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Investigation of the Origin of Hueco Bolson and Mesilla Basin Aquifers (US and Mexico) with Isotopic Data Analysis

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Abstract: An important tool to identify the origin of a groundwater resource is the use of isotopic signatures. Isotopic signatures give us the age of water and provide information as to the water's origin, potential transit at geologic structures, source of salinization, and possible recharge points. The purpose of this study was to collect and analyze well samples to evaluate isotopic tracers ($\delta^{18}O$ and tritium) in the transboundary Conejos-Médanos/Mesilla aquifer located between the US and Mexico. This new analyzed information was compared with the isotopic information available in the US Mesilla and US-MX Hueco basins generated by previous works, which described the common origin of the Hueco Bolson and Mesilla Basins aquifers. This study used isotopic analysis to validate the theory of the original formation and interconnectivity of both transboundary basins. This research presents new data of $\delta^{18}O$ and tritium, and a comparison with previous published data from other workers, versus the known global meteoric water line (GMWL) and the Rio Grande evaporation line (RGEL). Results show that the groundwater at the transboundary aquifer features an evaporated isotopic signal, which is consistent with referenced published data that discusses the geologic history of aquifer formations at the studied area. This study is important because isotopic studies from the area were nonexistent and because isotopic data can explain recharge scenarios that relate to groundwater quality.

Keywords: isotopes; transboundary aquifers assessment; Hueco Bolson; Mesilla Basin; Conejos-Médanos/Mesilla aquifer; groundwater

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1. Introduction

In the Paso del Norte (PdN) transboundary aquifers region, located between the United States and Mexico, where New Mexico, Texas, and Chihuahua meet, the climate is semiarid. Water is increasingly scarce due to surface supply reductions caused by drought and climate change, increased demands from growing regional populations, and municipal and industrial (M&I) expansion affecting availability for environmental demands. Based on these reductions, there is an urgent need for better understanding and management of the quantity and quality of the region's scarce water resources. In this binational region, groundwater is the main source for agriculture and M&I water demands; therefore, understanding the origin of groundwater recharge is critical for better management and long-term sustainability of the basin's groundwater [1,2]. Estimation of groundwater recharge can be made via different methods, such as the general water balance approach, field measurement, or isotopic studies. The evaluation is more accurate when isotope and geochemistry methods are combined [3,4]. Isotope and geochemistry methods are complementary tools that distinguish different water sources and provide information on the origin of groundwater, age of water, residence time, and recharge points [4–7].

1.1. Isotope Study

Isotopes in water molecules work as natural tracers. The isotopic composition of continental precipitation depends on the water's origin and pathway, which begins the moment it leaves the sea in the form of evaporation and ends when the sample is collected [8]. Additionally, isotopes exist in stable or unstable forms [5,6]. Stable isotopes for oxygen are ^{16}O, ^{17}O, ^{18}O, and for hydrogen are protium (^{1}H) and deuterium (^{2}H, D). When these isotopes are combined to form a water molecule, they also provide an isotopic composition that translates into a powerful hydrology tracer. A pair of isotopes commonly used in hydrology is the $\delta^{18}O$ combination, which is compared using the global meteoric water line (GMWL) to show the percentage of isotope present in the sample.

Another isotope used in hydrology is tritium, an unstable isotope of hydrogen (^{3}H or T). In the same manner as ^{14}C, tritium originates from neutrons (n) present in cosmic rays due to nuclear reactions with nitrogen present in the atmosphere; the following chemical reaction indicates this formation $^{14}N + n \rightarrow {}^{12}C + {}^{3}H$ [9,10]. After this reaction, the tritium joins the hydrological cycle in the atmospheric part [9,10]. In hydrology, tritium has been used to distinguish new waters from old waters, because of its short half-life of 12.3 years [5,7], and its predictable timing of origin during nuclear explosions in contact with the atmosphere.

In this research, we focus on the transboundary area formed by the Hueco Bolson and Conejos-Médanos/Mesilla Basin aquifers of the middle Rio Grande watershed. Our investigation includes isotopic and geochemical data collected from the Mexican portion of the Mesilla Basin aquifer referred to as the "Conejos-Médanos Aquifer" in Mexico. These data were obtained via a comprehensive field and laboratory analysis. The analysis was compared with a similar study on the US side of the Mesilla Basin [11]. In order to cover the entire transboundary area, we also included data from the Hueco Bolson Aquifer [12]. In the conclusion section of this work, we compare our results with the study reported by Hawley and Kottlowski (1969) [13], which indicates that the waters present in the Hueco Bolson and Conejos-Médanos/Mesilla Basin aquifer were part of a single aquifer before the formation of the *Sierra de Juárez* (Juarez Mountain Range).

1.2. Rio Grande

One of the most important rivers in the US is the Rio Grande, or the Rio Bravo as it is called in Mexico (Figure 1). The Rio Grande watershed has an area of approximately 924,300 miles^2 (2,394,000 km^2) and includes regions in both the US and Mexico [14]. With a length of about 1900 miles (3060 Km), it is the 20th longest river in the world, the 5th longest river in North America, and is the 2nd longest American river after the Mississippi [15]. The Rio Grande begins in the San Juan Mountains of southern Colorado, which are part of the Rocky Mountains, and flows through New Mexico and Texas. In the south, the Rio Grande marks the borderline between the US and Mexico [16]. In Mexico, the river runs through Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas, finally ending in the Gulf of Mexico. The Rio Grande has two international dams, Falcon and La Amistad, that are managed by the International Boundary and Water Commission/Comisión Internacional de Limites y Agua (IBWC/CILA) [14]. Figure 1 shows the entire watershed of the Rio Grande from Colorado to the Gulf of Mexico.

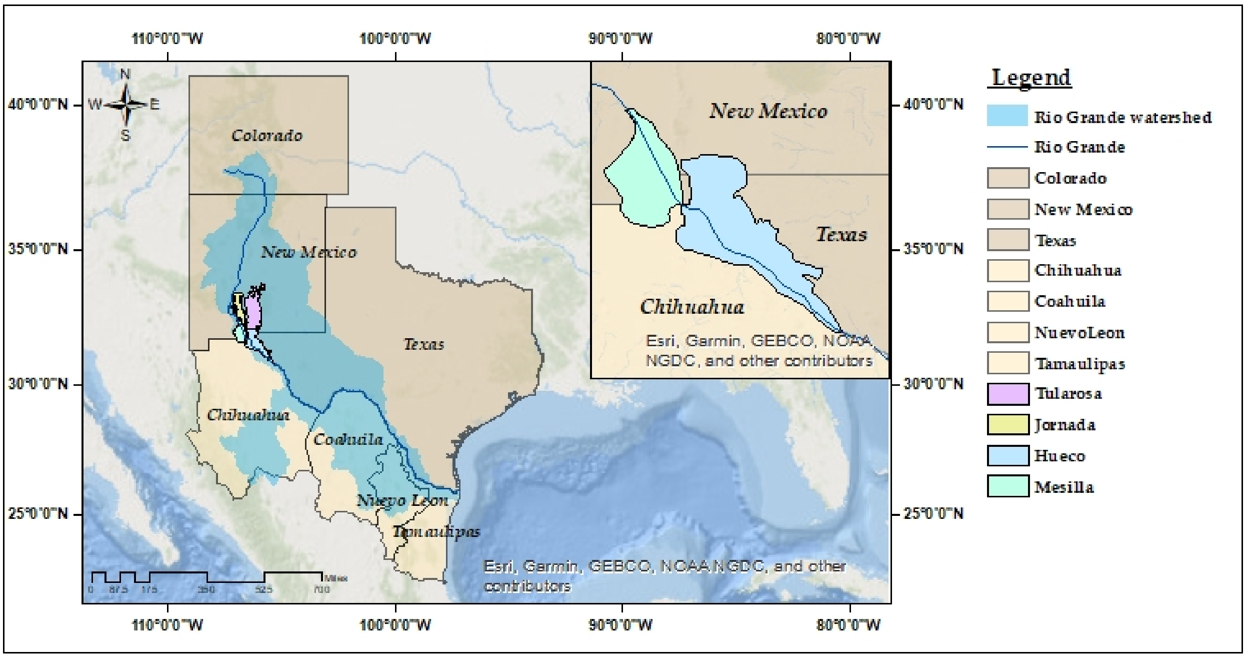

Figure 1. Map of Rio Grande watershed and river mainstem through the seven states in the US and Mexico.

