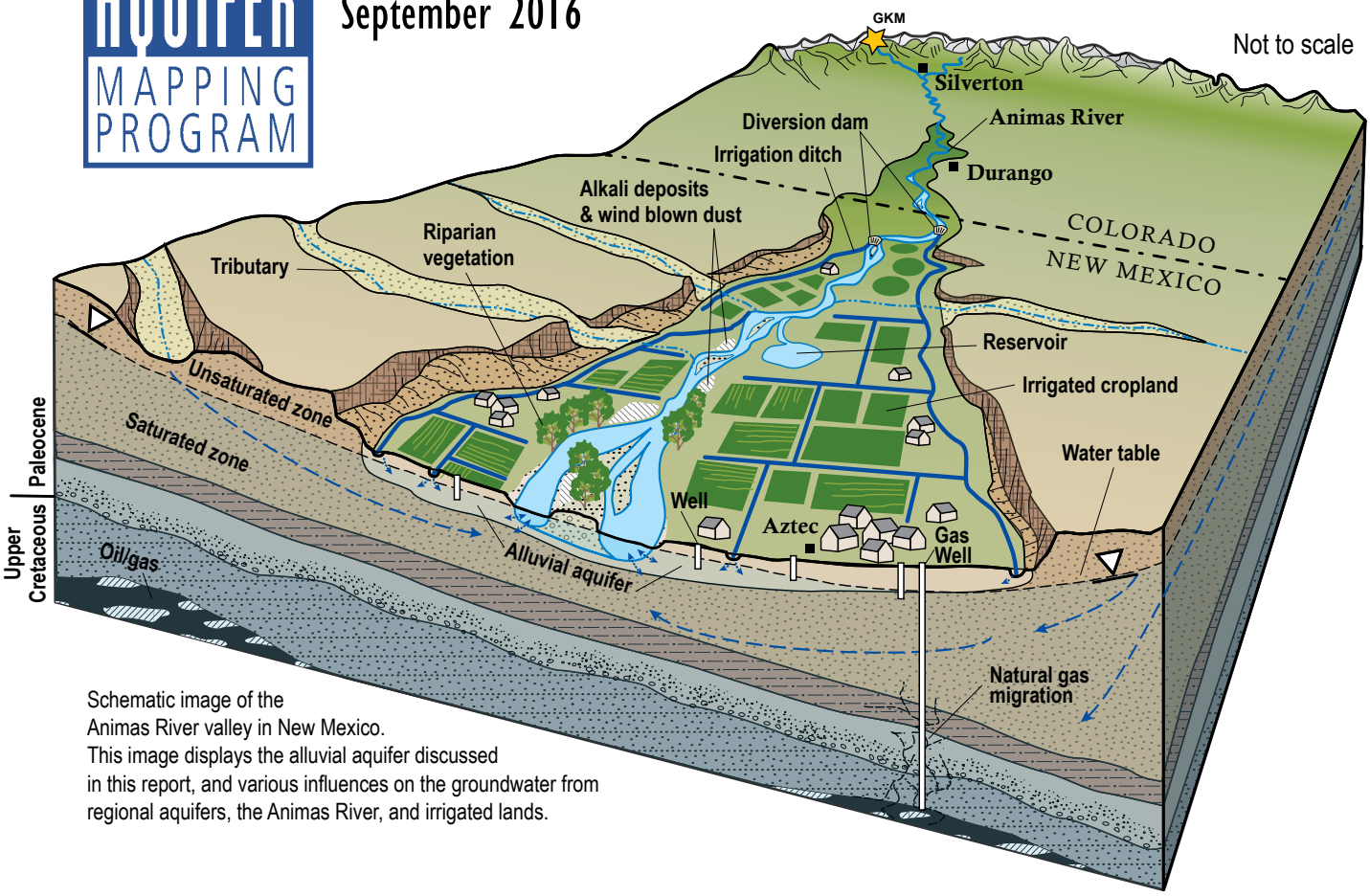
Groundwater Monitoring along the Animas River, New Mexico: Summary of Groundwater Hydraulics and Chemistry from August 2015 to June 2016

Stacy Timmons, Ethan Mamer and Cathryn Pokorny

AQUIFER MAPPING PROGRAM

Final Technical Report
September 2016



Schematic image of the Animas River valley in New Mexico. This image displays the alluvial aquifer discussed in this report, and various influences on the groundwater from regional aquifers, the Animas River, and irrigated lands.

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PROJECT FUNDING

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I. INTRODUCTION

The New Mexico Bureau of Geology and Mineral Resources (NMBGMR) is a research and service division of New Mexico Tech, serving as the state's geologic survey. After the August 5, 2015 Gold King Mine released metal and sludge-laden water into Cement Creek and the Animas River, our agency undertook a hydrologic assessment of the Animas River and its nearby alluvial aquifer in New Mexico, from the Colorado state line to Farmington, NM. The purpose of this project is to evaluate possible effects from the mine release on the shallow groundwater near the Animas River. To accomplish this, it requires understanding the seasonal changes to the surface water-groundwater hydraulics and long-term monitoring of the groundwater quality conditions along the NM reach of the Animas River.

In August 2015, in collaboration with other agencies (U.S. Geological Survey (USGS), NM Office of the State Engineer (NMOSE), and NM Environment Department (NMED)), we collected groundwater level measurements at over 100 locations along the Animas River. Water quality samples were initially collected by the U.S. Environmental Protection Agency (U.S. EPA) and their contractors in August 2015. Using the network of private domestic wells established in August 2015, we developed a repeat sampling program for groundwater quality and a groundwater levels along the Animas River valley. The well sites discussed in this report are found on Figure 1. This report serves as a final summary of the work completed between August 2015 and June 2016, which include sampling events in January, March, and late May-early June 2016. Additionally, we also incorporate water quality results from the U.S. EPA's August 2015 results, and the water level measurements from August 2015.

Regional geology

The Animas River in northwest New Mexico flows over the northwestern margin of the San Juan Basin (Figure 3). The Animas River from the CO-NM border flows through the Quaternary alluvial deposits. Most private domestic wells in the valley rely on the alluvial aquifer for drinking water and irrigation, with well depths of about 30 to 60 feet. The underlying and surrounding geology along the Animas River from Riverside to Farmington transitions from younger to older bedrock going southward. In the Riverside—Cedar Hill region, the nearby surrounding hills/mesas are composed primarily of Eocene (~50–55 Ma) San Jose Formation and Paleocene (~60–65 Ma) Nacimiento Formation. The Nacimiento Formation interfingers with the Paleocene Ojo Alamo Sandstone, which is more predominant around Aztec, New Mexico. Along the river in the proximity of Farmington, outcrops of late Cretaceous (~75 Ma) Kirtland Shale are found. The majority of the New Mexico reach of the Animas River flows over the Nacimiento Formation deposits. There are no major structural features (i.e. faults or folds) along the river corridor.

II. METHODS

Well sites used in this study are found in Tables 1 and 2, not including every U.S. EPA sampled sites. Appendix A is comprehensive, with all wells sampled or visited, with the sites provided from U.S. EPA sampling in August 2015. All site locations discussed in this report are shown on Figure 1.

Well sites listed in Table 1 were located using handheld GPS locations. Recently, a LiDAR dataset was flown (October 2014), which we acquired from Earth Data Analysis Center at University of New Mexico. The dataset collected over the Animas River Valley was simplified to a 1 m^2 resolution with an elevation accuracy of 7–16 cm. The improved spatial resolution of the LiDAR dataset allows us to more accurately estimate the water level elevation based on the higher resolution ground surface elevation.

To understand the general groundwater flow dynamics throughout the alluvial aquifer a water table was contoured for each sampling period from wells found in Table 2. For the purposes of groundwater level contouring, the Animas River was considered to be to hydrologically linked to the water table. The elevation of the river was determined by using a network of three USGS flow gauges found along the Animas River, in addition to the LiDAR dataset. The stage of the river during which the LiDAR dataset was collected was correlated with the three river gauge elevations to more accurately represent river stage during each sampling period. In order to accurately estimate the groundwater flow dynamic between the river and the alluvial aquifer, each well was compared with its closest corresponding river stage. This allowed us to observe the magnitude of the groundwater flow; to, or from the river. Water levels were measured following USGS protocols for a steel tape measurement device with repeat measurements to within 0.02 ft. All manual groundwater level measurements are found in Appendix B. Larger files of water level data from pressure transducers with data recorders are available upon request.

Well selection priorities for water chemistry sampling included 1) proximity to Animas River, 2) proximity to irrigation ditches, 3) wells that were previously sampled by U.S. EPA in August 2015, and 4) wells with owners that were cooperative and willing to permit repeated sampling. Sampling protocols used by NMBGMR are described in more detail in Timmons et al. (2013), and for this project include purging the well until field parameters are stable (pH, dissolved oxygen, specific conductivity, oxidation-reduction potential (ORP), and temperature). Most of these wells are shallow domestic wells and used regularly, therefore well bore water is mobile (frequently in use). For this project, samples were collected for total and dissolved trace metals, cations, anions, and stable isotopes of hydrogen and oxygen.

In this region, seasonal sampling for the Animas River is variable and can include high flows (during snowmelt) and low flows (baseflow, winter), as well as irrigation onset and monsoon storm events (Figure 2). For this study, we examined the "baseflow" conditions on the Animas River from January 18–20, 2016 for groundwater levels, and water chemistry sampling occurred from January 25–27, 2016. Upon initiation of snowmelt, and onset of distribution of irrigation water in the Animas Valley, we collected water levels and water chemistry samples from wells between March 14–18, 2016. Capturing approximately the peak of snowmelt runoff, with high flow rates through the Animas River, we collected water levels and water chemistry samples again between May 31-June 3, 2016. Groundwater level measurements are found in Appendix B, and chemical data from water sampling are presented in Appendix C.

Table 1. Inventory of wells shown on Figure 1 (excluding EPA sampled sites), with location, site and construction information. Complete data set is available in Appendix A electronically. bgs = below ground surface.

WELL LOCATION				SITE INFORMATION			WELL CONSTRUCTION					
Point ID	**UTM Easting NAD83** Zone 13	**UTM Northing NAD83** Zone 13	**Altitude** (ft)	**OSE well ID**	**Water sample**	**Water level**	**Well depth** (ft bgs)	**Screen top** (ft bgs)	**Screen bottom** (ft bgs)	**Completion date**	**Driller's static water level** (ft bgs)	**Static water elevation** (ft)
AR-0001	226179	4076700	5496	SJ-00186		x	31	11	31	5/4/77	4	5492
AR-0002	226165	4076890	5501			x	7					
AR-0003	226176	4076850	5497			x	27					
AR-0004	233702	4079960	5661			x	58					
AR-0005	233838	4080950	5642	SJ-03939		x	62			11/2/10		
AR-0006	228880	4078170	5538	SJ-03793	x	x						
AR-0007	226463	4076570	5505	SJ-03663		x	32	27	32	7/21/06	8	5497
AR-0008	226419	4076530	5504	SJ-02653	x	x	21	16	21	7/30/95	8	5496
AR-0009	226908	4076480	5524	SJ-02265		x						
AR-0010	225194	4076660	5517		x	x	38					
AR-0011	228764	4079220	5604	SJ-04048		x	52			12/29/13	4	5600
AR-0012	228771	4078750	5577			x	18					
AR-0013	226943	4076640	5514			x	8					
AR-0014	226943	4076640	5514			x	23					
AR-0015	226741	4077060	5512		x	x	29					
AR-0016	230933	4078710	5573	SJ-01722		x	20			5/27/83	8	5565
AR-0017	230984	4078740	5571	SJ-01722POD2	x	x	17	12	17	8/19/07	3	5568
AR-0018	230841	4078390	5580	SJ-03821		x	13			9/5/08	1	5579
AR-0019	231810	4078110	5647	SJ-03718		x	68	63	68	8/29/06	41	5606
AR-0020	229016	4079450	5621	SJ-01310		x	67			1/27/83	50	5571
AR-0021	232008	4080090	5630	SJ-03790		x	49	44	49	1/15/08	35	5595
AR-0022	231982	4080100	5624			x						
AR-0023	234008	4081640	5643	SJ-02814	x	x	31	26	31	3/22/98	8	5635
AR-0024	226448	4076370	5511	SJ-02553		x	25					
AR-0025	223102	4073990	5600	SJ-03614		x	48	43	48	1/28/08	31	5569
AR-0026	225273	4077390	5540			x	40					
AR-0027	224833	4077610	5567			x	48					
AR-0028	219814	4073190	5413			x	20					
AR-0029	220655	4074210	5457			x						
AR-0030	220865	4073910	5428			x	18					
AR-0031	219294	4072630	5384		x	x	14					
AR-0032	208636	4070270	5204	SJ-03538	x	x	20	4	18	11/29/04	4	5200
AR-0033	224318	4065440	5363	SJ-03376		x	27	22	27	9/7/03	13	5350
AR-0034	221070	4074330	5453			x						
AR-0035	214281	4067770	5304			x	40			1/1/14		
AR-0036	210453	4069790	5258			x						
AR-0037	223013	4074270	5589	SJ-03110		x	320	280	320	8/9/01	54	5535
AR-0038	221948	4074690	5443		x	x	35					
AR-0039	214003	4067760	5293			x						
AR-0040	221341	4073530	5426			x						
AR-0041	221789	4074810	5467			x						
AR-0042	221710	4074690	5463			x						
AR-0043	221080	4074680	5495			x						
AR-0044	221393	4073400	5441		x	x	32					
AR-0045	224756	4065690	5403			x						
AR-0046	220537	4074320	5464			x						

Table 1.—Continued

WELL LOCATION				SITE INFORMATION			WELL CONSTRUCTION					
Point ID	**UTM Easting NAD83** Zone 13	**UTM Northing NAD83** Zone 13	**Altitude** (ft)	**OSE well ID**	**Water sample**	**Water level**	**Well depth** (ft bgs)	**Screen top** (ft bgs)	**Screen bottom** (ft bgs)	**Completion date**	**Driller's static water level** (ft bgs)	**Static water elevation** (ft)
AR-0047	214003	4067760	5293		x	x						
AR-0048	222819	4074140	5578			x						
AR-0049	220176	4074020	5459			x						
AR-0050	219667	4073420	5444			x						
AR-0051	220096	4073740	5429			x						
AR-0052	238534	4087080	5748			x						
AR-0053	234797	4082930	5656	SJ-00986	x	x	104			8/2/79	80	5576
AR-0054	235654	4084290	5684	SJ-02049		x	26	20	25		8	5676
AR-0055	235008	4082850	5665			x						
AR-0056	234810	4083080	5657		x	x						
AR-0057	232064	4080490	5638	SJ-03209		x	49	44	49	6/25/02	32	5606
AR-0058	235190	4084200	5678	SJ02656	x	x	21	16	21	8/10/97	9	5669
AR-0059	233406	4081960	5659	SJ-04130	x	x	50					
AR-0060	233423	4082020	5664	SJ-04129	x	x	60					
AR-0061	233148	4081590	5643	SJ-02903	x	x	49	0	49	2/24/99	31	5612
AR-0062	233161	4081680	5677			x						
AR-0063	235309	4083430	5672			x						
AR-0064	234812	4083020	5659	SJ_02972	x	x	15	10	15	1/17/00	5	5654
AR-0065	234946	4082450	5695			x						
AR-0066	235177	4083100	5666			x						
AR-0067	235954	4082950	5721	SJ-03543		x	61	0	61	7/9/05	30	5691
AR-0068	234296	4081460	5654			x						
AR-0069	234659	4082709	5656	SJ-03497		x	30	14	28	12/2/74	10	5646
AR-0070	234425	4082180	5675			x						
AR-0071	234364	4082272	5657			x						
AR-0072	234462	4082686	5653	SJ-03720		x	21	16	21	4/9/07	6	5647
AR-0073	235546	4084255	5682		x	x						
AR-0074	238641	4087350	5743	SJ-03124	x	x	20	8	18	12/3/01	5	5738
AR-0075	238293	4087200	5733		x	x						
AR-0076	234795	4082090	5689	SJ-03756		x	41	36	41	12/7/06	20	5669
AR-0077	238501	4087240	5740		x	x						
AR-0078	238070	4086990	5736	SJ-0318	x	x	20	11	19	6/19/00	8	5728
AR-0079	238162	4086870	5741			x						
AR-0080	238130	4086890	5733	SJ-03670	x	x	26	20	26	9/2/05	10	5723
AR-0081	238644	4086260	5782			x						
AR-0082	237843	4086310	5737			x						
AR-0083	237541	4086200	5727			x						
AR-0084	237693	4086178	5732			x						
AR-0085	240596	4088880	5783			x						
AR-0086	238419	4087760	5788	SJ-00560		x	39			2/2/78	25	5763
AR-0087	238528	4087440	5739			x						
AR-0088	238408	4087580	5753	SJ-03623		x	30	25	30	2/4/06	16	5737
AR-0089	238494	4086880	5757			x						
AR-0090	238508	4086530	5762			x						
AR-0091	238071	4086730	5744			x						
AR-0092	238124	4085370	5791			x						
AR-0093	238302	4087607	5749		x	x						

