use Survey data which the TWDB uses for water resources planning (TWDB, 2020c)" to "TWDB staff compile the information received from approximately 7,000 annual surveys from public water systems and industrial facilities and estimate water use for irrigation, livestock, mining, and rural domestic purposes to generate historical water use estimates which the TWDB uses for water resources planning (TWDB, 2020c)" (WSP)

The text has been revised as described in comment 26.

27. Section 3.1, Page 17, Paragraph 4: Please change "TWDB staff (2021)" to "TWDB (2021)" where it appears in the text. (KC)

The text has been revised as described in comment 27.

28. Section 3.1, page 17, paragraph 2: Please change "…categories on annual surveys of public water suppliers and major manufacturing and power producing entities" to "…categories on annual surveys of public water suppliers and major manufacturing, non-oil and gas mining and power producing entities" (WSP)

The text has been revised as described in comment 28.

29. Section3.1, page 17, last paragraph and Page 19, Table 5: Please make the descriptions consistent. (WSP)

Comment was addressed within Section 3.1 with additional clarifying language provided.

30. Section 3.1, Page 18, paragraph 3: Please change "…the estimated water use per animal from the Texas A&M AgriLife Research" to "…the estimated water use per animal from the Texas A&M AgriLife Extension and various research." (WSP)

The text has been revised as described in comment 30.

31. Section 3.1, Page 18, Table 3: All surveyed water uses are self-reported. Please add 'self-reported to all categories. Additionally, the descriptions for irrigation and mining are not consistent with the content of the section. Please indicate the time frame reflected in this table (the most current method? Or as of 2020). (WSP)

Comment addressed through revisions to Table 3.

32. Section 3.1, Page 18, paragraph 2: Please revise the text to indicate that consumed water volumes are calculated based on self-reported consumptive use volume percent data instead of power plant configuration. (WSP)

The text has been revised as described in comment 32.

33. Section 3.1, Page 18, last paragraph: Please add the following statement: "Estimated oil and gas water use for fracking activities have been based on water use volumes collected through the FracFocus database since 2012." (WSP)

The additional statement was added as described in comment 33.

34. Section 3.1, Page 20, Table 6: Please change "A combination of reported water use by various entities and additional estimates based on prior-year research" to "A combination of reported water use by various entities and hydraulic fracturing use estimates from FracFocus database" (WSP)

The text has been revised as described in comment 34.

35. Section 3.1, Page 20, last paragraph: Please change "other research conducted by Texas Agricultural Experiment Station" to "other research conducted by the Texas A&M AgriLife Extension and other researchers." (WSP)

The text has been revised as described in comment 35.

36. Section 3.1, Page 21, Table 7 (2003-present): Please revise the following statement for clarity: "TWDB staff changes resulted in inconsistent calculation methodologies, yet year-to-year consistency improved after 2004." (WSP)

Statement was removed as we were unable to describe how year to year consistency was improved, or to attribute this statement to a specific TWDB staff member. This statement was provided to us by TWDB and was included within the Task 1 report for this work, approved by TWDB.

37. Section 3.1 Page 17, Paragraph 1, Sentence 2: This sentence is incorrect. TWDB conducted annual surveys prior to 1984, as well as summaries of estimated pumpage prior to 1984 (in conjunction with State Water Plans and reports to legislature). In 1984, the Water Use Survey began to annually summarize surveyed data and estimated pumpage. Please reword sentence to be accurate. (CR)

The text has been revised as described in comment 37.

38. Section 3.1, Page 17, Paragraph 2, Sentence 1 and Sentence 2: Please note that TWDB supplements summaries of municipal and industrial with estimated use for entities not surveyed. These estimates may be supplemented with special studies (such as for mining) or other approaches. Texas Water Code requiring surveyed entities to complete and return the survey to TWDB did not apply in early phases of the Water Use Survey Program. This requirement was enacted in the 77th Legislation, Senate Bill 2, effective September 1, 2001. (CR)

The text has been revised as described in comment 38.

39. Section 3.1, Tables 3 and 7. Please note that approaches for estimates for irrigation have varied throughout time. Please see the following summary and please update Tables 3 and 7 text as needed: (CR)

    <u>Irrigation Surveys (1958-2000)</u>

    From 1958 to 2000, irrigation surveys were conducted through a joint effort between TWDB and the U.S. Department of Agriculture's–Natural Resources Conservation Services (NRCS). Through this partnership irrigated acres, on-farm crop irrigation application rates, and irrigation survey maps were developed for every county in the state. The first map was based on the 1958 irrigation season; it was reproduced every 5 years from 1964-1994 and then for the last time in 2000. The Agricultural Water Conservation Department maintains the data and maps from those surveys, for historical reference.

    <u>Annual Estimates between Surveys (1985-2000)</u>

    TWDB estimated irrigation in 1984 for the State Water then from 1985 to 2000, staff began estimating on-farm irrigation water use every year. The estimates were calculated based on per-acre irrigation water use estimates, varying by crop, provided by the NRCS, and irrigated acreage data obtained from the Texas Agricultural Statistics Service (TASS). Where there were gaps in the TASS county data, staff referred to the most recent 5-year NRCS on-farm irrigation survey.

    <u>Transition Period (2001 & 2002)</u>

    After 2000, the NRCS was no longer able to perform the on-farm irrigation survey. From 2001 to 2002, staff estimated on-farm irrigation water use based on data from the NRCS' 2000 on-farm irrigation survey, TASS irrigated acreage data, and then adjusted for rainfall conditions.