1.3. Previous Studies

Starting in 1970, geomorphology, geophysics, hydrological prospecting, water quality, and isotopic studies have been carried out for various basins in the states of Texas and New Mexico (US) and Chihuahua (Mexico). These studies were conducted in Mexico by the Municipal Water and Sanitation Board (Junta Municipal de Agua y Saneamiento, JMAS) [17], the National Water Commission (Comisión Nacional del Agua, CONAGUA) [18], the Mexican Geological Service (Servicio Geológico Mexicano, SGM) [19], the Autonomous University of Juarez City (Universidad Autónoma de Ciudad Juárez, UACJ) [20,21], the Autonomous University of Chihuahua (Universidad Autónoma de Chihuahua, UACH) [20], the Comisión Internacional de Límites y Aguas-Mexican section (CILA) and International Border and Water Commission, US section (IBWC) [14,19,22]. On the US side, studies were conducted by El Paso Water Utilities [23], the New Mexico Water Resources Research Institute (NMWRRI) [24,25], New Mexico State University (NMSU) [26,27], Texas A&M AgriLife Research Center [28] and the Transboundary Aquifer Assessment Program (TAAP) [29].

From the above-mentioned studies, the ones using environmental tracers such as $\delta^{18}O$ and tritium as well as and basic physicochemical parameters were selected for our analysis. These studies also provided the spatial distribution that enabled us to cover the area between the Hueco Bolson and Conejos-Médanos/Mesilla aquifers.

1.4. Study Area

Of the various aquifers along the Rio Grande, this study focuses on one of the most important transboundary regions between the United States and Mexico: the cross-border area of Juárez, Chihuahua in Mexico and Las Cruces, NM and El Paso, TX in the US. In this Paso del Norte or PdN transboundary region, groundwater uses are mainly supported by two transboundary aquifers: the Hueco Bolson and the Conejos Médanos/Mesilla Basin aquifers (Figure 1). Several communities along the US-Mexico border in New Mexico, Texas and Chihuahua depend on these aquifers for domestic, agricultural, and industrial water use [30]. In this study, special attention was given to the Mexican side of the Conejos-Médanos Basin aquifer where isotopic studies that could explain recharge scenarios in the area and their relationship with groundwater quality were nonexistent.

Cliett (1969) [31] mentioned that the geology of the Conejos-Médanos Basin aquifer is comparable to the Hueco Bolson aquifer, both having similar depositional environments on the geological time scale of the aquifers. Despite these similarities, they differ in their lithology and groundwater qualities, with differing sediments from contemporary basin fill within the surface area of the aquifer. Additionally, Cliett (1969) [31] defined that the two sediment units are hydraulically connected, meeting the aquifer at an estimated average depth of 152.4 m (500 ft). Regarding water levels, in the case of the shallow Hueco Bolson aquifer, along the agricultural zone of the Valle de Juárez, static levels were on average 12.19 m (40 ft) and superficially at 3 m (10 ft).

Hawley et al. (2009) [32] developed a hydrogeological model based on reports and peer-reviewed research to promote the exchange of information to provide a better understanding of water problems and possible alternative solutions to address them. His group's hydrogeological model includes the area of the Mesilla aquifer, a section of the Rio Grande in north-central Chihuahua, Mexico, and parts adjacent to the south of the Jornada del Muerto Basin, where the contact between the strata is shown as well as the basin's sedimentary fill. The basement that represents the bedrock and the tectonic characteristics of the area are reflected not only in the composition of the sedimentary fill, but also in the groundwater flow and chemistry according to its time of residence. The source of sediment fill in this aquifer was the surrounding mountains, consisting largely of Paleozoic sedimentary rocks inclined on a base of Precambrian rocks; these mountains also contain Tertiary volcanic rocks [31].

Appendix A (see Figure A1) shows the sedimentary Santa Fe Group with the evolution and tectonic faults of the basins in the southern region of the Rio Grande. In the past 25 million years, this region has had a profound effect on the distribution of the groupings in the lithofacies (strata) of the Santa Fe Group [33]. Hawley and Lozinsky (1992) [34] subdivided the Santa Fe Group into three stratigraphic units: lower, middle, and upper. These units are defined based on the general lithological character, the depositional environments of the fill, and the characteristics related to the post-depositional history.

Hawley and Swanson (2022 in revision) [35], show that the hydrogeological framework controls on groundwater flow and chemistry in the transboundary—aquifers system west of the lower Mesilla Valley (MeV) and PdN transboundary aquifers systems in this area—are comprised of: 1) thick Santa Fe Group (SFG) rift-basin fill (as much as 600 m), and 2) the thin ($\leq$20 m) alluvial aquifers of the inner-river valley. They also recognized that at least the upper part of the SFG aquifer system was present in Chihuahua, located as far south as the Federal Highway 2 corridor west of the Juarez and Sapello mountain ranges in Mexico. In regard to groundwater quality in the transboundary Mesilla/Conejos-Médanos Basin aquifer, Hawley and Swanson (2022 in revision) [35] address that the ongoing research has demonstrated that very large quantities of fresh to slightly saline water are stored in the basin-fill aquifer system, where most groundwater in storage is at least 11ka and was recharged during the last glacial/pluvial stage of the Late Pleistocene Epoch (~29 to 11 ka).

2. Materials and Methods

The Conejos-Médanos Basin data were collected from the JMAS wells on the Mexican side of the Mesilla Basin aquifer. We collected sixteen samples (Figure 2a,b) on 9 and 10 June 2016. Sampling was conducted in collaboration with the JMAS team, Grupo CARSO, and the UACJ Environmental Engineering laboratory. The sixteen samples were analyzed for physicochemical and metallic parameters by Garcia-Vasquez in the UACJ Environmental Laboratory. A total of nine of these samples were analyzed for $\delta^{18}O$ and tritium isotopes in the Isotopic Hydrologic Laboratory at the Mexican Institute of Water Technology (IMTA) (Figure 3).

(**a**) (**b**)

Figure 2. Sampling with JMAS, Grupo CARSO, UACJ Environmental Laboratory: (**a**) sampling water in the Conejos Médanos from JMAS well set with the UACJ Environmental Laboratory, (**b**) sampling team members of CARSO, JMAS, this study, and UACJ Environmental Laboratory.

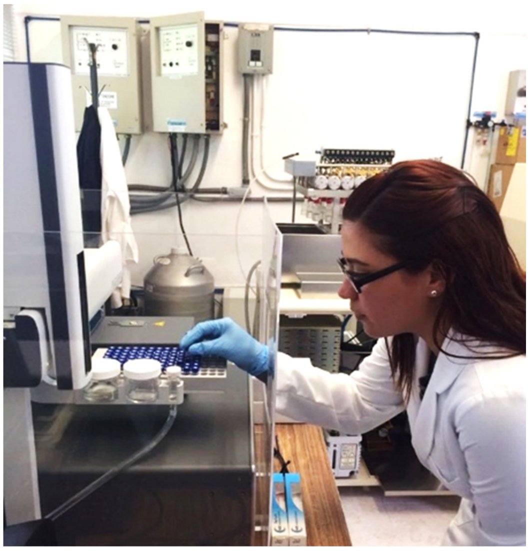

Figure 3. Analyzing stable isotopes ($\delta^{18}O$) samples at the Isotopic Hydrologic Laboratory (Laser analyzer Cavity Ringdown Spectrometer L2110-i Isotopic H_2O Picarro with high precision vaporizer A0211).

This study offers a significant contribution as it completes the characterization of the Conejos-Médanos/Mesilla Basin aquifer isotopic system by providing results from the Mexican side of the aquifer to the already existing data from the US side. To complete the system analysis in this region, we compared our results with similar previous research on the US side of the Mesilla Basin aquifer [11] and a study of the Hueco Bolson aquifer between the US and Mexican sides [12].

2.1. Mesilla Basin Aquifer Data

In 2010, Teeple (2017) [11] gathered 44 isotopic samples (Table 1) from four hydrologic units in the Mesilla Basin aquifer on the US side. He used the subdivision of the groundwater flow system outlined by Hawley and Lozinsky (1992) [34] to divide the study area. Subdivisions made by them were four hydrological units (Table 1) including the Rio Grande Alluvium, which is from a quaternary system and is part of the Santa Fe Group. The Santa Fe Group is a Tertiary system divided into three hydrogeologic units, the Upper, Middle, and Lower Santa Fe Group. The southern boundary in the study area of Teeple (2017) [11] was the border between the US and Mexico.

The aquifer was divided into four hydrogeological units based on the terrain stratigraphy and groundwater flow of the Mesilla aquifer as shown in Table 1.

Table 1. Samples in the Mesilla Basin aquifer by Teeple (2017) [11].

Area	Samples
Rio Grande alluvium (RGA)	3
Lower part of the Santa Fe Group (LSF)	4
Middle part of the Santa Fe Group (MSF)	24
Upper part of the Santa Fe Group (USF)	13
Total Samples	44

Teeple (2017) [11] gathered 44 samples from wells and sampled the same location at different depths from five sets of wells in different hydrologic units. For the first set of wells, TQ18, TQ19, TQ20, and TQ21, had depths of 55, 275, 280, and 200 ft, and hydrologic units of RGA, USF, MSF and LSF, respectively. For the second set of wells, TQ26, TQ27, TQ28, and TQ29, the depths were 47, 275, 275, and 280 ft, and the hydrologic units were RGA, USF, MSF and LSF, respectively. For the third set of wells, TQ31 and TQ32, the depths were 150 and 275 ft, and the hydrologic units were MSF and LSF, respectively. For the fourth set of wells, TQ34, TQ35, and TQ36, the depths were 135, 270 ft and one more unspecified, and the hydrologic units were USF, MSF and LSF, respectively. For the last set of wells, TQ40 and TQ41, the depths were 47 and 132, and the hydrologic units were USF and MSF, respectively. The coordinates for each set of wells are in Appendix B.

