Barton Springs
Edwards Aquifer
CONSERVATION DISTRICT

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Status Report for Aquifer Storage and Recovery Pilot Project: Ruby Ranch Water Supply Corporation, Hays County, Central Texas

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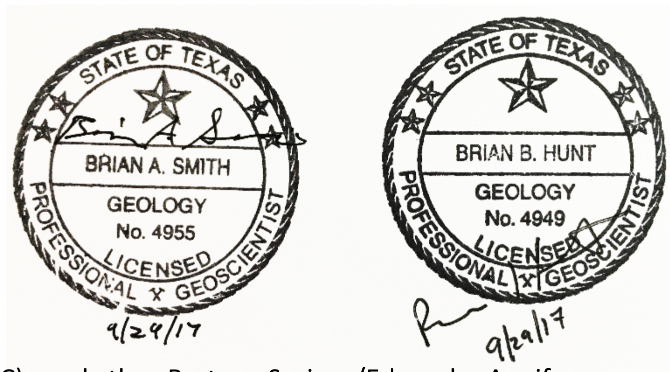

Summary

The Ruby Ranch Water Supply Corporation (RRWSC) and the Barton Springs/Edwards Aquifer Conservation District (District) cooperated on a project to test the Middle Trinity Aquifer as a reservoir for storage and recovery of fresh Edwards Aquifer groundwater. In March 2017, the Texas Commission on Environmental Quality (TCEQ) granted permission to conduct an ASR pilot project (Ruby Ranch's Class V UIC authorization no. 5X2500126). The pilot project consists of multi-step tests with increasing volumes of injected water in each successive step predicated upon successful results at each step. This report serves as a status report for the project at the completion of two phases of testing and prior to an anticipated third phase.

Phase 1 occurred in April 2017 with an injection of 50,000 gallons of Edwards Aquifer groundwater into the Middle Trinity (Cow Creek Formation) Aquifer. Subsequent extraction from the Middle Trinity totaled 83,700 gallons. Phase 2 occurred in May 2017 with an injection of 280,632 gallons of Edwards Aquifer groundwater into the Middle Trinity Aquifer. Subsequent extraction from the Middle Trinity in May and June 2017 totaled 381,000 gallons. Water levels, field parameters, and lab analyses were collected during the test.

From the results of the two steps of injection and extraction, it was clear that the Middle Trinity Aquifer is capable of receiving the injected Edwards water at the planned flow rates and of storing the injected Edwards water for an indefinite period of time. The chemistry of the two mixed waters also appears to be compatible as the quality of the extracted water met primary drinking water standards of TCEQ and the U.S. Environmental Protection Agency during pilot testing. Analyses for arsenic in the extracted water show that mobilization of arsenic is minimal, given conditions under which the Phase 1 and Phase 2 recovery tests were conducted.

Phase 3 of the testing is planned to begin in October 2017 and continue through May 2018, and to increase the volume of injection and the duration of storage.

Introduction

The Ruby Ranch Water Supply Corporation (RRWSC) and the Barton Springs/Edwards Aquifer Conservation District (District) have cooperated on a project to test the Middle Trinity Aquifer as a reservoir for storage and recovery of fresh Edwards Aquifer groundwater. RRWSC must blend its Edwards and Trinity water to satisfy quality standards and could use additional permitted Edwards water. By injecting fresh Edwards water that can be permitted by the District when there is no District-declared drought, RRWSC can have a greater quantity of water available for summer-time usage by their customers.

The District has been working within its statutory authority and regulatory purview to find ways to reduce dependence on the Barton Springs segment of the Edwards Aquifer. One potential source of water is fresh Edwards groundwater pumped during non-drought conditions and stored in an aquifer storage and recovery (ASR) system using the Middle and Lower Trinity Aquifers as the receiving formations or "reservoirs".

An analysis by the District in 2004 of available Edwards Aquifer groundwater indicated that under extreme drought conditions and high rates of pumping, flow from Barton Springs could decrease to the point that the endangered salamanders would not survive and that close to 20% of the water-supply wells in the District could go dry. It was also determined that under non-drought conditions, additional groundwater production could be permitted; however pumpage under those permits would not be available under District-declared drought. The District's permitting structure allows continued permitting of interruptible pumpage within the all-conditions Modeled Available Groundwater (MAG) of 16 cubic feet per second (cfs) through the issuance of Conditional Production Permits. The District has four classes of conditional permits (Class, A, B, C, and D) with each class having progressively more restrictive conditions and curtailment requirements. The most restrictive class, Class D, requires 100% curtailment upon the declaration of Stage II Alarm Drought, but more importantly, it is only available for groundwater production from wells associated with ASR projects where stored water is recovered and used to supplement or substitute freshwater Edwards Aquifer supplies during District-declared drought (District Rule 3-1.24.F). However, the rule is most notable as an indicator of the District's deliberate efforts to implement policies to accommodate such projects when it provides potential drought relief to the over-allocated freshwater Edwards Aquifer.

RRWSC applied to the Texas Commission on Environmental Quality (TCEQ) for permission to conduct an ASR test, and on March 16, 2017 they received a letter from TCEQ giving approval for the test (Ruby Ranch's Class V UIC authorization no. 5X2500126; **Appendix A**).

Setting

The test site is located in the RRWSC service area and Ruby Ranch subdivision within the District. The supply well and source of injection water is from the RRWSC#4 well completed in the Edwards Aquifer. The injection and extraction well is the RRWSC#5 completed in the underlying Middle Trinity aquifer about 120 feet from the source water well (**Figure 1**).

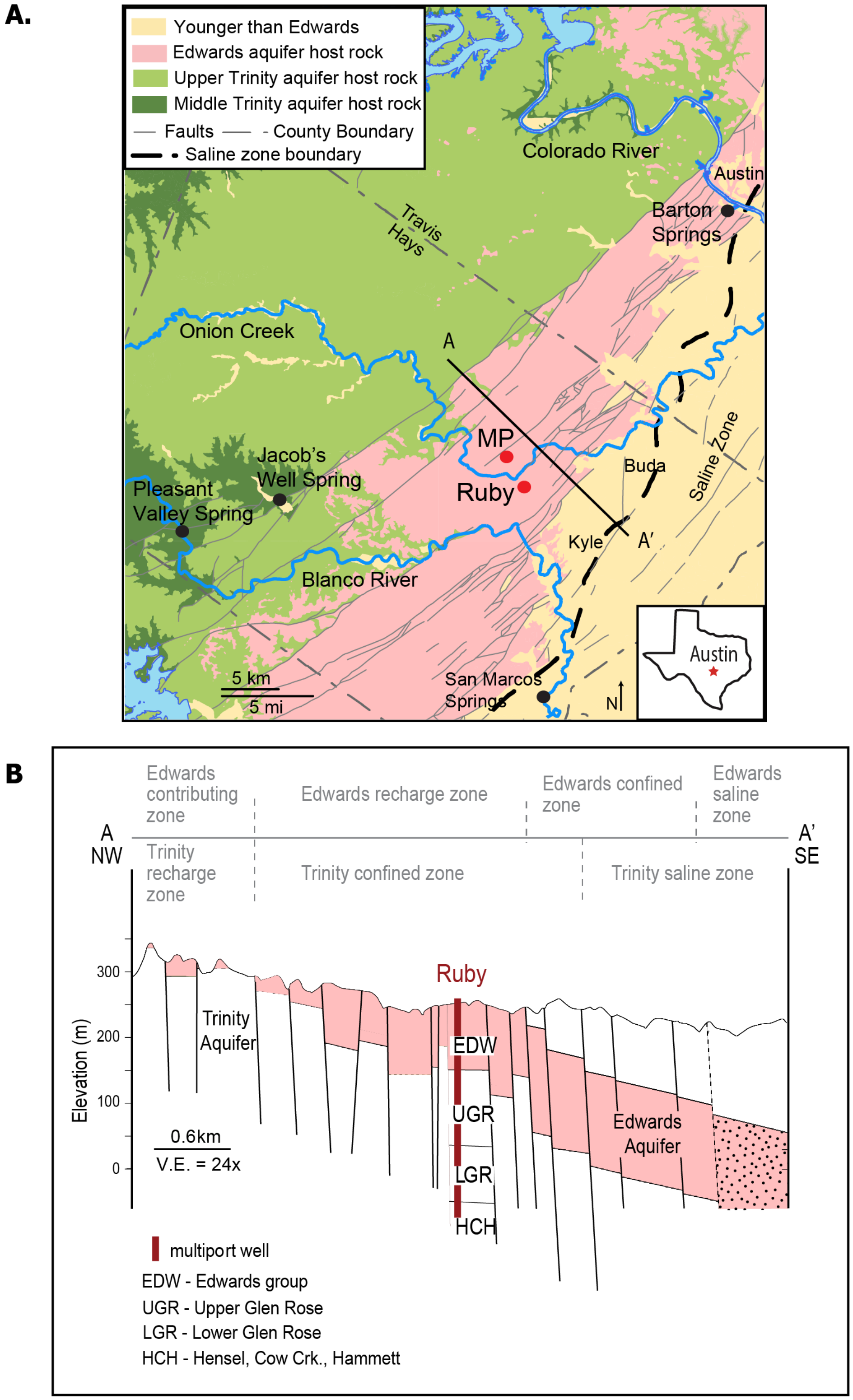

Figure 1. *Regional location map (A) and cross section (B) of the Edwards and Trinity Aquifers in the study area. Ruby symbol denotes Ruby ASR test well (RRWSC#5). MP symbol represents the District's multiport monitor well. Figure modified from Wong et al., 2014.*

Hydrogeology

The test area is located within the recharge zone of the Edwards Aquifer. The Edwards Aquifer is a prolific karst aquifer system consisting largely of limestone and dolomite (**Figures 1 and 2**). Recent studies (Wong et al., 2014) indicate that the upper portions of the Upper Glen Rose are in hydrologic communication with the overlying Edwards Group units. For regulatory purposes, the Edwards Aquifer in the study area is composed of the Edwards Group and the upper-most 150 ft of the Upper Glen Rose. The RRWSC#4 Edwards well was drilled in 2001 to a depth of 405 feet and is completed within the Edwards Group and Upper Glen Rose (**Figure 3**).

The Trinity Aquifer is composed of the Trinity Group geologic units divided into three general hydrostratigraphic units: the Upper, Middle, and Lower Trinity Aquifers. The focus of this testing is upon the Middle Trinity Aquifer, and specifically the Cow Creek Formation of the Middle Trinity. The RRWSC#5 well is completed in the Cow Creek unit of the Middle Trinity Aquifer. The well has a total depth of 1,140 ft (**Figure 3**) with open-hole completion to only the Cow Creek Formation. Below is a brief description of the units that make up the Trinity Aquifer units. The reader is referred Wierman et al., 2010 for more information.

The Middle Trinity Aquifer within the study area is hydrologically isolated from the overlying Edwards Aquifer due to the presence of aquitard units within the lower Upper Glen Rose and also with upper Lower Glen Rose (Smith et al., 2013; Wong et al., 2014; Hunt et al., 2016). The Middle Trinity Aquifer consists of the lowermost Lower Glen Rose, Hensel, and Cow Creek formations (**Figure 3**).

The Lower Glen Rose is generally composed of reef and skeletal grain limestones and generally supplies fresh water to wells in the Hill Country. Biostromes and reef facies of the Lower Glen Rose are important water-bearing units locally, with variable water quantity and quality. The Hensel formation in the study area is about 40 ft thick and is dominantly silty shale and dolomite deposited in a marine enviroment. The Hensel is not an aquifer and instead acts as a semi-confining layer over the Cow Creek in the study area (Wierman et al., 2010).

The Cow Creek Formation is the target hydrogeologic unit of the ASR testing in this study. The Cow Creek is composed of a grain-skeletal limestone, over a fine-grained oyster wakestone to dolomite. The Cow Creek is very porous and permeable and is the primary water-bearing unit within the Middle Trinity Aquifer. The formation was subaerially exposed and subjected to meteoric water infiltration during early Hensel time (Loucks, 1977). Consequently, early diagenesis of the limestone created vuggy porosity. The underlying fine crystalline dolomite has well-developed porosity and both carbonates produce water in the Hill Country.

The Hammett Shale underlies the Cow Creek and is a highly plastic shale. The Hammett Shale is the regional confining unit separating the Middle Trinity Aquifer from the Lower Trinity Aquifer.

Structure

The study area is within the Balcones Fault Zone (BFZ), a zone of en-echelon normal faulting with throws generally down to the southeast. Although faults occur in the study area, no major faults (>100 ft throw) are known in the vicinity of the test area (**Figure 2**). The structural gradient in the study area is about 120 ft/mi. The thickness of the Cow Creek in the study area averages about 75 ft (Wierman et al., 2010). Relay ramps are an important structural style in the BFZ and provide aquifer continuity between and across faults (Collins and Hovorka, 1997; Hunt et al., 2015).

Middle Trinity (Cow Creek) Aquifer Parameters

An aquifer test was conducted on the Ruby Ranch #5 (Cow Creek) in support of a pumping permit application to the District (Geos, 2011; **Appendix B**). Data from this report and the Ruby Ranch multiport monitor well (Hunt et al., 2016), provides the best information about the aquifer parameters of the Middle Trinity in the study area. The aquifer test results for the Cow Creek are comparable to other Middle Trinity wells (Hunt et al., 2010).Below are hydraulic parameters from the Ruby Ranch #5 well (Geos, 2011):

- Well yield about 220 gpm
- Specific capacity of 1.3 gpd/ft
- Transmissivity 4,600 gpd/ft (615 ft^2/d) median
- Storativity 6.0E-5

Water Levels

In the study area, the water levels (head) of the unconfined Edwards Aquifer are higher than those in the Middle Trinity Aquifer. However, recent studies have shown the presence of aquitard units within the Upper and Lower Glen Rose formations inhibit vertical flow from the Edwards and Middle Trinity (and visa versa), despite the vertical head gradients (Smith et al., 2013; Wong et al., 2014; Hunt et al., 2016).

Depths to water of the Middle Trinity Aquifer in the study area vary according to hydrologic conditions and the location of the well. In the study area the depth to water in the Middle Trinity at the Ruby Ranch multiport well vary about 40 feet from 195 to 156 ft depth to water (620 to 660 ft-msl). Static depths to water in the RRWSC#4 Edwards Aquifer and RRWSC#5 Middle Trinity wells were about 135 and 200 ft, respectively, during the testing.

Recharge and Groundwater Flow

The Middle Trinity units are exposed at the surface about 12 miles to the west of the study area, and receive recharge from rainfall on the outcrop and losing streams (Mace et al., 2000). The direction of groundwater flow is generally down the structural dip of the geologic units to the southeast. **Figure 2** illustrates the general direction of flow from a 2009 potentiometric surface map (Hunt and Smith, 2010). The hydrologic gradients are about 40 ft/mi in the study area (Wierman et al., 2010).

A simple calculation of average linear velocity using Driscoll (1986) is described below, where:

> Average linear velocity = (Hydraulic conductivity, K * hydraulic gradient, i) / porosity
> K = 8.2 ft/d
> i = 40 ft/mile or 0.008
> Porosity = 20% or 0.2

Based on these assumptions, the velocity is estimated at about 0.3 ft/day. The low values of tritium (^{3}H) and carbon-14 (radiocarbon or ^{14}C) sampled in the Ruby Ranch #5 support the estimated relatively slow flow velocities. The related matter of the age of groundwater is being addressed in a separate geochemical investigation involving the interpretation of ^{14}C and ^{3}H isotopes from more than 100 wells (including multiport wells) and sources of surface water in central Texas. ^{14}C and ^{3}H are widely used in studies of groundwater age because they are naturally occurring radionuclides with very different half-lives (5730 years for ^{14}C and 12.43 years for ^{3}H). Interpretations are not straightforward, owing to post-recharge processes that affect the measurement of ^{14}C and ^{3}H in groundwater. With respect to water wells, the ^{14}C

and ^3H data cover the Edwards Aquifer and the Upper, Middle, and Lower Trinity Aquifers. Interpretations of the data will offer greater insight into the range of groundwater ages in each aquifer. This will help to refine conceptual models of recharge throughout the area, as well as address questions related to potential interaction of surface water and groundwater as well as inter-aquifer communication.