Table 1.—Continued

WELL LOCATION				SITE INFORMATION			WELL CONSTRUCTION					
Point ID	UTM Easting NAD83 Zone 13	UTM Northing NAD83 Zone 13	Altitude (ft)	OSE well ID	Water sample	Water level	Well depth (ft bgs)	Screen top (ft bgs)	Screen bottom (ft bgs)	Completion date	Driller's static water level (ft bgs)	Static water elevation (ft)
AR-0094	238533	4086880	5757		x	x						
AR-0095	238427	4086390	5763			x						
AR-0096	239376	4087870	5752			x						
AR-0097	237753	4085610	5742			x						
AR-0098	243692	4092040	5860			x						
AR-0099	241689	4091530	5823	SJ-02083	x	x	23	18	23	10/23/86	10	5813
AR-0100	244788	4105410	6057			x						
AR-0101	243570	4091280	5841		x	x						
AR-0102	243793	4092680	5857	SJ-03683	x	x	23	18	23	12/29/05	9	5848
AR-0103	243531	4091290	5842		x	x						
AR-0104	240539	4089310	5783		x	x						
AR-0105	240618	4088995	5780		x	x						
AR-0106	242278	4091200	5825		x	x						
AR-0107	243814	4092330	5849			x						
AR-0108	243019	4091940	5874	SJ-02504	x	x						
AR-0109	243778	4092150	5846	SJ-03067	x	x	20					
AR-0110	244588	4097170	5931		x	x						
AR-0111	242411	4090900	5826		x	x						
AR-0112	243470	4091200	5839		x	x						
AR-0113	243418	4091190	5839		x	x						
AR-0114	243169	4091580	5859			x						
AR-0115	243666	4091830	5863		x	x						
AR-0116	243507	4095780	5953			x	69					
AR-0156	243694	4092265	5860	SJ-03069	x	x	35			8/1/76	10	5850
AR-0181	215547	4069320	5331	SJ-00184	x	x	30					
AR-0207	243480	4095630	5945		x	x						
AR-0208	235162	4083104	5665			x	28					
AR-0209	233169	4081107	5618			x	19					

Table 2. Sites measured or sampled by NMBGMR for this study, indicating sites visited in January, March, June 2016.

	AUG 2015	JAN 2016		MARCH 2016		JUNE 2016	
Site ID	Water level	Water level	Water quality	Water level	Water quality	Water level	Water quality
AR-0001	x	x		x		x	
AR-0002	x						
AR-0003	x	x		x		x	
AR-0004	x	x		x		x	
AR-0005	x	x		x		x	
AR-0006*	x	x	x	x	x	x	x
AR-0007**	x	x				x	
AR-0008*	x	x	x	x	x	x	x
AR-0009	x						
AR-0010*	x	x	x	x	x	x	x
AR-0011	x						
AR-0012	x	x		x		x	
AR-0013	x						
AR-0014	x						
AR-0015*	x	x	x	x	x		x
AR-0016	x	x		x		x	
AR-0017*	x	x	x	x	x	x	x
AR-0018	x	x		x		x	
AR-0019	x	x		x		x	
AR-0020	x	x		x		x	
AR-0021	x	x		x		x	
AR-0022	x						
AR-0023*	x	x				x	x
AR-0024	x	x		x		x	

Table 2.—Continued

	AUG 2015	JAN 2016		MARCH 2016		JUNE 2016	
Site ID	Water level	Water level	Water quality	Water level	Water quality	Water level	Water quality
AR-0025	x	x				x	
AR-0026	x	x		x		x	
AR-0027	x	x		x		x	
AR-0028**	x	x				x	
AR-0029	x	x		x		x	
AR-0030	x						
AR-0031*	x	x				x	x
AR-0032	x						
AR-0033	x						
AR-0034	x	x		x		x	
AR-0035	x						
AR-0036	x						
AR-0037	x						
AR-0038*	x	x	x	x	x	x	x
AR-0039	x						
AR-0040	x						
AR-0041	x	x		x		x	
AR-0042	x						
AR-0043	x						
AR-0044	x	x		x		x	
AR-0045	x						
AR-0046	x	x		x		x	
AR-0047	x						
AR-0048	x	x		x		x	
AR-0049	x						
AR-0050	x						
AR-0051	x	x		x		x	
AR-0052	x						
AR-0053	x	x		ND			
AR-0054	x						
AR-0055	x						
AR-0056	x	x				x	
AR-0057	x	x		x		x	
AR-0058*	x	x			x		x
AR-0059*	x	x	x	x	x	x	x
AR-0060	x	x		x		x	
AR-0061	x						
AR-0062	x						
AR-0063	x	x		x		x	
AR-0064	x						
AR-0065	x	x		x		x	
AR-0066	x	x		x		x	
AR-0067	x	x		x		x	
AR-0068	x	x		x		x	
AR-0069	x						
AR-0070	x						
AR-0071	x	x		x		x	
AR-0072	x	x		x		x	
AR-0073*	x	x	x	x	x	ND	
AR-0074*	x	x	x	x	x		x
AR-0075*	x	x	x	x	x	x	x
AR-0076	x						
AR-0077	x	x		x		x	
AR-0078	x	x		x		x	
AR-0079	x						
AR-0080	x	x		x		x	
AR-0081	x	x		x		x	
AR-0082	x	x		x		x	
AR-0083	x	x		x		x	
AR-0084	x	x		x		x	
AR-0085	x						
AR-0086	x						
AR-0087	x	x		x		x	
AR-0088	x						
AR-0089	x						
AR-0090	x						
AR-0091	x						
AR-0092	x	x		x		x	
AR-0093	x	x		ND			
AR-0094	x	x		x		x	
AR-0095	x						
AR-0096	x	x		ND			
AR-0097	x						
AR-0098	x						
AR-0099	x	x		x		x	
AR-0100	x						
AR-0101	x	x		ND			
AR-0102*	x	x	x	x	x	x	x
AR-0103	x	x				x	
AR-0104	x	x		x		x	
AR-0105	x	x		ND			
AR-0106*	x	x	x	x	x		x
AR-0107	x						
AR-0108	x						
AR-0109	x						
AR-0110*	x			x	x	x	x
AR-0111	x	x		x		x	
AR-0112*	x	x	x	x	x	x	x
AR-0113	x	x		ND			
AR-0114	x	x		x		x	
AR-0115	x						
AR-0116**	x	x				x	
AR-0156*		x	x	x	x	x	x
AR-0181*		x	x	x	x	x	x
AR-0207*			x	x	x		x
AR-0208**		x				x	
AR-0209**						x	

* Sites with water levels and water quality sampling
** Sites with continuous data recorders for water levels
ND = Removed from repeat list

III. RESULTS

Regional Hydraulic Conditions

Following the August 2015 Gold King Mine (GKM) release, a groundwater level measurement network was established using private irrigation or private domestic wells. The goal was to observe the fluctuations of the water table throughout the Animas River Valley from the Colorado border to Farmington, NM in order to identify sections of the river where groundwater and surface water may have chemical or water quality interactions. Repeat water level measurements are important to understand the seasonal fluctuation in a groundwater system, particularly one that is hydraulically connected to surface water features such as the Animas River, or irrigation ditches. Following the August GKM release, measurements of depth-to-water (groundwater level or water level elevation) were completed four times in this network. The four water level measurement campaigns were scheduled as to capture hydraulic conditions at distinct seasonal transitions (Figure 2). The initial water level measurement period in August 2015 included 111 wells, and represented monsoon season along with irrigation season. The monitoring network was set to 50 to 80 wells for the following periods of measurement, including baseflow (January 2016), initial snowmelt/onset of irrigation season (March 2016), and peak snowmelt/extended irrigation season (May-June 2016). Occasionally, wells were not measured during one or more of the measurement campaigns due to scheduling conflicts, freezing well conditions or if well owners opted out of the program. Table 2 shows the well listing with the frequency of monitoring.

The first round of water level measurements from 111 wells were collected in August 2015, during monsoon season and while irrigation had been underway for several months. More importantly, the August measurements characterize the hydraulic conditions in the valley at the time of the GKM spill, highlighting portions of the alluvial aquifer that may have been impacted. Using these water level measurements, the water table throughout the valley was contoured (Figure 4A). Four of the wells had water level elevations measured below the stage of the river in August 2015, by 0.32 ft on average. The wells below river stage elevation were AR-0060, AR-0063, AR-0075, and AR-0096.

The measurements conducted in January 2016 represent baseflow conditions in the Animas River, when flow in the river is dominated by addition of regional groundwater. During this period, 74 wells were measured to construct the January 2016 water table map (Figure 4B). Compared to August, the average water level elevation declined during this period by 2.18 ft. The majority of the decline took place distal from the river (Table 3). The water level in eleven wells was below the stage of the river by 1.59 ft on average. The wells with water level elevations below river stage elevation were AR-0053, AR-0058, AR-0059, AR-0060, AR-0075, AR-0096, AR-0101, AR-0103, AR-0105, AR-0112, and AR-0113. These eleven wells, which may suggest losing conditions along the Animas River, are located between Aztec and Cedar Hill, NM, in the northern portion of the study area.

The third round of measurements were conducted in March 2016 during the transition from

Table 3. Analysis of the fluctuations in groundwater level (in feet) based on distance from the river between each sampling period. To compare the change in water level between individual sampling periods the more recent water level average measurement was subtracted from the previous average water level. Only wells with measurements from each of the four periods were used in this analysis (52 wells). (n = the number of wells in each of the 'distance from river' categories).

	Groundwater level fluctuations relative to distance from Animas River			Total water level change (ft)
Distance from river	**<500 ft** (n=15)	**500–1500 ft** (n=17)	**>1500 ft** (n=20)	
January 2016 vs. August 2015	-1.02	-1.73	-3.43	-2.18
March 2016 vs. January 2016	0.05	-0.86	-1.95	-1.02
June 2016 vs. March 2016	2.73	3.13	4.04	3.36

winter baseflow conditions and the onset of the irrigation season. Sixty wells were measured during this interval and used to delineate the water table (Figure 4C). The average groundwater level declined by another 1.02 ft since the previous measurement period in January. Seven of the wells, located between Aztec and Cedar Hill, NM, were below the stage of the river by 1.76 ft on average. The wells with water level elevations below river stage elevation were AR-0059, AR-0060, AR-0075, AR-0087, AR-0094, AR-0103, and AR-0112. Wells that may suggest losing conditions are found north of Aztec, with a cluster near Inca, NM.

The measurements conducted from May 31st - June 3rd, 2016 capture the hydrologic conditions during peak snowmelt runoff, when the river is at its highest stage. The 12 year average peak in snowmelt runoff for the Animas River below Aztec, NM (USGS:09364010) has typically occurred between May 21st and June 8th. This year, 2016, the peak occurred between June 6th and June 12th. During this sampling period, 65 wells were measured to construct the June 2016 water table map (Figure 4D). Between the March measurements and early June the average water level elevation increased by 3.36 ft. While on average the water table and river were highest during this period, seven of the wells were still below the stage of the river by 0.78 ft on average. The wells below river stage elevation were AR-0056, AR-0060, AR-0063, AR-0072, AR-0075, AR-0087, and AR-0102.

Our observations show that in a broad sense, the Animas River is gaining water from the groundwater, as groundwater from the surrounding valley flows downhill, or down gradient, discharging to the river. However, by looking at the water levels in close proximity to the river, we found that the water table gradient can be nearly flat ("low gradient"). In some locations (indicated as red points on the water table maps, Figure 4), we observed that the water table elevation is below river elevation, suggesting that the river could add water to the groundwater (a losing river). With a flat water table, fluctuations in the river stage can turn a slightly gaining reach to a slightly losing reach. The difference between groundwater elevations and the river stage elevation is small (less than 1 ft), so it may not be detected by coarse resolution water table mapping. We must also consider effects from pumping groundwater and the cone of depression that may be created along the river when a well pumps. These dynamic effects on the alluvial aquifer were not tested in this evaluation, but are another potential effect on groundwater and surface water interactions and flow directions.

Another way to observe the changes in groundwater levels, similar to the summary presented in Table 3, is by presenting change results on a map. Figure 5 shows a series of maps that calculate the change in depth to water between seasonal measurements. A negative value and a red colored point indicate that water level dropped between the earlier and the later water level measurement (i.e. August 2015 to January 2016). A rise in groundwater level between periods of measurement is indicated by a green point and a positive value. The larger symbol size is proportional to greater change observed.

The result of this series of maps in Figure 5 shows that the water levels are quite responsive to seasonal changes, with declines in the depths to water measurements all along the Animas River alluvial valley. It is also notable that in the region around Inca and just southwest of Aztec, we see larger responses. In baseflow and early snowmelt periods (January and March), these two regions have the largest declines (~6–15 ft), while during peak snowmelt, with irrigation season, these regions also have the largest increases (~6–12 ft).

Detailed Hydraulic Conditions

NMBGMR installed pressure transducers with continuous data recorders in four unused wells to collect water level and temperature data every 12 hours. The first two wells, AR-0007, and AR-0028, started in September 2015 (Figure 6A). Two additional wells, AR-0116, and AR-0208, started in January 2016 (Figure 6B). From a continuous record of groundwater level, we can see brief fluctuations in water levels that help us understand local or regional effects on the water table in the area. These records of water level change were plotted alongside a precipitation record from Aztec (GHCND:USC00290692), a USGS Animas River flow gauge just below Aztec (USGS:09364010), and a record of flow in nearby irrigation ditches (http://meas.ose.state.nm.us).

AR-0007 and AR-00028 are located in the southern portion of the study area. AR-0007 is just north of Farmington, 1,500 ft west of the river, and is 20 ft deep. AR-0028 is located 4 miles southwest of Aztec, 300 ft east of the Animas River, and is 32 ft deep. These two southern well records are plotted alongside the 'North Farmington' irrigation ditch gauge. Sharp spikes in the river stage correspond closely with large

storms in the area, or upriver, in the Animas River catchment. In general, both pressure records show a close hydraulic connection between the water level in the wells and the Animas River stage, small rises in the water level in both wells correlate with sudden rises in river stage.