Tritium results shown by Teeple (2017) [11] were analyzed at the Menlo Park Tritium Laboratory in Menlo Park, CA under the procedures of Östlund and Werner (1962) [36] and Thatcher et al. (1977) [37].

The analyses for stable isotope ratios of δD and $\delta^{18}O$ in Teeple (2017) [11] were conducted at the USGS Stable Isotope Laboratory in Reston, Va. Under the described methods in Révész and Coplen (2008b) [38].

This study was carried out on the US side of the Mesilla aquifer in cooperation with the USGS, IBWC, NM WRRI, NMSU, Texas AgriLife Research, TWRI, and Texas A&M. The results from the 44 samples in the Teeple (2017) [11] study were predominantly Na-HCO3 or a Na-SO4-HCO3 geochemistry water groups. For tritium, the results indicate negative values, which means there was no tritium content because of the decay. Teeple (2017) [11] mentioned that results show groundwater flows are generally from the north to south-southeast and that there is a pattern of groundwater discharging in the PdN.

2.2. Hueco Bolson Aquifer Data

Previous studies of the Hueco Bolson aquifer on the Mexican side indicate an increasing trend of calcium and sulfate ions with total dissolved solids (TDS) of more than 750 mg/L. This shows a deterioration in water quality during the 1965–1999 period [39].

Eastoe et al. (2007) [12] conducted an analysis of the isotopic concentration in the Hueco Bolson. They made a subdivision of hydrologic units (Table 2). This subdivision encompasses the Hueco Bolson Aquifer in both the US and Mexico.

Table 2. Samples in Hueco Bolson Aquifer by Eastoe et al. (2007) [12].

Area	Samples
Hueco Bolson Aquifer, El Paso County, Texas	35
Hueco Bolson Aquifer, Chihuahua	31
Hueco Bolson Aquifer, Doña Ana and Otero Countries, New Mexico	5
Hueco Bolson Aquifer, Hudspeth County and east El Paso County, Texas	4
Total Samples	75

Eastoe et al. (2007) [12] gathered 75 samples of groundwater and precipitation. Groundwater was sampled from public and private wells; precipitation samples were from the Juarez region. Stable oxygen and hydrogen isotopes were measured with a gas source isotope radio-frequency mass spectrometer (Finnigan). The delta value was standardized with the Vienna Standard Mean Ocean Water (VSMOW). Liquid scintillation spectrophotometry was used for tritium analysis. The stable and unstable isotope analysis was carried out in the laboratory at the University of Arizona.

Results from stable isotope data showed four types of groundwater recharge. The authors identified two sources of recharge from the Rio Grande and another two sources of recharge from local precipitation.

Previous studies used to perform this assessment were selected as they have published the same type of analysis and data samples in different locations. Table 3 shows the data from the sources referred to in this study by the author.

Table 3. Data collected from different authors used in this investigation.

Source	Year	$\delta^{18}O$	Tritium	Coordinates	Aquifer
Eastoe et al.	2007				Hueco (US/MX.)
Teeple	2010				Mesilla (US)
This study	2015				Conejos Médanos (MX.)

Appendix B (see Table A1) contains a record of all the data used to perform the analysis. "ID" means the identification of the sample in this study; "Source" is the name of the well sampled; "Date" refers to the year when the sample was taken; "Latitude and longitude" mean the sample coordinates; "$\delta^{18}O$ and T" refer to the isotopic values obtained for oxygen, hydrogen, and tritium, respectively; and "Group," to the group previously named by the authors. Additionally, from Eastoe et al. (2007) [12], A = Rio Grande, B = Rio Grande near the Sierra de Juárez, C = Upper Hueco Bolson, D = South of the Hueco Bolson, and E = Middle Hueco Bolson. The other acronyms used are Upper Santa Fe (USF), Middle Santa Fe (MSF), Lower Santa Fe (LSF), and Rio Grande Alluvion (RGA) from Teeple (2017) [11]. In this study, the Conejos Médanos Basin is labeled (CM).

3. Results

Hydrogeochemical results show groundwater ions are predominantly $Cl+SO_4$ and HCO_3, throughout the area. There is a mixture of waters that have the main components Na^+, Cl^- and SO_4^- ions. Due to the type of sediment fill deposit around the Conejos Médanos aquifer, the presence of these ions throughout the aquifer was expected. Geochemically, this reflects the rock interaction that predominates in this area and reveals current rock deterioration through the mineralization of the waters throughout the region of the Conejos Médanos aquifer.

Figure 4 shows the Mesilla and Hueco aquifers and geographical locations of the samples collected by this study, Teeple (2017) [11], and Eastoe et al. (2007) [12].

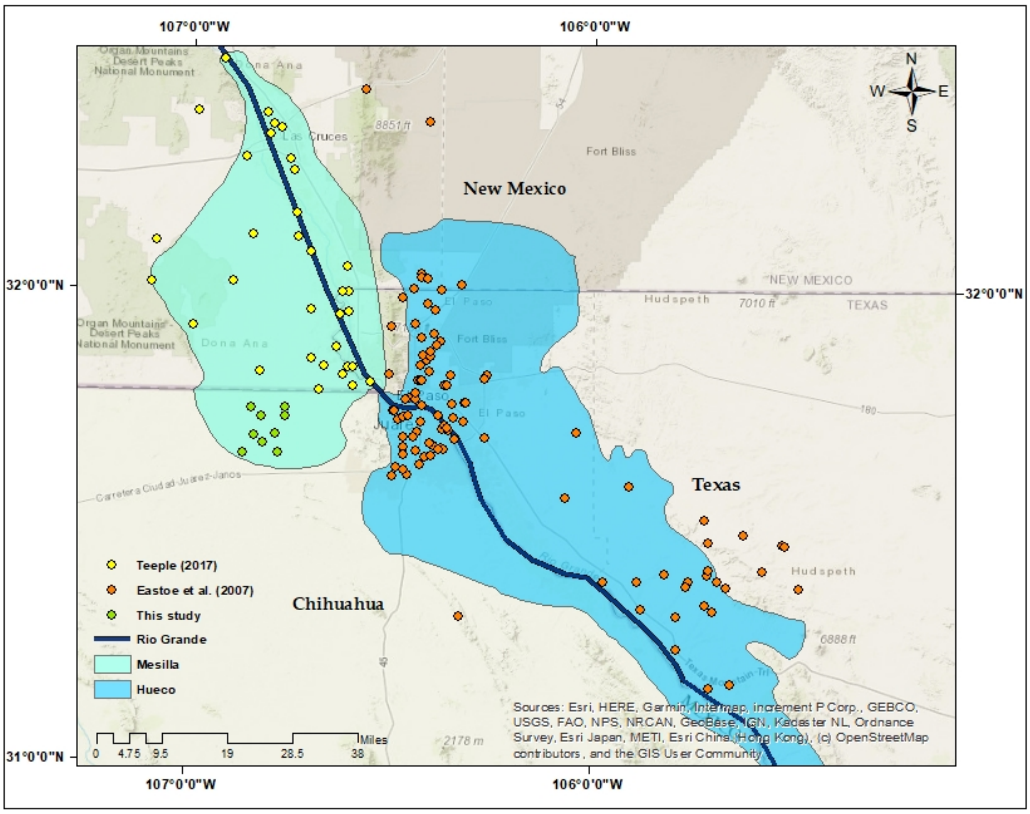

Figure 4. Location of samples collected in this study (green), Teeple (2017) [11] (yellow), and Eastoe et al. (2007) [12] (orange).

3.1. Tritium

The tritium results obtained in this study (Figure 4, green points) in the Conejos Médanos Basin varied from −0.70 to 0.58 Tritium Units (TU), which is a non-significant tritium content because the absence of tritium or values below <0.5 TU indicate that the age of waters is not greater than 50 years. This is an important finding because it indicates that the water present in this zone is not of recent origin, which demonstrates that there is no recharge in this zone. Furthermore, this study does not report any significant tritium concentrations in the Conejos Médanos Aquifer.

The Mesilla Basin aquifer results obtained by Teeple (2017) [11] indicate the presence of pre-boom waters, which refers to water recharged prior to 1950. Teeple (2017) [11] found high concentrations of tritium in two samples collected from wells in the Rio Grande Alluvium; the values were 4.6 TU (T Q18) and 7.5 TU (T Q26). In the Hueco Bolson, the highest concentrations followed the same path as the Mesilla Basin aquifer [12].