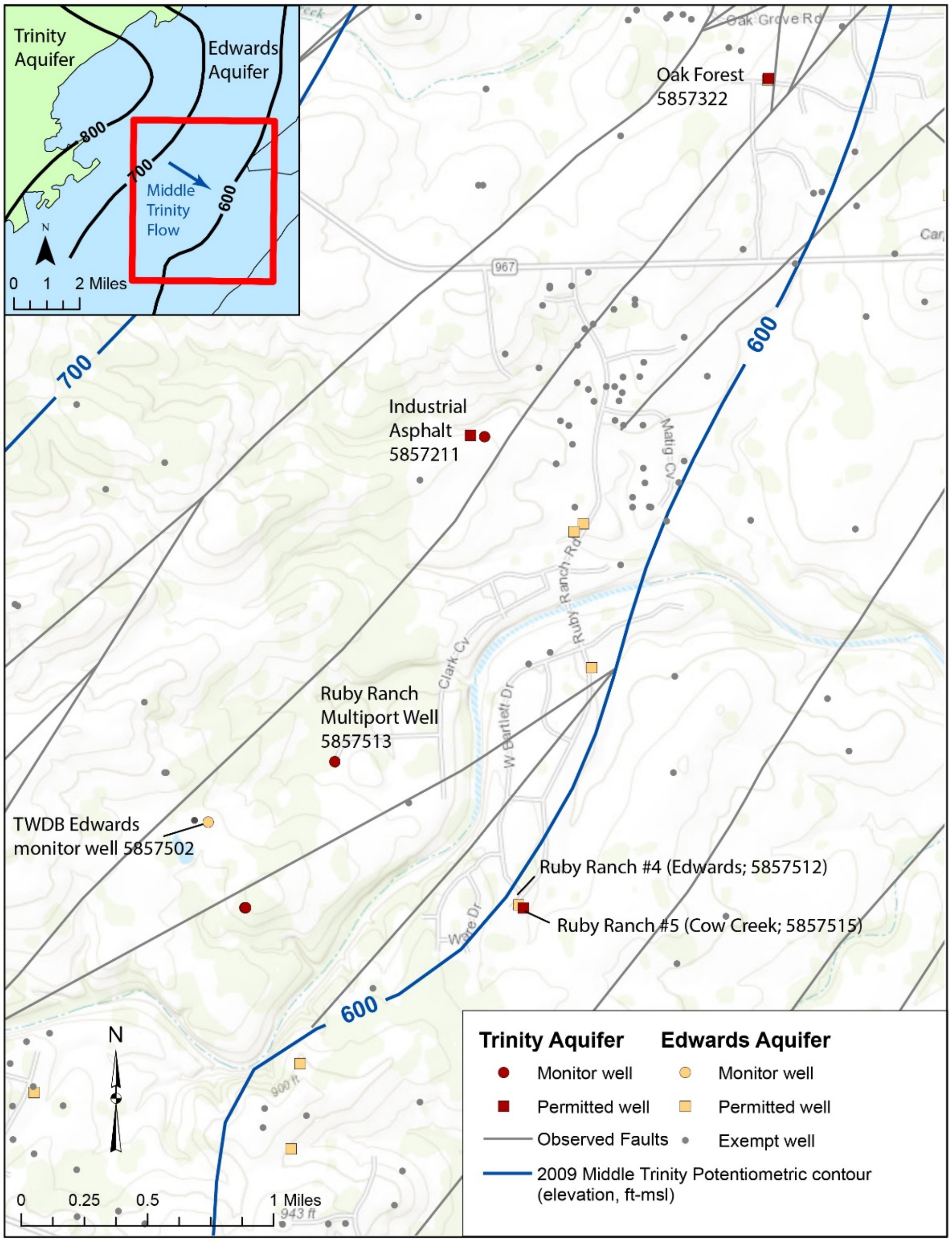

Figure 2. *Location map showing wells and faults in the area. Inset map shows the aquifers and potentiometric map of the Middle Trinity indicating flow to the southeast in the study area.*

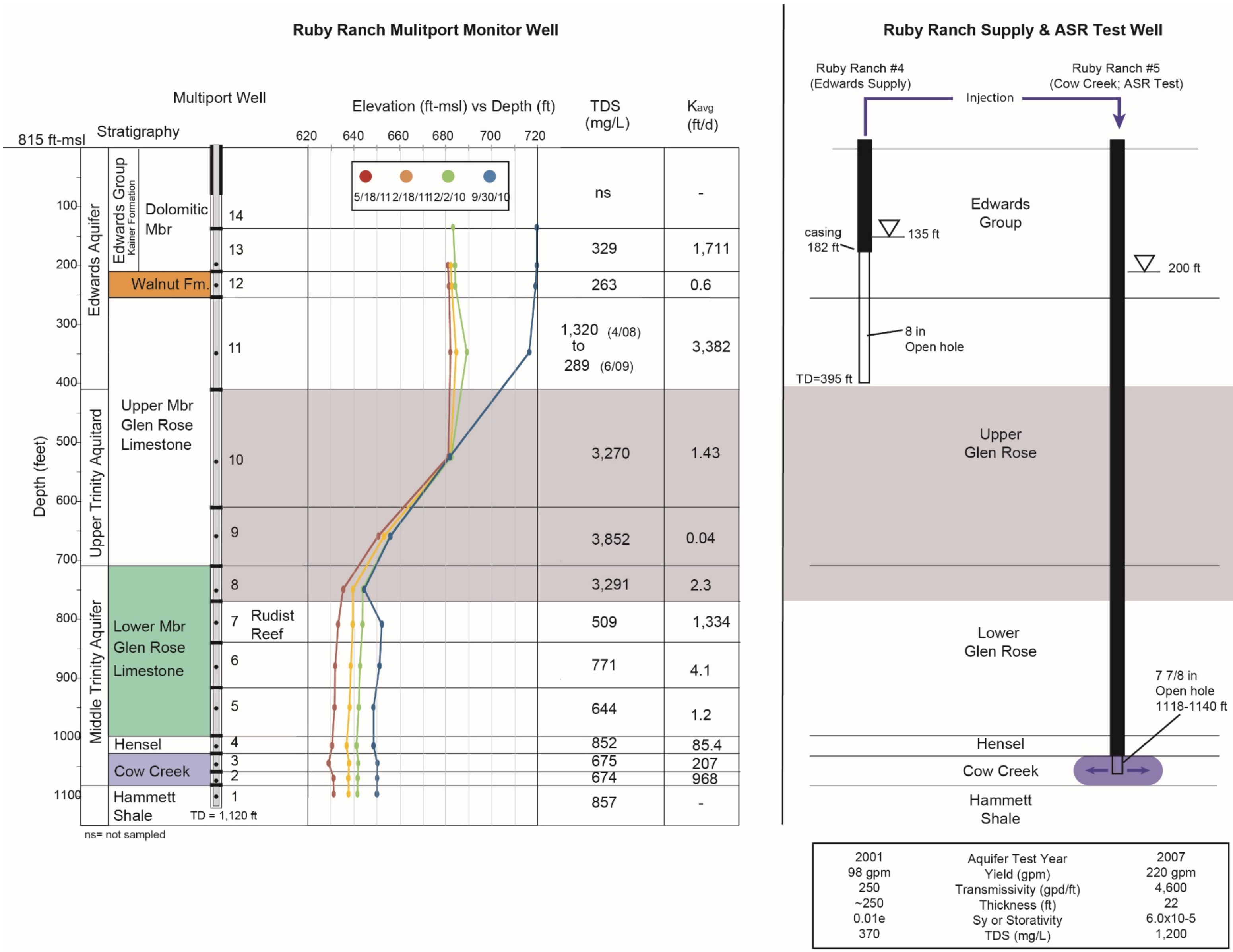

Figure 3. *Detailed hydrostratigraphy, well completion, and hydrogeologic data of the study area.*

ASR Pilot Test

RRWSC applied to the TCEQ for permission to conduct an ASR test, and on March 16, 2017 they received a letter from TCEQ giving approval for the test (Ruby Ranch's Class V UIC authorization no. 5X2500126; **Appendix A**). This approval was to conduct tests to determine the feasibility of storing water from the Edwards Aquifer in the Cow Creek Formation (Middle Trinity) for later recovery. The test project envisioned a multi-step process with increasing volumes of injected water in each successive step predicated upon successful results at each step. Major objectives of the project were to determine any impact to water chemistry and to the formation, and clarifying the physical parameters governing the injected water "bubble".

ASR Test Design and Methods

In preparation for the ASR tests temporary plumbing – pipes, valves, metering – was installed for manually conducting the pilot project. ASR testing was conducted between April 19 and June 29, 2017. Two phases (or cycles) of injection and extraction were conducted. Field parameters and water samples were collected during the test. Various instruments and procedures were used to collect data during the test (**Figure 4**).

Figure 4. *Photograph of RRWSC#5 ASR test well. Temporary PVC pipe was used to inject stored Edwards Water. Also shown are the equipment used to measure water levels and field parameters. The storage tank in the distance holds Edwards water prior to injection.*

Figure 5. *Photograph of RRWSC#5 ASR test well equipped for continuous water level and field parameter measurements.*

Data collected during the project include:

Chemistry

- Baseline water-quality data from samples RRWSC#4 (Edwards) and RRWSC#5 (Trinity). Data collected during extraction from Ruby #5. Analyses included major anions and cations, and were conducted by the LCRA Environmental Services Laboratory, a NELAP certified laboratory (**Appendix C**). Most data can be found at the TWDB's Water Data Interactive website at: (http://www2.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer)
- Continuous monitoring of water quality from injection and extraction using In-Situ 9500 and Horriba mulitparameter probes. These probes measured the following parameters: temperature, conductivity, turbidity, pH, dissolved oxygen, and oxidation/reduction potential.
- Specific sampling and analyses for dissolved arsenic and iron. Results include field and LCRA laboratory analyses (**Appendix C**). Arsenic results were expedited by the LCRA.
- XRD/XRF (x-ray) analysis of samples of Cow Creek Formation for bulk chemical/mineralogical composition (**Appendix D**). This was used to identify constituents in the reservoir that could potentially come into solution in the stored water. The sample was from a recent well drilled near Driftwood (5764613), about 6 miles west.

Water Levels

- Pressure transducer within the injection well (RRWSC#5) to record water-level data at one-minute intervals. Monitoring water levels in the closest Middle Trinity Aquifer well (5857513, Ruby Ranch multiport well).

Flow Rates and Volume

- Monitoring of injection and extraction flow rates from the RRWSC#5.

Test Results

A summary of the sequence of events for the two phases are shown in **Table 1**.

Table 1. *Summary of Phase 1 and 2 activities*

	Date	***Activity***	***Detail***
Background	3/3/2017 8:30	RRWSC#5 Background chemistry	Field parameters, major and minor ions
	4/19/2017 16:18	RRWSC#5 Background chemistry	Field parameters, major and minor ions
Phase 1	4/20/2017 8:00	Phase 1 injection begins	90-100 gpm; pressure transducer logging
	4/20/2017 16:30	Phase 1 injection ends	50,000 gallons total injected
	4/24/2017 9:00	Phase 1 extraction begins	90-100 gpm; continuous field parameters; pressure transducer logging
	4/24/2017 12:30	extraction	20,000 gallons
	4/24/2017 15:56	extraction	40,000 gallons; major & minor ions
	4/24/2017 20:30	Phase 1, official extraction ends	65,705 gallons
	4/25/2017 11:30	Phase 1 continued extraction	83,700 gallons total pumped
Phase 2	5/1/2017 14:00	Phase 2 injection begins	40 gpm; Continuous field parameters; pressure transducer logging
	5/1/2017 20:00	Phase 2 injection	12,700 gallons
	5/6/2017 11:15	Phase 2 injection ends (118 hrs)	280,632 gallons total injected
	5/16/2017 8:55	Phase 2 extraction begins after 10 day hiatus	Continuous field parameters (added ORP); pressure transducer logging; HACH arsenic kit test readings
	5/16/2017 16:40	Phase 2 extraction ~7 hrs	44,000 gallons; LCRA lab samples: major and minor ions
	5/23/2017	Phase 2 extraction begins again after 6 day hiatus and lab results returned	Continuous field parameters (added ORP); pressure transducer logging; HACH arsenic kit test readings
	6/19/2017	Phase 2 extraction ends	Assorted Fe and As analyses; Total pumped volume 381,000 gallons

Phase 1

Phase 1 started on April 20, 2017 with 50,000 gallons of Edwards Aquifer water from RRWSC#4 well injected into RRWSC#5. Beginning on April 24, approximately 84,000 gallons of water were pumped out of RRWSC#5. A summary of water-quality data from Phase 1 is shown in **Table 2.** **Figure 6** shows Phase 2 water levels in the Trinity well during injection and extraction combined with conductivity of the extracted water.

Phase 2

The injection portion of Phase 2 occurred between May 1, 2017 and May 6, 2017 with 280,000 gallons of Edwards Aquifer water injected into RRWSC#5. The extraction phase began on May 16, 2017 when 44,000 gallons of water were pumped out of Ruby well #5. Samples were collected and analyses were reviewed before pumping was started again on May 23, 2017. Between May 23, 2017 and June 19, 2017, 381,000 gallons were pumped from RRWSC#5. A summary of water-quality data from Phase 2 are shown in **Table 3. Figure 7** shows Phase 2 water levels in the Trinity well during injection and extraction combined with conductivity of the extracted water.

Water levels and Injection Bubble

During Phases 1 and 2, Edwards Aquifer water was injected into the Trinity well at a rate of about 90 and 40 gallons per minute (gpm), respectively. The water level in the well rose about 12 ft during Phase I and 6 ft during Phase 2. Once injection stopped, the water level in the well quickly returned to pre-injection levels. **Figure 8** shows the modeled rise in head due to injection, which closely agrees with measured values in **Figures 6 and 7**.As the injected water was pumped from the well during the extraction period, water levels dropped about 7 ft (**Figures 6 and 7**).

No water level response could be attributed to Phases 1 and 2 in the nearest Middle Trinity monitor well (5764613). This well is a multiport monitor well located about 1.5 miles to the west of the Ruby Ranch subdivision (**Figure 2**).

Table 5 shows the estimated radial distance of the injected Edwards Aquifer water within the Cow Creek for various assumed Cow Creek effective porosities. The estimate assumes complete displacement (no mixing) and injection of 280,000 gallons. The estimates indicate that the "bubble" of fresh Edwards Aquifer water is relatively small and is likely contained within the property of the RRWSC.

Table 2. *Summary of water-quality data from historic, background, and extraction sampling during Phase 1. Laboratory results provided in* ***Appendix C****.*

	Background				Phase 1 Extraction		
Well	**RR#4 Edwards**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**
Volume	n/a	n/a	n/a	n/a	20,000 gal pumped	40,000 gal pumped	65,700 gal pumped
Date	6/28/2006	6/23/2010	3/3/2017 8:30	4/19/2017 16:18	4/24/2017 12:30	4/24/2017 15:56	4/24/2017 20:30
Lab/ Data Source	ELS	ELS	ELS (Drinking water)	ELS	ELS	ELS	ELS
Conductivity (uS/cm)	590	1572	1560	1640	1351.54	1514.07	1617.92
pH	7.18	7.0	7.62	6.95	7.28	7.29	
DO (mg/L)						2.45	
Temp ©	21.62	27.93		27.12	26.8	26.7	
ORP (mV)	nd	nd	nd	nd	nd	nd	nd
Calcium (mg/L)	68.5	170	164	153		132	
Magnesium (mg/L)	35.4	114	109	111		92.5	
Sulfate (mg/L)	37	677	726	657		536	
Chloride (mg/L)	10	16	14.8	13.6		12.9	
Bicarbonate (mg/L)	323.4	313.6	256	261		254	
Sodium (mg/L)	6.1	23.9	25.2	24.2		20.7	
Potasium (mg/L)	1.5	12.4		13.6		11.5	
Fluoride (mg/L)	.03	2.11	2.22	2.06		1.89	
Iron (ug/L)	<30	603	284	1000		658	
Arsenic lab (ug/L)	<1	<2.0	<1.00	<1.00	2.29	2.36/2.2	2.69
Arsenic HACH Kit (ug/L)	nd	nd	nd	nd	nd	nd	nd
Strontium (ug/L)	11000	17,300		17700		15200	
Sillica (mg/L)	11.3	13.8		13.2		12.3	
TDS (mg/L)	342	1201	1210	1161		987	

nd= no data

Table 3. *Summary of water-quality data from background and extraction during Phase 2. Laboratory results provided in* ***Appendix C****.*

	Edwards Injection Water			**Phase 2 Extraction**		
Well	**RR #4 Edwards Well**	**RR #4 Edwards Tank**	**RR #4 Edwards Tank**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**
Volume	n/a	n/a	97,400 gallons injected	Mix; Extract begins	44,000 gal pumped	
Date	5/1/2017 14:00	5/1/2017 14:00	5/3/2017 8:00	5/16/201714:20	5/16/2017 16:40	5/26/2017 12:45
Lab/ Data Source	BSEACD	BSEACD	BSEACD	ELS/BSEACD	ELS/BSEACD	ELS/BSEACD
Conductivity (uS/cm)	732	750	741	1,300	1,430	1,570
pH	7.84		8.24	8.55	8.53	
DO (mg/L)	6.4	7.25	7.04	0.22	0.13	0.15
Temp ©	21.27		21.72	21.21	24.78	
ORP (mV)	nd	nd	nd	-67	-86	-122
Calcium (mg/L)	63.7				102	
Magnesium (mg/L)	27.3				62.9	
Sulfate (mg/L)	32.9				296	
Chloride (mg/L)	12.7				12	
Bicarbonate (mg/L)	299.0				246	
Sodium (mg/L)	7.11				15.1	
Potasium (mg/L)	1.28				7.19	
Fluoride (mg/L)	0.25				1.39	
Iron (ug/L)	<50				380	
Arsenic Lab (ug/L)	<1			1.89	1.88/2.09	3.19
Arsenic HACH Kit (ug/L)	nd	nd	nd	1 to 2	0 to 1	1 to 2
Strontium (ug/L)	6800				11600	
Sillica (mg/L)	11.4				11.9	
TDS (mg/L)	313				858e	

nd= no data; e= estimated based upon 0.6 of conductivity

Table 4. *Summary of water-quality data from HACH testing kit and field parameters during Phase 2 extraction.*

Date/Time	Ferrous Iron (mg/L)	Total Iron (mg/L)	Arsenic (ug/L)	Conductivity (uS/cm)	ORP (mV)	Notes
5/16/2017 9:20	0.71	0.9		1090	-30	
5/16/2017 10:25	Nd	Nd	0	1160	-50	
5/16/2017 10:36	0.52	0.57		1170	-58	
5/16/2017 12:30	0.44	0.47	0	1300	-67	
5/16/2017 13:20	0.5	0.49	3 to 4	1340	-67	RRWSC#4 (Edwards) Ferrous Iron: 0.01; Total Iron: 0.00
5/16/2017 14:00	Nd	Nd	1 to 2	1330		
5/16/2017 14:20	Nd	Nd	1 to 2	1360		As sample (LCRA)
5/16/2017 14:30	0.47	0.49		1370	-80	
5/16/2017 15:30	Nd	Nd	0			RRWSC#4 (Edwards) Arsenic: 0
5/16/2017 15:50	0.42	0.41		1430		
5/16/2017 16:30	Nd	Nd	1	1430	-89	As sample (LCRA) & TWDB suite
5/25/2017 11:00	0.94	0.88	0-1	1530	-90	3.4k gals pumped when sampled
5/26/2017 12:30	0.87	0.79	0-1	1590	-89	1.1 k gals pumped when sampled (Submitted sample to LCRA)
6/1/17 9:30	0.99	0.89	0-1	1800	-32	
6/16/2017	0.72	0.77	0-1	2060	-78	
6/29/2017	0.86	0.99	0-2	2150		BSEACD intern Django Doster took measurements