> <u>*TWDB Methodology (2003-2009)*</u>
>
> *Beginning in 2003, TWDB entered into an agreement with the U.S. Department of Agriculture's Farm Service Agency (FSA) to get acreage data for irrigated crops in each county of the state. It is important to note that after that, starting in 2003, water use estimates were no longer just on-farm irrigation water use estimates. Staff started accounting for conveyance loss, wastewater reuse, and included more non-traditional crop types (e.g. golf courses). In some regions, staff estimated irrigation application rates based on an evapotranspiration data from weather stations maintained by the Texas A&M AgriLife Research and Extension Service. Staff obtained surface water permit data for irrigation water releases/diversions from the Texas Commission on Environmental Quality (TCEQ). Staff compared annual irrigation estimates to TASS data. Staff requested that Texas groundwater conservation districts review and comment on annual draft irrigation estimates.*
>
> <u>*Current Methodology (2010 – Present)*</u>
>
> *Expanding upon the 2003–2009 methodology, staff began utilizing geographic information systems to refine irrigation rates based on quantitative adjustment factors derived from gridded climatological data. Remote sensing is also used to improve geographic allocation of reported surface water diversions and irrigated acres. Staff compares annual irrigation estimates to more and more external sources of data when they become readily available: U.S. Department of Agriculture's National Agricultural Statistics Service, Agricultural Census, Farm and Ranch Irrigation Surveys, and the U.S. Geological Survey irrigation water use reports. Staff encourages comments and revisions of the irrigation estimates by qualified local irrigation water experts, in addition to groundwater conservation districts (e.g. irrigation districts). (excerpts from internal draft work process document)*

The tables have been updated to incorporate information provided in comment 39.

40. Table 5, Page 19: The "Non-surveyed Municipal Use Milestones" are transposed for the years noted. Please update the table to note that, "…block-level census data…" is the approach used for 2010-present and that," County-wide number of total connections…" applies to Historical – 2010. (CR)

Table 5 has been revised as described in comment 38.

41. Table 7, Page 21, Row 1981-1983: TWDB did not estimate irrigation values using linear regression. Online downloads of historical summaries by counties are not an option for 1981-1983. Please remove this sentence. (CR)

Sentence has been removed.

42. Table 7, Page 21, Row 1985 - 2002: TWDB estimated irrigation in 1984 for the State Water Plan and then annually from then on. Please rephrase this from 1984 -2000. (CR)

Comment was addressed as requested.

43. Section 3.1, Page 20, Paragraph 1, Sentence 5: Please change "2002" to "2000". (CR)

The year has been revised as described in comment 43.

44. Section 3.1, Page 21, Last Paragraph, Sentence 3: Mandatory Water Use Surveys became law September 1, 2001 (https://capitol.texas.gov/tlodocs/77R/billtext/html/SB00002F.htm) Please remove, "For example, increased groundwater pumping reported for municipal and industrial uses in the year 2000 is possibly influenced by the Water Use Survey becoming mandatory in 1999." (CR)

Sentence has been removed.

45. Figure 367, Page 461: Please correct spelling of Val Verde County in figure legend. (CR)

Spelling has been corrected in figure legend.

46. Section 3.2.2, Page 24, last paragraph: The content states "While we found our selected thresholds were reasonably applicable across the study area, they may not be equally applicable within other portions of Texas. Adjustment of the thresholds may be justified for specific areas with relatively low pumping amounts to address potential sensitivity to relatively small changes in pumping". Please describe in more detail how this should be adjusted (based on any pumping threshold or range) by water use category defining "relatively low pumping & relatively small changes in pumping". (WSP)

Comment addressed in Section 3.2.2

47. Section 3.2.4, Page 28, paragraph 2 below the bullet list: Please elaborate why these other data evaluations are not proved to be universally beneficial for these analyses. (WSP)

Comment addressed in Section 3.2.4.

48. Section 4.1.2: Please look at Hutson and others, 2004 for rural capita use coefficients. (CR)

Comment was addressed by further reviewing the provided reference. No changes to the provided analysis or pumpage estimates were made. Hutson and others (2004) provides state totals (self-supplied domestic water for Texas in 2000 is 131 Mgpd or 147,000 ac-ft/year but does not break it down by county. The source data for Hutson and others (2004) does not contain rural capita use coefficients for Texas counties.

49. Section 4.2: Please address the following issues in the text: (AD)

    a. The proposed methodology does not exclude dryland farming from their estimation of irrigation demand. This is important because there is a significant amount of dryland production in the study area.

    b. Pecos county is not a fair sample of the study area to test this methodology it is a best-case scenario because agricultural fields are accurately identified remotely in this arid county and there is a smaller percent of dryland production.

    c. TWDB irrigation estimates are based on crop acreage. Please note that a 100-acre field with two crops in a year would be calculated as 200 acres.

    d. In estimating irrigation demand, runoff and soil moisture availability should not be disregarded. Effective precipitation is a critical factor, precipitation in too large or too small events is lost to runoff or evaporation, respectively, and has little effect on the crops.

    e. The proposed irrigation estimate data should be in agreement with local groundwater conservation district data in order to be defensible and accepted.

Comment is addressed in Section 4.2, in Section 5.2.36, and in Section 6.

50. Section 4.2, Page 468, paragraph 2: The text states “we developed refined estimates of where crops are planted within the study area”. This is the most challenging part of the entire irrigation water use estimating process. Please describe how it was done for each year back to the 1980s. (WSP)

Comment addressed in Section 4.2.

51. Section 4.2, Page 468, Paragraph 3: Please discuss how the method to address Water Use Survey irrigation anomalies factors or does not factor when farmers plant summer and winter crops, discussed on page 470. (CR)

Comment addressed in Section 4.2.

52. Section 4.3, Page 478, paragraph 4: Net generation was used in this methodology. Please describe how you handled negative net generation values. (WSP)

Comment addressed in Section 4.3.

53. Section 4.3, Figure 380: As was done for assessing the anomaly methodology for mining water use, please review the demand projection methodology for the steam-electric power use category for assumption similarities (e.g., fuel-type usage). The associated Work Process Document and projection methodology from the Water Supply Planning Division is included with these comments for the contractor to review. Please review the documents to see how mining, livestock, and steam-electric water use are estimated for the future. (WSP)

Comment was not addressed as estimating future demands was outside the scope of work for this project, which focused entirely on assessing pumpage from 1984-2018.

54. Section 4.3, Figure 381: The figure title is on the separate page. Please revise to report formatting to correct his. (WSP)

Comment addressed as requested.

55. Section 4.3, Page 482, paragraph 4: The content states that only net power generation values are publicly available from EIA. Please note that the gross generation values for major power sellers are available from EIA table - Form EIA-923, Power Plant Operations Report. (WSP)

The text has been revised to include "We used net generation instead of gross generation to estimate groundwater pumpage because it was available for the entire study period from 1984 to 2018 whereas gross generation values are only available from 2011 onwards."