Figure 5 shows values over 2 TU for the samples taken by Eastoe et al. (2007) [12] near the Rio Grande Alluvium. These tritium concentration values range from 2.6 to 14.2 TU, which points to recharge points within the study's area. The area with recharge points and possible recharge near these points is in the alluvium of the Rio Grande, which is consistent with what other authors mentioned in their studies.

Recharge points in the Rio Grande, in the Conejos-Médanos/Mesilla Basin, and Hueco Bolson aquifers are present on the surface and exist mostly at the piedmont slopes of the mountains adjacent to the Rio Grande Alluvium. This indicates that in the Mexican portion of the Mesilla Basin, the water is old and does not have significant recharge areas. Thus, in the rest of the points with values <2 TU, there is no recharge, at least in the sampled points.

Data collection by the different authors occurred in 2006, 2010, and 2015. Although the collection of samples occurred at different times, for this analysis the variation in residence time from one sample to another is not significant because they are valid in time and space.

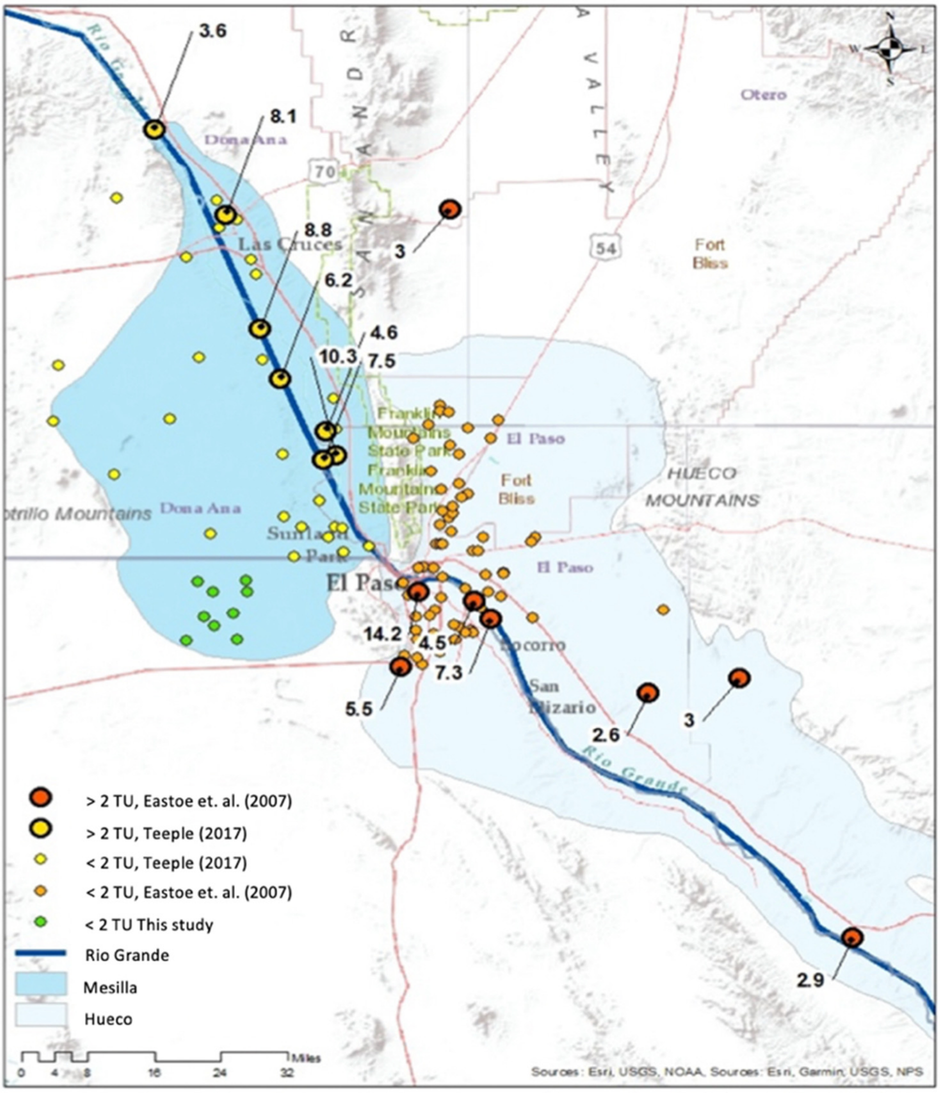

Figure 5. Tritium concentration values of more than 2 TU. The red points with black borders represent values more than 2 TU from Eastoe et al. (2007) [12]. The yellow points with black borders show the values with more than 2 TU from Teeple (2017) [11]. The orange points indicate values lower than 2 TU from Eastoe et al. (2007) [12]. The yellow points indicate values lower than 2 TU from Teeple (2017) [11]. The green points indicate values lower than 2 TU from this study. The Mesilla Basin aquifer is featured in blue, and the Hueco Bolson in light blue. The line in dark blue shows the Rio Grande mainstream.

3.2. Oxygen 18 ($\delta^{18}O$)

Figure 6 shows a compilation of the sample points. The samples are grouped into numbers and letters. The letters are given by the author and apply only to the samples taken by Eastoe et al. (2007) [12]. The data gathered from Eastoe et al. (2007) [12] are featured in orange squares (Group A), circles (Group B), and diamonds (Group C); each shape represents a different group given by the author. The data from this study are shown by green circles; and the data by Teeple (2017) [11] in yellow circles. The values of all points were compared with the GMWL and the RGEL to determine the changes in the water's isotopic composition, produced by different processes. A total of three groups were obtained.

Group 1 is in the GMWL and is made up of samples from group C. Some of these were taken by Eastoe et al. (2007) [12] from the Hueco Bolson (orange diamonds), while five samples came from the Teeple (2017) [11] study (yellow circles). Group C comes from the Franklin and Organ Mountains. Eastoe et al. (2007) [12] mentioned that similar water could be originating in the Juarez Mountains (Sierra de Juárez). On the other hand, the five samples from Teeple (2017) [11] (yellow points) are TQ12, TQ14, TQ16, TQ30, and TQ32 (See Appendix B). These samples were taken in the Mesilla Basin near the Rio Grande Alluvium, which means that water from the river is present in these locations. In Group 1, waters are located in or near the GMWL because no current depletion can be seen in the isotopes.

Group 2 results feature 14 samples close to the line while the rest are slightly above the line. Of those first fourteen samples, three (orange squares) are E1, E2, and E3 (See Appendix B); they are part of Group A and were taken by Eastoe et al. (2007) [12] in the Hueco Bolson aquifer in Chihuahua, near the Rio Grande. These three samples have an isotopic composition of $\delta^{18}O$, which varies slightly between −8.6 and −9.4. Another nine samples (yellow points) were TQ00, TQ03, TQ09, TQ13, TQ18, TQ23, TQ24, TQ25, and TQ36 (See Appendix B); they were taken by Teeple (2017) [11] and show an isotopic composition of $\delta^{18}O$ with a variation of −7.74 to −8.97. The last of the fourteen samples found in RGEL were taken by this study in the Conejos-Médanos set of wells of the JMAS; these featured an isotopic composition of $\delta^{18}O$ and a variation of −8.83. The rest of the Group 2 samples that are slightly above the RGEL were taken by this study and Teeple (2017) [11] in the Mesilla/Conejos-Médanos Basin.

The results of stable $\delta^{18}O$ isotopes in this study are not near the GMWL, but they are near the RGEL. According to Teeple (2017) [11], and Witcher et al. (2004) [24], these results could indicate that groundwater has a Rio Grande isotopic signature from the ancestral Rio Grande and this could be a sign of evaporated waters. In addition, they show that recharge sources include precipitation, bedrock fissure water, and irrigation return water. Finally, they also point to water evaporation.

Group 3 is made of three samples which are in or near the RGEL. This group is formed by three samples from Group A taken by Eastoe et al. (2007) [12] in the Hueco Bolson aquifer in Chihuahua near the Rio Grande. The group is made up of Group B (orange circles), taken by Eastoe et al. (2007) [12] and consisting of samples collected beneath the urban area of Juárez City and the Rio Grande floodplain in El Paso. The geographical area in which the samples were collected is a semi-arid area where evaporation processes occur; this phenomenon could have affected the process. This dataset falls below the GMWL, indicating that water has evaporated. Group 3 is also formed by samples taken by Teeple (2017) [11].

The study by Teeple (2017) [11] reports that values of less than −80.0 and −10.5 $\delta^{18}O/\delta D$ (‰) have an apparent age of less than 10,000 carbon-14 years before present (1950). Samples from this age are found near the Rio Grande Alluvion. Values greater than −80.0 and −10.5 $\delta^{18}O/\delta D$ (‰) have an age greater than 10,000 carbon-14 years before present (1950). Samples of this age are found in the southeast of the Mesilla Basin aquifer, near the Hueco Bolson and the Juarez Mountains. Such a group of results is consistent with results from this study in the Conejos-Médanos region and with those of Group C, from Eastoe et al. (2007) [12], which are marked as Group 3 in Figure 6.