Table 5. *Table of the radial distance (feet) of the injection bubble for various porosity values. Assume laterally contained within the Cow Creek (75 ft thick), no mixing, and an injection volume of 280,000 gal (37,515 cubic feet).*

	Effective Porosity					
	0.05	**0.1**	**0.15**	**0.2**	**0.25**	**0.3**
Radial Distance (ft)	56	40	33	28	25	23

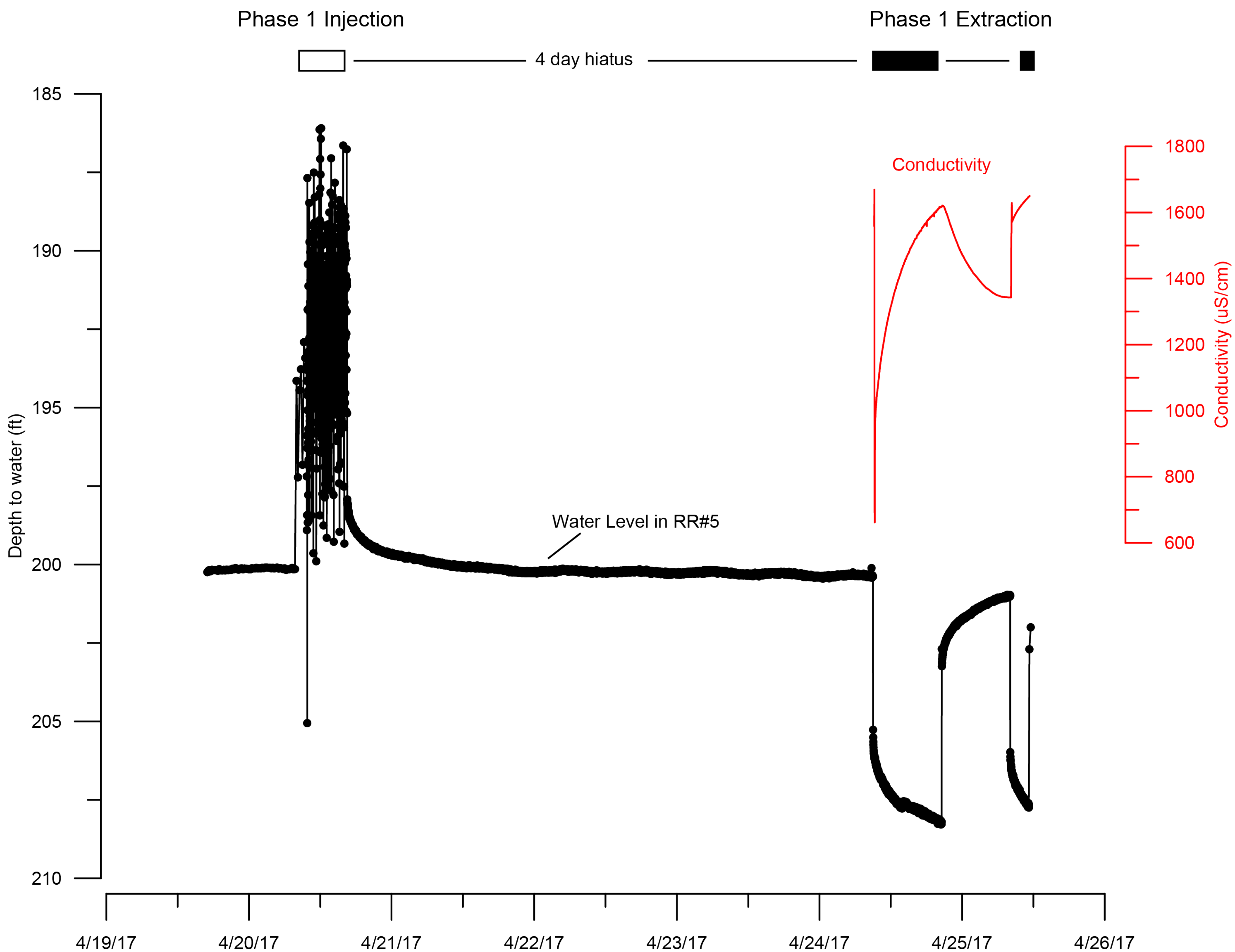

Figure 6. *Hydrograph of the water level and conductivity data during Phase 1 testing of the RRWSC#5.*

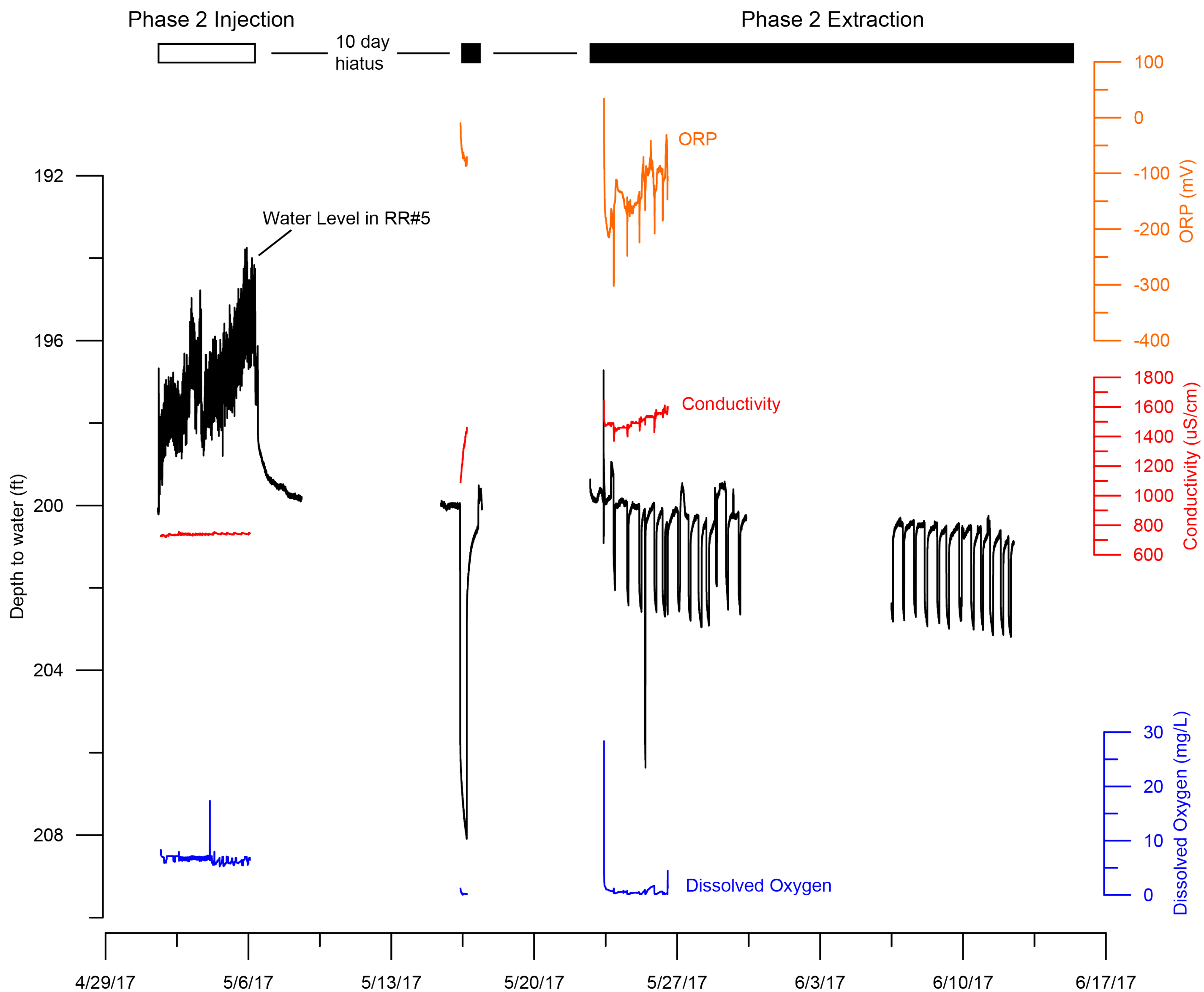

Figure 7. *Hydrograph of the water level, conductivity, ORP, and DO data during Phase 2.*

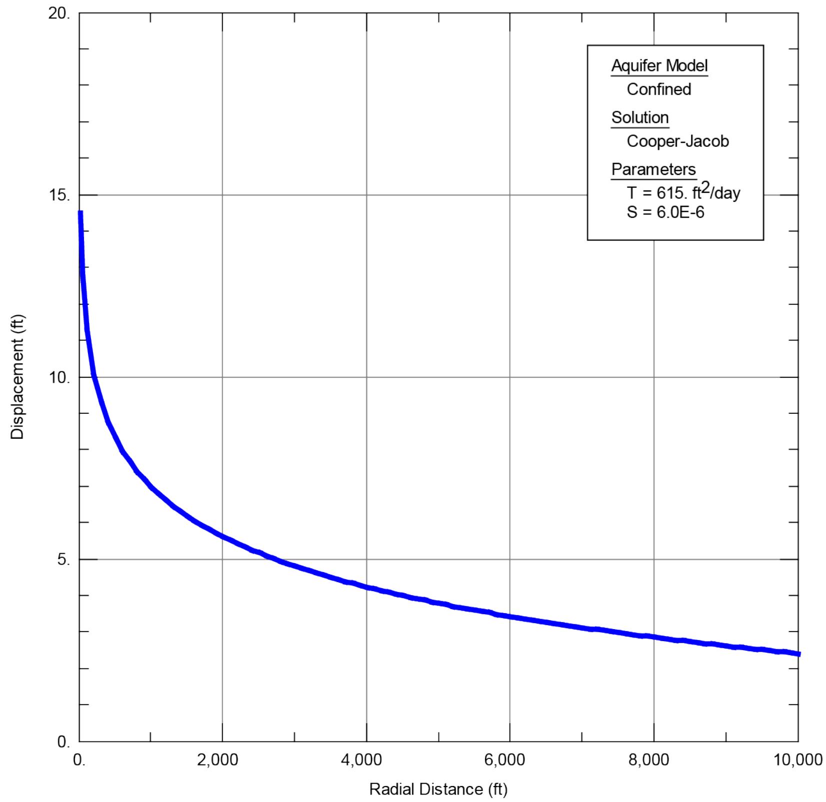

***Figure 8** Modeled potentiometric results of injection into the RRWSC#5 (Cow Creek) at 40 gpm after 7,000 minutes (~116 hrs) similar to the Phase 2 injection.*

Geochemistry

The Ruby Ranch multiport well has 14 discrete zones (**Figure 3**) completed in the Edwards and Trinity Aquifers and provides detailed geochemical data for source and receiving water characterization. **Figure 9**, a Durov diagram, illustrates the chemical composition of groundwater samples from the Ruby Ranch multiport well (5857513 of **Figure 2**). This appears to be typical of the range of hydrochemical facies of aquifers in the study area. Groundwater from the 14 zones varies in chemical composition from calcium-magnesium-bicarbonate (Ca-Mg-HCO_3) and calcium-carbonate (Ca-HCO_3) in Edwards aquifer Zones 11–13, to magnesium-calcium-sulfate (Mg-Ca-SO_4) in Middle and Upper Trinity aquifer Zones 8–10, and magnesium-calcium-sulfate-bicarbonate (Mg-Ca-SO_4-HCO_3) in Middle Trinity aquifer zones 1–7. Total dissolved solids range from ~350 mg/L or less in the Edwards Aquifer to between 450 and 850 mg/L in Middle Trinity zones 1–7, and from 2,800 to 3,800 mg/L in the sulfate-dominant groundwater of Upper Trinity zones 8–10.

All geochemical sampling results from the pilot testing are provided in **Appendix C** and summarized in **Tables 2 and 3**. The Durov diagram shown in **Figure 10** illustrates the hydrochemical compositions of the RRWSC#4 Edwards injection water (Ca-HCO_3 facies) and the RRWSC#5 Cow Creek native receiving waters (Mg-Ca-SO_4 facies). Also shown is the chemistry of the produced water for Phases 1 and 2 after 40,000 and 44,000 gallons of water were produced after injection, respectively.

Mixing models developed with Geochemist's Workbench© v. 11 (GWB) reveal that Phase 1 produced water consisting of a mixture of 20 percent Edwards groundwater and 80 percent Cow Creek groundwater after 40,000 gallons were pumped from the well. Phase 2 produced water is 35 percent Edwards and 65 percent Cow Creek after 44,000 gallons were pumped from the well. **Figure 11** adds the modeled mixtures (M1 and M2) to **Figure 10**. **Table 6** lists the concentrations of major metals and nonmetals for the Edwards, Cow Creek, P1 and P2 samples, along with the modeled concentrations for M1 and M2. The table also includes saturation indices (calcite, dolomite, fluorite, gypsum, and halite) calculated by GWB, based on the WATEQ4F thermodynamic data base (Ball and Nordstrom, 1991, rev. 2001). The models assumed simple mixing according to the specified ratios and did not attempt to force equilibration with dolomite or calcite, or other reactions such as adsorption or desorption. The data to address such matters are lacking at this time, but more detailed models should be developed in forthcoming stages of the project. Nonetheless, the very close match between the modeled and actual compositions indicates that the modeled results, as specified above, are representative of the groundwater mixtures that make up the P1 and P2 samples. Points representing M1 and M2 overlie P1 and P2 in the metals and nonmetals trilinear fields, in the square cross plot representing metals and nonmetals, and in the TDS field (**Figure 11**).

The saturation indices referred to above and listed in **Table 6** indicate that the Edwards source and Cow Creek receiving waters are undersaturated with respect to fluorite (CaF_2), gypsum ($CaSO_4 \cdot 2H_2O$), and halite (NaCl). Edwards source water is saturated with respect to calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), and Cow Creek is undersaturated with respect to both minerals. The Phase 1 and Phase 2 samples are saturated with respect to calcite and dolomite and undersaturated with regard to fluorite, gypsum, and halite. Iron concentrations and iron minerals are addressed in the following section (Arsenic Geochemistry) of this report.

Saturation indices are interpreted as indicators of the ***potential*** for dissolution (negative values) or precipitation (positive values), but they should not be used to infer that either process ***will*** occur, or that either process will occur at a known rate. It is also important to note that saturation indices might change from positive to negative (or vice versa) as a function of minor variations in the composition of water over time or in response to variations in analytical accuracy and precision.

Table 6. *Saturation indices within various groundwaters with respect to mineral phases.*

Sample ID	Unit	Edwards	Cow Creek	Phase 1	Phase 2	20:80 Mix	35:65 Mix
pH	SU	7.82	6.95	7.29	8.53	7.051	7.14
Temperature	C	21.27	27.12	26.7	24.78	25.95	25.07
Ca++	mg/l	63.7	153	132	102	135.2	121.8
Mg++	mg/l	27.3	111	92.5	62.9	94.29	81.76
Sr++	mg/l	6.8	17.7	15.2	11.6	15.52	13.89
Na+	mg/l	7.11	24.2	20.7	15.1	20.79	18.23
K+	mg/l	1.28	13.6	11.5	7.19	11.14	9.297
HCO3-	mg/l	304	265.4	258.3	250.1	318.2	315.4
SO4--	mg/l	32.9	657	536	296	532.5	439
Cl-	mg/l	12.7	13.6	12.9	12	13.42	13.28
F-	mg/l	0.25	2.06	1.89	1.39	1.699	1.428
SiO2(aq)	mg/l	11.4	13.2	12.3	11.9	12.84	12.57
TDS	mg/l	313	1161	987	858	991.9	864.9
				Saturation Indices			
Calcite	log Q/K	0.5426	-0.1119	0.1568	1.322	-0.07738	0.02545
Sat/Unsat		Saturated	Unsaturated	Saturated	Saturated	Unsaturated	Saturated
Dolomite	log Q/K	1.021	-0.00719	0.5128	2.781	0.04074	0.217
Sat/Unsat		Saturated	Unsaturated	Saturated	Saturated	Saturated	Saturated
Fluorite	log Q/K	-2.255	-0.408	-0.4974	-0.7757	-0.5969	-0.7242
Sat/Unsat		Unsaturated	Unsaturated	Unsaturated	Unsaturated	Unsaturated	Unsaturated
Gypsum	log Q/K	-2.146	-0.8025	-0.9053	-1.185	-0.9002	-0.9904
Sat/Unsat		Unsaturated	Unsaturated	Unsaturated	Unsaturated	Unsaturated	Unsaturated
Halite	log Q/K	-8.626	-8.129	-8.211	-8.359	-8.214	-8.245
Sat/Unsat		Unsaturated	Unsaturated	Unsaturated	Unsaturated	Unsaturated	Unsaturated