The two pressure records show surprisingly distinct trends in groundwater level. AR-0007, located 4 miles southwest of Aztec, shows a similar trend to the majority of well trends in the area. The water level declines from the peak in the fall following the end of the growing season and continues to decline as the irrigation ditches are shut off. The water level continues to decline until the late spring, and then begins to rise sharply. The rise coincides with the beginning of irrigation season, with the ditches flowing. The rise may also be attributed to the arrival of spring snowmelt and the rising of the river stage.

The hydrograph record in AR-0028, located just north of Farmington, has a very different trend. The water level at the beginning of the record in the fall is at a low, before beginning to rise in October. Water level rises steadily before leveling out at the beginning of March, and appears to decline slightly before rising sharply at the beginning of April, similar to AR-0028, with the onset of irrigation and snowmelt.

AR-0116 and AR-0208 are located in the northern portion of the study area. AR-0116 is located 1 mile south of the Colorado border, 2,250 ft west of the river, and is 69 ft deep. AR-0208 is located 2.7 miles northeast of Aztec, NM, 1,500 feet east of the river, and is 28 ft deep. These two northern well hydrographs are plotted alongside the 'Twin Rocks' irrigation ditch gauge.

Of all 4 monitoring sites, AR-0116 is farther from the river than the other pressure transducers records, and it is furthest north. Also, where the rest of the pressure transducers are in wells closer to the river, where the groundwater is less than 15 ft bgs, the water level at AR-0116 is ~50 ft bgs. The small scale fluctuations observed on the other hydrographs is absent and AR-0116 has a smoothly declining water level. At the beginning of May the water level in the well begins to rise gradually, approximately coincident with when irrigation began in the northern reach of the Animas River.

AR-0208, northeast of Aztec, NM, is in an area where the water table is quite shallow, only 2-3 ft bgs. The water level in this well declines steadily from highs in early February throughout the entire record. This well shows no response to the beginning of irrigation season.

Water Chemistry Conditions

The NMBGMR team conducted three repeat sampling events along the Animas River between January and June 2016, attempting to sample the same wells each outing. As a summary, during January 25–27, 2016, we collected 16 water chemistry samples; March 14–17, 2016, we repeat sampled a total of 18 groundwater samples; and from May 31-June 3, 2016 a total of 19 samples were collected. Tables 1 and 2 list the locations of wells that were sampled, with the complete results of sampling found in Appendix C. A map of sampled wells is shown on Figure 1. Table 4 shows a summary of each period of NMBGMR sampling with average values for field parameters and major ions. Well owners have been notified of their results in writing after sample analyses are complete and reviewed.

Table 4. Summary of field parameters and major ions during different sample periods.

		TDS (mg/L)	Temperature (°C)	ORP (mV)	Dissolved Oxygen (mg/L)	Ca (mg/L)	Na (mg/L)	Mg (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	Total Fe (mg/L)	Total Mn (mg/L)
January	Average	759	13	29.9	1.9	169.6	55.6	21.3	339.7	32	278	0.98	0.78
	Maximum	1330	17	447.4	7.2	335	142	29	419	123	702	4.58	6.48
	Minimum	388	8.8	-101.6	0.1	91.3	19.7	12.5	250	17	95.8	0.022	0.005
March	Average	733.5	12.8	45.3	2.5	160.1	57.7	20.6	334.8	29.6	276.6	1.16	0.437
	Maximum	1360	16.9	164.4	8.9	336	152	32.4	439	67.2	720	3.77	4.46
	Minimum	392	7.3	-116.8	0.17	88.9	19.9	12.5	232	17.5	97.6	0.1	0.002
May/June	Average	793	13.5	87.9	2.4	180.1	55.2	21.9	325.2	27.6	326.1	0.64	0.307
	Maximum	2380	16.1	558.2	10.12	564	180	56.8	458	89.5	1330	1.86	2.25
	Minimum	315	9.8	-101.9	0.04	61.9	20	8.71	210	14.3	73.4	0.107	0.001

Major ions

By mapping the major ions from the well water samples using a Stiff diagram, we can see general trends in water chemistry spatially. The maps shown in Figure 7 include symbols, which depict the meq/L cation content (Na, Ca, and Mg) on the left side of the symbol, and anion content (Cl, HCO_3, and SO_4) on the right side. The maps in Figure 7 show that there is little change in the overall ion chemistry from one sample period to the next. We can observe a trend of lower ion content in the northern reaches of the Animas River alluvial aquifer, and higher ion content in the southern sections (south of Aztec, approximately).

Results of groundwater samples displayed on a Piper diagram (Figure 8) show that samples collected by NMBGMR (Figure 8A) are comparable to samples collected by U.S. EPA in August 2015 (Figure 8B). However, the U.S. EPA samples (Figure 8B) have higher levels of sodium and chloride than the wells sampled by NMBGMR. The dominant water type for the Animas River aquifer appears to be Ca-HCO_3 to Ca-SO_4. Figure 8C shows samples from the surrounding geologic formations, not including the Animas alluvial aquifer (data from Kelley et al., 2014). Water samples from the Animas alluvial aquifer samples have some similarities, especially with anions, to water sourced from the Ojo Alamo Formation (Toa), the Nacimiento Formation (Tn) and the San Jose Formation (Tsj). This comparison supports the hypothesis that there is a component of the groundwater in the Animas River alluvial aquifer that is derived from the surrounding regional geology, and that some groundwater is going into the Animas River (as a gaining river). The Piper diagram in Figure 8D shows the repeated NMBGMR samples for each well location. It is apparent from Figure 8D that the dominant water type for these wells stays fairly constant from one sample period to another.

Water quality

U.S. EPA samples from August 2015 indicated that some wells had elevated levels of iron, manganese, sulfate, and aluminum above secondary MCL recommendations. These data were compiled from data provided to the state of New Mexico after the sampling was completed. Original documentation on sampling or analysis protocols from U.S. EPA or contractors is not available. This leaves some unanswered questions about data collection, reporting or possible transcription errors.

Results of water chemistry sampling in January 2016 revealed that some private domestic wells had elevated levels of iron, manganese, aluminum, and sulfate. One well, AR-0075, had total iron at 4.58 mg/L which is above the secondary recommendation (0.3 mg/L), and total manganese at 6.4 mg/L, which is above the health advisory level (1.6 mg/L). We compared results from the January 2016 water chemistry sampling with previous results from U.S. EPA collected in August 2015 for manganese and iron (Figures 9, 10). The result of this analysis showed that in most samples manganese and iron were higher in the January 2016 measurements than in August 2015. Other wells that have elevated levels of both iron and manganese in January include AR, 0006, AR-0017, AR-0074, AR-0112 and AR-0156.

Results of March 2016 water chemistry sampling again indicated that several private domestic wells had elevated levels of iron, manganese, aluminum and sulfate (above secondary recommendations). Again, AR-0075, had total iron at 2.8 mg/L which is above the secondary recommendation (0.3 mg/L), and total manganese at 4.46 mg/L, which is above the health advisory level (0.3 mg/L). Other wells that have elevated levels of both iron and manganese in March include AR-0006, AR-0017, AR-0074 and AR-0112.

The samples collected in late May-early June, 2016 showed similar results with elevated levels of iron, manganese and sulfate (above secondary recommendations). Wells AR-0074, AR-0075 and AR-0112 continue to have levels of iron and manganese above recommended levels, but no wells on this round had elevated aluminum.

In each sample period, the elevated levels of iron and manganese occur in the Cedar Hill and Inca regions (Figures 11 and 12). These are areas where we have also noted possible changes from gaining to losing, from the Animas River to groundwater (Figure 4). Results shown in Figures 9 and 10 indicate that levels of total iron and manganese in some wells increased since the August sampling by U.S. EPA (such as AR-0017, AR-0058, AR-0059, and -0102), while others have fluctuated more (AR-0075 and -0156). Comparison of water quality time series results and maps suggest a hypothesis that water quality variations may be related to seasonal influences on the groundwater table. Perhaps minor seasonal changes in gradient along the Cedar Hill and Inca reaches of the Animas, particularly at baseflow river levels, have an impact to groundwater quality related to changes in the oxidizing or reducing conditions in the shallow groundwater. Example wells that have very low gradient groundwater—surface water

elevations with water quality issues include AR-0075 and AR-0112. Then, when irrigation and snowmelt begins, there is a dilution effect.

Stable Isotope Analyses

Results from stable isotopes of hydrogen (δD) from all groundwater samples range from -93 to -104 ‰, and oxygen ($\delta^{18}O$) from -12.5 to -14.4‰ (Table 5; Figure 13). Samples from groundwater collected during the 3 sample periods in 2016 differ very little for samples at the same well sites (Figure 14). The very "light" ranges of these values suggest that groundwater in the Animas River valley is predominantly recharged by winter precipitation.

Starting with the March 2016 sampling period, we collected stable isotopes from the Animas River at three locations (Table 5; Figure 1, 13). In March, these results are "heavier" relative to most groundwater samples, meaning their isotope ratios are more in the range of -95 to -96 ‰ δD, and -13.5 to -13.4 ‰ $\delta^{18}O$. Interestingly, the only groundwater stable isotope samples that plot in a similar range are from well site AR-0006. This well location is very close to the river and irrigation ditches. One hypothesis for the similarity of this groundwater to the Animas River water is that this well was strongly influenced by river or irrigation water input. Animas River samples from June 2016, during peak snowmelt conditions, are significantly lighter, which reflects the snowmelt source of river water at that

Table 5. Summary of stable isotopes.

Point ID	Site type	Sample date	H_2r	$O^{18}r$
AR-0006	groundwater	26-Jan-16	-95.9	-13.41
AR-0006	groundwater	15-Mar-16	-96.1	-13.47
AR-0006	groundwater	01-Jun-16	-95.8	-13.48
AR-0008	groundwater	27-Jan-16	-100.2	-13.97
AR-0008	groundwater	14-Mar-16	-100.6	-13.99
AR-0008	groundwater	01-Jun-16	-100.7	-13.97
AR-0010	groundwater	27-Jan-16	-103	-14.15
AR-0010	groundwater	14-Mar-16	-103	-14.26
AR-0010	groundwater	31-May-16	-102.1	-14.1
AR-0015	groundwater	27-Jan-16	-104.1	-14.4
AR-0015	groundwater	16-Mar-16	-104	-14.44
AR-0015	groundwater	01-Jun-16	-104	-14.29
AR-0017	groundwater	27-Jan-16	-103.9	-14.36
AR-0017	groundwater	15-Mar-16	-103.9	-14.36
AR-0017	groundwater	01-Jun-16	-103.9	-14.31
AR-0023	groundwater	03-Jun-16	-103.1	-14.35
AR-0031	groundwater	31-May-16	-92.7	-12.45
AR-0038	groundwater	25-Jan-16	-101.5	-14.03
AR-0038	groundwater	17-Mar-16	-101.2	-14.09
AR-0038	groundwater	31-May-16	-101.1	-13.96
AR-0058	groundwater	15-Mar-16	-99.4	-13.89
AR-0058	groundwater	01-Jun-16	-99.2	-13.73
AR-0059	groundwater	26-Jan-16	-100.7	-14.09
AR-0059	groundwater	15-Mar-16	-101.2	-14.14
AR-0059	groundwater	01-Jun-16	-99.4	-13.8
AR-0073	groundwater	26-Jan-16	-103.5	-14.33
AR-0073	groundwater	15-Mar-16	-103.5	-14.44
AR-0074	groundwater	27-Jan-16	-100.5	-14.1
AR-0074	groundwater	16-Mar-16	-99.1	-13.94
AR-0074	groundwater	03-Jun-16	-100.1	-14.1
AR-0075	groundwater	27-Jan-16	-101.5	-14.24
AR-0075	groundwater	16-Mar-16	-100.1	-14.12
AR-0075	groundwater	02-Jun-16	-97.7	-13.75
AR-0102	groundwater	26-Jan-16	-101.6	-14.22
AR-0102	groundwater	17-Mar-16	-101.1	-14.22
AR-0102	groundwater	02-Jun-16	-101	-14.15
AR-0106	groundwater	26-Jan-16	-100.6	-14.11
AR-0106	groundwater	17-Mar-16	-99.4	-14.04
AR-0106	groundwater	02-Jun-16	-98.5	-13.88
AR-0110	groundwater	17-Mar-16	-98.9	-14.03
AR-0110	groundwater	03-Jun-16	-98.3	-13.63
AR-0112	groundwater	26-Jan-16	-99.7	-14.07
AR-0112	groundwater	16-Mar-16	-99.6	-14.1
AR-0112	groundwater	02-Jun-16	-98.9	-13.84
AR-0156	groundwater	27-Jan-16	-100.4	-14.09
AR-0156	groundwater	16-Mar-16	-99.8	-14.12
AR-0156	groundwater	02-Jun-16	-99.5	-14.05
AR-0181	groundwater	25-Jan-16	-99.9	-13.99
AR-0181	groundwater	14-Mar-16	-99	-13.97
AR-0181	groundwater	31-May-16	-99.1	-13.78
AR-0207	groundwater	26-Jan-16	-98.3	-13.79
AR-0207	groundwater	17-Mar-16	-98.2	-13.88
AR-0207	groundwater	03-Jun-16	-98.5	-13.84
AR-0501	surface water	17-Mar-16	-95.7	-13.58
AR-0501	surface water	02-Jun-16	-103.4	-14.76
AR-0502	surface water	17-Mar-16	-95.7	-13.53
AR-0502	surface water	01-Jun-16	-102.1	-14.51
AR-0503	surface water	18-Mar-16	-95.6	-13.53
AR-0503	surface water	31-May-16	-100.8	-14.34

time. Groundwater changes very little over the period of sampling, in terms of stable isotopes.

Preliminary Conclusions

We hypothesize that groundwater in the Animas alluvial aquifer is composed of three main components, 1) regional groundwater from surrounding aquifers, 2) Animas River water, and 3) Animas River water via irrigation distribution. The quantity of these inputs likely varies over the year, depending on surface water flow in the Animas River.

With long-term environmental, mine-related, and anthropogenic impacts to water quality along the Animas River, it is important to continue to monitor groundwater quality. Currently, based on the small dataset of 16–19 repeat sampled wells, we do not see any direct effects to the shallow alluvial aquifer from the Gold King Mine spill in August 2015. We do, however, see elevated levels of iron, manganese, sulfate and occasionally aluminum in groundwater around the Animas River. We hypothesize, based on numerous anecdotal accounts from land owners, that the water quality changes in summer months with snowmelt, higher river flows and increased irrigation distribution. We observe a decrease in the levels of iron and manganese, which are the dominant constituents of concern above the MCL guidelines found in the groundwater. Aluminum levels in a few wells were higher in winter months than in summer, higher flow months. Continued monitoring of groundwater quality, through consistent and repeated measurements, is the only way to confirm or disprove any affects to groundwater related to the Gold King Mine or other contaminant concerns over time.

IV. FUTURE WORK

With future funding, it is important to consider sampling groundwater outside of the Animas alluvial aquifer, which would provide improved end-member comparisons (i.e. regional groundwater). Additionally, comparison of geochemistry and stable isotopes from surface water and irrigation water would aide in the understanding of the composition of inputs to the alluvial aquifer. Analysis of well site depth and distance from the river, with special attention to metals of concern, would also be an important analysis. Adding sites with continuous water quality monitoring can improve the understanding of the background changes in water quality in between sampling events. This may be accomplished with continuous monitoring of groundwater conductivity, with periodic water quality sampling for comparison.