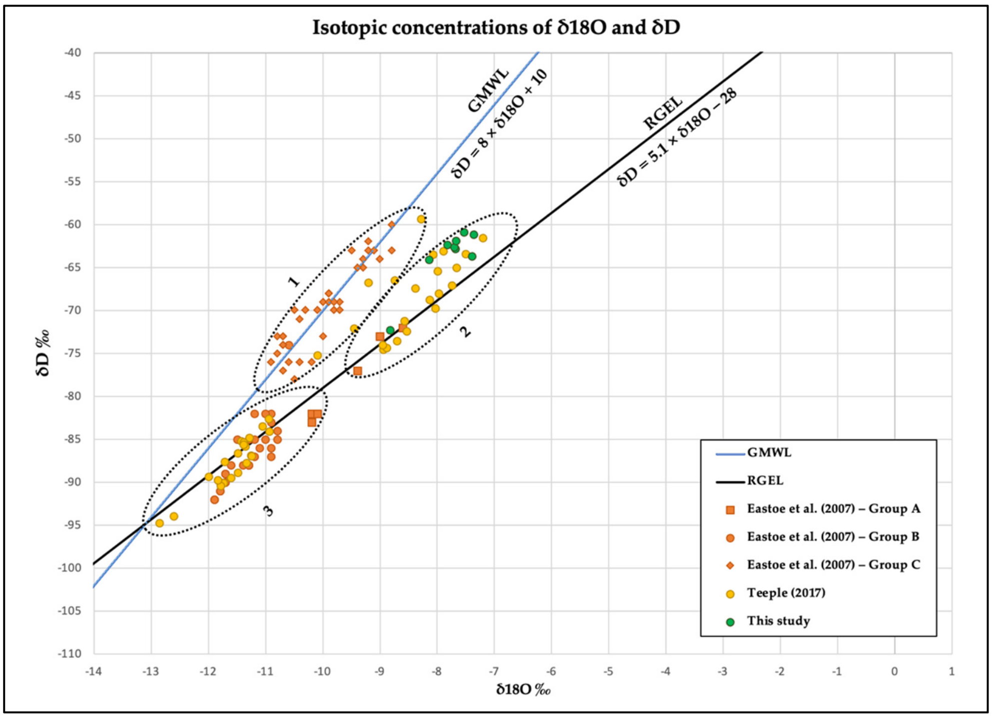

Figure 6. Plot of $\delta^{18}O/\delta D$ (‰) in groundwater from this study, Eastoe et al. (2007) [12] and Teeple (2017) [11] was compared to the global meteoric water line (GMWL) and Rio Grande evaporation line (RGEL). The graph was divided into three groups, these groups considered all the samples in Appendix B. Group 1) is formed by water samples from the Mesilla and Hueco basins taken by Teeple (2017) [11] and Eastoe et al. (2007) [12]. Group 2) consists of samples from the Hueco Bolson and the Mesilla/Conejos-Médanos Basin aquifers, and they are samples taken by this study, Teeple (2017) [11] and Eastoe et al. (2007) [12]. Group 3) contains samples from the Mesilla Basin aquifer and the Bolson del Hueco; the samples were taken by Teeple (2017) [11] and Eastoe et al. (2007) [12].

4. Conclusions

According to the age determined by the results of the isotopic concentration and the $\delta^{18}O/\delta D$ of the water, Group 2 is formed by old water. Occasionally an addition of ^{18}O is caused by dissolution processes, and this can increase with geothermal activity; having this geothermal change could have caused a movement to the right of the GMWL. This, in Figure 6, indicates that the "*X*" axis, which is ^{18}O, moved to the right, achieving a greater concentration of ^{18}O. On the contrary, the "*Y*" axis, which represents a ^{16}O concentration, decreased. This change to a concentration greater than ^{18}O and lower than ^{16}O results in an isotopically heavier $\delta^{18}O$ signature but without any change in the $\delta^{2}H$ signature [2,24]. Most of the groundwater samples that are plotted along the displaced GMWL represent isotopically lighter water, with δD values of less than −80.00 per thousand and $\delta^{18}O$ values of less than −10.50 per thousand [40]. This isotopic signature indicates that the samples in Group 2 probably underwent water recharge during the relatively humid and cool Pleistocene climate [40].

According to Witcher et al. (2004) [24] and Bumgarner (2012) [40], the GMWL in the studied area has been displaced and represents ancient groundwater and geothermal groundwater, from which ^{18}O of the rocks have been obtained. This was due to an exchange processes that typically occurs with the water-rock interaction and probable hydrothermal alteration. Such an alteration occurs when the oxygen present in the groundwater is exchanged due to the composition of the rock, temperature, texture, and length of contact [24].

The compilation of isotopic data provided by this article is important as it allows for the comparison of water samples from different locations in the US-Mexico borderland area of the Hueco Bolson and Mesilla Basin aquifers. The locations of the samples collected contribute to understanding the water origin of the studied area.

Hawley and Kottlowski (1969) [13] established that the Rio Grande flowed across the western area of the Juarez Mountains and that water from the Rio Grande drained into the Cabeza de Baca Ancient Lake, going through the sedimentary deposits which are presently part of the Mesilla Basin aquifer [3]. However, with the formation of the Juarez Mountains in the Quaternary period, the Rio Grande changed its course, carving its way through the El Paso Canyon over the course of recent geological times, flowing between the Franklin Mountains and the Juarez Mountains through the canyon that formed between the neighboring mountains [13].

As different authors mention, a primary source of recharge into the Mesilla Basin aquifer system is the Rio Grande Alluvium in the Mesilla Valley because of the seepage losses from the riverbed. From previous and new data evaluated, we conclude that the Conejos-Médanos Basin aquifer has the same source of water as the Hueco Bolson does from Group A of Eastoe et al. (2007) [12]. The Group A samples were taken near the Rio Grande at the foot mountain in the Juarez Mountains. Moreover, as was expected, the Group 1 samples collected by Teeple (2017) [11] at the south of the Mesilla Valley to the Conejos Médanos Basin aquifer signal the presence of the same type of water in this area.

In conclusion, the samples collected and analyzed by this study complete the description of the Hueco Bolson and the Mesilla/Conejos-Médanos Basin at the US-Mexico transboundary area. According to previous study results shown for Group 2, a stable isotope $\delta^{18}O$ concentration falls below the GMWL in the evaporated zone, which indicates that these are old waters that have undergone evaporation, horizontal infiltration, or dissolution processes. Moreover, groundwater values indicate that groundwater recharge sources include precipitation, bedrock fissure water, or both. Furthermore, results are consistent with findings by Eastoe et al. (2007) [12], Teeple (2017) [11], Hawley and Kottlowski (1969) [13], Witcher et al. (2004) [24], and Bumgarner (2017) [40], whose findings indicate that the groundwater is not recent and that it was recharged thousands of years ago when the climate was more humid, which could be the cause for the same isotopic content in the Hueco Bolson and Conejos-Médanos/Mesilla Basin aquifers near the Juarez Mountains.

Author Contributions: Conceptualization, A.C.G.-V., A.G.-O., Z.S., A.F.; methodology, A.C.G.-V., A.G.-O.; analysis, A.G.-O.; writing—original draft preparation, A.C.G.-V., A.G.-O., Z.S., A.F.; writing—review and editing, A.C.G.-V., A.G.-O., Z.S., A.F.; project administration, A.C.G.-V., A.G.-O., Z.S., A.F.; funding acquisition, A.C.G.-V., A.G.-O., Z.S., A.F. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The date presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