56. Table 62: Please indicate the units for water use in this table. (KC)

Comment addressed in label for Table 62.

57. Section 4.4, Page 484, paragraph 4: Please revise Method 2 to explain how water volumes by source are calculated. (WSP)

Comment addressed in Section 4.4.

58. Section 4.4, Page 488: Please note that TWDB staff calculate total non-surveyed oil and gas water use estimates based on FracFocus data and apply estimated water source split percentages (groundwater/surface water and brackish/fresh) from the 2012 BEG Study (Nicot). (WSP)

Comment addressed in Section 4.4.

59. Section 4.5, Page 493, Last sentence: Text indicates including option for writing applicable multi-aquifer well package. Please clarify if this applies to all categories or just Manufacturing. (CR)

The text has been revised to include "in all use categories" as described in comment 59.

60. Section 4.5, Pages 493 to 499; It is unclear how anomalies in manufacturing will be estimated in areas of the test county or other counties in the study area. Please expand on the approach, other than combination of manufacturing and mining analysis. (CR)

The text has been revised as described in comment 60 to expand on the approach.

61. Section 4.6, Page 500, paragraph 2: Please change “Texas Department of Agriculture livestock population reports” to USDA-NASS and change “Data is typically compiled by the TWDB Conservation Division” to “Data is typically compiled by the TWDB Projections and Socioeconomic Analysis department”. (WSP)

The text has been revised as described in comment 61.

62. Section 4.6, Page 502, last sentence: Please describe how the TWDB surface water estimates were investigated. (WSP)

Comment was addressed in Section 4.6.

63. Section 4.6, Page 500, Table 64: Please note that the TWDB Projections and Socioeconomic Analysis department has been updating per-animal water use over time as better data become available. For example, water use for chickens has been adjusted due to more cooling systems used in facilities. The TWDB staff estimates water use for beef cattle and dairy cattle separately using different water use units. (WSP)

The additional information in comment 63 was added to Section 4.6 paragraph 2.

64. Section 4.6, Page 502: Please note that USDA-NASS conducts an annual survey between Census years and TWDB staff estimates livestock inventory using the survey data. (WSP)

The text has been revised as described in comment 64.

65. Section 5.1.1, Page 507: Please use upper case for the first letter of “water use survey”. (KC)

The text has been revised as described in comment 65.

66. Section 5.1.5, Page 511: Please elaborate on the reason for using method #1 for mining estimate again, as it was ruled out from analysis in Section 4.4. (KC)

Method #1 was not ruled out from being used in the mining estimate as indicated by Figure 385 (page 487). Our methodology considered estimates from both modified BEG and USGS. In general, we used the more conservative pumping values estimated by the different methods when a significant information gap was identified.

67. Figure 402: Please revise this figure to make the legend legible. (KC)

The figure was revised to make the legend legible.

68. Section 5.1.5, Page 512, last sentence: Please specify the data source of the surface water mining use data. The referenced website does not list the information specifically. (WSP)

The location of the surface mines was obtained from the referenced website and is presented in Figure 402. Water use estimates for these mines were obtained using outreach efforts to the mine staff as well as using the information provided in the groundwater database maintained by TWDB. The process is described in the report.

69. Section 5.1.5, Page 514, last paragraph: The content states "To identify the data gaps, we assumed that the Water Use Survey does not consider estimates of fresh groundwater pumping due to oil and gas usage whereas the U.S. Geological Survey database accounts for all the mining usage estimate including oil and gas.". This statement is incorrect. Please revise the text to state that the TWDB staff estimated total fracking water use and applied the water source split ratio from the 2012 BEG study. Here is the data used by TWDB staff since 2012. (WSP)

Play	Play ID	GW-fresh	SW-fresh	Reuse	Brackish
Anadarko	1	40%	10%	20%	30%
Barnett	2	18%	74%	5%	3%
Bossier	3	67%	29%	5%	0%
Eagle Ford	4	72%	8%	0%	20%
Haynesville	5	67%	29%	5%	0%
Miscellaneous	6	74%	18%	5%	3%
None	9	74%	18%	5%	3%
Olmos	7	72%	8%	0%	20%
Permian	8	68%	0%	2%	30%
Permian-Far West	10	20%	0%	0%	80%

Comment addressed in Section 5.1.5.

70. Section 5.1.5 Mining: Please revise the text to clarify how surface water mining use data was estimated. (WSP)

Acknowledged. Text has been updated in the report.

71. Section 5.1.6: Please describe your method to link manufacturing facilities and wells in the TWDB groundwater database and the Submitted Driller's Reports database. (WSP)

The text has been revised as described in comment 71. The following text was added at the end of the second paragraph: "If there had been a change in entity ownership, the wells were typically listed in the databases under another owner's name with the same TWDB survey number. In this way, we were able to track well locations in the TWDB databases even though there had been changes in ownership over time."

72. Section 5.2.1, Pages 517 to 521: Please note that the footprint for the Ogallala and Pecos Valley was changed midway through this analysis and much of the pumping originally contributed to the Ogallala was switched to the Pecos Valley. To adjust for this reallocation much of the pumping allocated to the Ogallala in earlier periods of the pumping should be reallocated to the Pecos. The analysis suggests the opposite was done (Figure 405). Please revise the calculations to reflect these changes and revise the associated text. (CR)

Comment was addressed in Section 5.2.1.

73. Figure 438: This figure is missing from the text, please add. (IJ)

The figure has been added as described in comment 73.

74. Figure 439, Page 558: Text refers to livestock not listed in figure. Please update figure so text and figure coincide. (CR)

The figure has been added as described in comment 73, which also addresses comment 74.

75. Figure 440: This figure is not cited in the text. Please delete the figure or add a citation in the text. (IJ)

The figure has been cited as described in comment 75.

76. Figure 447: This figure is cited in the text before Figure 446. Please renumber these two figures and revise the text accordingly. (IJ)

The text has been revised as described in comment 76.