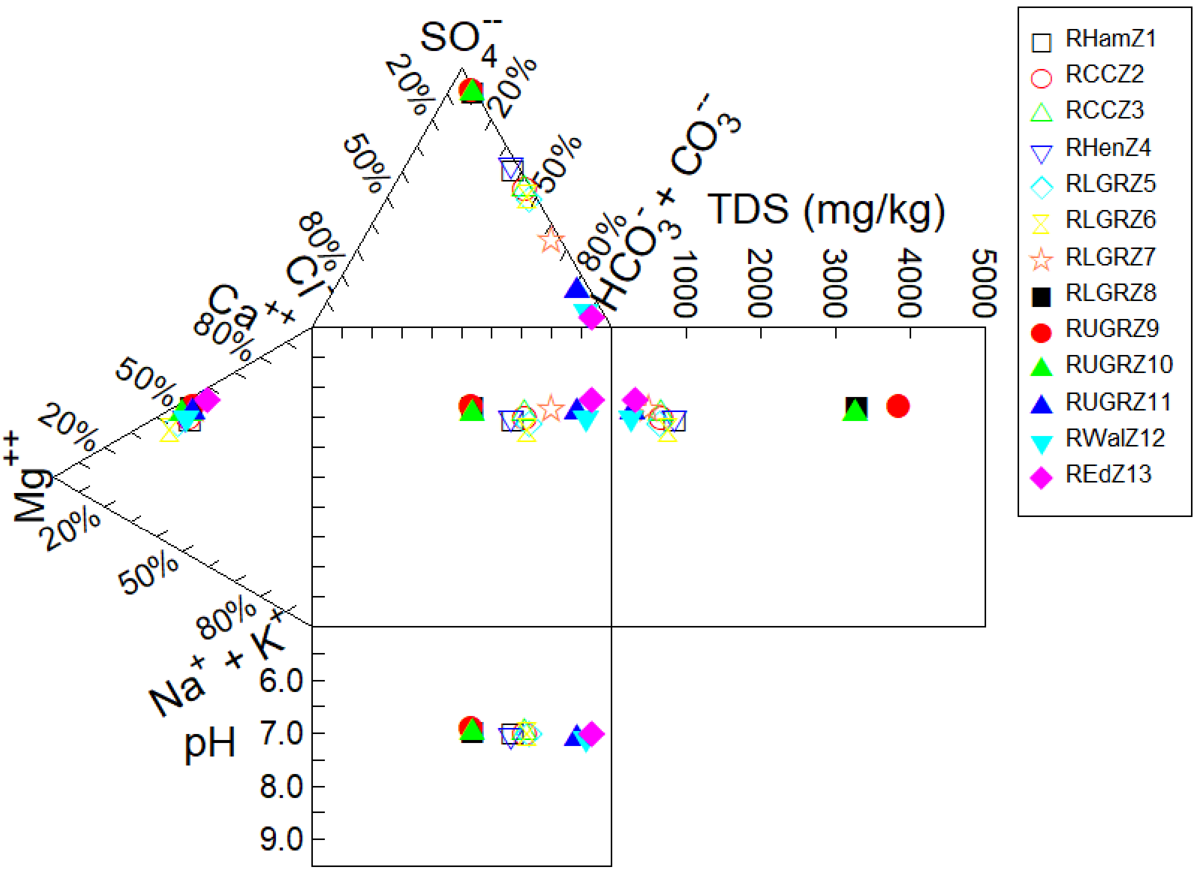

Figure 9. *Durov diagram showing the hydrochemical compositions of groundwater that vary from (1) Ca-Mg-HCO3 and Ca-HCO3 in the (Edwards aquifer, Zones 11 - 13), to (2) Mg-Ca-SO4 in the Middle and Upper Trinity aquifers (Zones 8 – 10). Below Zone 8, the compositions are dominantly (3) Mg-Ca-SO4-HCO3 in the Middle Trinity aquifer.*

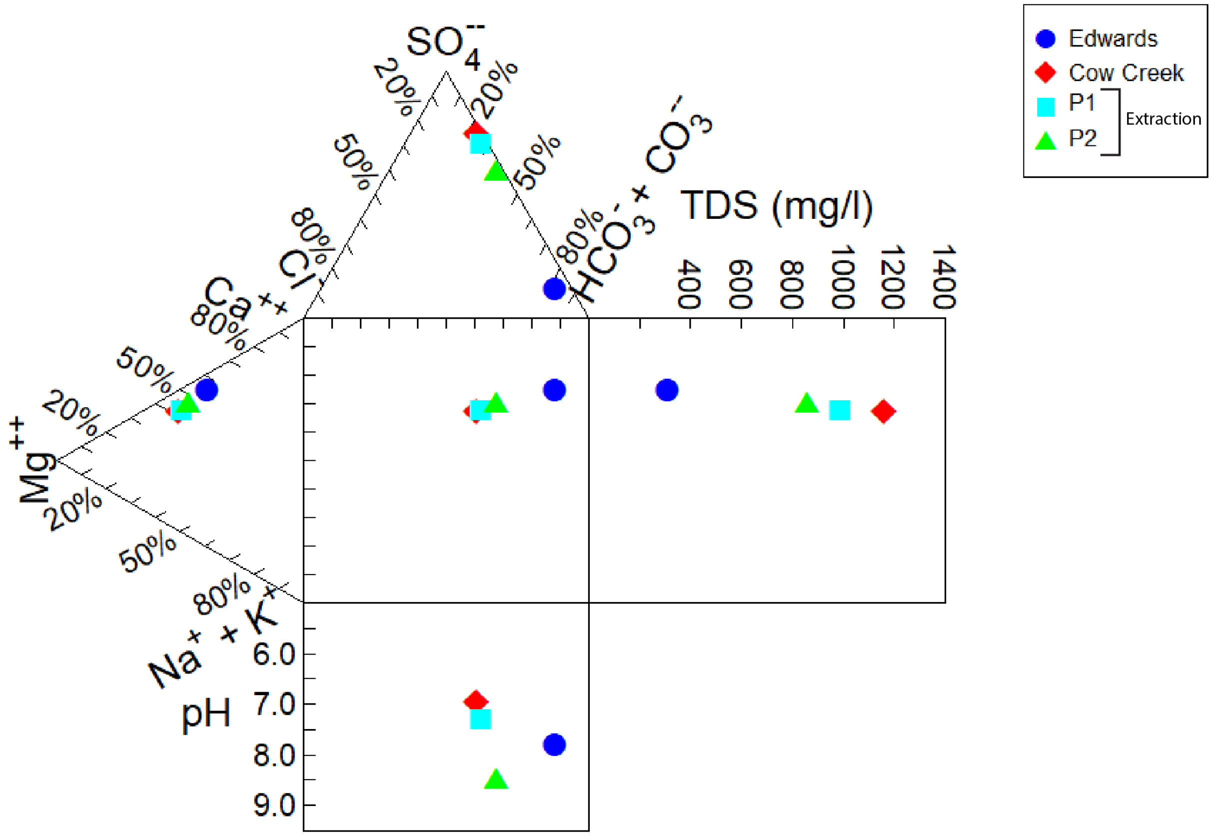

Figure 10. *Durov diagram showing the hydrochemical compositions of the RRWSC#4 Edwards source or injection water (Ca-HCO3), RRWSC#5 Cow Creek receiving waters (Mg-Ca-SO4). Phase 1 (P1) and Phase 2 (P2) water chemistry are shown after 40,000 and 44,000 gallons were produced after injection, respectively.*

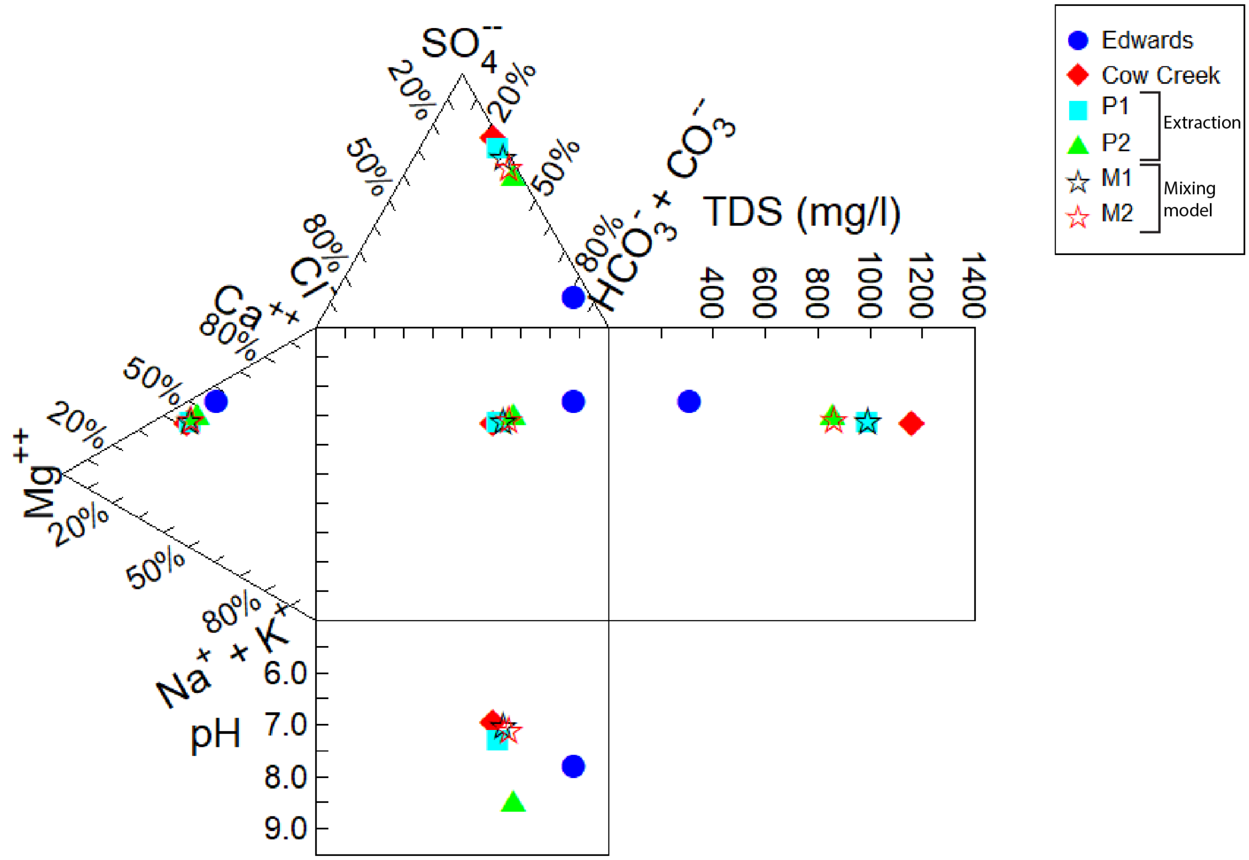

Figure 11. *Durov diagram from figure 10 showing the mixing model results.*

Arsenic Geochemistry

Because of concerns about mobilization of arsenic from host rocks, additional analyses for arsenic were made during the extraction phases of the tests. Some samples were collected for analysis by the LCRA laboratory on an expedited schedule (**Tables 2 and 3**). Other analyses were made in the field with test strips to detect low levels of arsenic (**Table 4**). Analyses of groundwater from the Edwards source well (RRWSC#4) and the Middle Trinity well (RRWSC#5) prior to the Phase 1 injection showed that arsenic concentrations were less than the detection level of 1.0 microgram per liter (ug/L). During Phase 1 extraction, the concentration of arsenic was 2.2 to 2.7 ug/L; and during Phase 2 extraction, the concentration of arsenic was 1.9 to 3.2 ug/L. The U.S. Environmental Protection Agency lists the maximum contaminant level (MCL) of arsenic as 10.0 μg/L.

It is important to note differences in dissolved oxygen (DO) concentrations in Edwards and Cow Creek groundwaters (see **Table 3**) as factors to be considered in the mobilization of arsenic in recovery water from RR#5. The mineral associations of arsenic in the Cow Creek are not well understood at this time. The XRD/XRF analyses in **Appendix D** show that arsenic is present within the predominantly dolomite matrix, but the analyses do not show the specific mineral or minerals with which arsenic occurs. Oxygenated waters injected at early ASR sites in Florida were the key factors that led to the release of arsenic in concentrations greater than the 10-μg/L MCL (Arthur, Dabous, and Cowart 2002; Price and

Pichler 2006; Jones and Pichler 2007), primarily from pyrite (FeS_2) and arsenopyrite (FeAsS). The occurrence of arsenic in groundwater at ASR sites in Florida was not observed until the early stages of cycle testing, and the mineral associations were discovered only after investigators examined cores and cuttings from the storage zone (Suwannee Limestone).

The concentration of arsenic in Phase 1 and Phase 2 recovery samples was well below the 10-μg/L MCL. In both the source water and the receiving water, the concentration of arsenic was reported to be less than 1.0 μg/L (**Table 2**). The higher arsenic concentrations reported for the Phase 1 and Phase 2 samples are probably related to the effect of oxidative dissolution of ferrous iron minerals disseminated within the Cow Creek. The DO concentration in the Edwards source water was 6.4 mg/L (**Table 3**). DO was not analyzed in the Cow Creek receiving water (**Table 2**), but it is unlikely that the concentration would be greater than a few tenths of a mg/L. This assumption is based on the DO measurement of 0.13 mg/L in the Phase 2 produced water (**Table 3**). The DO concentration reported for the Phase 1 recovered water was 2.45 mg/L, which is unexpectedly high for confined Cow Creek groundwater. That measurement probably reflects the mixing of oxygen-rich Edwards water with DO-deficient water of the Cow Creek.

The concentration of iron reported in receiving water is difficult to interpret, compared with concentrations in the two recovery samples. The concentrations in the recovery samples appear to be related to the dissolution of iron minerals, a geochemical process that would lead to the mobilization of associated arsenic. The higher iron concentration (1.0 mg/L) reported for the receiving water is not consistent with that model. The arsenic concentration in the receiving water was reported to be less than 1.0 μg/L (**Table 2**). If arsenic-bearing iron minerals were undergoing dissolution to yield an iron concentration of 1.0 mg/L, one would expect the concentration of arsenic to be greater than the method detection limit. Corrosion of the casing could account for the elevated iron and the low arsenic concentrations because the source of the iron is not derived from arsenic-bearing iron minerals of the Cow Creek.

It will be necessary to monitor arsenic concentrations on a regular basis, especially with increasing storage time in the Cow Creek. Initial geochemical speciation modeling with GWB shows that the dominant species of arsenic is in the form of the monoprotonated arsenate $HAsO_4^{-}$. The dominance of this species is illustrated in the form of an Eh-pH diagram (**Figure 12**).

Eh-pH diagrams represent the stability fields of different redox-sensitive dissolved and mineral species within the stability limits of water. **Figure 12** shows the stability fields of different oxidized (arsenate, As^{5+}) and reduced (arsenite, As^{3+}) species of arsenic. Arsenate species are in stability fields 1-4 of the diagram, and arsenite species are in fields 5-7. The points in stability field 3 are based on pH measurements and ORP measurements, adjusted to Eh by adding 0.20 volts (V) to each ORP measurement recorded during recovery testing. The cluster of points indicates very little variability with respect to pH and Eh. All the points lie entirely with field 3. In addition to ORP, the mobility of different arsenate and arsenite species is highly dependent on pH (Goldberg, 2002), and the points plotted on **Figure 12** appear to lie within the upper range of pH measurements at which arsenate tends to adsorb to various iron minerals (Goldberg, 2002). If the pH of the source and receiving water remains stable, the potential for purely pH-driven mobilization should not be expected to be a significant factor in the release of arsenic. However, under the current and planned injection procedures, it is unlikely that there will be any significant change in pH. Under conditions observed in RRWSC#5, the primary factor accounting for the occurrence of arsenic in the recovery samples is oxidative dissolution. This can be managed by treatment processes that strip DO from water prior to injection, or by minimizing introduction of oxygen into the source water prior to injection.

The results of the recovery tests indicate that a small mass of arsenic was mobilized during each test. This illustrates that arsenic is available and mobile. Additional points to be addressed over time are (1) the minerals with which arsenic is associated in the Cow Creek, (2) the form of association, that is, adsorption or absorption, and (3) the factors that control the stability of the minerals with which arsenic is either adsorbed or absorbed.

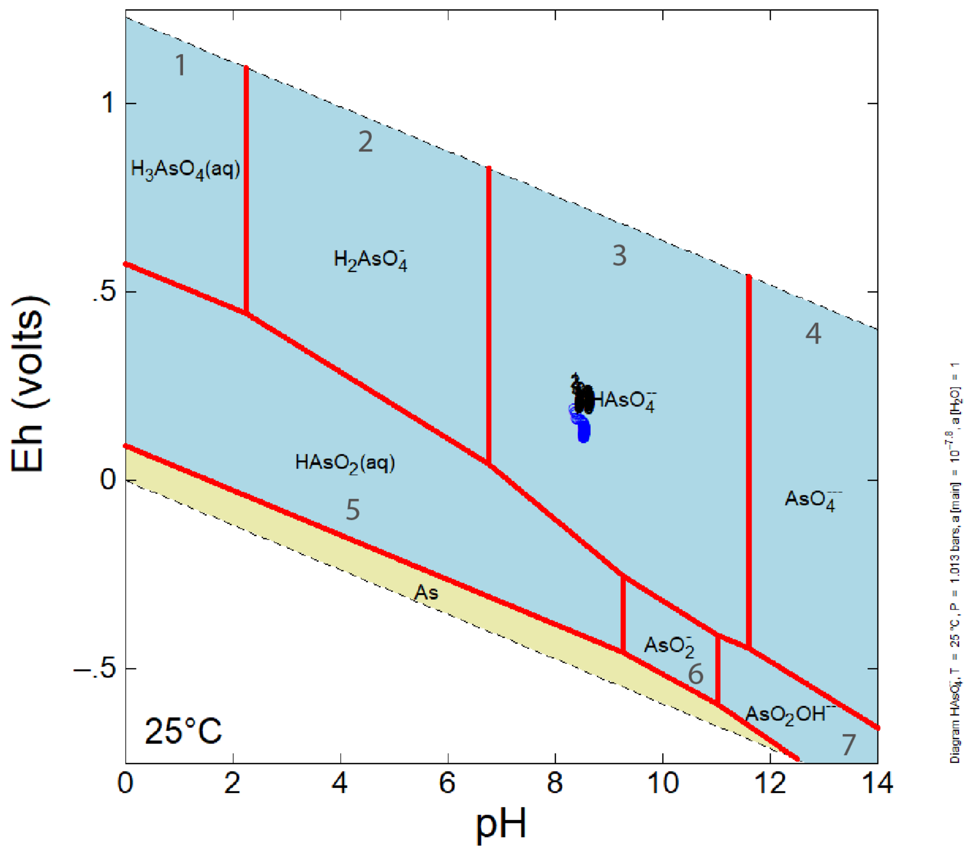

Figure 12. *Eh-pH diagram for AS-O system. The points plotted with the stability field are based on ORP measurements (corrected to yield Eh) during the recovery phase.*

Conclusions

From the results of the two phases of injection and extraction in the Middle Trinity Aquifer, it was clear that the aquifer is capable of receiving the water at the planned flow rates and of storing the injected Edwards water for an indefinite period of time.

The chemistry of the mixture of the two waters also appear compatible as the quality of the extracted (and highly mixed) water met all primary drinking water standards during the pilot testing. Analyses for arsenic in the extracted water show that the concentration of arsenic has not exceeded, nor approached, the 10-μg/L MCL. Routine monitoring of arsenic concentrations will be required during extended storage periods and all phases of groundwater recovery.