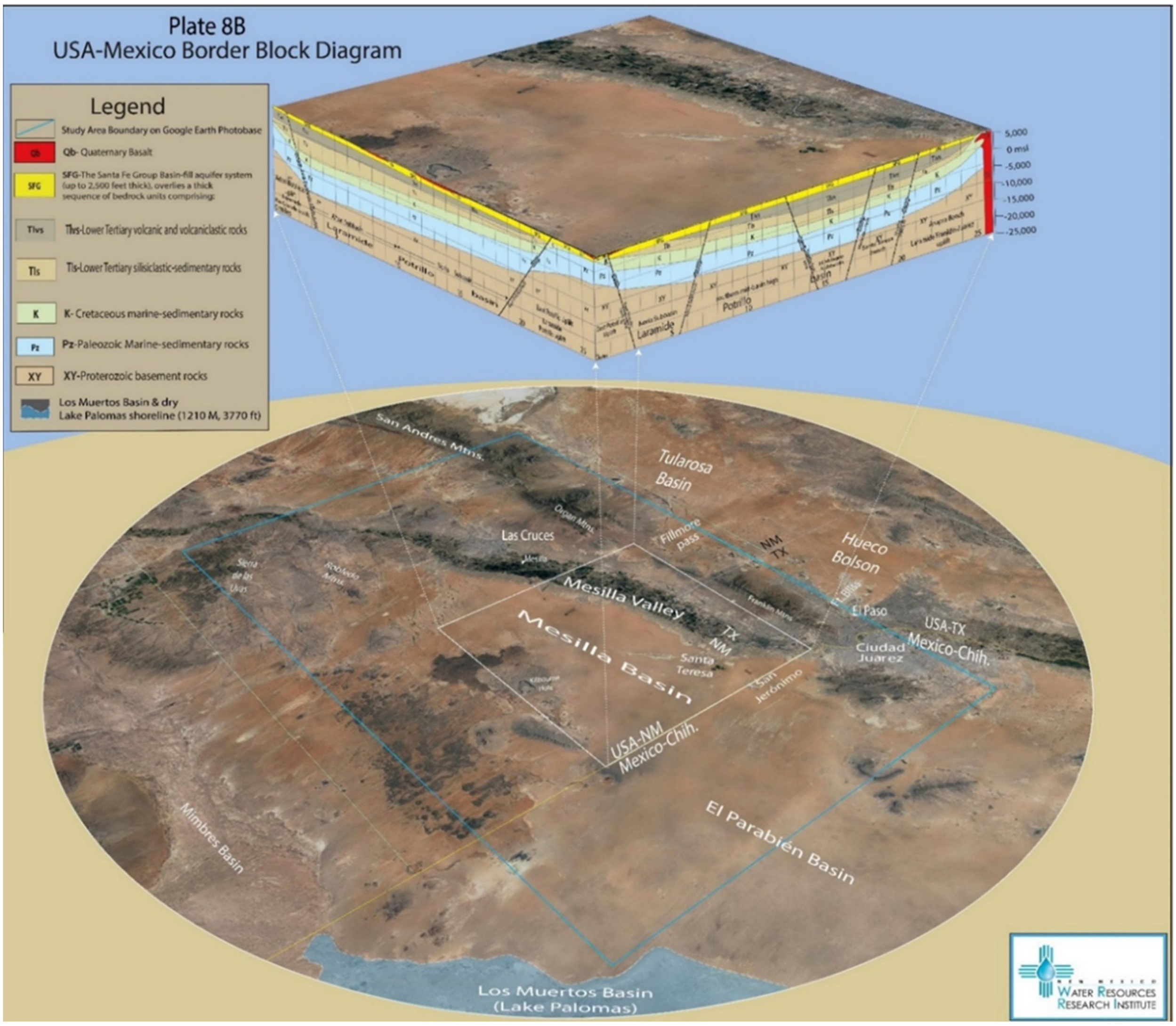

Figure A1. Northeast-facing block diagram of the southern Mesilla Basin, with its southern panel at the International-Boundary [35].

Appendix B

Details of data used for this study are in Table A1.

Table A1. Data used for this study.

ID	SOURCE	DATE	LATITUDE	LONGITUDE	$\delta^{18}O$	D	*T*	GROUP
E 1	JMAS well 3Z	2006	31.686	−106.339	−9.4	−77	7.3	A
E 2	JMAS well 9R	2006	31.745	−106.493	−8.6	−72		A
E 3	JMAS well 19R	2006	31.647	−106.415	−10.2	−83		A
E 4	JMAS well 53R	2006	31.606	−106.494	−9	−73	5.5	A
E 5	JMAS well 62	2006	31.745	−106.489	−10.2	−82		A
E 6	JMAS well 141	2006	31.701	−106.434	−10.1	−82		A
E 7	EPWU well 9	2006	31.772	−106.454	−11.5	−85	−0.5	B
E 8	EPWU well 14	2006	31.769	−106.463	−11.2	−85	1.2	B
E 9	EPWU well 408	2006	31.755	−106.421	−10.9	−82	1.6	B

Table A1. *Cont.*

ID	SOURCE	DATE	LATITUDE	LONGITUDE	$\delta^{18}O$	D	*T*	GROUP
E 10	EPWU well 414	2006	31.704	−106.356	−11.2	−82	−0.5	B
E 11	EPWU well 420	2006	31.735	−106.383	−10.6	−74	−0.6	B
E 12	JMAS well 1R	2006	31.725	−106.481	−10.8	−84		B
E 13	JMAS well 5	2006	31.61	−106.456	−10.9	−86	1.2	B
E 14	JMAS well 13RR	2006	31.625	−106.487	−10.9	−83	−0.5	B
E 15	JMAS well 17R	2006	31.731	−106.47	−10.9	−87		B
E 16	JMAS well 42R	2006	31.63	−106.426	−10.8	−85	1.4	B
E 17	JMAS well 47	2006	31.667	−106.374	−11.3	−88		B
E 18	JMAS well 50R	2006	31.66	−106.437	−11.7	−89	−0.4	B
E 19	JMAS well 56R	2006	31.662	−106.369	−11.6	−88		B
E 20	JMAS well 76	2006	32.357	−106.409	−11	−85	3	B
E 21	JMAS well 82R	2006	31.667	−106.467	−11.7	−89	−0.6	B
E 22	JMAS well 84	2006	31.651	−106.466	−11.9	−92		B
E 23	JMAS well 99R	2006	31.69	−106.443	−11.8	−91		B
E 24	JMAS well 115	2006	31.672	−106.394	−11.4	−88		B
E 25	JMAS well 120	2006	31.651	−106.4	−11.7	−90		B
E 26	JMAS well 130	2006	31.662	−106.381	−11.2	−87		B
E 27	JMAS well 134	2006	31.621	−106.466	−11	−82		B
E 28	JMAS well 142	2006	31.689	−106.468	−11.3	−85	−0.5	B
E 29	JMAS well 161	2006	31.735	−106.456	−11.1	−86		B
E 30	JMAS well 151	2006	31.706	−106.371	−11.8	−90	−0.7	B
E 31	JMAS well 165	2006	31.675	−106.402	−11.9	−92	−0.4	B
E 32	JMAS well 180	2006	31.731	−106.343	−11.7	−90	−0.9	B
E 33	JMAS well 183	2006	31.72	−106.424	−11.8	−91		B
E 34	JMAS well 186	2006	31.852	−106.41	−11.8	−90		B
E 35	JMAS well 193	2006	31.891	−106.378	−11.3	−88		B
E 36	West Windmill Bowen	2006	31.983	−106.473	−9.2	−63	1.2	C
E 37	LF4	2006	32	−106.377	−9.5	−63	−0.8	C
E 38	Vista Hills Blue well	2006	31.762	−106.317	−10.8	−75	−0.5	C
E 39	Well 2 Vista Hills	2006	31.761	−106.315	−10.8	−73	−0.6	C
E 40	Wheeler well #3B	2006	31.687	−106.265	−10.7	−77	−0.5	C
E 41	EPWU well 18	2006	31.769	−106.437	−10.9	−76	−0.8	C
E 42	EPWU well 20A	2006	31.841	−106.427	−9.3	−65	−0.6	C
E 43	EPWU well 25	2006	31.899	−106.423	−10	−69	−0.5	C
E 44	EPWU well 33	2006	31.957	−106.392	−9.3	−64	−0.5	C
E 45	EPWU well 42	2006	31.972	−106.409	−9.9	−68	−0.6	C
E 46	EPWU well 45	2006	31.798	−106.368	−10.3	−70	−0.9	C
E 47	EPWU well 52	2006	31.928	−106.442	−9.2	−62	−0.5	C
E 48	EPWU well 55	2006	31.862	−106.422	−9.9	−69	−0.6	C
E 49	EPWU well 63	2006	31.798	−106.361	−10.4	−71	0.5	C
E 50	EPWU well 69	2006	31.759	−106.347	−10.7	−73	−0.4	C
E 51	EPWU well 83	2006	31.715	−106.366	−10.2	−76	4.5	C
E 52	EPWU well 93	2006	31.819	−106.352	−10.7	−73	−0.7	C
E 53	EPWU well 519	2006	31.907	−106.392	−9.9	−68	−0.9	C
E 54	EPWU well 404	2006	31.722	−106.32	−10.7	−74	1.1	C
E 55	EPWU well 416	2006	31.709	−106.36	−10	−73	1.7	C
E 56	Well 2B Ft. Bliss	2006	31.829	−106.406	−10.1	−70	−0.5	C
E 57	Well 5A Ft. Bliss	2006	31.808	−106.432	−9	−64	−0.5	C
E 58	Well 6A Ft. Bliss	2006	31.808	−106.426	−8.8	−63	0.5	C
E 59	Well 7 Ft. Bliss	2006	31.808	−106.422	−9.8	−70	−0.4	C
E 60	Well 10 Ft. Bliss	2006	31.859	−106.403	−9.7	−70	0.5	C
E 61	Well 11 Ft. Bliss	2006	31.87	−106.403	−9.7	−69	−0.4	C
E 62	Well 12 Ft. Bliss	2006	31.885	−106.388	−9.8	−69	−0.5	C
E 63	Intl. Garment Proc. No.4	2006	31.82	−106.261	−10.4	−76	1.1	C
E 64	Intl. Garment Proc. No.1	2006	31.812	−106.267	−10.6	−76	1.5	C