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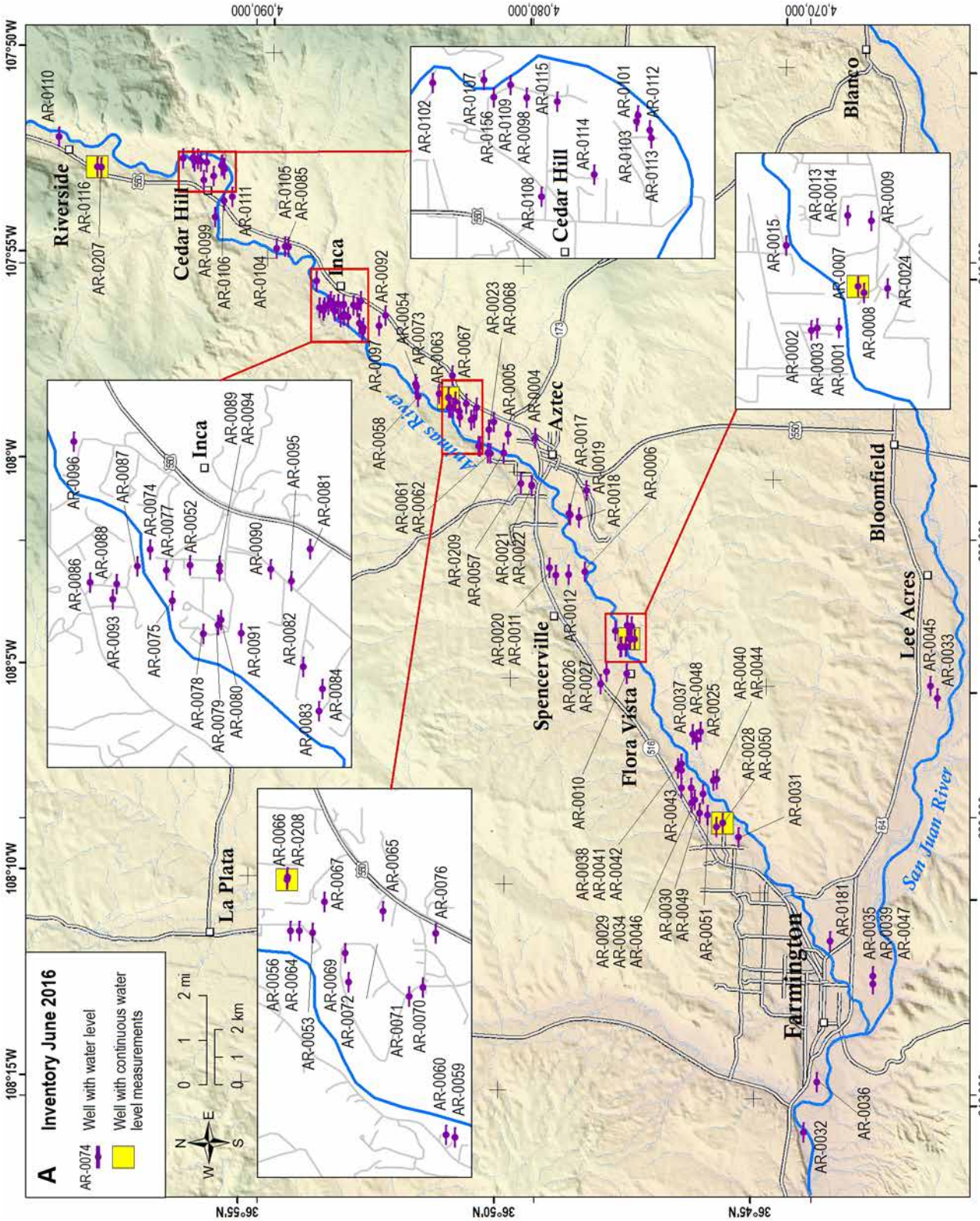


Figure 1. Locations of wells utilized in this assessment of the alluvial aquifer along the Animas River. **A**—Wells used for water level elevations and continuous water level monitoring.

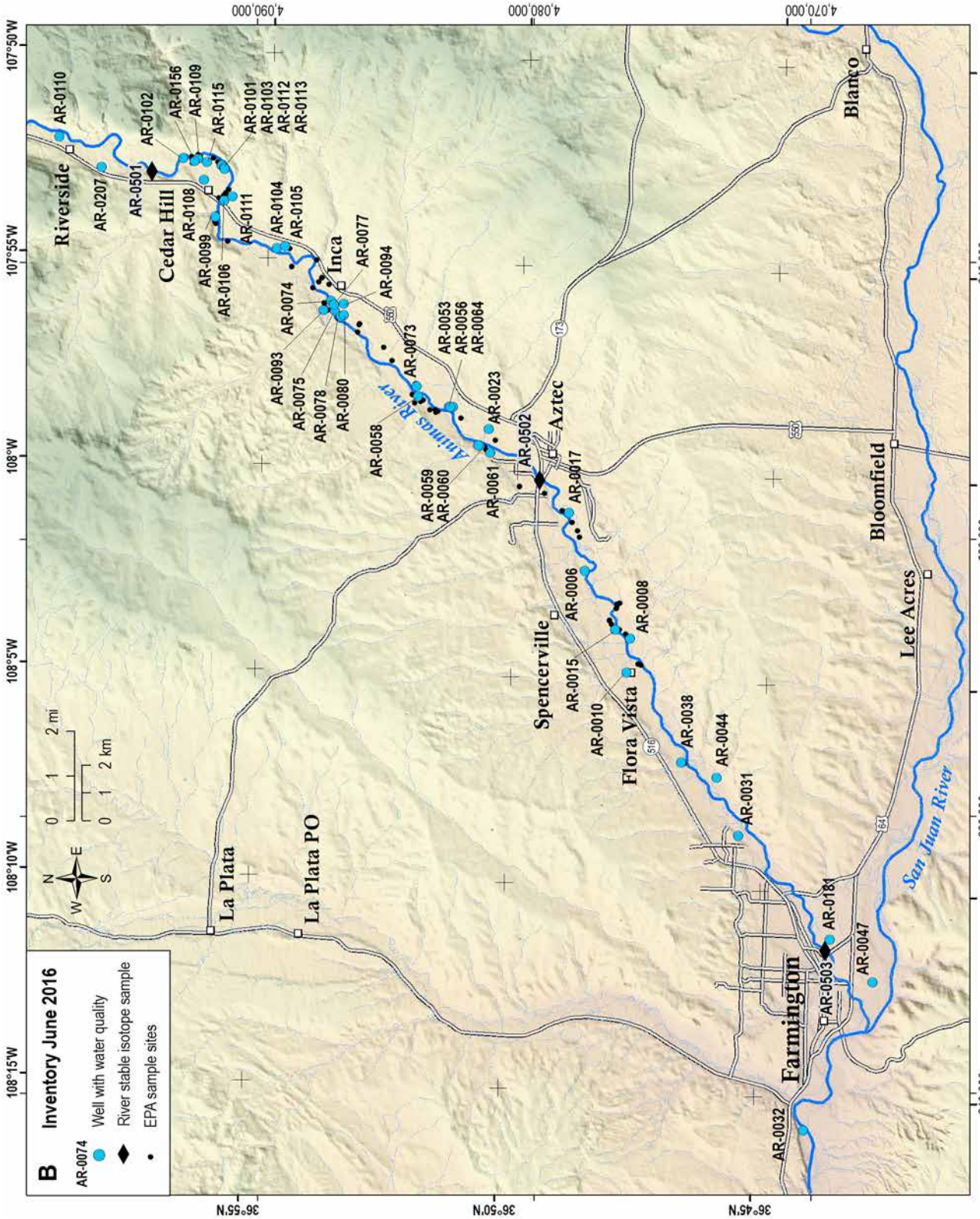


Figure 1. Locations of wells utilized in this assessment of the alluvial aquifer along the Animas River. **B**—Wells and surface water sites sampled for water chemistry by NMBGMR and EPA. Surface water sites were only sampled for stable isotope analyses.

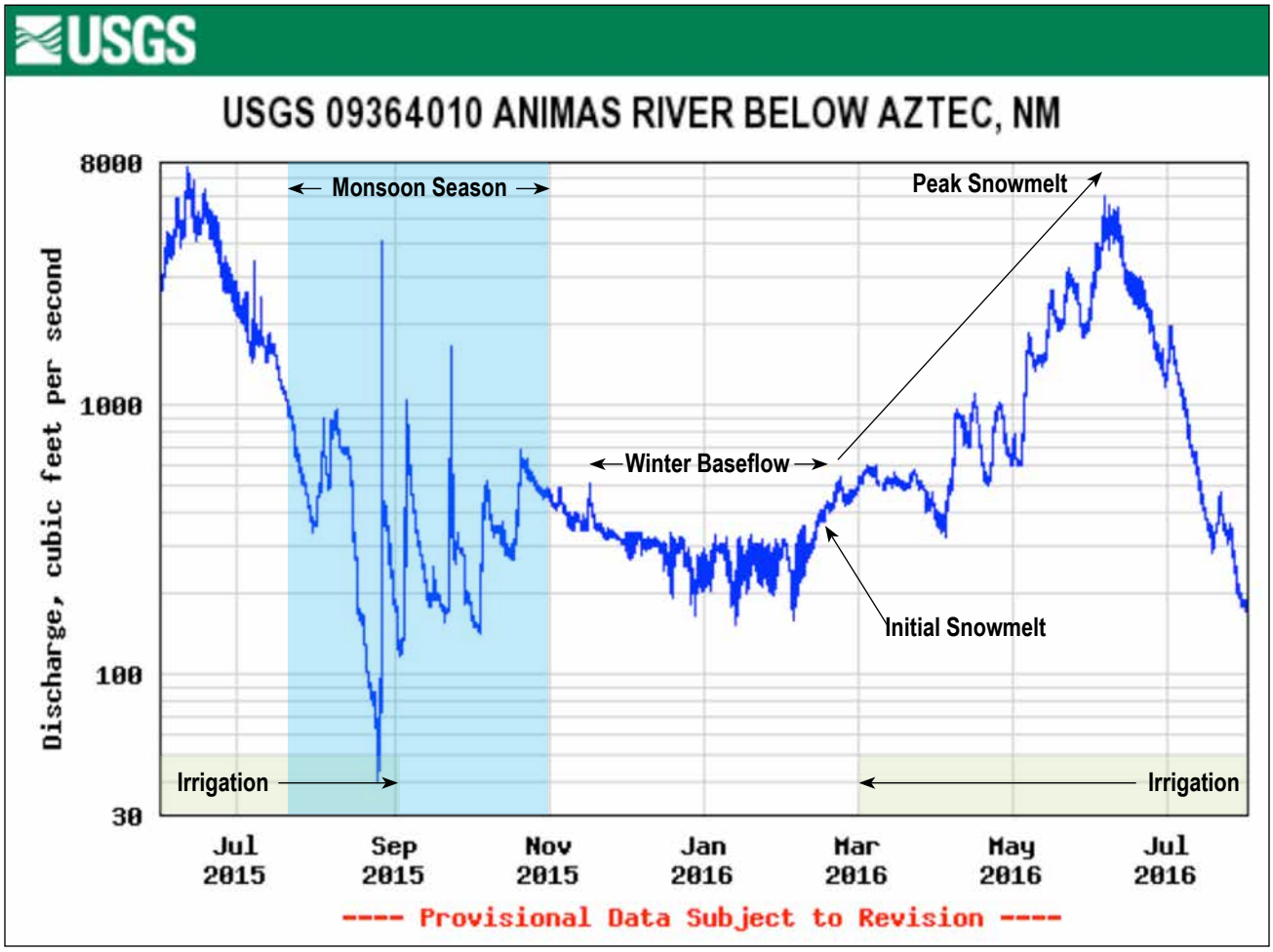


Figure 2. The discharge hydrograph in cubic feet per second, from the USGS gage at Aztec, New Mexico shows the primary "flow seasons" applying to this study, from August 2015 to August 2016. The winter months from November to March are baseflow, or low discharge conditions, with minor fluctuations due to storm events. In March, the flow rates begin to rise as snowmelt begins, coincident with onset of the irrigation season. The hydrograph also shows peak snowmelt in June, and fluctuations in flow due to monsoon season in late July to early October.

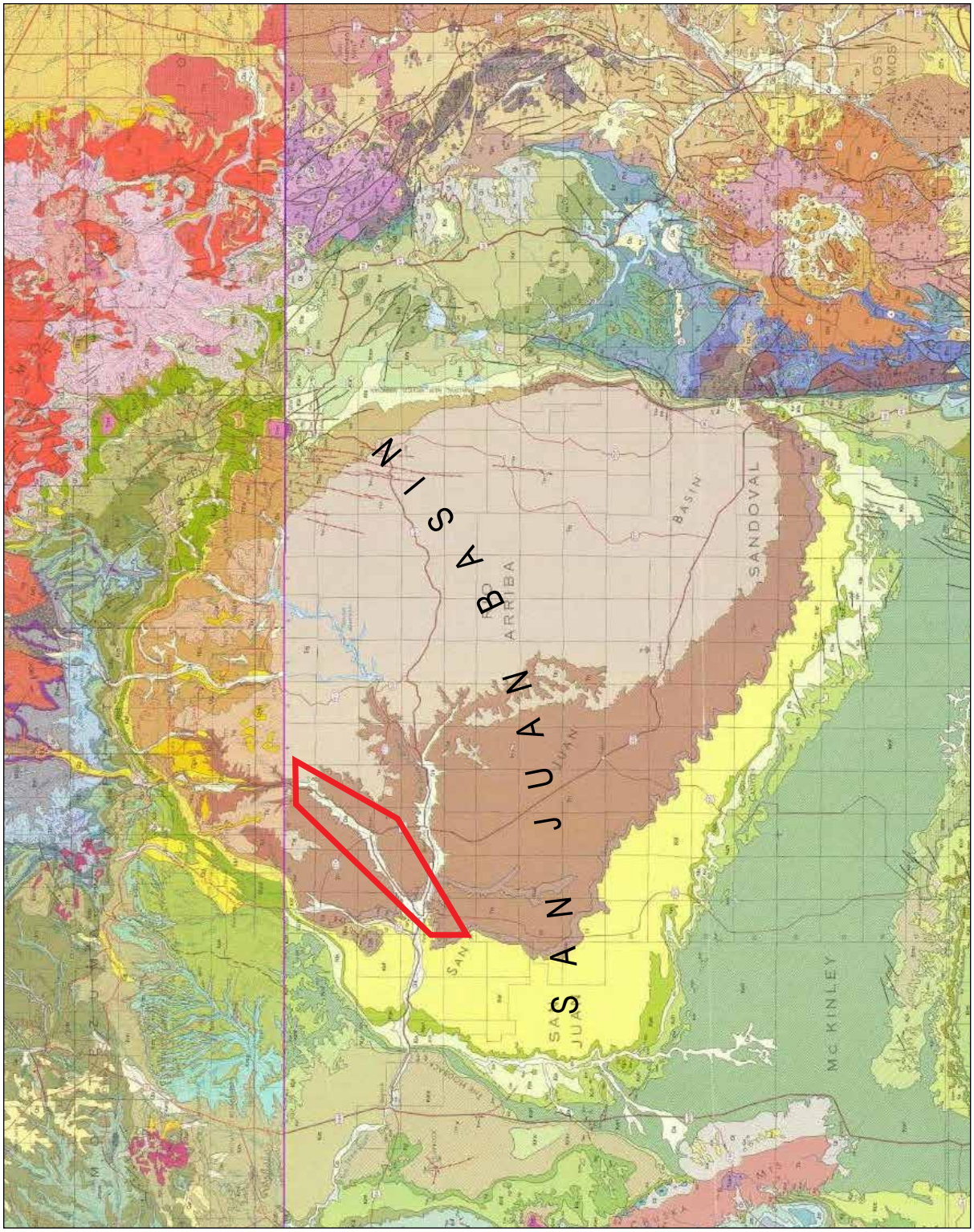


Figure 3. Compiled geologic maps of the region, highlighting the location of this study of the Animas River in New Mexico. Map created from http://ngmdb.usgs.gov/maps/mapview/. The Animas River in New Mexico flows in the alluvial aquifer, noted here as pale yellow. The northern section of the study area has bedrock in the San Jose Formation (light brown), the central section of the study area is comprised of Nacimiento Formation (dark brown), and the area near Farmington has outcrops of Kirtland Shale (yellow). The study area sits on the northwest margin of the San Juan Basin.