77. Page 529: Figure 410d is not for manufacturing. Please revise the figure or text to correct this error. (KC)

The text has been revised as described in comment 77. There was no pumpage for manufacturing from the Edwards-Trinity (Plateau) in Bandera County.

78. Figure 424, Figure 425: Figures were not mentioned in the text. Please delete the figure or add a citation in the text. (KC)

The text has been revised as described in comment 78.

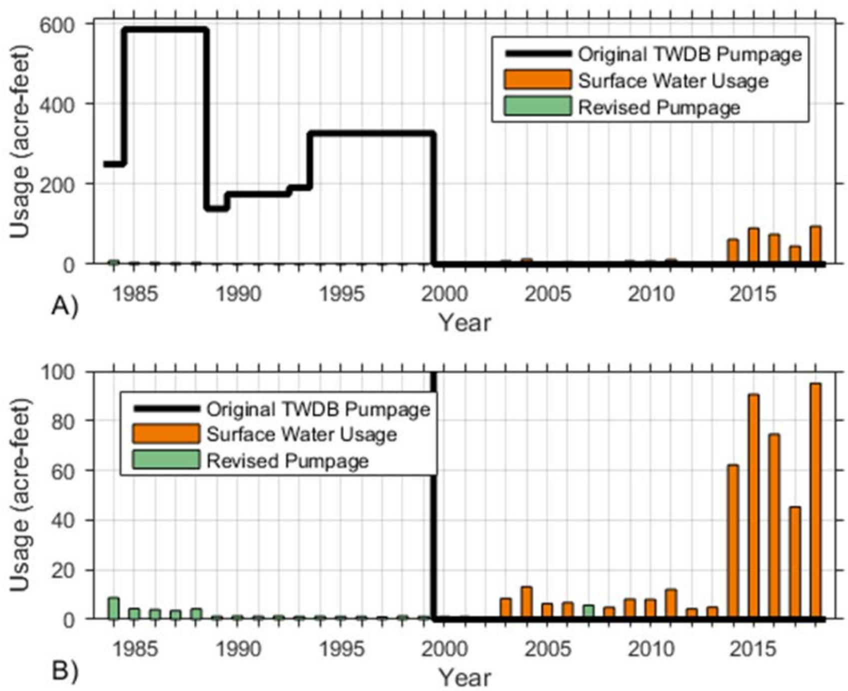
79. Section 5.2.4, Surveyed Municipal: "Further research is recommended to verify whether the pumping that was undertaken…" Please conduct this research and included in this study or explain why it should be included within a separate study. (KC)

Comment was addressed in Section 5.2.4.

80. Section 5.2.4, Manufacturing, Page 546: Please explain the reason for applying lower values that were reported in 2006 to the prior years? (KC)

The text has been revised in Section 5.2.4 as described in comment 80.

81. Figure 437, Page 556: Please specify the difference between A and B in this figure. (KC)



Comment is addressed in Section 5.2.6 as requested.

82. Section 5.2.7, Page 558: Please correct the error text that appears instead of Figure 438. (KC)

The figure has been added in Section 5.2.7 as requested in comment 82.

83. Section 5.2.9, Irrigation, Page 565: The citation for Figure 447 appears before Figure 446 in the text. Please renumber the figures and revise the citations. (KC)

The figure captions and citations have been revised as described in comment 83.

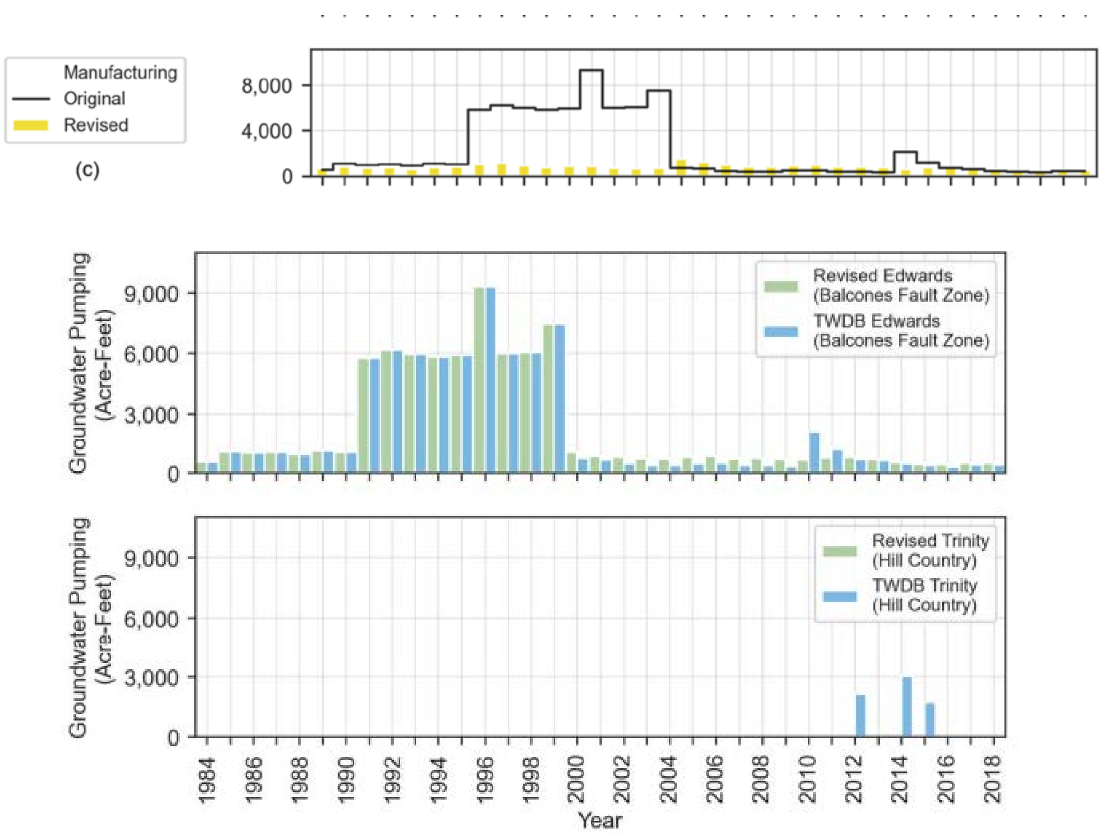
84. Section 5.2.10, Surveyed Municipal, Page 569: Please change "Edwards Trinity (High Plains)" to "Trinity (Hill Country)". (KC)

Comment was addressed in Section 5.2.10.