Table A1. *Cont.*

ID	SOURCE	DATE	LATITUDE	LONGITUDE	$\delta^{18}O$	D	*T*	GROUP
E 65	Chaparral Edna	2006	32.036	−106.426	−9.9	−68	−0.5	C
E 66	Chaparral Sylvia	2006	32.028	−106.426	−9.1	−63	−0.8	C
E 67	Chaparral Rosencrans	2006	32.025	−106.41	−9.4	−65		C
E 68	Rinchem well	2006	32.004	−106.446	−10.7	−74	−0.7	C
E 69	Rhino pump well	2006	32.012	−106.325	−10.5	−70	−0.5	C
E 70	JMAS well 221	2006	31.73	−106.464	−10.5	−78	14.2	C
E 71	LF1	2006	31.983	−106.337	−8.5	−60	1	D
E 72	Esperanza PO	2006	31.16	−105.71	−6.3	−46	2.9	D
E 73	Indian Cliffs Ranch	2006	31.563	−106.066	−8.5	−67	2.6	E
E 74	Velarde	2006	31.587	−105.907	−6.8	−59	3	E
E 75	El Paso Lakes	2006	31.701	−106.038	−9.3	−69		E
T Q00	322320106551801	2010	32.48600	−106.9220	−8.53	−72.38	3.6	USF
T Q01	322233106590901	2010	32.37592	−106.98634	−11.26	−86.92	0	MSF
T Q02	322219106485001	2010	32.37200	−106.81400	−11.34	−87.71	0.3	MSF
T Q03	322054106475201	2010	32.34843	−106.79834	−8.71	−73.53	8.1	USF
T Q04	322024106463901	2010	32.34000	−106.77900	−11.25	−86.98	1.3	USF
T Q05	321934106482601	2010	32.32648	−106.80778	−11.79	−90.30	0.1	MSF
T Q06	321641106515401	2010	32.27800	−106.86500	−11.74	−90.06	−0.1	MSF
T Q07	321628106451501	2010	32.27426	−106.75417	−11.6	−89.46	0.3	MSF
T Q08	321501106443801	2010	32.25037	−106.74445	−11.49	−88.84	0.1	USF
T Q09	320939106441701	2010	32.16093	−106.73861	−8.95	−74.58	8.8	USF
T Q10	320654106504201	2010	32.11500	−106.84500	−11.71	−87.54	0	MSF
T Q11	320643106440401	2010	32.11181	−106.73448	−11.79	−90.41	0	MSF
T Q12	320604107051201	2010	32.10121	−107.08723	−8.75	−66.42	0	MSF
T Q13	320445106421001	2010	32.07927	−106.70333	−8.89	−74.40	6.2	USF
T Q14	320253106364001	2010	32.04800	−106.61100	−10.1	−75.16	0.1	USF
T Q15	320054106533901	2010	32.01510	−106.89473	−11.36	−85.8	0	USF
T Q16	320040107054601	2010	32.01121	−107.09668	−9.2	−66.71	−0.1	MSF
T Q17	315955106362201	2010	31.99649	−106.60694	−11.43	−85.18		MSF
T Q18	315940106372301	2010	31.99444	−106.62306	−8.04	−69.74	4.6	RGA
T Q19	315940106372302	2010	31.99444	−106.62306	−11.05	−83.41	0.2	USF
T Q20	315940106372303	2010	31.99444	−106.62306	−11.29	−84.76	0	MSF
T Q21	315940106372304	2010	31.99444	−106.62306	−11.39	−85.33	0	LSF
T Q22	315723106415201	2010	31.95677	−106.69833	−11.39	−85.6	0	MSF
T Q23	315712106361802	2010	31.95371	−106.60583	−7.97	−68.02	4.2	USF
T Q24	315712106361803	2010	31.95371	−106.60583	−8.96	−74.01	10.3	MSF
T Q25	315712106361804	2010	31.95371	−106.60583	−11.49	−86.65	0.9	LSF
T Q26	315646106374401	2010	31.94611	−106.62889	−8.57	−71.17	7.5	RGA
T Q27	315646106374402	2010	31.94611	−106.62889	−12.61	−93.96	−0.1	USF
T Q28	315646106374403	2010	31.94611	−106.62889	−12.85	−94.73	−0.1	MSF
T Q29	315646106374404	2010	31.94611	−106.62889	−11.84	−89.75	0	LSF
T Q30	315519106593101	2010	31.92200	−106.99200	−8.29	−59.36	0	MSF
T Q31	315245106380601	2010	31.87927	−106.63555	−12.0	−89.32	0	MSF
T Q32	315245106380602	2010	31.87927	−106.63555	−9.46	−72.09		LSF
T Q33	315114106414901	2010	31.85400	−106.69700	−10.93	−84.06	0	MSF
T Q34	315013106362601	2010	31.83705	−106.60777	−7.2	−61.57	−0.1	USF
T Q35	315013106362602	2010	31.83705	−106.60777	−7.51	−63.39		MSF
T Q36	315013106395301	2010	31.83705	−106.66527	−7.74	−67.08		MSF
T Q37	315006106354601	2010	31.83500	−106.59600	−7.67	−65.04		RGA
T Q38	314932106493401	2010	31.82594	−106.82527	−10.94	−82.65	0	MSF
T Q39	314908106371201	2010	31.81900	−106.62000	−7.89	−63.03	0.1	MSF
T Q40	314817106325801	2010	31.80483	−106.54999	−7.99	−65.41	1.3	USF
T Q41	314817106325802	2010	31.80483	−106.54999	−8.14	−68.74	0.1	MSF
T Q42	314746106353601	2010	31.79622	−106.59388	−8.38	−67.42	0.1	MSF
T Q43	314717106404401	2010	31.78800	−106.67900	−8.08	−63.5	0	MSF
TS 01	P1-CM-21	2015	31.65043	−106.8657	−7.39	−63.7	0.35	CM
TS 02	P3-CM-06	2015	31.68897	−106.8363	−7.69	−62.8	−0.16	CM

Table A1. *Cont.*

ID	SOURCE	DATE	LATITUDE	LONGITUDE	$\delta^{18}O$	D	*T*	GROUP
TS 03	P5-CM-24	2015	31.74661	−106.8465	−8.83	−72.3	−0.23	CM
TS 04	P7-CM-12	2015	31.7307	−106.820	−7.36	−61.2	−0.3	CM
TS 05	P9-CM-15	2015	31.7307	−106.820	−7.7	−62.6	−0.7	CM
TS 06	P11-CM-23	2015	31.65181	−106.7786	−7.68	−61.9	0.17	CM
TS 07	P12-CM-18	2015	31.69394	−106.7852	−7.54	−60.9	0.36	CM
TS 08	P16-CM-01	2015	31.7494	−106.7622	−8.15	−64.1	−0.23	CM
TS 09	P17-CM-14	2015	31.72955	−106.7593	−7.82	−62.3	0.44	CM

ID: Identification of samples, *E* by Eastoe et al. (2007) [12], *T* by Teeple (2017) [11], *TS* by This study.