Figure 4A. Groundwater elevation contours for the Animas River valley alluvial aquifer in four set images (**A**—August 2015, **B**—January 2016, **C**—March 2016, **D**—June 2016). In areas with dense enough water level measurements, we refined the contours to 5 ft intervals.Well points in red are locations where the measured groundwater level is below the estimated elevation of the Animas River at the time of measurement. These well locations may be along losing reaches of the Animas River, where the river is adding water to the alluvial aquifer.

August 2015

- August 2015 well point, groundwater elevation (ft elevation, above sea level)
- August 2015 groundwater measured elevation is estimated below river elevation
- August 2015 groundwater contour (ft elevation, above sea level)
- Animas River
- Road

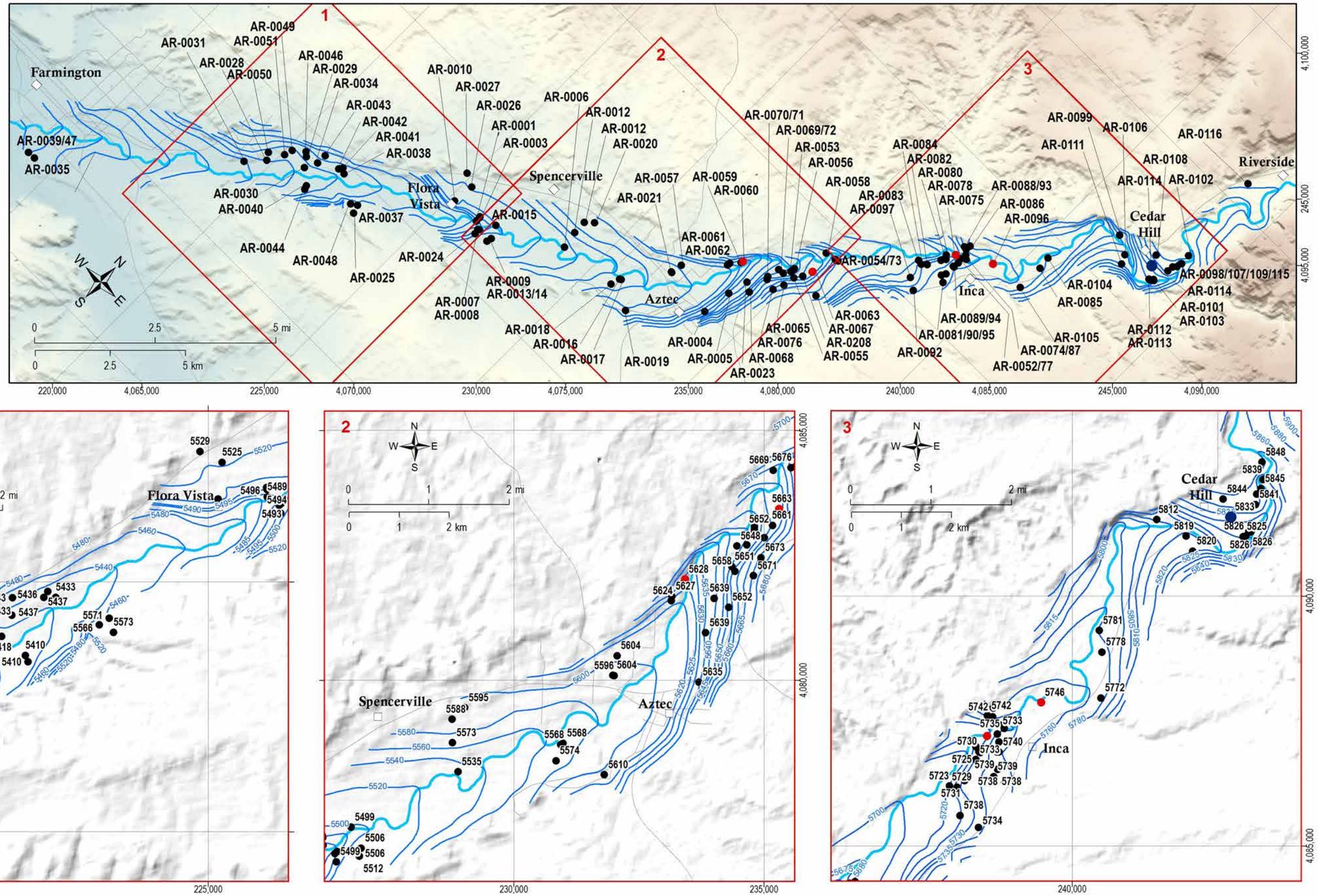


Figure 4B. Groundwater elevation contours for the Animas River valley alluvial aquifer in four set images (**A**—August 2015, **B**—January 2016, **C**—March 2016, **D**—June 2016). In areas with dense enough water level measurements, we refined the contours to 5 ft intervals.Well points in red are locations where the measured groundwater level is below the estimated elevation of the Animas River at the time of measurement. These well locations may be along losing reaches of the Animas River, where the river is adding water to the alluvial aquifer.

January 2016

- January 2016 well point, groundwater elevation (ft elevation, above sea level)
- January 2016 groundwater measured elevation is estimated below river elevation
- January 2016 groundwater contour (ft elevation, above sea level)
- Animas River
- Road

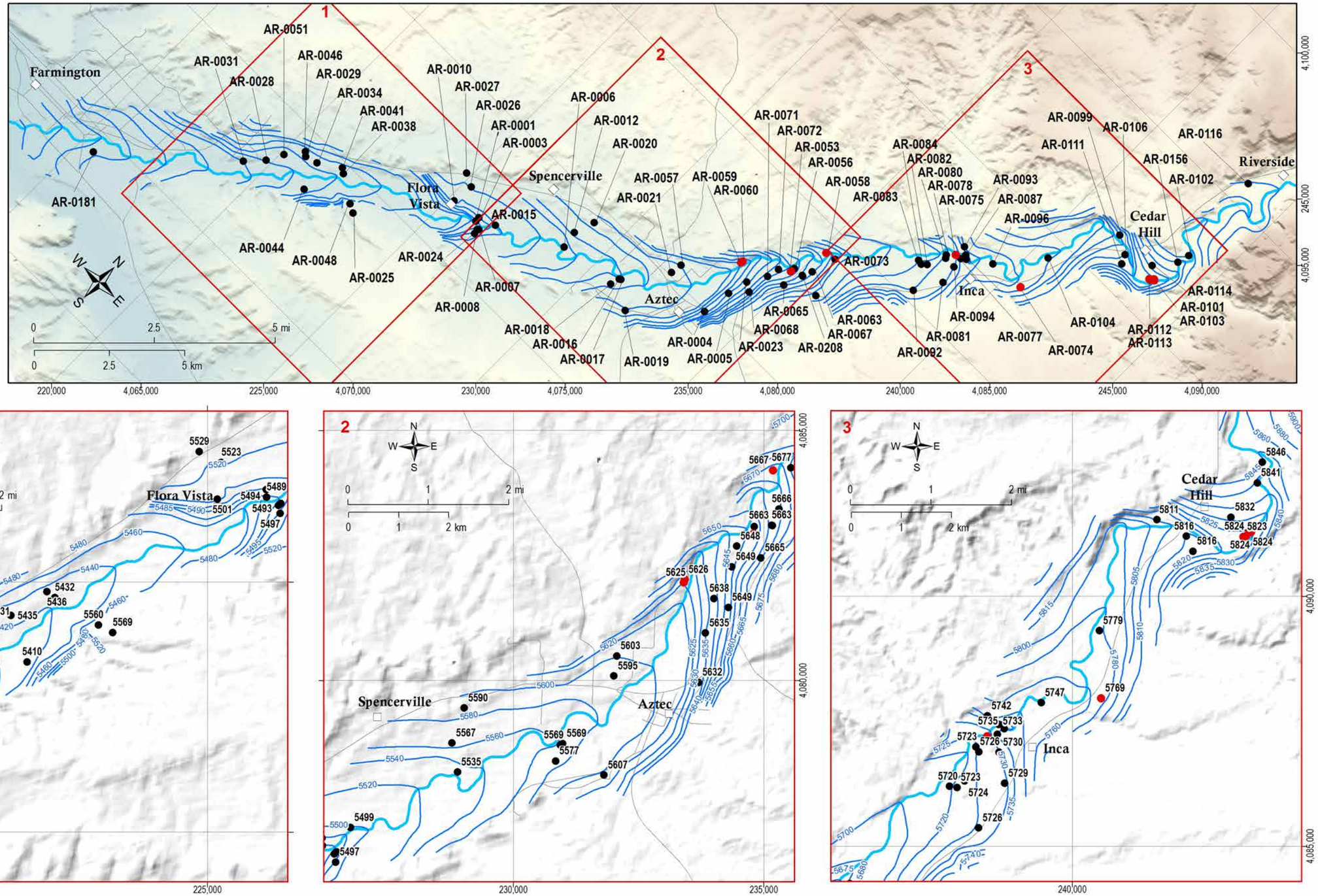
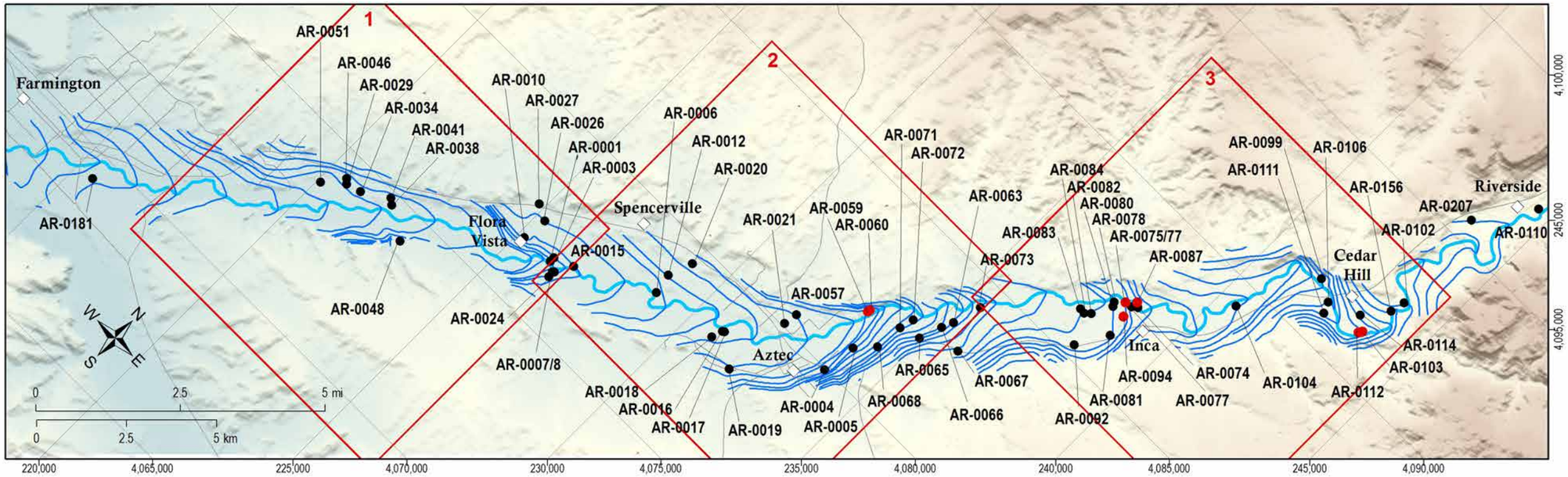
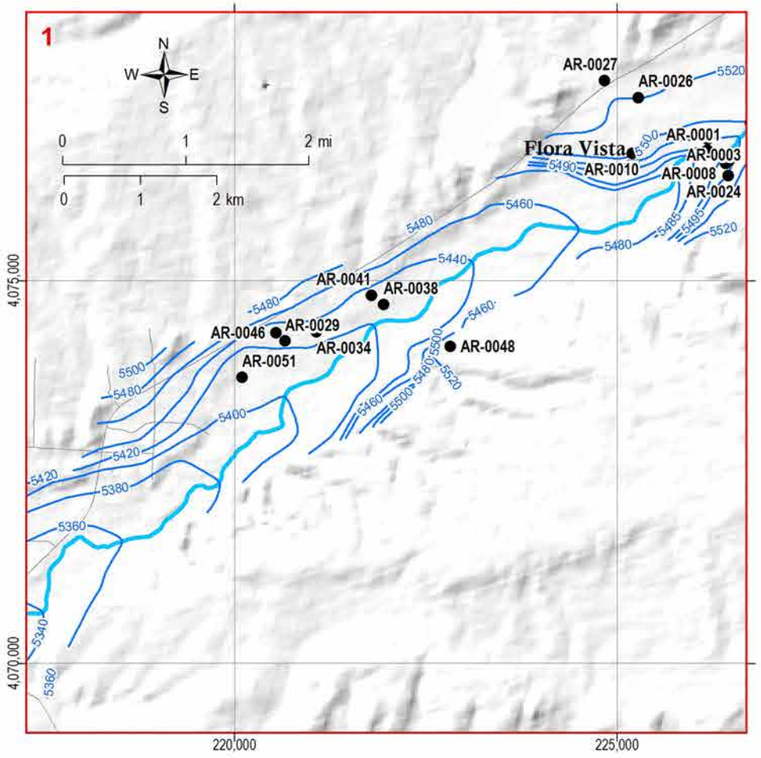


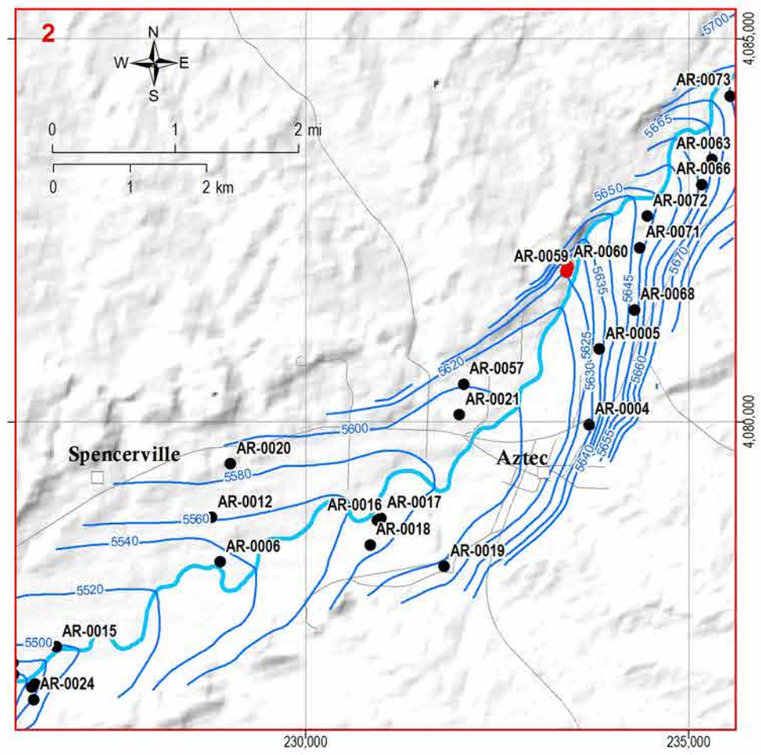
Figure 4C. Groundwater elevation contours for the Animas River valley alluvial aquifer in four set images (**A**—August 2015, **B**—January 2016, **C**—March 2016, **D**—June 2016). In areas with dense enough water level measurements, we refined the contours to 5 ft intervals.Well points in red are locations where the measured groundwater level is below the estimated elevation of the Animas River at the time of measurement. These well locations may be along losing reaches of the Animas River, where the river is adding water to the alluvial aquifer.