Future Work

Phase 3 of the testing is planned to begin in October 2017 through May 2018 and increase the volume of injection and the duration of storage. Current plans are to inject up to 7 million gallons of Edwards water.

Acknowledgments

Thomas Doebner and Dale Olmstead of the Ruby Ranch WSC, in consultation with the District staff and Joe Vickers, implemented and operated the ASR pilot test. District staff and Joe Vickers collected data during the testing. Kendall Bell-Enders and Vanessa Escobar of BSEACD helped with initial discussion, planning, and regulatory aspects of the project. Robin Gary (BSEACD) provided editorial review of this report.

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List of Appendices

FINAL REPORT

RUBY RANCH WATER SUPPLY CORPORATION
AQUIFER STORAGE AND RECOVERY PILOT PROJECT
HAYS COUNTY, TEXAS

OWNER: RUBY RANCH WSC
P.O. BOX 1585
BUDA, TEXAS 78610-1585

PWS NO. TX1050122
CN: 603033564
RN: 102681285

TCEQ UIC CLASS V INJECTION AUTHORIZATION NO. 5X2500126

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SEPTEMBER 2019

TABLE OF CONTENTS

Acknowledgements

Thomas Doebner and Dale Olmstead, Ruby Ranch Water Supply Corporation, in cooperation with Joe Vickers, The Wellspec Company, and Brian Smith, Ph.D., P.G., Brian Hunt, P.G., and Justin Camp of the Barton Springs Edwards Aquifer Conservation District implemented and operated the ASR Project described in this report. These individuals dedicated many hours of professional efforts in the development, performance and evaluation of this Project.

FINAL REPORT
RUBY RANCH WATER SUPPLY CORPORATION AQUIFER STORAGE AND RECOVERY (ASR) PILOT PROJECT
HAYS COUNTY, TEXAS
SEPTEMBER 2019

PROJECT OVERVIEW

The Ruby Ranch Water Supply Corporation (RRWSC) and the Barton Springs Edwards Aquifer Conservation District (BSEACD) have conducted a cooperative project to test the Middle Trinity Aquifer (specifically, the Cow Creek Formation) as a reservoir for storage and recovery of fresh Edwards Aquifer groundwater. RRWSC has five (5) public water supply wells. RRWSC's Well No. 4 is in the Edwards Aquifer and produces high-quality water that may be supplied to its customers directly without treatment, other than disinfection. RRWSC's Well No. 5, completed in the Cow Creek Formation of the Middle Trinity Aquifer, produces poor quality water that can only be used for public supply when blended with Edwards Aquifer water produced from Well No. 4 or by constructing costly water treatment facilities to recondition Cow Creek Formation water to drinking water standards. Due to high demands for Edwards Aquifer water, the BSEACD is seeking means to reduce dependence on the Edwards Aquifer, especially during drought conditions. One potential source of water is fresh Edwards Aquifer groundwater pumped during non-drought conditions and stored in the Cow Creek Formation in an aquifer storage and recovery (ASR) system.

BACKGROUND

In January 2017, RRWSC applied for a Class V Authorization to conduct a Pilot Test on Well No. 5 for the TCEQ. In March 2017, the TCEQ granted permission under Application UIC Authorization No. 5X2500126 to RRWSC, in cooperation with the BSEACD, to conduct a multi-year pilot study to evaluate the feasibility of using Edwards Aquifer water produced from the RRWSC's Well No. 4 for injection and extraction from RRWSC's Middle Trinity Aquifer (specifically the Cow Creek Formation) Well No. 5. The Pilot Project was conducted in four phases.

Phase 1 occurred in April 2017 with the injection of 50,000 gallons of Edwards Aquifer groundwater into the Cow Creek Formation. Subsequent extraction from the Cow Creek Formation totaled 65,700 gallons. Phase 2 occurred in May 2017 with the injection of 280,000 gallons of Edwards Aquifer groundwater into the Cow Creek Formation. Subsequent extraction from the Middle Trinity Aquifer occurred in May and June 2017, totaling over 300,000 gallons. The results and findings of RRWSC Phase 1 and Phase 2 efforts, which included an evaluation of groundwater levels, field parameters and laboratory analyses, are presented in a *Status Report for Aquifer Storage and Recovery Pilot Project: Ruby Ranch Water Supply Corporation, Hays County, Central Texas*[1]. Phase 3 occurred in October 2017 and involved the injection and

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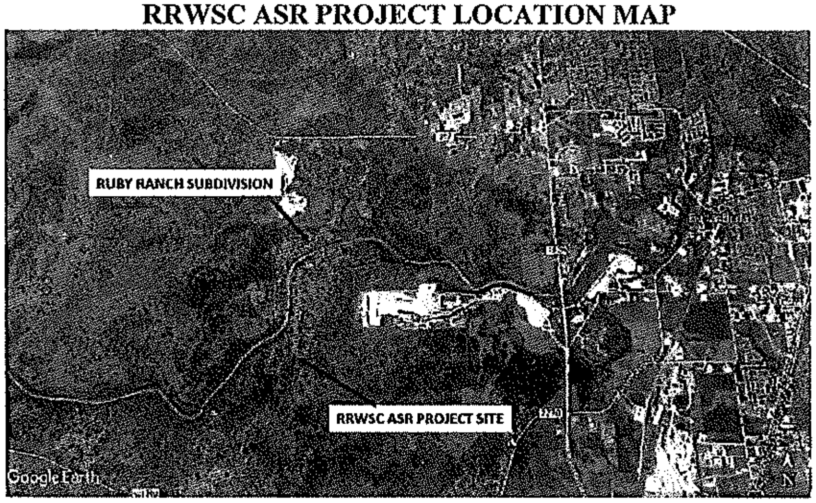
[1]Smith, B.A., Ph.D. P.G., Hunt, B.B., P.G., Camp, J., Darling, B.K., Ph.D., P.G., and Vickers, J., P.G., Status Report for Aquifer Storage and Recovery Pilot Project: Ruby Ranch Water Supply Corporation, Hays County, Central Texas. Technical Note 2017-0930, 28 pgs.

extraction of 9,000,000 and 4,466,700 gallons, respectively. Phase 4 occurred December 12, 2018 through July 18, 2019, with the injection of approximately 11,000,000 gallons of Edwards Aquifer groundwater water into the Cow Creek Formation via Well No. 5, as well as the subsequent extraction of about 1.8 million gallons of Edwards Aquifer groundwater from the Cow Creek Formation.

The RRWSC provides potable water service to retail customers within Texas Public Utility Commission Water CCN 12849 located in Hays County, Texas (see Figure 1). The Project is located within a secured fenced area at RRWSC Water Plant No. 2.

FIGURE 1
RRWSC ASR PROJECT LOCATION MAP



ASR PROJECT OPERATION OVERVIEW

From an operational standpoint (see ASR flow schematic in Figure 3), it is the goal and intent for RRWSC to:

1. Produce Edwards Aquifer water via Well No. 4 (see Figure 4) during the typically low domestic water use period occurring between November 1 and April 30 each calendar year;
2. Store extracted water via the Well No. 5 ASR process (see Figures 5 and 6) in the Cow Creek Formation for subsequent extraction;
3. Blend[2] ASR recovered water with Edwards water produced from Well No. 4 prior to the RRWSC ground storage tanks; and
4. Distribute the blended water to RRWSC customers during the usually high domestic water use period occurring between May 1 and October 31 of each calendar year.

[2] Currently, RRWSC is blending ASR recovered water with Edwards Aquifer water on a 50/50 basis prior to entry into RRWSC ground storage tanks.

FIGURE 2
RRWSC ASR SITE PLAN

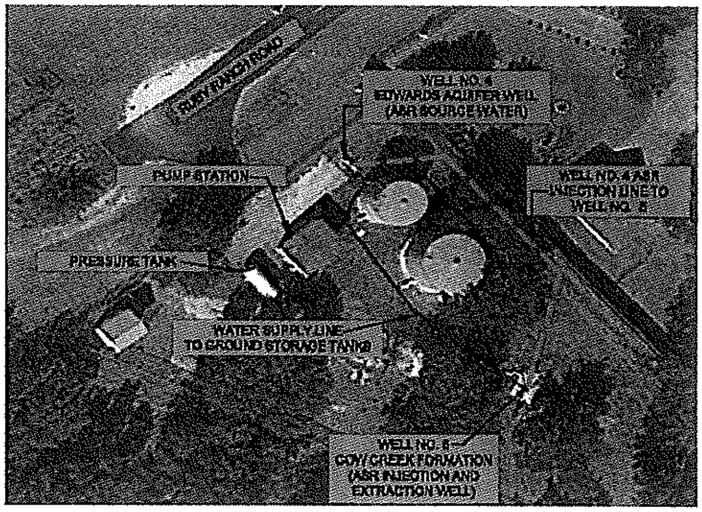


FIGURE 3
ASR FLOW SCHEMATIC

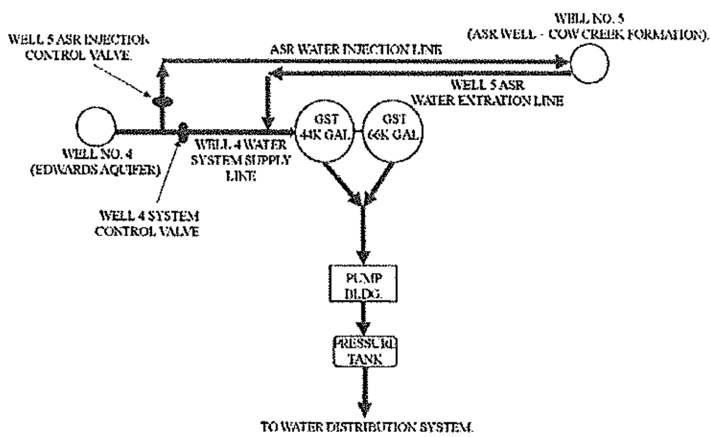


FIGURE 4
RRWSC WELL NO. 4 – ASR WELLHEAD IMPROVEMENMENTS

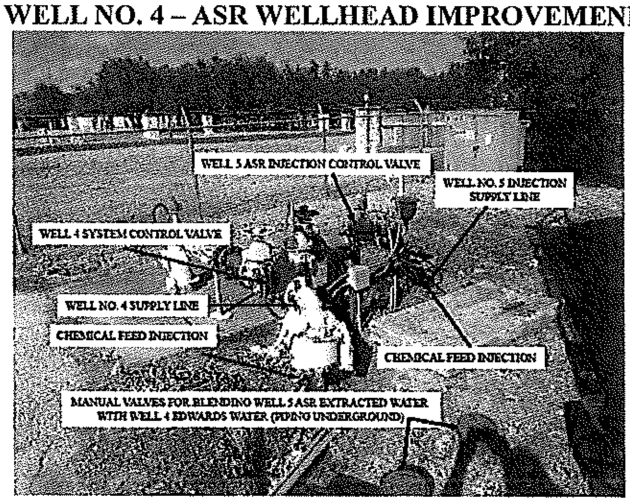


FIGURE 5
RRWSC WELL NO. 5 (TRINITY WELL – ASR INJECTION AND EXTRACTION)

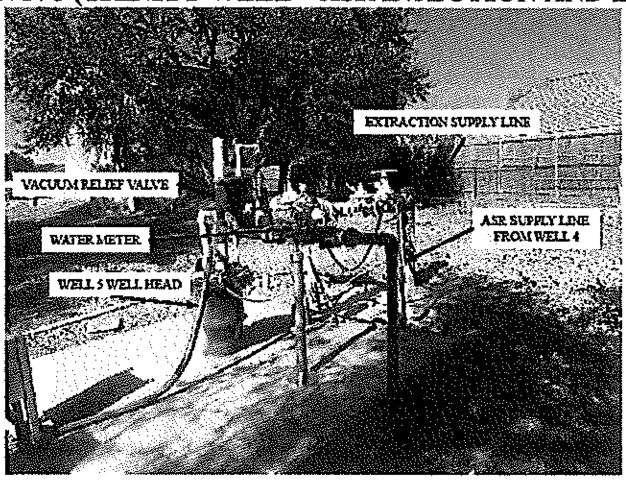
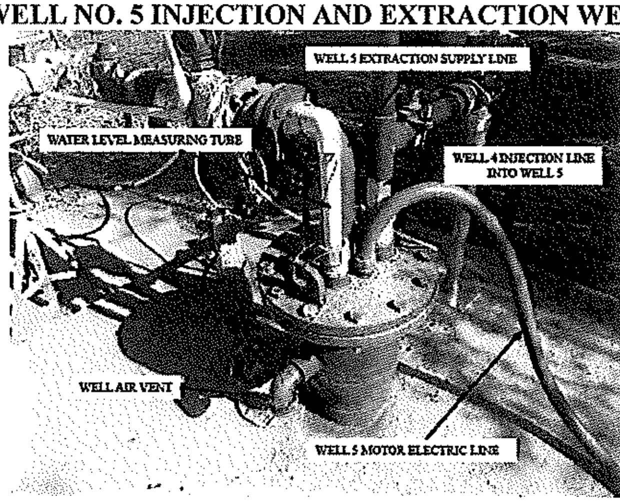


FIGURE 6
RRWSC WELL NO. 5 INJECTION AND EXTRACTION WELLHEAD



HYDROGEOLOGY

The following is an adapted excerpt from the *Status Report for Aquifer Storage and Recovery Pilot Project: Ruby Ranch Water Supply Corporation, Hays County, Central Texas*[3] describing the Project hydrogeology setting:

> The test area is located within the recharge zone of the Edwards Aquifer. The Edwards Aquifer is a prolific karst aquifer system consisting largely of limestone and dolomite (Figures 7 and 8). Recent studies (Wong et al., 2014) indicate that the upper portions of the Upper Glen Rose are in hydrologic communication with the overlying Edwards Group units. For regulatory purposes, the Edwards Aquifer in the study area is composed of the Edwards Group and the

[3]Smith, B.A., Ph.D. P.G., Hunt, B.B., P.G., Camp, J., Darling, B.K., Ph.D., P.G., and Vickers, J., P.G., Status Report for Aquifer Storage and Recovery Pilot Project: Ruby Ranch Water Supply Corporation, Hays County, Central Texas. Technical Note 2017-0930, 28 pgs.

upper-most 150 ft of the Upper Glen Rose. The RRWSC#4 Edwards well was drilled in 2001 to a depth of 405 feet and is completed within the Edwards Group and Upper Glen Rose (Figure 9).

The Trinity Aquifer is composed of the Trinity Group geologic units divided into three general hydro-stratigraphic units: The Upper, Middle, and Lower Trinity Aquifers. The focus of this testing is upon the Middle Trinity Aquifer, and specifically the Cow Creek Formation of the Middle Trinity. The RRWSC#5 well is completed in the Cow Creek unit of the Middle Trinity Aquifer. The well has a total depth of 1,140 ft (Figure 9) with open-hole completion to only the Cow Creek Formation. Below is a brief description of the units that make up the Trinity Aquifer units. The reader is referred Wierman et al., 2010 for more information.

The Middle Trinity Aquifer within the study area is hydrologically isolated from the overlying Edwards Aquifer due to the presence of aquitard units within the lower Upper Glen Rose and also with upper Lower Glen Rose (Smith et al., 2013; Wong et al., 2014; Hunt et al., 2016). The Middle Trinity Aquifer consists of the lowermost Lower Glen Rose, Hensel, and Cow Creek formations (Figure 9).

The Lower Glen Rose is generally composed of reef and skeletal grain limestones and generally supplies fresh water to wells in the Hill Country. Biostromes and reef facies of the Lower Glen Rose are important water-bearing units locally, with variable water quantity and quality. The Hensel formation in the study area is about 40 ft thick and is dominantly silty shale and dolomite deposited in a marine environment. The Hensel is not an aquifer and instead acts as a semi-confining layer over the Cow Creek in the study area (Wierman et al., 2010).

The Cow Creek Formation is the target hydrogeologic unit of the ASR testing in this study. The Cow Creek is composed of a grain-skeletal limestone, over a fine-grained oyster wake-stone to dolomite. The Cow Creek is very porous and permeable and is the primary water-bearing unit within the Middle Trinity Aquifer. The formation was subaerially exposed and subjected to meteoric water infiltration during early Hensel time (Loucks, 1977). Consequently, early diagenesis of the limestone created vuggy porosity. The underlying fine crystalline dolomite has well-developed porosity and both carbonates produce water in the Hill Country.

The Hammett Shale underlies the Cow Creek and is a highly plastic shale. The Hammett Shale is the regional confining unit separating the Middle Trinity Aquifer from the Lower Trinity Aquifer.

FIGURE 7
REGIONAL LOCATION MAP (A) AND CROSS SECTION (B) OF THE EDWARDS AND TRINITY AQUIFERS IN THE STUDY AREA. RUBY SYMBOL DENOTES RUBY ASR TEST WELL (RRWSC#5). MP SYMBOL REPRESENTS THE DISTRICT'S MULTIPORT MONITOR WELL. (FIGURE MODIFIED FROM WONG ET AL., 2014)

A.