85. Section 5.2.10, Manufacturing, Page 573: Figure 448c shows significant drops in pumping for manufacturing from Edwards (BFZ) Aquifer. Please elaborate on the reasons in the text. (KC)

The text in Section 5.2.10 has been revised as described in comment 85.

86. Figure 448, Page 568: Figure 448c doesn't match with Figure 395 in Section 4.5. Please revise the figures as appropriate to correct this inconsistency. (KC)



Comment was addressed in Section 5.2.10.

87. Section 5.2.11, Livestock, Page 579: Figure 454 is not cited in the text. Please add discussion of Lipan Aquifer pumpage in Concho County. (KC)

Figure and text have been revised as described in comment 87.

88. Section 5.2.13, Irrigation, Page 587: Water needs from the Pecos Valley Aquifer were 0 to 8 acre-feet, but there are no wells in the Pecos Valley Aquifer footprint. Please explain how the water volumes were handled. (KC)

Comment was addressed within Section 5.2.13.

89. Section 5.2.13, Page 591, Paragraph 1: Please change “Figure 69” to “Table 69”. (KC)

Text has been revised as described in comment 89.

90. Section 5.2.14, Non-Survey Municipal, Page 594: The original pumping in Figure 473 is different from the one in Figure 471d. Please explain the differences or revise the figures as appropriate. (KC)

Comment addressed in Section 5.2.14.

91. Section 5.2.14, Irrigation, Page 595: Figure 474 is different from irrigation in Figure 472. Please revise the figure as appropriate for consistency. (KC)

Comment was addressed in Section 5.2.14.

92. Section 5.2.14, Mining, Page 596: The text in this paragraph is inconsistent with Figure 471b. Please revise the text or figure for consistency. (KC)

This comment appears to be for 5.2.13 Culberson County. Our methodology considered estimates from both modified BEG and USGS. USGS mining-use data primarily influenced the final mining use estimates in Culberson County since it provided the more conservative (larger) estimate. With the electronic deliverables to this report, we have included

93. Section 5.2.14: The irrigation pumpage estimates for Culberson County seem very high considering that just a small area of the Edwards-Trinity (Plateau) Aquifer occurs along the eastern border of the county. Please review these estimates and revise or justify why they are so high. (IJ)

Comment is addressed in Section 5.2.14.

94. Section 5.2.15, paragraph 1: Please change “… and Figure 477 …” to “… Figure 478 …”. (IJ)

Text has been revised as described in comment 94.

95. Section 5.2.15, paragraph 6: Please change “1898” to “1989”. (IJ)

Text has been revised as described in comment 95.

96. Section 5.2.15, Surveyed Municipal, Page 600: Please explain the acronym, MHP. (KC)

Northgate MHP refers to Northgate Mobile Home Park. Text has been revised as described in comment 96.

97. Section 5.2.15, Mining, Page 607: The different patterns found between the number of enhanced oil recovery wells and the pumping volume. enhanced oil recovery wells increased from 15 to 1017, pumping volume is fairly stable. This case was found in many other counties as well. Please explain the situation. (KC)

This comment appears to be for Ector County based on the EOR well counts reported. The reported well counts were incorrect. The correct well counts are 539 in 1980 and 850 in 2000. The pumping use associated with EOR wells has a correlation with the number of EOR wells. However, the water well use per EOR well has changed significantly over the years and is also based on the type of EOR well (BEG, 2012). Furthermore, our methodology considered estimates from both modified BEG and USGS.

98. Section 5.2.15, Mining, Manufacturing, Page 607: Please correct the figure and table numbers cited in these sections. (IJ)

Comment has been addressed in Section 5.2.15.

99. Section 5.2.15, Livestock, Page 607: Please correct the figure and table numbers cited in these sections. (IJ)

Figure number has been revised as described in comment 99.

100. Section 5.2.16, Mining, Page 611: Please change Figure 486b to Figure 486d. (KC)

Figure number reference has been revised as described in comment 100.

101. Section 5.2.16, Manufacturing, Page 612: Please cite a figure number. (KC)

Figure number reference has been added as described in comment 101.

102. Section 5.2.17, Page 614: Please delete “Figure 417”. (IJ)

Extra text has been deleted as described in 102.

103. Section 5.2.17, Mining, Page 618: Please clarify in the text whether the percent for each aquifer is based on the total pumping after allocating the pumping volume over the study years. (KC)

Yes. That is how the percent pumping for each aquifer has been reported.

104. Section 5.2.18, Mining, Page 625: Please explain why the enhanced oil recovery wells increased from 15 to 1017 while the pumping volume is not following the pattern. (KC)

This comment appears to be for Ector County based on the EOR well counts reported. The reported well counts were incorrect. The correct well counts are 3,523 (1984) and 4,472 (2018) for Edwards-Trinity aquifer and 314 (1984) and 475 (2018) for Pecos Valley aquifer. For more information, a table has been provided that lists the number of EOR wells tagged to each aquifer for the years 1984 and 2018 based on the information provided in the RRC database.

105. Section 5.2.19, Page 629: Please include a more detailed explanation for the differences between computed and original TWDB irrigation pumpage estimates. (IJ)

Comment is addressed within Section 5.2.19.

106. Section 5.2.20, Irrigation, Page 635-637: The statements made in the text do not correspond with the data in Figures 511 and 512. Please revise the text and the figures for consistency. (KC)

Comment is addressed within Section 5.2.20.

107. Section 5.2.20, Power, Page 639: Please change Figure 515c to Figure 515b. (KC)

Figure reference has been fixed as described in comment 107.

108. Figure 518: Please revise the figure caption to explain the significance of (a) and (b). (IJ)

Comment was addressed in Section 5.2.21.

109. Section 5.2.22, Livestock, Page 651: Please include the discussion of livestock pumping in the Lipan Aquifer. (KC)

Comment addressed in section 5.2.22.