March 2016

- March 2016 well point, groundwater elevation (ft elevation, above sea level)
- March 2016 groundwater measured elevation is estimated below river elevation
- March 2016 groundwater contour (ft elevation, above sea level)
- Animas River
- Road







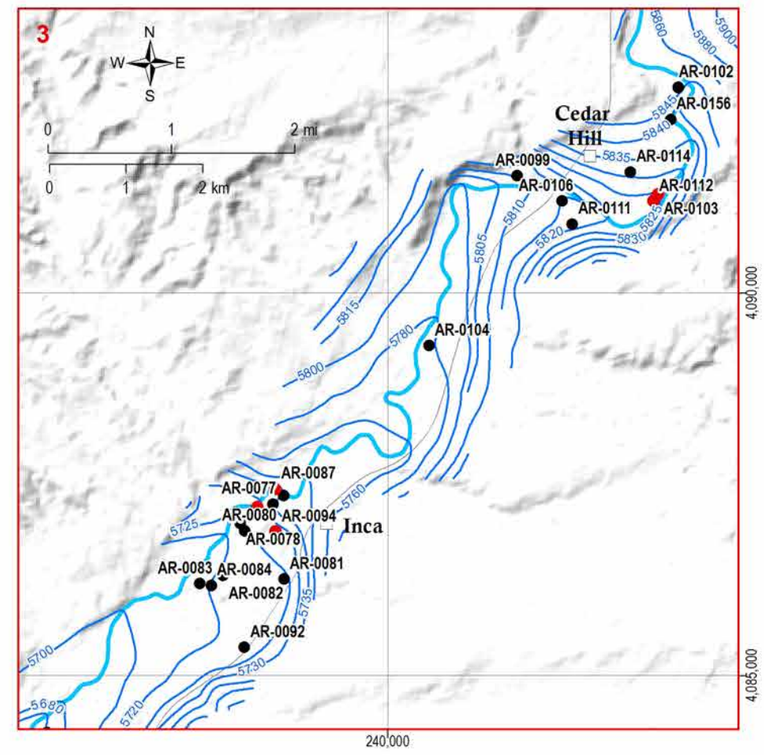
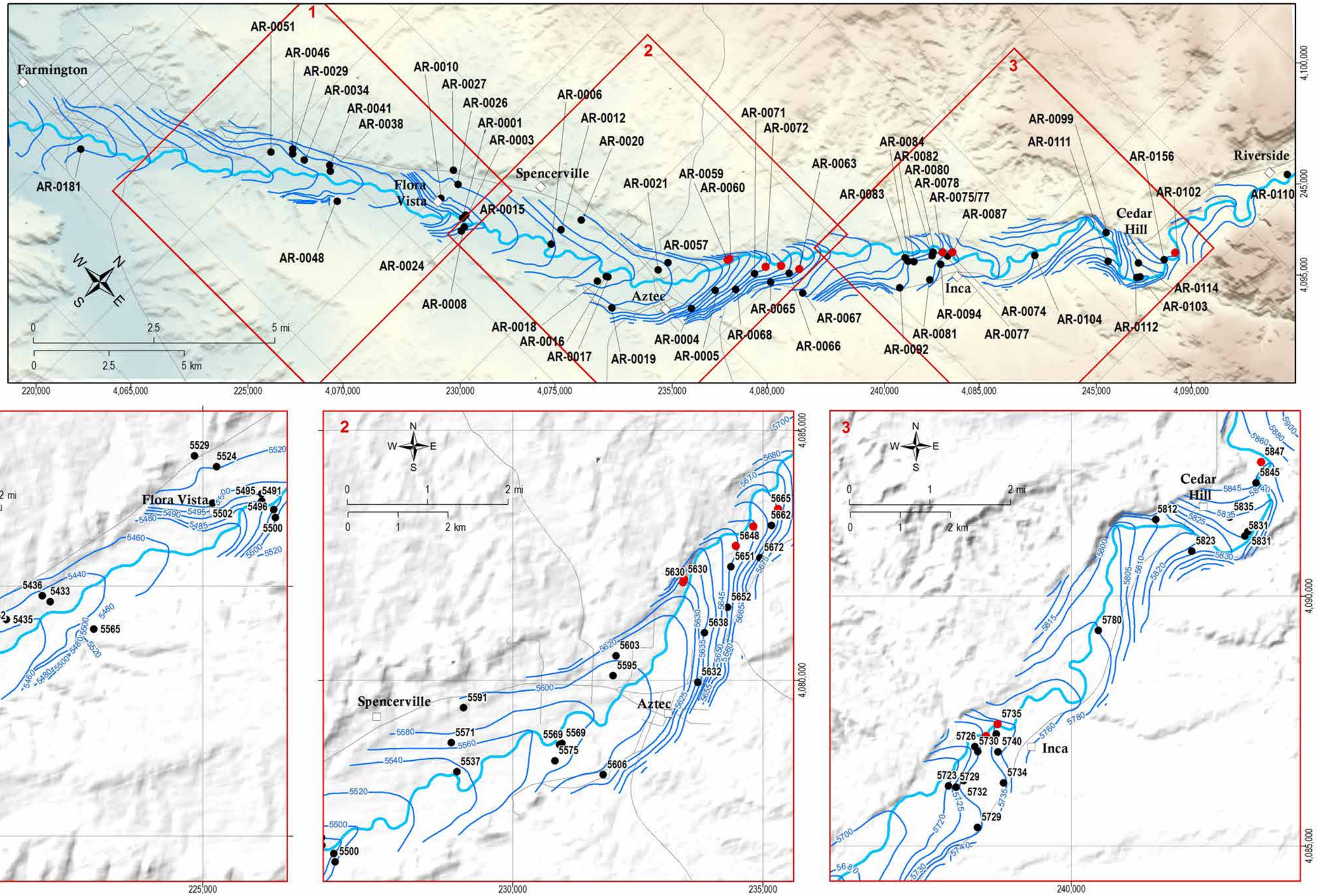


Figure 4D. Groundwater elevation contours for the Animas River valley alluvial aquifer in four set images (**A**—August 2015, **B**—January 2016, **C**—March 2016, **D**—June 2016). In areas with dense enough water level measurements, we refined the contours to 5 ft intervals.Well points in red are locations where the measured groundwater level is below the estimated elevation of the Animas River at the time of measurement. These well locations may be along losing reaches of the Animas River, where the river is adding water to the alluvial aquifer.

June 2016

- June 2016 well point, groundwater elevation (ft elevation, above sea level)
- June 2016 groundwater measured elevation is estimated below river elevation
- June 2016 groundwater contour (ft elevation, above sea level)
- Animas River
- Road



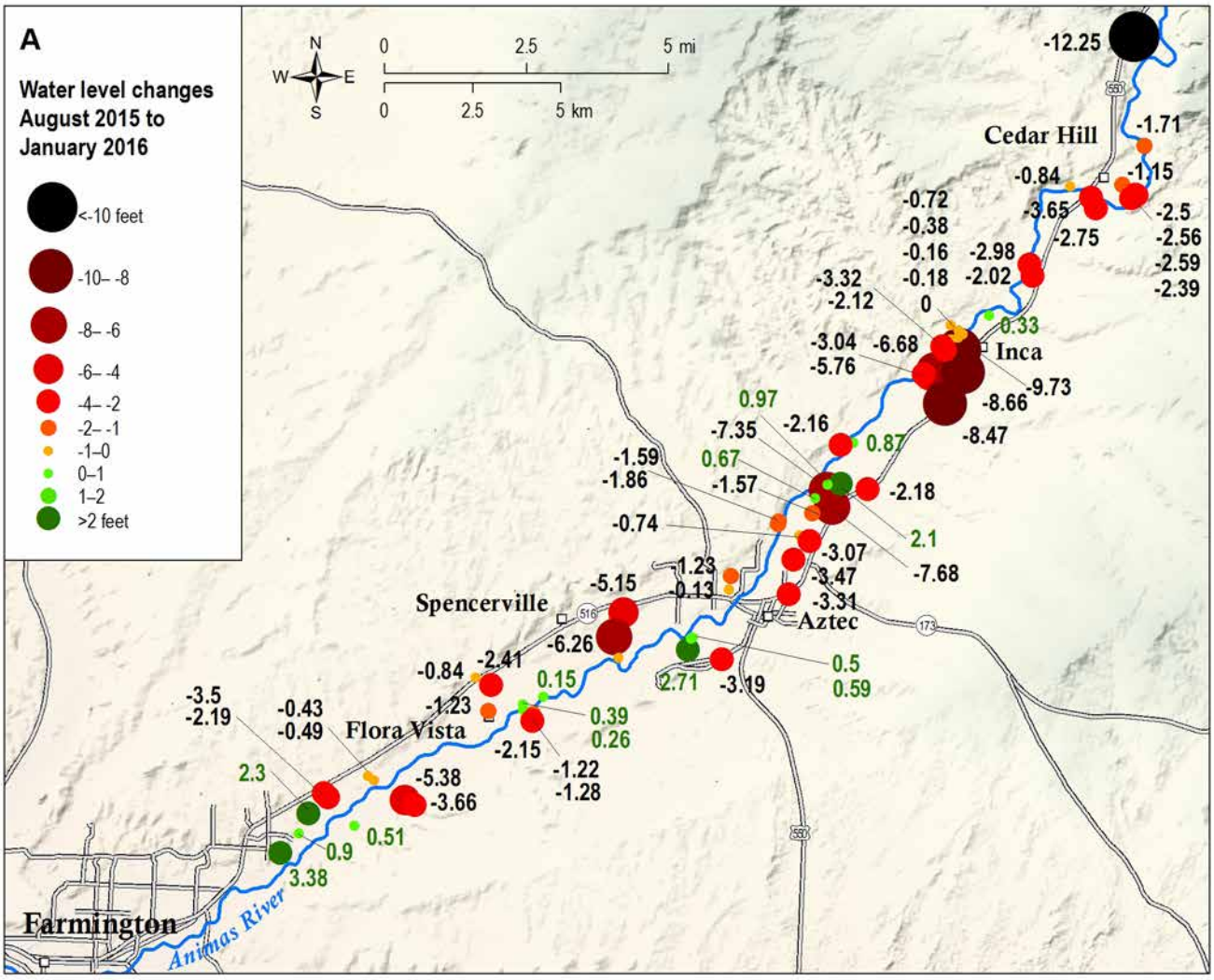


Figure 5. Groundwater level change maps. **A**—Change in groundwater levels observed between August 2015 and the January 2016 water level in the same wells.

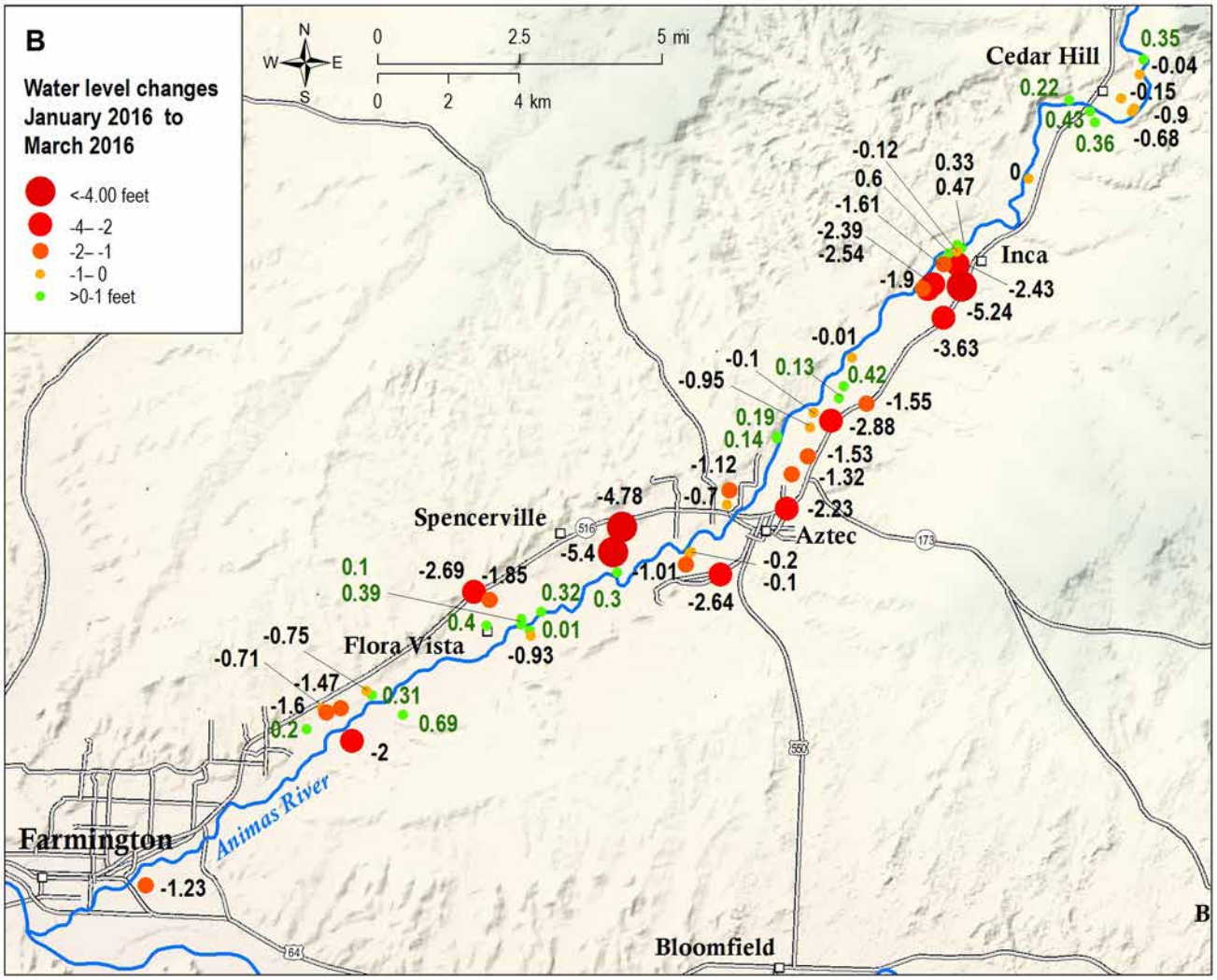


Figure 5. Groundwater level change maps. **B**—Change between January 2016 and March 2016.