B

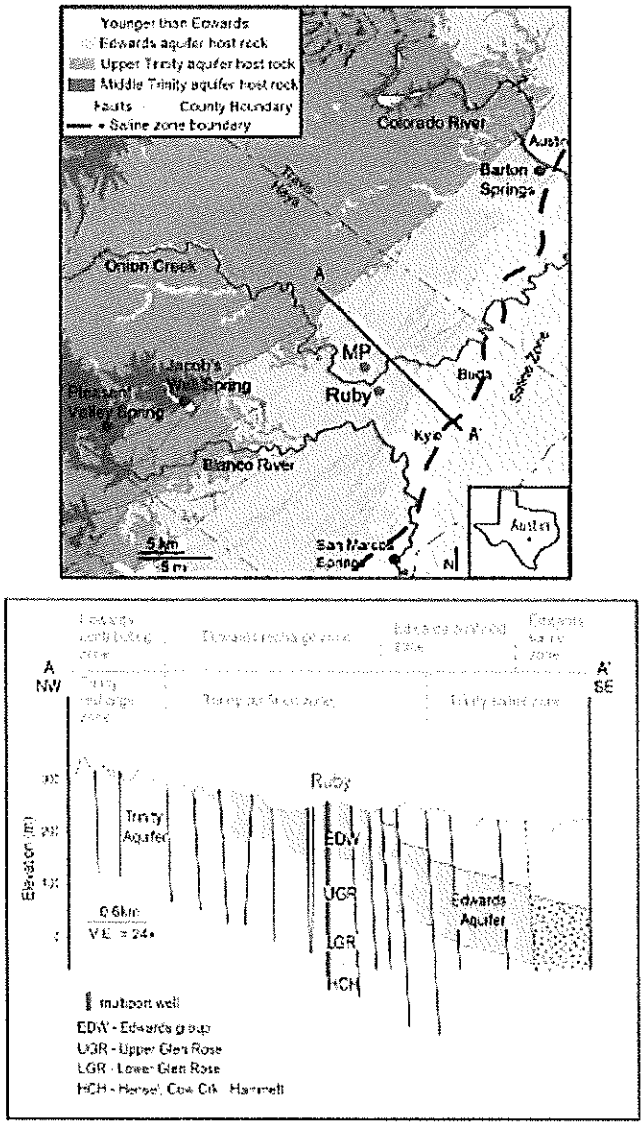


FIGURE 8
LOCATION MAP SHOWING WELLS AND FAULTS IN THE AREA. INSET MAP SHOWS THE AQUIFERS AND POTENTIOMETRIC MAP OF THE MIDDLE TRINITY INDICATING FLOW TO THE SOUTHEAST IN THE STUDY AREA[4].

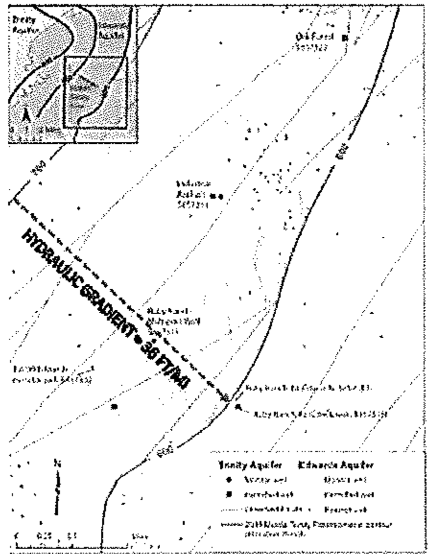
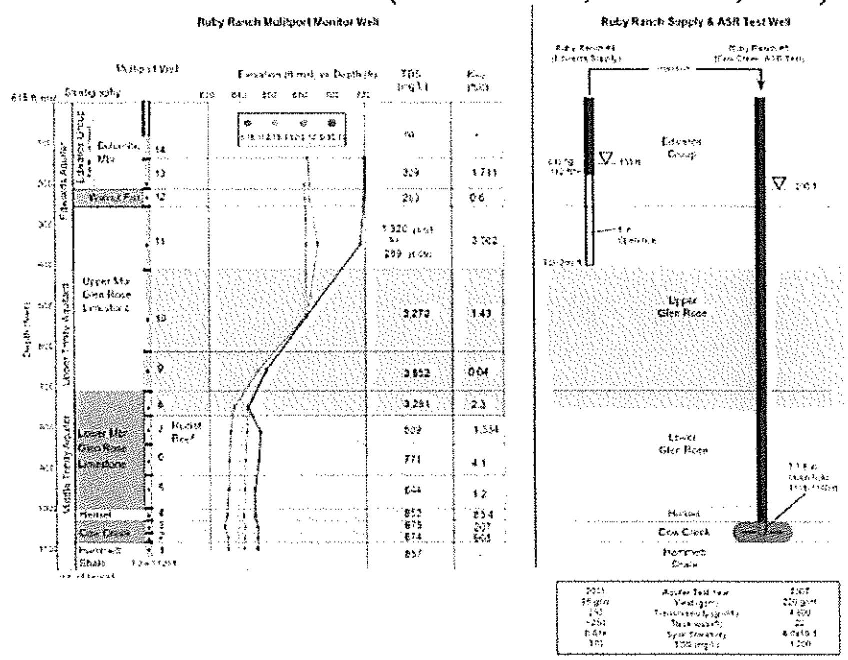


FIGURE 9
DETAILED HYDROSTRATIGRAPHY, WELL COMPLETION, AND HYDROGEOLOGIC DATA OF THE STUDY AREA. (Source: Smith, Ph.D. P.G., et. al.)



[4] Ibid., Smith, et.al., 2017

GROUNDWATER STORAGE AND DIRECTION OF FLOW

Edwards Aquifer water produced from Well No. 4 was injected, by gravity (i.e., at atmospheric pressure), into Well No. 5 and stored in the Cow Creek Formation. Well No.5—drilled in January 2010—was completed in the Cow Creek Formation (see Figure 10). In 2011, an aquifer test was conducted on Well No. 5 by Geos (Geos, 2011) that provides the following hydraulic parameters for this well (Hunt, et. al., 2010):

Well Yield	220 gpm (approximate)
Specific Capacity	1.3 gpd/ft
Transmissivity	4,600 gpd/ft
Storativity	0.00006

The direction of groundwater flow in the Middle Trinity/Cow Creek Formation is located down the structural dip of the geologic units to the southeast. The potentiometric surface map (Hunt and Smith, 2010) for the study area is shown in Figure 8. As illustrated in this figure, the hydrologic gradient in the study area is approximately 36 ft/mi from northwest to southeast. The average linear velocity of groundwater movement in the Cow Creek Formation, using Driscoll (1986), is calculated as follows:

Average Linear Velocity = (Hydraulic Conductivity, K times Hydraulic Gradient, i) / Porosity

K = 8.2 ft/day

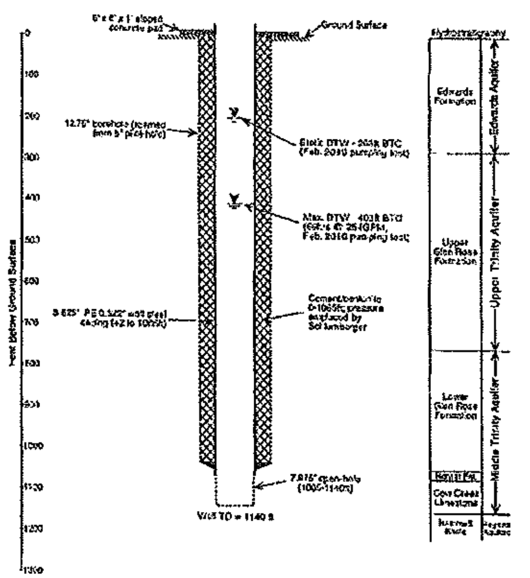
i = 36 ft/mi or 0.007 ft per ft

Porosity = 20%

Or

Average Linear Velocity = (8.2 x 0.007) / 0.20 = 0.3 ft/day.

FIGURE 10
WELL NO. 5 SCHEMATIC AND STRATIGRAPHY
(Source: Geos Consulting)



ASR VOLUMES

RRWSC conducted and completed its ASR Pilot Project, as summarized in Table 1 and Phases 3 and 4 are presented in detail in Appendix A.

TABLE 1
SUMMARY OF RRWSC ASR PROJECT

	Date	*Activity*	*Detail*
Background	3/3/2017 8:30	RRWSC#5 Background Chemistry	Field parameters, major and minor ions
	4/19/2017 16:18	RRWSC#5 Background Chemistry	Field parameters, major and minor ions
Phase 1	4/20/2017 8:00	Phase 1 injection begins	90-100 gpm; pressure transducer logging
	4/20/2017 16:30	Phase 1 injection ends	50,000 gallons total injected
	4/24/2017 9:00	Phase 1 extraction begins	90-100 gpm; continuous field parameters; pressure transducer logging
	4/24/2017 12:30	Extraction	20,000 gallons
	4/24/2017 15:56	Extraction	40,000 gallons; major & minor ions
	4/24/2017 20:30	Phase 1, official extraction Ends	65,705 gallons
	4/25/2017 11:30	Phase 1 continued extraction	83,700 gallons total pumped
Phase 2	5/1/2017 14:00	Phase 2 injection begins	40 gpm; Continuous field parameters; pressure transducer logging
	5/1/2017 20:00	Phase 2 injection	12,700 gallons
	5/6/2017 11:15	Phase 2 injection ends (118 hrs.)	280,632 gallons total injected
	5/16/2017 8:55	Phase 2 extraction begins a halted for lab results	Continuous field parameters (added ORP); pressure transducer logging; HACH arsenic kit test readings
	5/16/2017 16:40	Phase 2 extraction ~7 hrs.	44,000 gallons; LCRA lab samples: major and minor ions
	5/23/2017	Phase 2 extraction continues as lab results returned	Continuous field parameters (added ORP); pressure transducer logging; HACH arsenic kit test readings
	6/19/2017	Phase 2 extraction ends	Assorted Fe and As analyses; Total pumped volume 381,000 gallons
Phase 3	10/11/2017	Phase 3 injection begins	Continuous field parameters; pressure transducer logging; HACH arsenic kit and iron test readings
	05/16/2018	Phase 3 injection ends	9,000,015 gallons; LCRA lab samples
	07/27/2018	Phase 3 extraction	Continuous field parameters; pressure transducer logging; HACH arsenic kit and iron test readings

	11/06/2018	Phase 3 extraction ends	4,466,700 gallons, LCRA lab samples
Phase 4	12/12/2018	Phase 4 injection begins	Continuous field parameters; pressure transducer logging; HACH arsenic kit and iron test readings
	05/12/2019	Phase 4 injection ends	11,001,226 gallons; LCRA lab samples
	07/01/2019	Phase 4 extraction begins	LCRA lab samples; Continuous field parameters; pressure transducer logging; HACH arsenic kit and iron test readings
	08/12/2019	Phase 4 official extraction ends	1,810,800 gallons; LCRA lab samples; Continuous field parameters; pressure transducer logging; HACH arsenic kit and iron test readings

PHASE 1

Phase 1 activities primarily focused on installing and testing Well No.4 and Well No. 5 wellheads and connecting infrasture improvements and evaluation of the physical mechanics associated with the ASR Project. Preceding Phase 1 injection and extraction activities, RRWSC, in cooperation with the BSECD, installed wellhead piping improvements and manual control valves. Phase 1 injection (i.e., water produced from Well No. 4 – Edwards Aquifer well and injected into Well No. 5 – Trinity Aquifer Well) commenced at 0800 on April 20, 2017 and ended at 1630 the same day. During this 8-hour period, 50,000 gallons of Edwards Aquifer water was injected into Well No. 5 at an average injection rate of 98.0 gpm. Phase 1 water extraction from Well No. 5, at a production rate of 90-100 gpm, commenced at 0900 on April 24, 2017 and continued intermediately (i.e, water was not extracted continuously), ending at 1130 on April 25, 2017. During this 23-hour period, 83,700 gallons of water was extracted from Well No. 5 and flushed to the ground. A summary of the water quality data from Phase 1 is shown in Table 2. Figure 11 shows Phase 2 water levels in Well No. 5 during the injection and extraction combined with conductivity of the extracted water.

TABLE 2
SUMMARY OF WATER-QUALITY DATA FROM HISTORIC, BACKGROUND, AND EXTRACTION SAMPLING DURING PHASE 1 (Smith, et. al., 2017)

	Background				Phase 1 Extraction		
Well	RR#4 Edwards	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity
Volume	n/a	n/a	n/a	n/a	20,000 gal pumped	40,000 gal pumped	65,700 gal pumped
Date	6/28/2006	6/23/2010	3/3/2017 8:30	4/19/2017 16:18	4/24/2017 12:30	4/24/2017 15:56	4/24/2017 20:30
Lab/ Data Source	ELS	ELS	ELS (Drinking water)	ELS	ELS	ELS	ELS
Conductivity (uS/cm)	590	1572	1560	1640	1351.54	1514.07	1617.92
pH	7.18	7.0	7.62	6.95	7.28	7.29	
DO (mg/L)						2.45	
Temp ©	21.62	27.93		27.12	26.8	26.7	
ORP (mV)	nd	Nd	nd	nd	nd	nd	nd
Calcium (mg/L)	68.5	170	164	153		132	
Magnesium (mg/L)	35.4	114	109	111		92.5	
Sulfate (mg/L)	37	677	726	657		536	
Chloride (mg/L)	10	16	14.8	13.6		12.9	
Bicarbonate (mg/L)	323.4	313.6	256	261		254	
Sodium (mg/L)	6.1	23.9	25.2	24.2		20.7	
Potassium (mg/L)	1.5	12.4		13.6		11.5	
Fluoride (mg/L)	.03	2.11	2.22	2.06		1.89	
Iron (ug/L)	<30	603	284	1000		658	
Arsenic lab (ug/L)	<1	<2.0	<1.00	<1.00	2.29	2.36/2.2	2.69
Arsenic HACH Kit (ug/L)	nd	Nd	nd	nd	nd	nd	nd
Strontium (ug/L)	11000	17,300		17700		15200	
Silica (mg/L)	11.3	13.8		13.2		12.3	
TDS (mg/L)	342	1201	1210	1161		987	

PHASE 2

Phase 2 activities primarily focused on testing the efficiency and mechanics for the ASR injection and extration process. Between May 1, 2017 and May 6, 2017, 280,000 gallons of Edwards Aquifer water were injected into Well No. 5. The extraction phase commenced on May 16, 2017, when 44,000 gallons of water were extracted out of Well No. 5. Samples were collected and analyses reviewed before pumping started again on May 23, 2017. Between May 23, 2017 and June 19, 2017, 381,000 gallons were extracted from Well No. 5. A summary of water quality data from Phase 2 is shown in Table 3. Phase 2 water levels in the Trinity well during injection and extraction, combined with conductivity of the extracted water, is shown in Figure 11. ASR water injection rates into Well No. 5 varied from 40-100 gpm. Water extraction from Well No. 5 occurred at a rate of 100 gpm. The extracted water was diverted to RRWSC's ground storage tanks and mixed with Edwards Aquifer water pumped from Well No. 4, prior to distribution to RRWSC water customers.

FIGURE 11
HYDROGRAPH OF THE WATER LEVEL, CONDUCTIVITY, ORP, AND DO DATA DURING PHASE 1 (Smith, et. al., 2017)

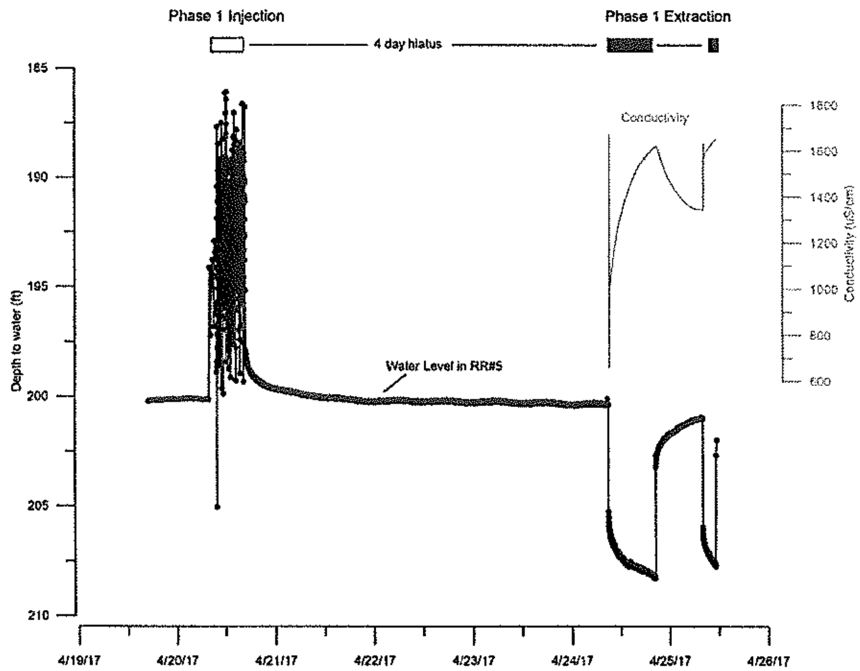
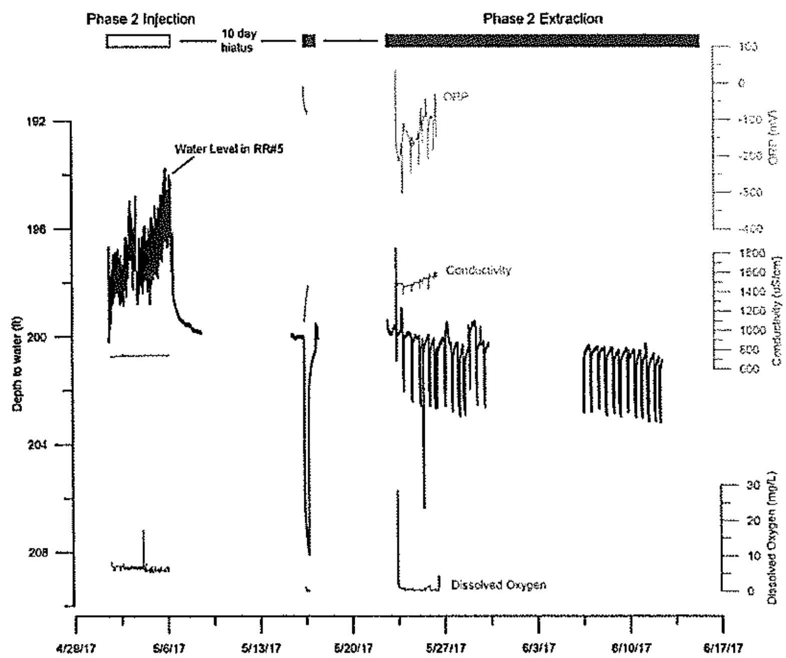


TABLE 3
SUMMARY OF WATER-QUALITY DATA FROM BACKGROUND AND EXTRACTION DURING PHASE 2 1 (Smith, et. al., 2017)

	Edwards Injection Water			Phase 2 Extraction		
Well	**RR #4 Edwards Well**	**RR #4 Edwards Tank**	**RR #4 Edwards Tank**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**	**RR#5 Middle Trinity**
Volume	n/a	n/a	97,400 gallons injected	Mix; Extract begins	44,000 gal pumped	
Date	5/1/2017 14:00	5/1/2017 14:00	5/3/2017 8:00	5/16/201714:20	5/16/2017 16:40	5/26/2017 12:45
Lab/ Data Source	BSEACD	BSEACD	BSEACD	ELS/BSEACD	ELS/BSEACD	ELS/BSEACD
Conductivity (uS/cm)	732	750	741	1,300	1,430	1,570
pH	7.84		8.24	8.55	8.53	
DO (mg/L)	6.4	7.25	7.04	0.22	0.13	0.15
Temp ©	21.27		21.72	21.21	24.78	
ORP (mV)	nd	nd	nd	-67	-86	-122
Calcium (mg/L)	63.7				102	
Magnesium (mg/L)	27.3				62.9	
Sulfate (mg/L)	32.9				296	
Chloride (mg/L)	12.7				12	

Bicarbonate (mg/L)	299.0				246	
Sodium (mg/L)	7.11				15.1	
Potassium (mg/L)	1.28				7.19	
Fluoride (mg/L)	0.25				1.39	
Iron (ug/L)	<50				380	
Arsenic Lab (ug/L)	<1			1.89	1.88/2.09	3.19
Arsenic HACH Kit (ug/L)	nd	nd	nd	1 to 2	0 to 1	1 to 2
Strontium (ug/L)	6800				11600	
Silica (mg/L)	11.4				11.9	
TDS (mg/L)	313				858e	

FIGURE 12
HYDROGRAPH OF THE WATER LEVEL, CONDUCTIVITY, ORP, AND DO DATA DURING PHASE 2 1 (Smith, et. al., 2017)



PHASE 3

Phase 3 activities centered on improving ASR injection and extraction processes, and evaluating injection and extraction efficiency and water quality. Phase 3 injection activities commenced on October 11, 2017 and ended on May 15, 2018. During this 115-day period, 9,000,015 gallons of water were injected into Well No. 5. Water extraction commenced on July 27, 2018 and ended on November 6, 2018. Over this 133-day period, 4,466,700 gallons of water were extracted from Well No. 5. Except for the first 225,000 gallons of extracted water flushed to the ground for iron mitigation, the extracted water flowed to the RRWSC's ground stoage tanks, where it was mixed with Edwards Aquifer water prior to being distributed to RRWSC's water customers.