110. Section 5.2.23, Non-Surveyed Municipal, Page 653: For the last sentence "However, our estimates do not…", please discuss the reason for not including the pumping from the Pecos Valley Aquifer. (KC)

There were no reported domestic wells within the Pecos Valley Aquifer outcrop, and therefore, no estimated domestic water use.

111. Section 5.2.24, Mining, Page 660: Figure 528b refers to livestock pumping. Please revise Figure 528 to include mining pumpage. (KC)

Text has been revised in Section 5.2.24 as described in comment 111.

112. Section 5.2.24, Livestock, Page 661: Please change Figure 528a to Figure 528b. (KC)

Figure reference has been revised as described in comment 112.

113. Section 5.2.25, Irrigation, Page 665: Text for irrigation pumpage from the Edwards-Trinity (Plateau) Aquifer and Figure 537 doesn't match. Please revise for consistency. (KC)

Text has been revised to match the figure.

114. Section 5.2.25, Manufacturing, Page 667: Please include the explanation in Figure 533c (Manufacturing from the Trinity HC Aquifer). (KC)

Text has been revised in Section 5.2.25 as described in comment 114.

115. Section 5.2.25, Livestock, Page 667: Please elaborate any insight on the difference of estimates between revisions and TWDB Water Use Survey. (KC)

Figures and text have been revised in Section 5.2.25 as described in comment 115.

116. Section 5.2.26, Irrigation, Page 669: Please change "Trinity (Hill Country) Aquifer" to "Edwards-Trinity (Plateau) Aquifer". (KC)

Text has been revised as described in comment 116.

117. Section 5.2.26, Livestock, Page 671: Please correct the error text. (KC)

Text has been revised as described in comment 117.

118. Section 5.2.26, Page 671: "Trinity (Hill Country) Aquifer" is an incorrect aquifer name in Kinney County. Please replace with Edwards-Trinity (Plateau) Aquifer. (KC)

Comment was addressed in Section 5.2.26.

119. Section 5.2.27, Irrigation, Page 674: The pumpage volume drops over 10 order magnitude. Please elaborate on the best possible reasons for this difference between the revision and the TWDB database. (KC)

Comment was addressed in Section 5.2.27.

120. Section 5.2.27, Livestock, Page 677: Trinity (Hill Country) Aquifer is an incorrect aquifer name. Please replace with Edwards-Trinity (Plateau) Aquifer. (KC)

Text has been revised as described in comment 120.

121. Section 5.2.28, Mining, Page 680: Enhanced oil recovery wells remains similar from 1980 to 2020. Pumping increased 4 times. Please elaborate on the reasons for the rising pumping. (KC)

This comment appears to be for Loving County. There were 94 active EOR wells in Loving County in 1980 which increased to 105 wells by 2020. The EOR well counts were 111 and 106 for the years 1984 and 2018 respectively. Our methodology considered estimates from both modified BEG and USGS. In 2010, there is a spike in the estimated pumping using the modified BEG method which is observed in our final estimates. From 2015 onwards, USGS estimates are significantly higher and cause a rise in the final estimates.

122. Section 5.2.29, Livestock, Page 683: This paragraph contradicts Figure 551a. Please revise the text or figure for consistency. (KC)

Text has been revised in Section 5.2.29 as described in comment 124.

123. Section 5.2.31, Municipal, Page 688-689: Please clarify whether pumping is from “Other Aquifer” or “Edwards-Trinity (Plateau) Aquifer”. (KC)

Comment has been addressed in Section 5.2.31.

124. Section 5.2.31, Manufacturing, Page 692: Please change “Figure 555b” to “Figure 555c”. (KC)

Text has been revised as described in comment 124.

125. Section 5.2.32, Surveyed, Page 694: Please add discussion about the update on the Trinity (HC) pumping. (KC)

Comment has been addressed in Section 5.2.32.

126. Section 5.2.32, Livestock, Page 699: Please revise the last sentence for consistency with the graphs. (KC)

Comment has been addressed in Section 5.2.32.

127. Section 5.2.32, Livestock, Page 699: Please propose an explanation for the sudden increase in livestock pumpage starting in 2005. (IJ)

LRE reviewed the data used to determine the estimate presented and found a slight mistake with the revised estimates for livestock distribution. The Figure has been revised in Section 5.2.32 as described in comment 127 and no longer has a sudden increase in livestock pumpage in 2005.

128. Section 5.2.34, Non-Surveyed, Page 706: Please provide insights into the significant difference between the TWDB Water Use Survey and the revision. (KC)

There is a large domestic use for the county but the majority of it is from the Ogallala aquifer. Only 3% of the reported domestic wells are within the ETP so the domestic use for the ETP was only 3% of the total domestic use for Midland County.

129. Section 5.2.36, Page 714: Remove the duplicate Figure 576 graph. (KC)

Figure has been removed as described in comment 129.

130. Section 5.2.36, Irrigation, Page 718: Please explain why there is no revised pumpage in the year 2011. (KC)

Comment addressed within Section 5.2.36

131. Section 5.2.36, Power, Page 725: The last paragraph starting with “The Rio Pecos…” is a repeating paragraph from Page 723. Please delete. (KC)

Text has been revised as described in comment 131.

132. Section 5.2.36, Mining, Page 726: Enhanced oil recovery wells number doubled, pumping volume stables. Please add an explanation for this trend. (KC)

This comment appears to be for Pecos County. In Pecos County, the number of EOR wells increased from 666 wells in 1980 to 1,257 wells in 2020. The EOR well counts were 1,043 and 1,290 for the years 1984 and 2018 respectively. Our methodology considered estimates from both modified BEG and USGS. Please note that the USGS estimates provided higher values in the initial years from 1980 to 1990 and lower values thereafter. These estimates are averaged out by the reverse trend in estimates provided by the modified BEG values which take into account the increase in EOR wells over time.

133. Figure 588, Page 731: Please complete the y-axis. (KC)

Comment has been addressed in Section 5.2.37.

134. Figure 598-599, Page 742-743: Please use the same graphic scale for the y-axis in both graphs. (KC)

Comment was partially addressed in Section 5.2.39, as graphics will not support identical scales. Graphics were revised to more appropriate scales for displaying each dataset.