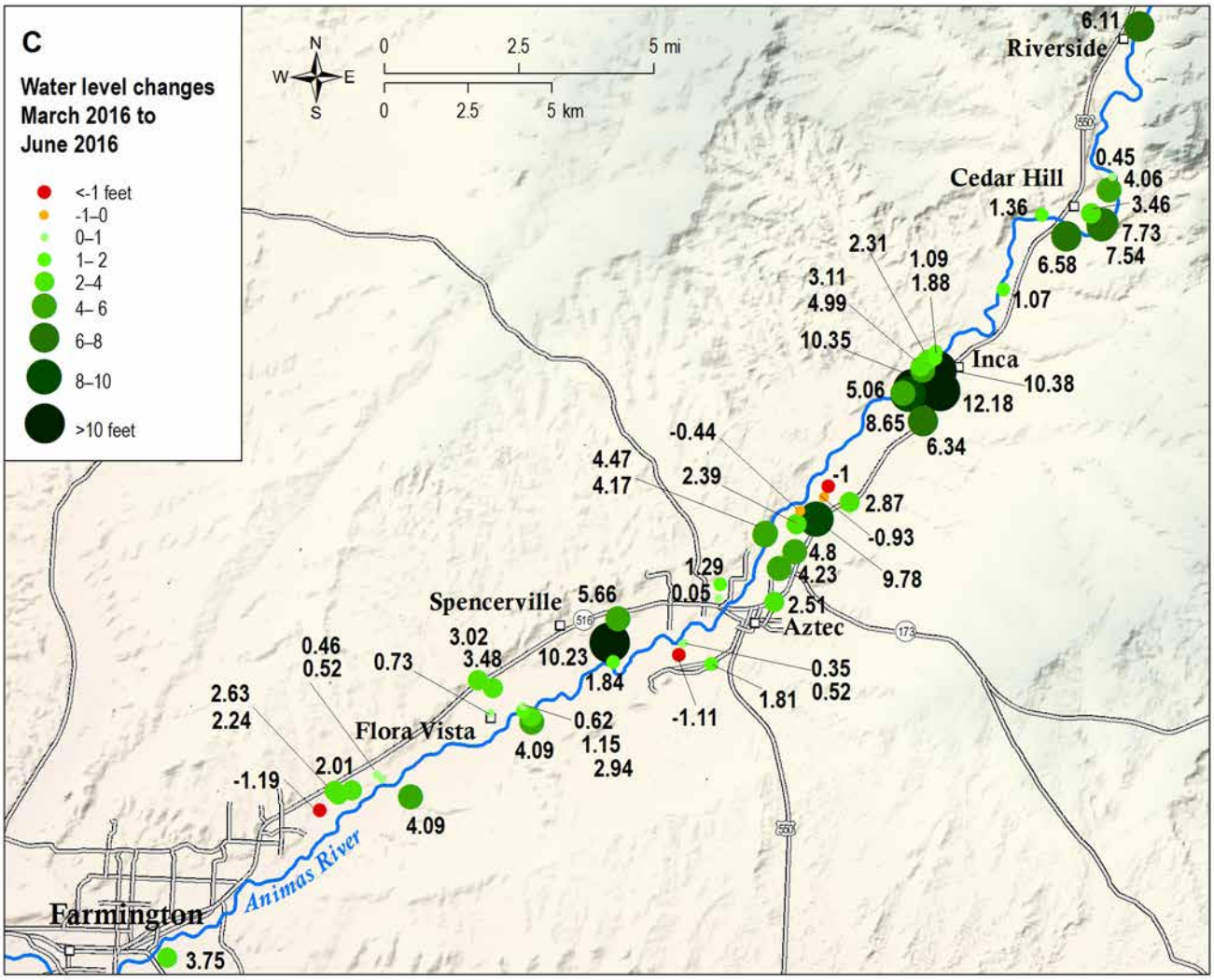


Figure 5. Groundwater level change maps. **C**—Change between March 2016 and May-June 2016.

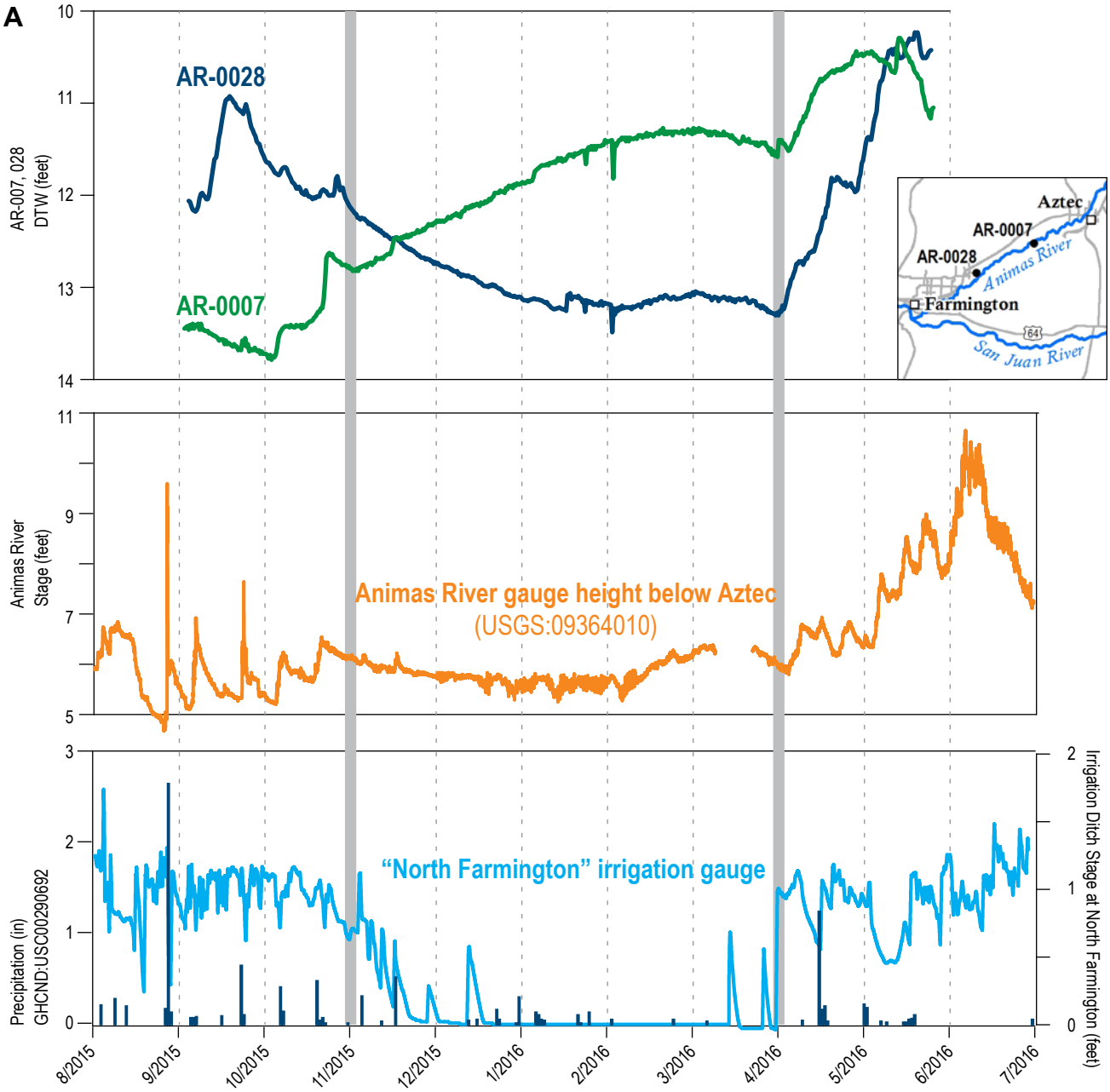


Figure 6A. Hydrographs from wells with continuous data recorders located in the southern half of the study area. Well AR-0007 is a total of 32 ft deep, and is located south of Aztec, on the east side of the river. Well AR-0028 is a total of 20 ft deep, and is located just north of Farmington, on the west side of the Animas River. The stage of the Animas river below Aztec (USGS:09364010), and a record of flow from the North Farmington irrigation ditch gauge are plotted along. Grey bars indicate the approximate brackets to irrigation season, April to November.

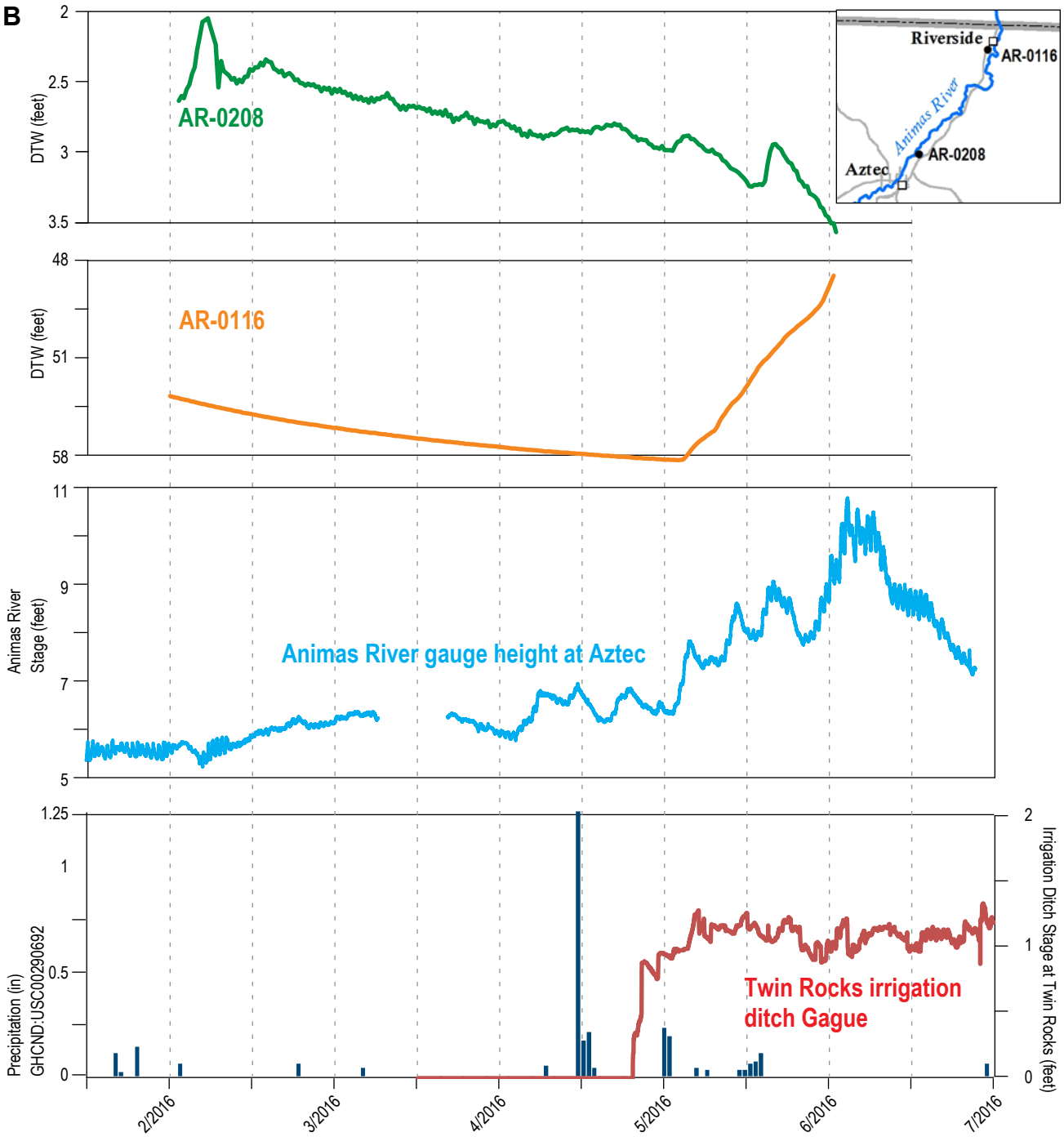


Figure 6B. Hydrographs from wells with continuous data recorders located in the northern half of the study area. Well AR-0116 is a total of 69 ft deep, and is located just south of the Colorado Boarder, on the west side of the river. Well AR-0208 is a total of 28 ft deep, and is located just north of Aztec, on the east side of the Animas River. The stage of the Animas river below Aztec (USGS:09364010), and a record of flow from the Ralston irrigation ditch gauge.

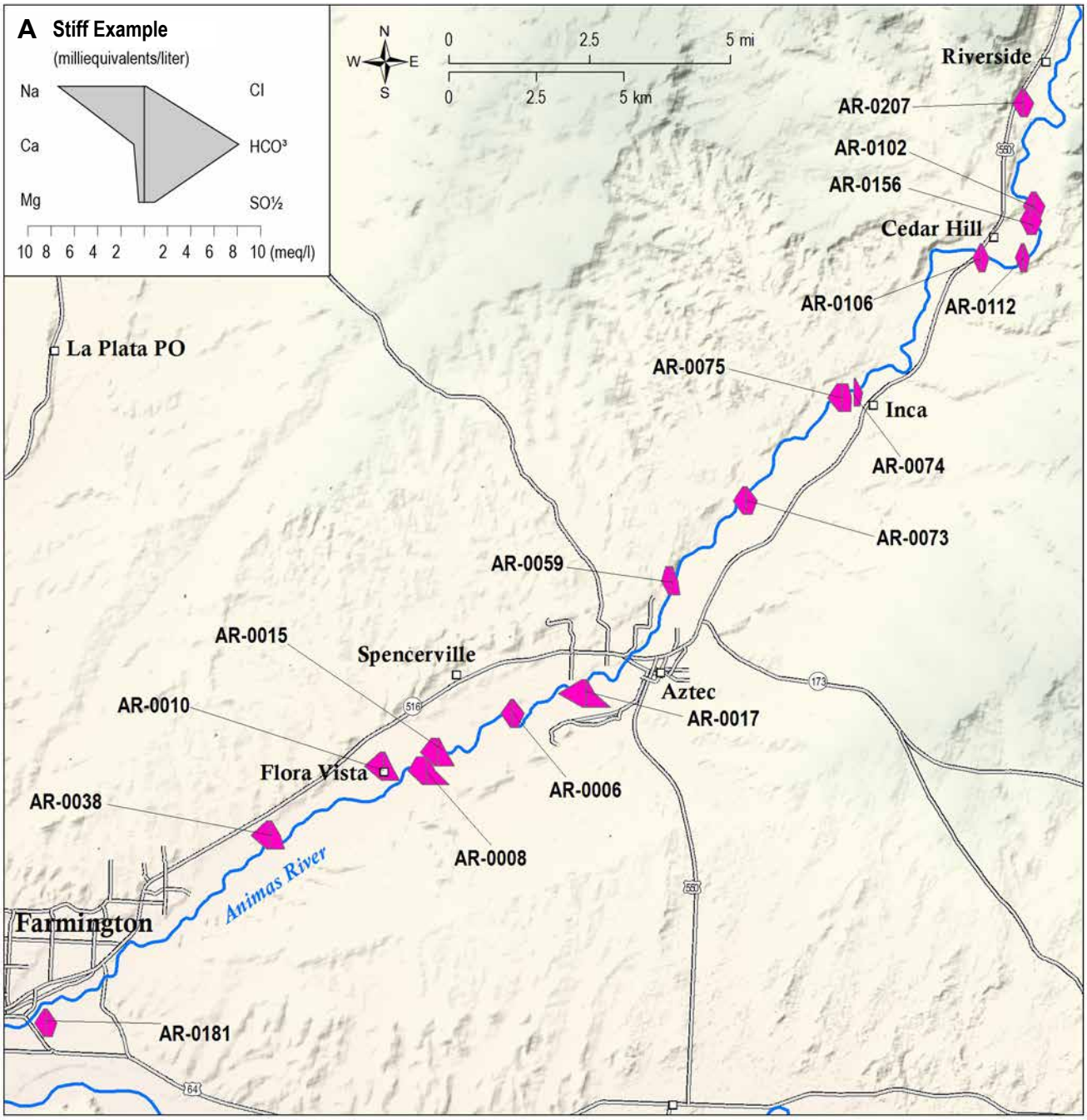


Figure 7. Maps showing stiff diagrams from January, March and May-June, 2016. The cation end-members (left side) are Na, Ca, and Mg; the anion end-members (right side) are Cl, HCO_3, and SO_4, all in meq/L. **A**—January 2016 NMBGMR sample results.