References

1. Chowdhury, A.H.; Uliana, M.; Wade, S. Ground water recharge and flow characterization using multiple isotopes. *Groundwater* **2008**, *46*, 426–436. [CrossRef] [PubMed]
2. Wood, W.W.; Sanford, W.E. Chemical and isotopic methods for quantifying ground-water recharge in a regional, semiarid environment. *Groundwater* **1995**, *33*, 458–468. [CrossRef]
3. Allison, G.B. *A Review of Some of the Physical, Chemical, and Isotopic Techniques Available for Estimating Groundwater Recharge. Estimation of Natural Groundwater Recharge*; Simmers, I., Ed.; NATO ASI Series; Springer: Dordrecht, The Netherlands, 1988; Volume 222, pp. 49–72.
4. Clark, I. *Groundwater Geochemistry and Isotopes*; CRC Press: Boca Raton, FL, USA, 2015.
5. Gat, J. *Isotope Hydrology: A Study of the Water Cycle*; Series on Environmental Science and Management; Imperial College Press: London, UK, 2010; ISBN 978-1-86094-035-4.
6. Allegre, C.J. *Isotope Geology*; Cambridge University Press: Cambridge, UK, 2008.
7. White, W.M. *Isotope Geochemistry*; John Wiley & Sons: Hoboken, NJ, USA, 2015.
8. Fontes, J.; Fritz, P. Environmental Isotopes in Groundwater Hydrology. In *Handbook of Environmental Isotope Geochemistry*; Springer: Berlin/Heidelberg, Germany, 1980.
9. Libby, W.F. Atmospheric Helium Three and Radiocarbon from Cosmic Radiation. *Phys. Rev.* **1946**, *69*, 671. [CrossRef]
10. Gat, J.R.; Mook, W.G.; Meijer, H.A. *Environmental Isotopes in the Hydrological Cycle*; Principles and Applications UNESCO/IAEA: Paris, France, 2001; Volume 2, pp. 63–67.
11. Teeple, A.P. *Geophysics- and Geochemistry-Based Assessment of the Geochemical Characteristics and Groundwater-Flow System of the U.S. Part of the Mesilla Basin/Conejos-Médanos Aquifer System in Doña Ana County, New Mexico, and El Paso County, Texas, 2010–12*; Scientific Investigations Report; U.S. Geological Survey: Reston, VA, USA, 2017.
12. Eastoe, C.J.; Hibbs, B.J.; Olivas, A.G.; Hogan, J.F.; Hawley, J.; Hutchison, W.R. Isotopes in the Hueco Bolson Aquifer, Texas (USA) and Chihuahua (Mexico): Local and General Implications for Recharge Sources in Alluvial Basins. *Hydrogeol. J.* **2007**, *16*, 737–747. [CrossRef]
13. Hawley, J.W.; Kottlowski, F.E.; LeMone, D.V. Quaternary geology of the south-central New Mexico border region. In *Border Stratigraphy Symposium, El Paso, TX, USA, 30 April 1969*; New Mexico Bureau of Mines and Mineral Resources: Socorro, NM, USA, 1969; Volume 104, pp. 89–115.
14. International Boundary and Water Commission, U.S. Section Texas Clean Rivers Program. In *Basin Highlights Report for the Rio Grande Basin in Texas*; US International Boundary & Water Commn: El Paso, TX, USA, 2010.
15. McNeese, T. The Rio Grande. In *Rivers in World History*; Chelsea House: Philadelphia, PA, USA, 2005; ISBN 978-0-7910-8244-7.
16. Britannica. Rio Grande: River, United States-Mexico. Available online: https://www.britannica.com/place/Rio-Grande-river-United-States-Mexico (accessed on 7 June 2021).
17. Junta Municipal de Agua y Saneamiento (JMAS) de Ciudad Juárez. *Junta Municipal de Agua y Saneamiento Plan Maestro de JMAS Juárez 2010*; JMAS: Ciudad Juárez, Mexico, 2010.
18. Comisión Nacional del Agua (CONAGUA). *Comisión Nacional del Agua: Actualización de la Disponibilidad Media Anual del acuífero Conejos-Médanos (0823), Estado de Chihuahua 2015*; CONAGUA: Coyoacán, Mexico, 2015.
19. Servicio Geológico Mexicano (SGM). *Comisión Internacional de Límites y Aguas-Sección Mexicana*; Servicio Geológico Mexicano Actividades Hidrogeológicas Del Acuífero Conejos/Medanos, Estado de Chihuahua, I Etapa. 2010; SGM: Pachuca, Mexico, 2010.
20. Soto-Ontiveros, A.; Granados-Olivas, A.; Pinales-Munguía, A.; Saúl-Solís, S.; McConnel Heyman, J. Evolución temporal del flujo del agua subterránea en Ciudad Juárez, Chihuahua aplicando modelación geoespacial. *Tecnociencia Chih.* **2018**, *12*, 103–113.
21. Mayer, A.; Heyman, J.; Granados-Olivas, A.; Hargrove, W.; Sanderson, M.; Martinez, E.; Vazquez-Galvez, A.; Alatorre-Cejudo, L.C. Investigating Management of Transboundary Waters through Cooperation: A Serious Games Case Study of the Hueco Bolson Aquifer in Chihuahua, Mexico and Texas, United States. *Water* **2021**, *13*, 2001. [CrossRef]
22. International Boundary & Water Commission. About the Rio Grande. Available online: https://www.ibwc.gov/CRP/riogrande.htm (accessed on 3 June 2021).
23. Bredehoeft, J.; Ford, J.; Harden, B.; Mace, R.; Rumbaugh, J. *Review and Interpretation of the Hueco Bolson Groundwater Model*; El Paso Water Utilities: El Paso, TX, USA, 2004.

24. Witcher, J.C.; King, J.P.; Hawley, J.W.; Kennedy, J.F.; Cleary, M.; Bothern, L.R. *Sources of Salinity in the Rio Grande and Mesilla Basin Groundwater*; New Mexico Water Resources Research Institute: Las Cruces, NM, USA, 2004.
25. Updegraff, C.D.; Gelhar, L.W. *Parameter Estimation for a Lumped Parameter Groundwater Model of the Mesilla Valley, New Mexico*; New Mexico Water Resources Research Institute: Las Cruces, NM, USA, 1977.
26. Samani, Z.; Bawazir, A.S.; Bleiweiss, M.; Skaggs, R.; Longworth, J.; Tran, V.D.; Pinon, A. Using Remote Sensing to Evaluate the Spatial Variability of Evapotranspiration and Crop Coefficient in the Lower Rio Grande Valley, New Mexico. *Irrig. Sci.* **2009**, *28*, 93–100. [CrossRef]
27. Ward, F.A.; Hurd, B.; Rahmani, T.; Gollehon, N. Economic Impacts of Federal Policy Responses to Drought in the Rio Grande Basin. *Water Resour. Res.* **2006**, *42*, 1–13. [CrossRef]
28. Ahn, S.; Abudu, S.; Sheng, Z.; Mirchi, A. Hydrologic impacts of drought-adaptive agricultural water management in a semi-arid river basin: Case of Rincon Valley, New Mexico. *Agric. Water Manag.* **2018**, *209*, 206–218. [CrossRef]
29. Alley, W.M. *Five-Year Interim Report of the United States–Mexico Transboundary Aquifer Assessment Program: 2007–2012*; US Department of the Interior, US Geological Survey: Charleston, SC, USA, 2013.
30. Sanchez, R.; Eckstein, G. Groundwater management in the borderlands of Mexico and Texas: The beauty of the unknown, the negligence of the present, and the way forward. *Water Resour. Res.* **2020**, *56*, 1–20. [CrossRef]
31. Cliett, T. Groundwater occurrence of the El Paso area and its related geology. In *Guidebook of the Border Region, Chihuahua and the United States: New Mexico Geological Society Twentieth Field Conference*; New Mexico Bureau of Geology & Mineral Resources: Socorro, NM, USA, 1969; Volume 209, p. 214.
32. Hawley, J.W.; Kennedy, J.F.; Granados-Olivas, A.; Ortiz, M.A. *Hydrogeologic Framework of the Binational Western Hueco Bolson–Paso Del Norte Area, Texas, New Mexico, and Chihuahua: Overview and Progress Report on Digital-Model Development*; WRRI Technical Completion Report 349; New Mexico Water Resources Research Institute: Las Cruces, NM, USA, 2009.
33. Conover, C.S. *Ground-Water Conditions in the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico*; US Government Printing Office: Washington, DC, USA, 1954.
34. Hawley, J.; Lozinsky, R.P. *Hydrogeologic Framework of the Mesilla Basin in New Mexico and Western Texas*; New Mexico Bureau of Mines and Mineral Resources: Socorro, NM, USA, 1992.
35. Hawley, J.W.; Swanson, B.H. Conservation of shared groundwater resources in the binational Mesilla Basin-El Paso Del Norte region–A hydrogeological perspective. In *Hydrological Resources in Transboundary Basins between Mexico and the United States: El Paso Del Norte and the Binational Water Governance*; Granados Olivas, A., Ed.; Universidad Autónoma de Ciudad Juarez (UACJ) and Universidad Autónoma de Chihuahua (UACH): Chiyoda City, Tokyo, 2022.
36. Révész, K.; Coplen, T.B. *Determination of the δ (2H/1H) of water: RSIL Lab Code 1574*; Révész, K., Coplen, T.B., Eds.; U.S. Geological Survey: Reston, Virginia, 2008.
37. Östlund, H.G.; Werner, E. The electrolytic enrichment of tritium and deuterium for natural tritium measurements. In *Tritium in the Physical and Biological Sciences Symposium*; International Atomic Energy Agency: Vienna, Austria, 1962.
38. Thatcher, L.L.; Janzer, V.J.; Edwards, K.W. *Methods for Determination of Radioactive Substances in Water and Fluvial Sediments*; US Government Printing Office: Washington, DC, USA, 1977; Volume 5, p. 95.
39. Del Hierro Ochoa, J.C. Comportamiento Hidrogeoquímico del Bolsón del Hueco en el área urbana de Ciudad Juárez, Chihuahua, México, 1965–1999. Ph.D. Thesis, Universidad Autónoma de Ciudad Juárez (UACJ), Ciudad Juárez, Mexico, 2009.
40. Bumgarner, J.R.; Stanton, G.P.; Andrew, P.T.; Thomas, J.V.; Payne, J.D.; Musgrove, M. *A conceptual model of the hydrogeologic framework, geochemistry, and groundwater-flow system of the Edwards-Trinity and related aquifers in the Pecos County Region, Texas*; U.S. Department of the Interior: Washington, DC, USA; U.S. Geological Survey: Reston, VA, USA, 2012.