135. Figure 599, Page 743: Please change "Trinity (Hill Country) Aquifer" to "Edwards-Trinity (Plateau) Aquifer" in the figure caption. (KC)

Figure caption has been revised as described in comment 135.

136. Section 5.2.39, Mining, Page 744: Please change "Figure 594c" to "Figure 594d". (KC)

Text has been revised as described in comment 136.

137. Section 5.2.40, Livestock, Page 748: Please add livestock pumping to Figure 600. (KC)

Livestock pumping is included in Figure 600b. No revisions made.

138. Section 5.2.41, Mining, Page 751: Instead of citing numbers of wells in 1980 and 2000, please cite the number of wells during the period of this study, 1984 through 2018. (IJ)

For Schleicher County: 1984 – 52 wells and 2018 – 108 wells. A separate table has been provided, that lists the number of EOR wells reported in the RRC database for the years 1984 and 2018.

139. Section 5.2.42, Non-Surveyed Municipal, Page 754: Please include the explanation of the pumping from the Lipan Aquifer. (KC)

Comment was addressed in Section 5.2.42.

140. Section 5.2.42, Mining, Page 757: Instead of citing numbers of wells in 1980 and 2000, please cite the number of wells during the period of this study, 1984 through 2018. (IJ)

For Sterling County: 1984 – 44 wells and 2018 – 97 wells. A separate table has been provided, that lists the number of EOR wells reported in the RRC database for the years 1984 and 2018.

141. Section 5.2.42, Livestock, Page 758: Please change "Runnels County" to "Sterling County". (KC)

Text has been revised as described in comment 141.

142. Section 5.2.43, Livestock, Page 762: Please change "Figure 603b" to "Figure 611b". (KC)

Text has been revised as described in comment 142.

143. Section 5.2.44, Non-Surveyed Municipal, Page 764: If the pumping assigned on the Trinity (Hill Country) moved to the Edward-Trinity (Plateau) Aquifer, please specify those updates. (KC)

There are very few domestic wells reported within the Trinity (Hill Country) Aquifer while are large portion of the reported wells are within the Edwards-Trinity (Plateau) Aquifer or Cross Timbers Aquifer. Thus, Trinity (Hill Country) Aquifer pumpage was reassigned to the Edwards-Trinity (Plateau) Aquifer.

144. Section 5.2.44, Livestock, Page 767: Please cite Figure 614b and Figure 615b in this paragraph. (KC)

Text has been revised as described in comment 144.

145. Section 5.2.46, Mining, Page 777: Enhanced oil recovery wells increased 8 times but pumping increased 2 times. Please add discussion of these trends. (KC)

This comment appears to be for Tom Green County. Our methodology considered estimates from both modified BEG and USGS. Please note that the USGS estimates provided higher values in the initial years from 1980 to 1985 and then stabilize thereafter. These estimates are averaged out by the reverse trend in estimates provided by the modified BEG values which take into account the increase in EOR wells over time.

146. Section 5.2.46, Manufacturing, Page 777: The entity "Goodyear Tire & Rubber Company" was applied in the surveyed municipal. Please clarify if there is additional pumping for manufacturing from the same entity. (KC)

Comment was addressed in Section 5.2.46.

147. Figure 638, Page 790: Please revise the y-axis units to be consistent with the other graphs in the report. (KC)

Comment was addressed in Section 5.2.48.

148. Section 5.2.50, Mining, Page 804: Enhanced oil recovery wells increased 3 times, but pumping was decreased. Please add discussion of these trends. (KC)

Assuming that this comment refers to Val Verde County. Our methodology considered estimates from both modified BEG and USGS. Please note that the USGS estimates provided higher values in the initial years till about the year 2000. These estimates are averaged out by the reverse trend in estimates provided by the modified BEG values which take into account the increase in EOR wells over time.

149. Section 5.2.50, Manufacturing, Page 805: Please cite Figure 650 in this section. (KC)

Text has been revised as described in comment 149.

150. Section 5.2.52, Mining, Page 818: Please change “Figure 659b” to “Figure 659d”. Figure 660b does not refer to mining pumping. Please delete this citation or revise Figure 660 and cite correctly. (KC)

Text has been revised as described in comment 150.

151. Figure 663: Please revise this figure moving the legend to the left so that it will not obscure the data. (IJ)

Comment was addressed in Section 5.2.52.

152. Appendix 4: Please move this appendix to follow Appendix 1. (IJ)

Comment was addressed as requested.

153. Appendix 4, Model Grid Creation (Structured) Required User Inputs: Please change “(GAM)” to “(GAM coordinate system)”. (IJ)

Text has been revised as described in comment 153.

154. Appendix 4, Toolbox Introduction & Overview: Please add the following statement, *“The toolbox was developed in ArcGIS Pro which relies on Python 3 for geoprocessing. We used this version because the MODFLOW scripting tools developed by the USGS (that is, FloPy) also use Python 3. These existing scripting tools allowed us to develop the well file tools within the current ArcGIS environment. ArcGIS version 10 uses Python 2.7 for geoprocessing. Python 2.7 is a deprecated version of the language and is not compatible with FloPy.”*. (IJ)

Text has been revised as described in comment 154.

155. Appendices: Please add page numbers to the appendices included in this report. (IJ)

Comment addressed as requested.

Draft geodatabase and data deliverables comments

General comments to be addressed

156. Please add metadata to all new feature classes added to the geodatabase. (IJ)

Comment has been addressed as requested.

Specific comments to be addressed

157. Subsection "Precipitation and Land Use Data", Pages 28 to 32: Suggest noting that anomalies with comparing groundwater irrigation to land use does not factor irrigation associated with surface water. This may approach be more applicable in West Texas where groundwater is more prominently used for irrigation than Central to East Texas (CR)

Text has been revised as described in comment 154.

158. Subsection "Well Completions", Pages 32 to 33: Suggest noting that anomalies with comparing groundwater irrigation to well completions does not factor irrigation associated with surface water. This may approach be more applicable in West Texas where groundwater is more prominently used for irrigation than Central to East Texas or for alluvial type aquifers associated with a perennial river. (CR)

Text has been revised as described in comment 154.