Figure 13 shows Phase 3 water levels (minimun water level each day) and cumulative water injected in Well No. 5 during the injection period. During Phase 3, water injection rates into Well No. 5 ranged between approximately 40-100 gpm. Figure 14 shows water levels and cumulative water extracted, at a rate of approximately 100 gpm, from Well No. 5 during the recovery period. A summary of the water quality data from Phase 3 is shown in Table 4.

FIGURE 13
HYDROGRAPH OF WATER LEVEL AND CUMULATIVE INJECTION VOLUME DURING PHASE 3

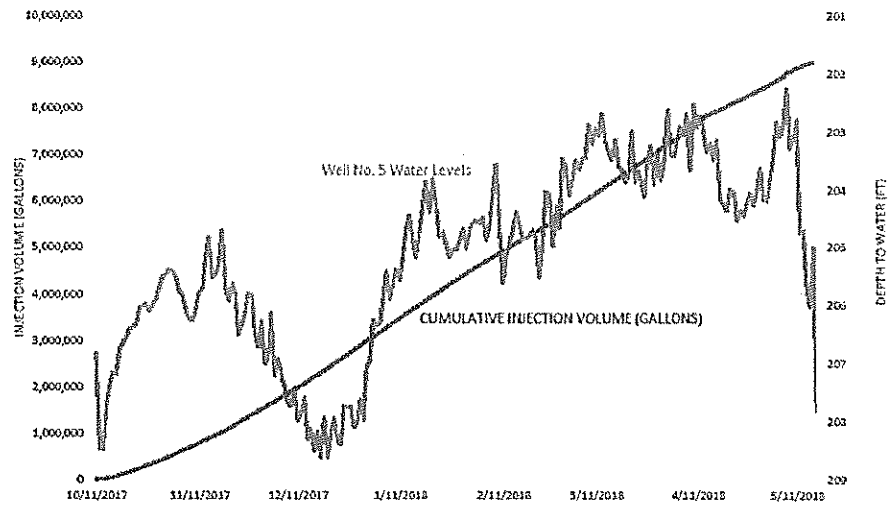


FIGURE 14
CUMULATIVE VOLUME OF EXTRACTED WATER AND WATER LEVEL GRAPH DURING PHASE 3

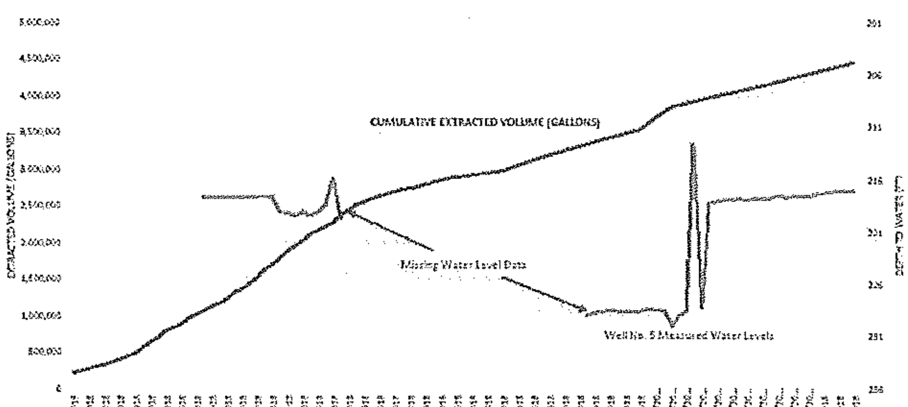


TABLE 4
SUMMARY OF WATER-QUALITY DATA FROM BACKGROUND AND EXTRACTION DURING PHASE 3

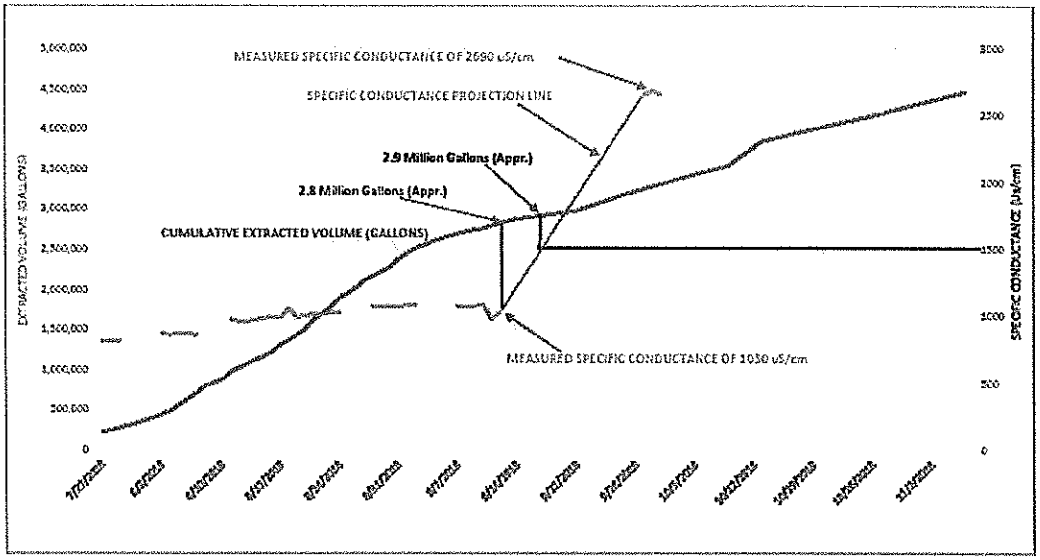
WATER QUALITY CONSTITUENT		BASELINE	PHASE 3				
		RR#4 Edwards	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity	RR#5 Middle Trinity
		100% Edwards	Mix; 3.4 mil gals recovered	Mix; 3.6 mil gals recovered	Mix; 3.9 mil gals recovered	Mix; 4.3 mil gals recovered	Mix; 4.5 mil gals recovered
		6/29/2018 11:15	10/4/2018 16:15	10/10/2018 13:45	10/17/2018 12:30	11/2/2018 13:15	11/7/2018 14:00
		BSEACD/TWDB	TWDB suite by Joe V	No sample	No sample	No sample	TWDB suite/BSEACD
Field Parameters							
Conductivity (uS/cm)		690	1220, (1160 lab)	1290	1300	1310	1240, (1220 Lab)
pH		7.18	7.29	6.99	6.62	6.7	7.23
DO (mg/L)			2.34	1.97	1.68	1.09	0.78
Temp C		21.62	25.44	24.4	24.42	24.33	24.99
ORP (mV)			-61	-39	-56	-145	-133
Lab- Major Ions							
Calcium (mg/L)	Ca++	67.4	121				132
Magnesium (mg/L)	Mg++	29.7	74.3				79.3
Sulfate Lab (mg/L)	SO-4	13.2	390				468
Chloride (mg/L)	Cl-	12	12.5				13.3
Bicarbonate (mg/L)	HCO-3	274	256				261
Sodium (mg/L)	Na+	6.81					19.4
Potassium (mg/L)	K+	1.07					8.73
Silica (mg/L)	SiO2	12.8					12.7
Strontium (mg/L)	Sr	1.22					12.1
Aluminum Total (mg/l)	Al						
Copper (mg/l)	C						
Lead (mg/l)	pB						
Manganese Total (mg/l)	Mn						
Zinc	Z						
Lab- Minor Ions							
Fluoride (mg/L)	F-	0.197	1.14				1.42
Bromide (mg/L)	Br-	0.07	0.11				0.11
Arsenic Lab (mg/L)	As	<1.00 (ug/L)					0.0044
Total Fe lab (mg/L)	Fe	<0.05					
Ammonia (mg/L)	NH3						
TDS (mg/L)		378	813				766
Tot Alk (mg/L)			256				261
Specific Conductance							
Nitrate/Nitrite Dis (mg/L)	NO-3		<0.02				
Nitrite as N (mg/l)							
Nitrate as N (mg/l)							
orthro-Phosphate (as P)							
Phosphorus, Total (as P)							
Hardness (mg/l)							
Hardness Calcium (mg/l)							
Residual Chlorine (mg/l)							
Total Coliform							
E. Coli							
pH							
Temperature C							
Ferrous Fe Kit	Fe+2						
Total Fe Kit (mg/L)	Fe+2		0.84				
Sulfate Kit (mg/L)	SO-4						
Arsenic Kit (mg/L)	As	n/a	0		0		

An examination of water quality of Edwards Aquifer water derived from Well No. 4 (i.e., Baseline Water Quality) compared to extracted water from Well No. 5 (following the recovery of over 3.6 million gallons of water) indicates that the recovery water at that point in the Phase 3 program resembled a quality more characteristic of ambient Cow Creek Formation water than Edwards Aquifer water. By way of example, conductivity of baseline Edwards Aquifer water shown in Table 4 is 690 uS/cm on June 29, 2018. This compares to an extracted water conductivity of over 1,220 uS/cm after more than 3.4 million gallons of water were extracted from Well No. 5. Likewise, sulfate concentrations increased from 13.2 mg/l (Edwards Aquifer Baseline) to 468 mg/l (Well 5 extracted water). Other water quality components shown in Table 4 reflect the magnitude of increase when comparing baseline water quality to extracted water quality for extraction volumes in excess of 3.4 million gallons. This further suggests that the Well No. 5 extracted water is more characteristic of Cow Creek Formation water and, possibly, indicates that the Edwards

Aquifer injection water "bubble" was not fully formed or of sufficient size to extract water volumes in excess of 3.4 million gallons.

Figure 15 depicts a graph of Phase 3 cumulative extracted volume and specific conductance. As illustrated, Phase 3 extracted water had a specific conductance for approximately 1,030 uS/cm cooresponding to an extacted water volume of 2.8 million gallons. When the extracted water volume reached 2.9 million gallons, specific conductance exceeded a projected concentration of 1,500 uS/cm[5]. Based on this analysis and assuming that the Cow Creek Formation is homogenies, a "safe" extraction volume versus injection volume ratio of 0.31 (or 30%) is projected (i.e., 2.8 million gallons extracted / 9.0 million gallons injected.

FIGURE 15
CUMULATIVE VOLUME OF EXTRACTED WATER AND MEASURED SPECIFIC CONDUCTANCE GRAPH DURING PHASE 3



PHASE 4

Phase 4 injection activities commenced on December 12, 2018 and ended on May 12, 2019. During this 151-day period, 11,001,124 gallons of water were injected into Well No. 5. This injection quantity, coupled with the 4,533,000 gallons of injected Phase 3 water that was not extracted as part of the Phase 3 program, resulted in a therotical recovery quality of approximately 15,000,000 gallons of recoverable water via Well No. 5. Phase 4 water extraction commenced on July 1, 2019 and ended, for purposes of this report, on August 12, 2019. Over this 43-day period, 1,810,800 gallons of water were extracted from Well No. 5. During this phase, water and extraction rates of 90 gpm were maintained. Water extracted from Well No. 5 during Phase 4 was blended on an approximate 50/50 ratio prior to entering RRWSC's ground storage tanks and subsequently distributed to RRWSC customers.

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[5] Based on correlation analysis of Well No. 5 extracted water, a specific conductance of 1500 uS/cm corresponds to a total dissolved concentration of 1,000 mg/l (i.e., TCEQ TDS limit for public drinking water supply).

Figure 16 shows Phase 4 water levels (minimun water level each day) and cumulative water injected in Well No. 5 during the injection period. Figure 17 depicts water levels and cumulative water extracted.

A summary of the water quality data from Phase 3 is shown in Table 4. This table lists major and minor ions, conductivity, total dissolved solids, pH, oxidation reduction potential, and other components associated with public drinking supples for Edwards Aquifer water from Well No. 4 extraction water, from Well No. 5, and for blended water entering the RRWSC public water system. The water sample collection dates for this comparative analysis are June 10, 2019 (Phase 4 pre-extraction date) and July 23, 2019, when approximately 1.8 million gallons of water was extracted from Well No. 5 and blended with Well No. 4 water. An evalutation of this data set indicates that the extracted water has a slight degradation in quality when compared to the Edwards Aquifer water, but well within TCEQ public drinking water standards.

FIGURE 16
HYDROGRAPH OF WATER LEVEL AND CUMULATIVE INJECTION VOLUME DURING PHASE 4

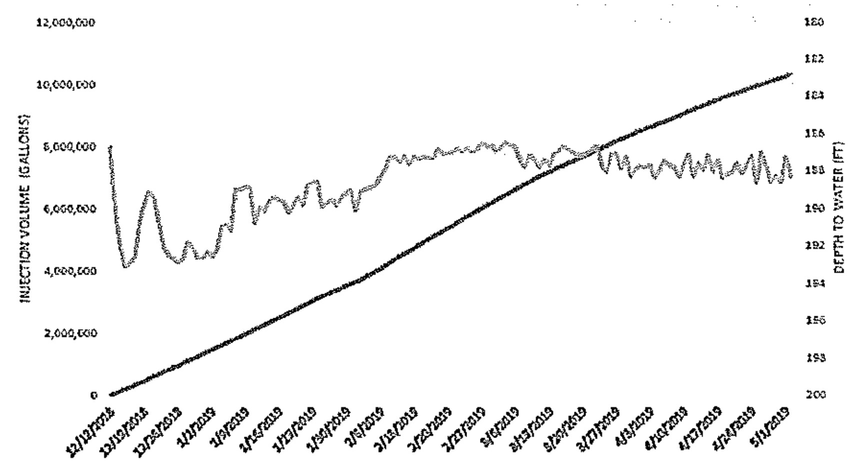


FIGURE 17
CUMULATIVE VOLUME OF EXTRACTED WATER AND WATER LEVEL GRAPH DURING PHASE 4

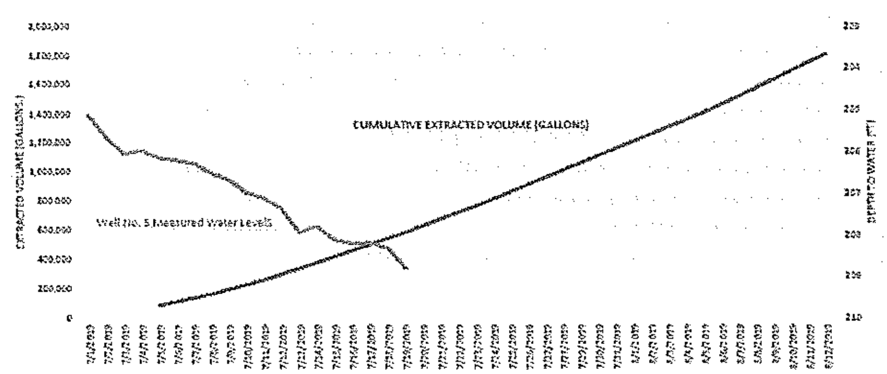
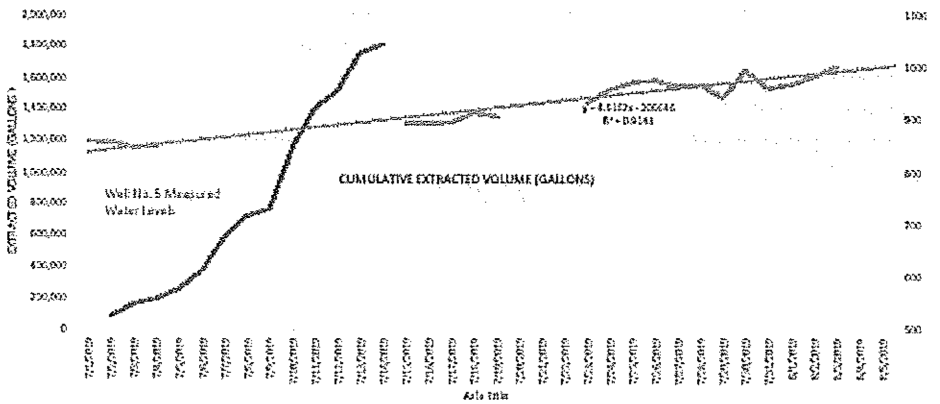