Suggestions for the Task 3 report

159. Tables 3 through 7: Please align description column to the left and the year column to the top for better readability. (WSP)

Tables have been revised as described in comment 159.

160. Please consider placing the surveyed and non-surveyed municipal in separate graphs since the surveyed and non-surveyed municipal pumping is discussed separately. (KC)

Due to the figure font size and figure size restrictions, we decided to combineVal surveyed and non-surveyed municipal pumping. Counties like Loving County, with all the uses, are an example of why they don't all fit in one figure and keep a consistent minimum font size and figure size.

161. Please add a Table of Contents to the navigation pane to help readers better navigate the report. (WSP)

Comment was addressed when creating the PDF document from the Microsoft Word document.

162. Please consider combining Section 4 and Section 5 - evaluation, test case and final methodology suggested for each category. It was difficult to follow the logic between Chapter 4 and 5 because Section 5 has many references to parts in Section 4. (WSP)

Comment was not addressed. This format for the final report was what appeared to be required based on our interpretation of the TWDB contract documents.

163. Please consider using the acronym for U.S. Department of Agriculture - National Agricultural Statistics Service (USDA-NASS) throughout the report. (WSP)

The text been revised as described in comment 163.

164. Please consider including a matrix table to show Land Use/Cover data classification with corresponding crop/livestock type used in the analyses. (WSP)

Comment was not addressed. Cropscape data is used for assigning crop locations within areas. Land Use/Cover data is not used for assessing livestock pumpage locations.

165. Section 3.1: The narrative characterizations of the surveyed and non-surveyed water use categories of the water use survey are difficult to consume. Additionally, some important elements of the TWDB method for estimating water use for more recent years included in the TWDB water use survey data are missing from the reports, such as estimates of fracking water use. Please consider reorganizing the section by water use category using subsections and discuss each method used for surveyed and non-surveyed estimates and include a more comprehensive description of the categorical use estimated by the TWDB, especially non-surveyed categories, including methodologies and assumptions for all categories. Please review supplemental Work Process Documents describing those methods in detail and enhance Section 3.1 to provide a better understanding of how non-surveyed water use estimates are developed by TWDB staff. (WSP)

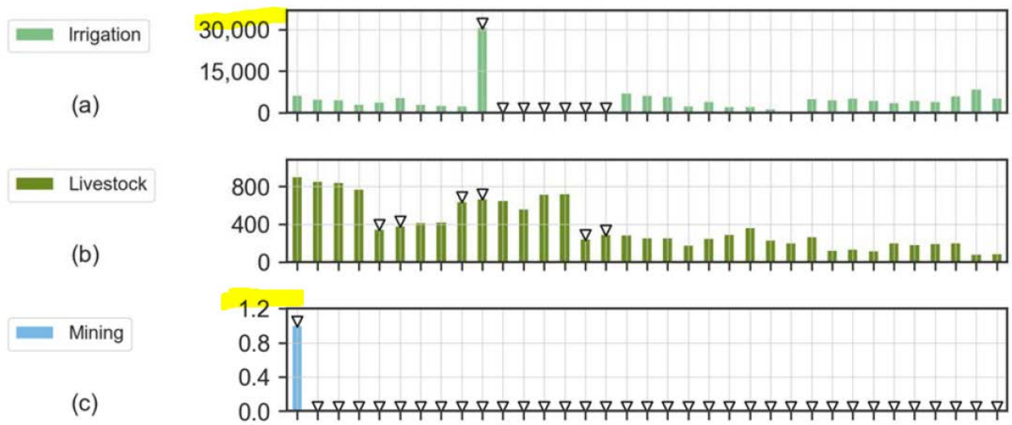
Comment was not addressed. The purpose of this project was not to document how TWDB staff develop estimates. We based the analyses presented herein on TWDB staff's documented methods.

166. We suggest tabulating key characteristics in the water use estimates so they align with the report's proposed methodologies. This will help the reader clearly understand what is currently done to estimate and project categorical use versus what is proposed by this study so consistent methodologies can be applied where appropriate. (WSP)

Comment was not addressed. We believe the report as stands is sufficiently clear to describe presented methodologies.

167. Please consider using the same scale on the Y-axis for groundwater pumping anomalies data within the county. Using different scales helps identify data inconsistencies but could

mislead readers. As shown below, a huge spike in the Mining category is negligible counting only 1.2 acre-feet compared to 30,000 acre-feet in Irrigation but is still requiring the same level of attention from the reviewer. The change would help TWDB staff to prioritize areas to review based on the magnitude of the data inconsistencies in each water use category contributing to the county total. (WSP)



Comment was not addressed. This comment was discussed during out Task 1 review. Having equal axis limits for all graphs will make most of the data invisible on the provided plots.

168. The municipal method of assigning usage based on service area could have limitations on historical data back to 1985 since boundaries could change significantly over time. Using median, average or snapshot data of a specific time frame to track back pumping data would be a reasonable approach. However, it should be noted that this could result in inconsistent data compared to actual pumpage. Please consider including discussions on assumptions and limitations of the suggested methods for addressing the inconsistency in pumping. (WSP)

Comment was not addressed. Actual pumpage is unknown, so establishing consistency is not possible.

169. Section 4.1.2, Page 465 and Figure 370, Page 466: This approach does not factor in public water supply boundaries. Would recommend excluding wells within public water boundaries. (CR)

Comment Addressed in Section 4.1.2.

170. Section 4.4, Pages 486 to 492: Suggest overlaying estimated non-surveyed mining with surveyed data as was done with previous categories. (CR)

Comment was not addressed. Section 4.4 outlined the methodology expected to be undertaken when reviewing the mining anomalies. This methodology was substantially modified during Task 3, as described in Section 5.1.5.

171. Section 2.2: Please consider including well data from the Railroad Commission of Texas used in the mining evaluation. (WSP)

Comment acknowledged. A worksheet has been provided that lists all the EOR wells that were identified to be present in the study area.

Suggestions for draft geodatabase and data file deliverables:

172. None.

Public Comments

None.