TABLE 5
SUMMARY OF WATER-QUALITY DATA FOR PHASE 4 EXTRACTION

WATER QUALITY CONSTITUENT		PHASE 4 STARTUP - BASELINE			PHASE 4 JULY 23, 2019		
		[illegible] Edwards	[illegible] Middle Trinity	[illegible] System	[illegible] Edwards	[illegible] Middle Trinity	[illegible] System
		6/10/2015	6/10/2015	6/10/2015	7/23/2019	7/23/2019	7/23/2019
		LCRA	LCRA	LCRA	LCRA	LCRA	LCRA
Field Parameters							
Conductivity (uS/cm)			853			918	
pH			7.03			6.5	
DO (mg/L)			0.16			0.66	
Temp C			22.3			23	
ORP (mV)			-643			-115.4	
Lab-Major Ions							
Calcium (mg/L)	Ca++	62.3	93.5	63	67.4	101	87.1
Magnesium (mg/L)	Mg++	28.7	45.3	37.3	26.7	52.1	32.7
Sulfate Lab (mg/L)	SO-4	53.1	175	158	32	200	153
Chloride (mg/L)	Cl-	12.7	14.3	7.5	13.5	13.1	15.5
Bicarbonate (mg/L)	HCO-3						
Sodium (mg/L)	Na+	7.58	8.85	9.72	7.51	11	11.1
Potassium (mg/L)	K+						
Silica (mg/L)	SiO2						
Strontium (mg/L)	Sr						
Aluminum Total (mg/L)	Al	<0.00500	<0.02	<0.00600	<0.00500	<0.00200	0.00517
Copper (mg/l)	Cu	0.00035	0.00415	0.00025	0.00237	0.00145	0.00485
Lead (mg/l)	Pb	<0.00050	<0.00050	<0.00100	<0.00500	<0.00150	<0.00100
Manganese Total (mg/l)	Mn	<0.00050	0.0613	<0.00150	<0.00150	0.0578	0.0264
Zinc	Zn	0.000154	0.0137	0.00847	0.00354	0.00031	0.0146
Lab-Minor Ions							
Fluoride (mg/L)	F-	0.348	0.356	0.0431	0.256	1.024	0.483
Bromide (mg/L)	Br-						
Arsenic Lab (mg/L)	As	<0.00050	0.00245	<0.00100	<0.00500	0.00515	0.00278
Total Fe lab (mg/L)	Fe	<0.0500	0.476	<0.0500	<0.0500	1.50	0.432
Ammonia (mg/L)	NH3						
TDS (mg/L)		372	513	326	346	537	372
Tot Alk (mg/L)		232	293	351	253	345	362
Specific Conductance		584	816	562	522	857	545
Nitrate/Nitrite Dis (mg/L)	NO-3						
Nitrite as N (mg/l)		<0.0500	<0.0500	<0.0100	<0.0100	<0.0150	<0.0100
Nitrate as N (mg/l)		0.428	<0.0500	0.183	0.516	<0.0100	0.357
ortho-Phosphate (as P)		<0.0500	0.17	<0.0100	<0.0100	0.0406	0.117
Phosphorus, Total (as P)		<0.0500	0.311	<0.50	<0.0500	0.852	0.507
Hardness (mg/l)		284	443	360	278	473	377
Hardness Calcium (mg/l)		155	253	165	168	260	218
Residual Chlorine (mg/l)		<0.5	<0.1	<0.02	<0.5	<0.5	<0.5
Total Coliform		Absent	Absent	Absent	Absent	Absent	Absent
E. Coli		Absent	Absent	Absent	Absent	Absent	Absent
pH		7.6	7.53	8.06	8.06	7.53	7.52
Temperature C		19.6	18.8	20.3	20.2	20.3	22
[illegible]	Fe+2						
[illegible]	Fe+2						
[illegible]	[illegible]						
[illegible]	[illegible]						

Figure 18 shows a graph of Phase 4 cumulative extracted volume (as of July 18, 2018) and specific conductance. As illustrated, Phase 4 extracted water had a specific conductance of approximately 1000 uS/cm cooresponding to an extacted water volume of approximately 1.8 million gallons. This correlates to a TDS concentraction of about 640 mg/l.

FIGURE 18
CUMULATIVE VOLUME OF EXTRACTED WATER AND MEASURED SPECIFIC CONDUCTANCE GRAPH DURING PHASE 3



APPENDIX A

RUBY RANCH WSC ASR PHASES 3 AND 4

TABULATED INJECTION AND EXTRACTED VOLUMES

RRWSC ASR Step 3

Injection

Date	Time	Meter	Gallons	Cumulative	Comments	
10/11/2017	11:00 AM	2,323,591			started	
10/11/2017	6:00 PM	2,331,015	7,424	7,424		
10/12/2017	7:00 AM	2,344,800	13,785	21,209		
10/12/2017	12:15 PM	2,423,423	78,623	21,209	line broke, water lost	
10/14/2017	10:30 AM	2,423,423	-	21,209	Restarted	
10/14/2017	6:30 PM	2,430,898	7,475	28,684		
10/15/2017	5:45 PM	2,448,802	17,904	46,588		
10/16/2017	12:45 PM	2,465,087	16,285	62,873		
10/18/2017	1:15 PM	2,508,500	43,413	106,286		
10/18/2017	2:50 PM	2,510,107	1,607	107,893		
10/21/2017	10:45 AM	2,578,950	68,843	176,736		
10/24/2017	10:10 AM	2,654,410	75,460	252,196	17.61 GPM	
10/28/2017	1:00 PM	2,763,715	109,305	361,501	18.43 GPM	October
10/31/2017	9:30 AM	2,845,120	81,405	442,906	19.81 GPM	442,906
11/2/2017	11:00 AM	2,909,175	64,055	506,961	21.57 GPM	
11/6/2017	4:30 PM	3,044,650	135,475	642,436	22.25 GPM	
11/9/2017	1:15 PM	3,130,590	85,940	728,376	20.83 GPM	
11/10/2017	4:15 PM	3,166,290	35,700	764,076	21.64 GPM	
11/13/2017	4:30 PM	3,267,500	101,210	865,286	23.51 GPM	
11/16/2017	8:30 AM	3,361,700	94,200	959,486	24.53 GPM	
11/18/2017	10:30 AM	3,437,250	75,550	1,035,036	25.18 GPM	
11/22/2017	8:30 AM	3,587,135	149,885	1,184,921	26.58 GPM	
11/24/2017	4:30 PM	3,681,950	94,815	1,279,736	28.22 GPM	November
11/30/2017	1:30 PM	3,923,850	241,900	1,521,636	28.59 GPM	1,078,730
12/4/2017	9:45 AM	4,086,550	162,700	1,684,336	29.39 GPM	
12/9/2017	12:30 PM	4,305,300	218,750	1,903,086	29.70 GPM	
12/14/2017	11:00 AM	4,517,670	212,370	2,115,456	29.87 GPM	
12/15/2017	3:10 PM	4,569,700	52,030	2,167,486	30.79 GPM	
12/18/2017	12:30 PM	4,699,760	130,060	2,297,546	31.26 GPM	
12/20/2017	12:30 PM	4,794,100	94,340	2,391,886	32.76 GPM	
12/23/2017	4:30 PM	4,946,300	152,200	2,544,086	32.94 Gpm	
12/27/2017	12:00 PM	5,130,600	184,300	2,728,386	33.57 GPM	December
12/31/2017	3:00 PM	5,339,500	208,900	2,937,286	35.17 GPM	1,415,650
1/2/2018	3:00 PM	5,439,800	100,300	3,037,586	34.83 GPM	
1/4/2018	10:30 AM	5,531,750	91,950	3,129,536	35.23 GPM	
1/8/2018	4:30 PM	5,733,850	202,100	3,331,636	33.35 GPM	

1/14/2018	5:15 PM	6,024,350	290,500	3,622,136	33.45 GPM	
1/18/2018	1:00 PM	6,211,250	186,900	3,809,036	33.95 GPM	
1/23/2018	2:30 PM	6,460,350	249,100	4,058,136	34.17 GPM	January
1/31/2018	4:30 PM	6,847,350	387,000	4,445,136	33.25 GPM	1,507,850
2/7/2018	11:30 AM	7,150,900	303,550	4,748,686	31.04 GPM	
2/12/2018	10:00 AM	7,370,900	220,000	4,968,686	30.94 GPM	
2/14/2018	12:30 PM	7,463,000	92,100	5,060,786	30.40 GPM	
2/23/2018	11:30 AM	7,821,450	358,450	5,419,236	27.79 GPM	February
2/28/2018	4:30 PM	8,054,950	233,500	5,652,736	31.13 GPM	1,207,600
3/5/2018	9:00 AM	8,270,750	215,800	5,868,536	31.97 GPM	
3/7/2018	4:00 PM	8,377,400	106,650	5,975,186	32.32 GPM	
3/10/2018	11:30 AM	8,511,200	133,800	6,108,986	33.04 GPM	
3/13/2018	2:45 PM	8,659,300	148,100	6,257,086	32.80 GPM	
3/17/2018	5:30 PM	8,857,550	198,250	6,455,336	33.46 GPM	
3/22/2018	4:15 PM	9,097,800	240,250	6,695,586	33.72 GPM	
3/24/2018	5:15 PM	9,197,900	100,100	6,795,686	34.05 GPM	
3/26/2018	5:00 PM	9,282,500	84,600	6,880,286	29.53 GPM	
3/29/2018	11:45 AM	9,417,300	134,800	7,015,086	33.66 GPM	March
3/31/2018	4:30 PM	9,528,900	111,600	7,126,686	35.26GPM	1,473,950
4/4/2018	2:00 PM	9,720,000	191,100	7,317,786	34.06 GPM	
4/6/2018	11:00 AM	9,814,700	94,700	7,412,486	35.07 GPM	
4/8/2018	3:00 PM	9,924,400	109,700	7,522,186	35.16 GPM	
4/11/2018	11:00 AM	10,067,800	143,400	7,665,586	35.15 GPM	
4/13/2018	6:00 PM	10,219,200	151,400	7,816,986	31.94 GPM	
4/17/2018	3:00 PM	10,342,800	123,600	7,940,586	29.86 GPM	
4/19/2018	9:30 AM	10,404,400	61,600	8,002,186	24.16 GPM	
4/22/2018	3:30 PM	10,523,200	118,800	8,120,986	25.38 GPM	
4/29/2018	1:00 PM	10,764,200	241,000	8,361,986	24.27 GPM	April
4/30/2018	7:00 PM	10,810,400	46,200	8,408,186	25.67 GPM	1,281,500
5/4/2018	5:20 PM	10,962,300	151,900	8,560,086	26.84 GPM	
5/7/2018	9:30 AM	11,089,900	127,600	8,687,686	33.14 GPM	
5/8/2018	1:45 PM	11,145,400	55,500	8,743,186	32.74 GPM	
5/11/2018	2:30 PM	11,274,400	129,000	8,872,186	29.55 GPM	
5/13/2018	1:30 PM	11,337,700	63,300	8,935,486	22.45 GPM	
5/14/2018	6:00 PM	11,367,200	29,500	8,964,986	17.25 GPM	
5/15/2018	7:15 PM	11,388,900	21,700	8,986,686	14.32 GPM	May
5/16/2018	12:30 PM	11,402,229	13,329	9,000,015	12.88 GPM	591,829
			(11,402,229)	(2,402,214)		
			-	(2,402,214)		
			-	(2,402,214)		
			-	(2,402,214)		

RRWSC Well #5
ASR Recovery
STEP RECOVERY

Date	Meter	Usage	Cululative	Comments/Conductivity
7/27/2018	34,081,400	225,000	225,000	6/15/20 to 7/27/18 Flushing and Iron Mitigation
7/29/2018	34,135,400	54,000	279,000	
7/30/2018	34,168,800	33,400	312,400	
7/31/2018	34,193,200	24,400	336,800	
8/2/2018	34,265,500	72,300	409,100	
8/4/2018	34,350,400	84,900	494,000	
8/6/2018	34,502,300	151,900	645,900	
8/7/2018	34,567,200	64,900	710,800	
8/8/2018	34,658,700	91,500	802,300	
8/10/2018	34,745,500	86,800	889,100	
8/11/2018	34,836,400	90,900	980,000	
8/13/2018	34,937,600	101,200	1,081,200	
8/14/2018	34,988,600	51,000	1,132,200	
8/15/2018	35,036,300	47,700	1,179,900	
8/16/2018	35,091,300	55,000	1,234,900	
8/17/2018	35,181,900	90,600	1,325,500	
8/18/2018	35,229,800	47,900	1,373,400	
8/19/2018	35,300,900	71,100	1,444,500	
8/20/2018	35,380,800	79,900	1,524,400	
8/21/2018	35,495,500	114,700	1,639,100	
8/22/2018	35,561,300	65,800	1,704,900	
8/23/2018	35,649,300	88,000	1,792,900	
8/24/2018	35,746,800	97,500	1,890,400	
8/26/2018	35,885,600	138,800	2,029,200	
8/27/2018	35,976,900	91,300	2,120,500	
8/29/2018	36,081,100	104,200	2,224,700	
8/30/2018	36,135,300	54,200	2,278,900	
8/31/2018	36,234,500	99,200	2,378,100	
9/2/2018	36,372,300	137,800	2,515,900	
9/4/2018	36,456,100	83,800	2,599,700	

9/6/2018	36,525,200	69,100	2,668,800	
9/8/2018	36,585,700	60,500	2,729,300	
9/10/2018	36,621,100	35,400	2,764,700	
9/12/2018	36,684,900	63,800	2,828,500	
9/14/2018	36,738,900	54,000	2,882,500	
9/21/2018	36,839,000	100,100	2,982,600	
9/24/2018	36,950,300	111,300	3,093,900	
9/27/2018	37,054,900	104,600	3,198,500	
9/28/2018	37,084,500	29,600	3,228,100	
10/3/2018	37,235,200	150,700	3,378,800	
10/4/2018	37,265,300	30,100	3,408,900	
10/9/2018	37,402,400	137,100	3,546,000	
10/13/2018	37,706,300	303,900	3,849,900	
10/17/2018	37,809,000	102,700	3,952,600	
10/20/2018	37,882,400	73,400	4,026,000	
10/26/2018	38,024,500	142,100	4,168,100	
10/29/2018	38,111,000	86,500	4,254,600	
11/6/2018	38,323,100	212,100	4,466,700	
		(38,323,100)	(33,856,400)	

RRWSC ASR Step 4 Injection

Date	Time	Meter	Gallons	Cumulative	Comments	
12/12/2018		102			Step 4 Injection Started	
12/12/2018	5:45 PM	22,380	22,278			
12/13/2018	11:30 AM	61,640	39,260	61,538		
12/14/2018	2:30 PM	134,053	72,413	133,951		
12/16/2018	11:30 AM	270,119	136,066	270,017		
12/17/2018	2:30 PM	346,690	76,571	346,588		
12/21/2018	11:00 AM	631,070	284,380	630,968		
12/22/2018	12:00 PM	702,780	71,710	702,678		
12/26/2018	9:00 AM	975,540	272,760	975,438		
12/31/2018	10:30 AM	1,340,100	364,560	1,339,998		
1/7/2019	10:00 AM	1,839,470	499,370	1,839,368		
1/12/2019	4:30 PM	2,217,680	378,210	2,217,578		
1/16/2019	11:00 AM	2,493,450	275,770	2,493,348		
1/25/2019	5:00 PM	3,192,450	699,000	3,192,348		
2/2/2019	11:00 AM	3,715,050	522,600	3,714,948		
2/17/2019	4:30 PM	5,112,500	1,397,450	5,112,398		
2/24/2019	3:00 PM	5,742,100	629,600	5,741,998		
3/2/2019	10:15 AM	6,265,300	523,200	6,265,198		
3/10/2019	3:30 PM	6,937,500	672,200	6,937,398		
3/31/2019	12:00 PM	8,419,800	1,482,300	8,419,698		
4/7/2019	5:00 PM	8,833,800	414,000	8,833,698		
4/14/2019	4:00 PM	9,290,800	457,000	9,290,698		
4/19/2019	12:45 PM	9,592,900	302,100	9,592,798		
4/27/2019	1:00 PM	10,023,300	430,400	10,023,198		
5/1/2019	9:45 AM	10,232,300	209,000	10,232,198		
5/2/2019	2:15 PM	10,308,300	76,000	10,308,198		
5/9/2019	2:30 PM	10,779,500	471,200	10,779,398		
5/12/2019	12:10 PM	11,001,226	221,726	11,001,124	Step 4 Injection Stopped	

RUBY RANCH ASR Step 4 Extraction

Date	Time	Meter	Gallons	Cumulative	Comments
7/1/2019	2:00 PM	38,630,000			Started ASR Step 4 Extraction
7/5/2019	9:30 AM	38,719,500	89,500	89,500	
7/8/2019	10:30 AM	38,797,300	77,800	167,300	
7/9/2019	2:30 PM	38,829,000	31,700	199,000	
7/11/2019	1:30 PM	38,891,900	62,900	261,900	
7/14/2019	2:30 PM	39,011,800	119,900	381,800	
7/19/2019	10:00 AM	39,216,300	204,500	586,300	
7/22/2019	11:15 AM	39,355,600	139,300	725,600	
7/23/2019	10:20 AM	39,397,700	42,100	767,700	
7/31/2019	1:20 PM	39,791,100	393,400	1,161,100	
8/5/2019	1:45 PM	40,037,400	246,300	1,407,400	
8/7/2019	12:00 PM	40,148,200	110,800	1,518,200	
8/11/2019	1:30 PM	40,384,000	235,800	1,754,000	
8/12/2019	10:30 AM	40,440,800	56,800	1,810,800	
			(40,440,800)	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	
			-	(38,630,000)	