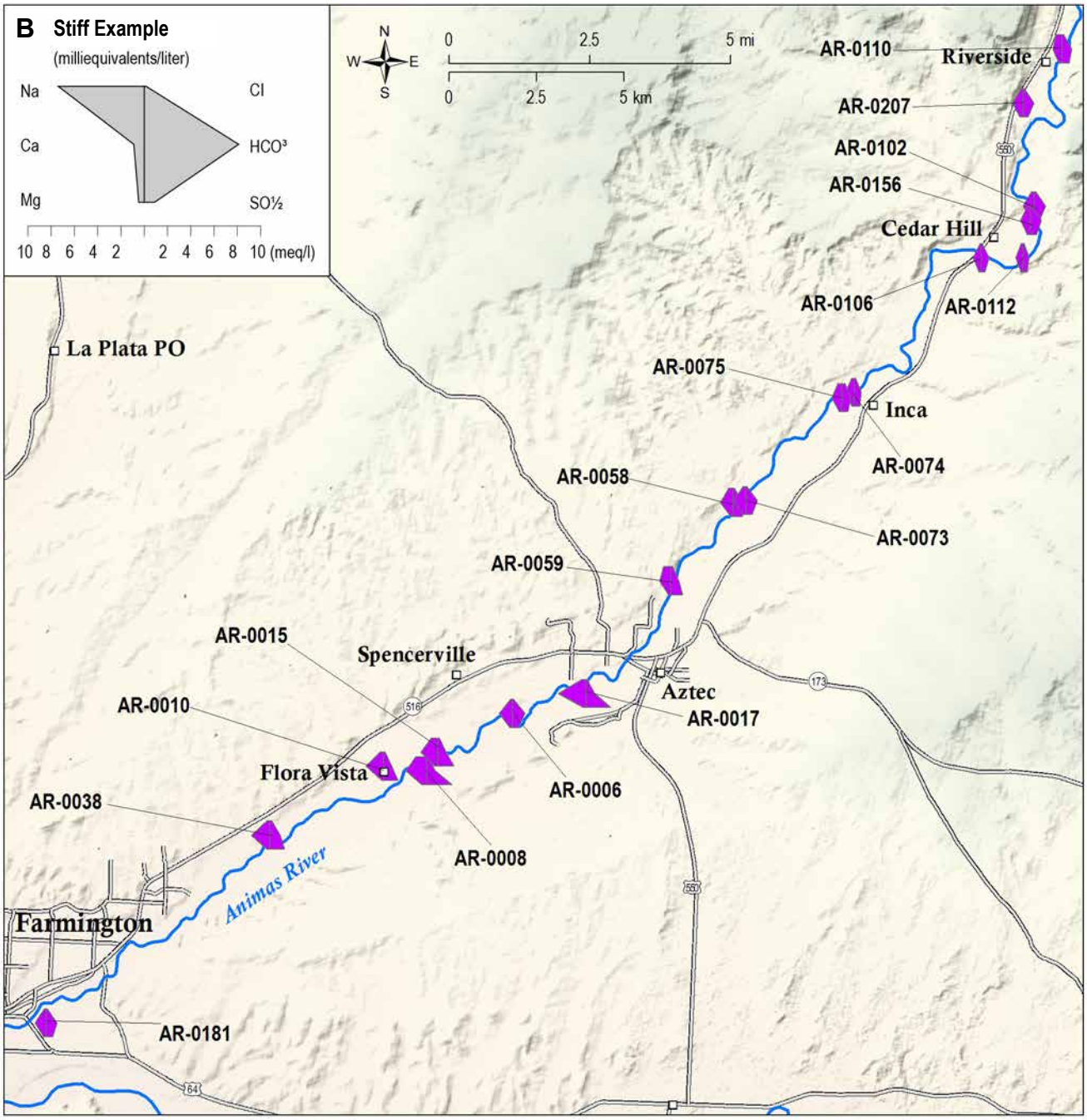


Figure 7. Maps showing stiff diagrams from January, March and May-June, 2016. The cation end-members (left side) are Na, Ca, and Mg; the anion end-members (right side) are Cl, HCO_3, and SO_4, all in meq/L. **B**—March 2016 NMBGMR sample results.

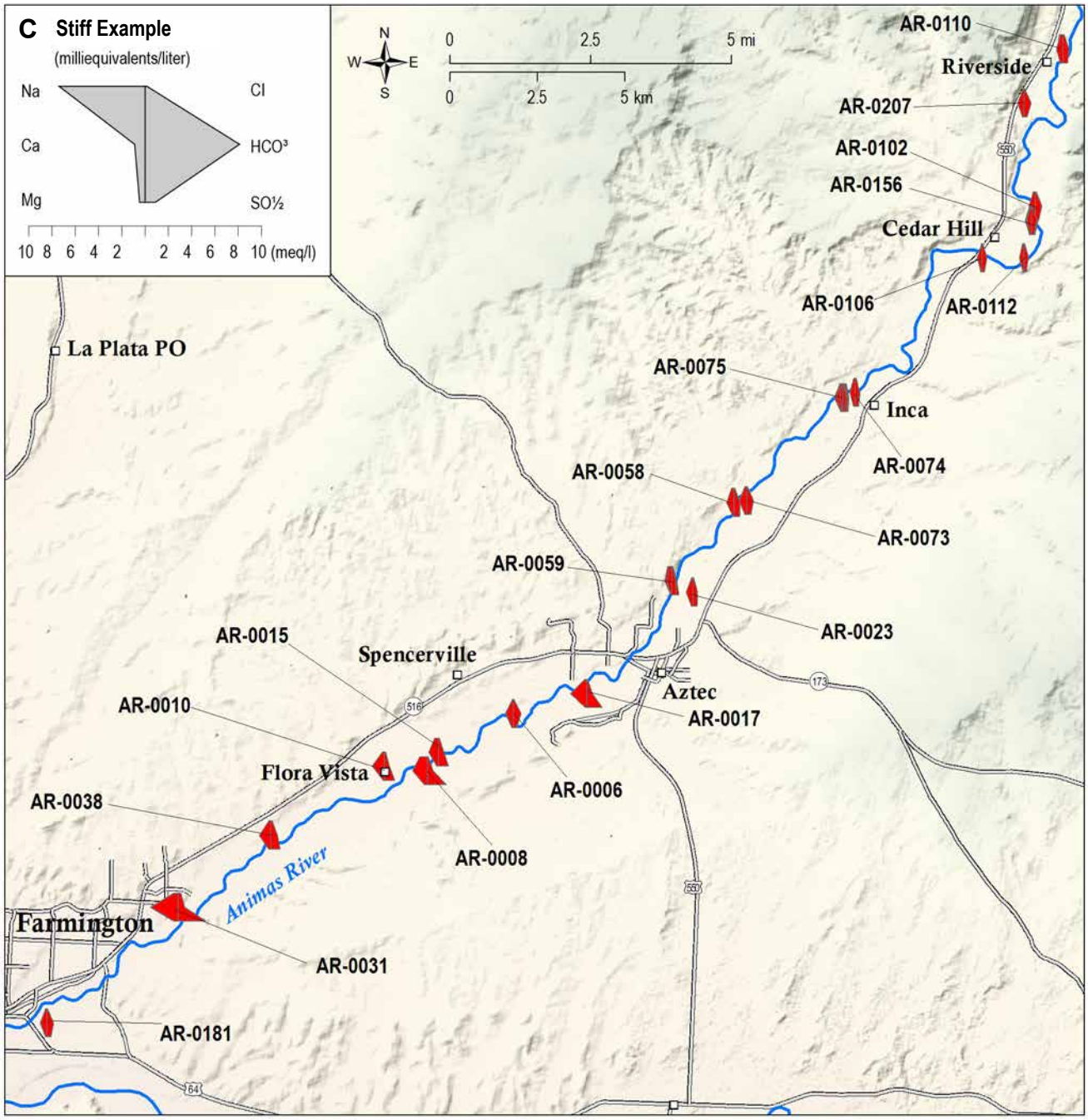


Figure 7. Maps showing stiff diagrams from January, March and May-June, 2016. The cation end-members (left side) are Na, Ca, and Mg; the anion end-members (right side) are Cl, HCO_3, and SO_4, all in meq/L. **C**—May-June 2016 NMBGMR sample results.

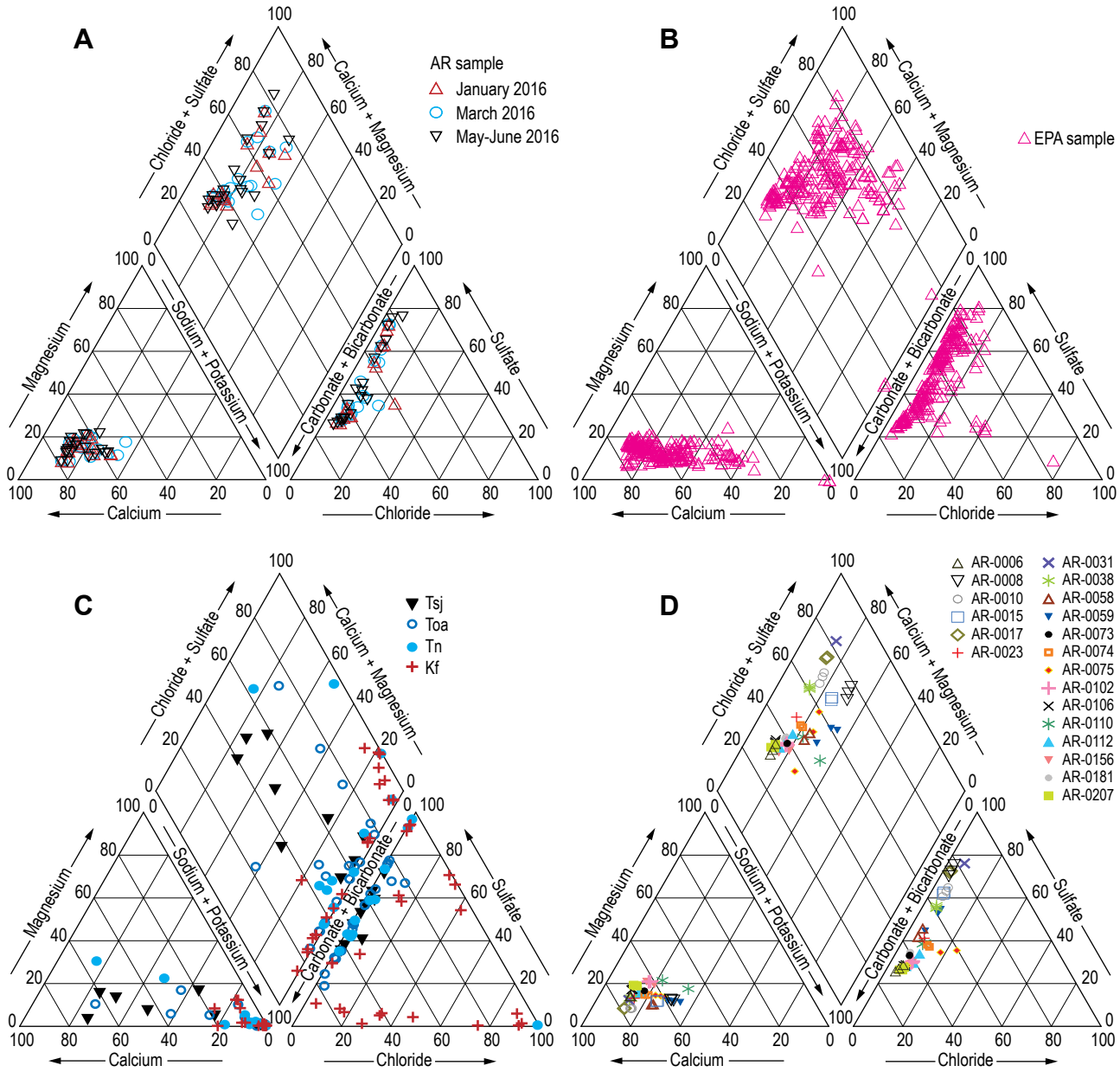


Figure 8. Piper diagrams showing **A**—NMBGMR samples from January, March and May-June 2016, **B**—U.S. EPA samples from August 2015, **C**—Regional groundwater samples from Kelley et al. (2014) from geologic formations including Tsj (San Jose Fm), Toa (Ojo Alamo Fm), Tn (Nacimiento Fm), and Kf (Fruitland Fm); **D**—Repeated NMBGMR samples.

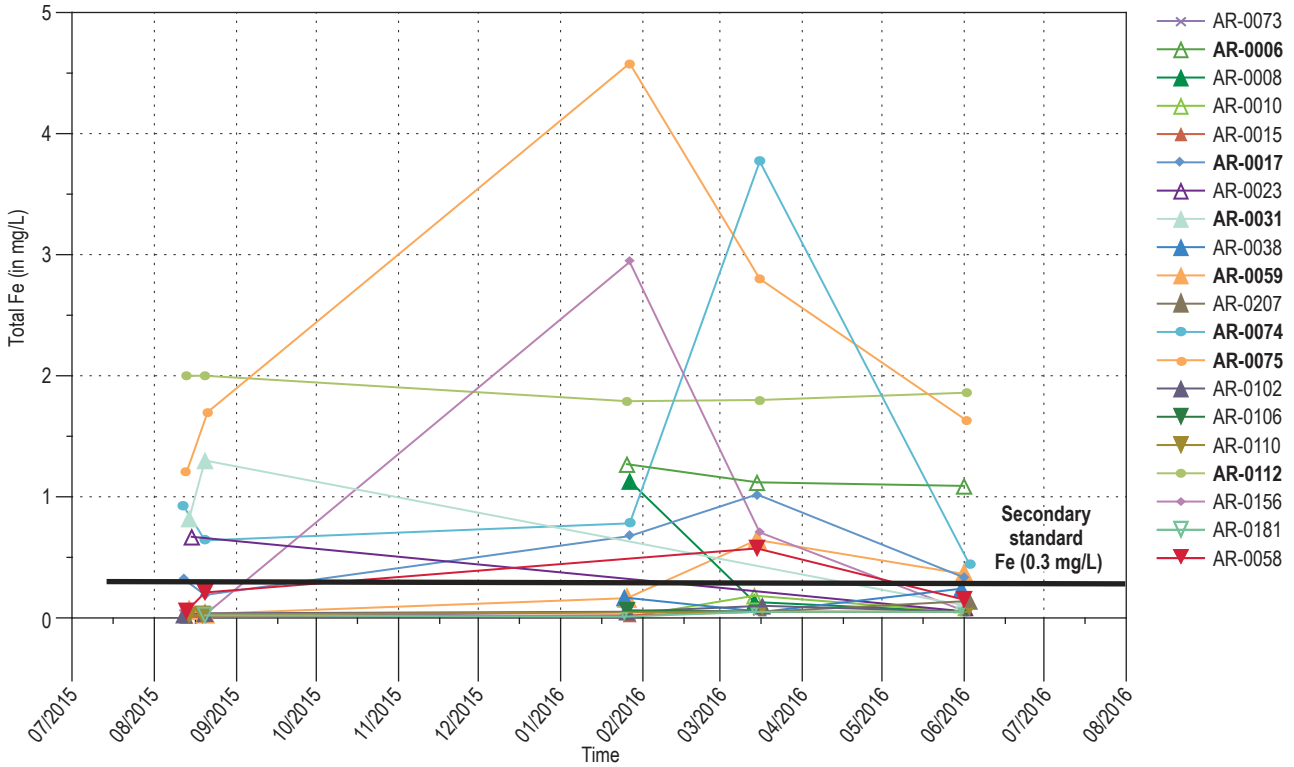


Figure 9. Total iron (Fe) from repeat sampled wells, showing trends with time. Samples collected in August are U.S. EPA results; samples from January, March and May-June, 2016 are NMBGMR results. Many of the wells have higher levels of total iron in the winter (January) sample period, which decrease in March and May-June as irrigation and snowmelt season begins. The secondary MCL for iron is 0.3 mg/L, showing that many of the wells here are above this level.

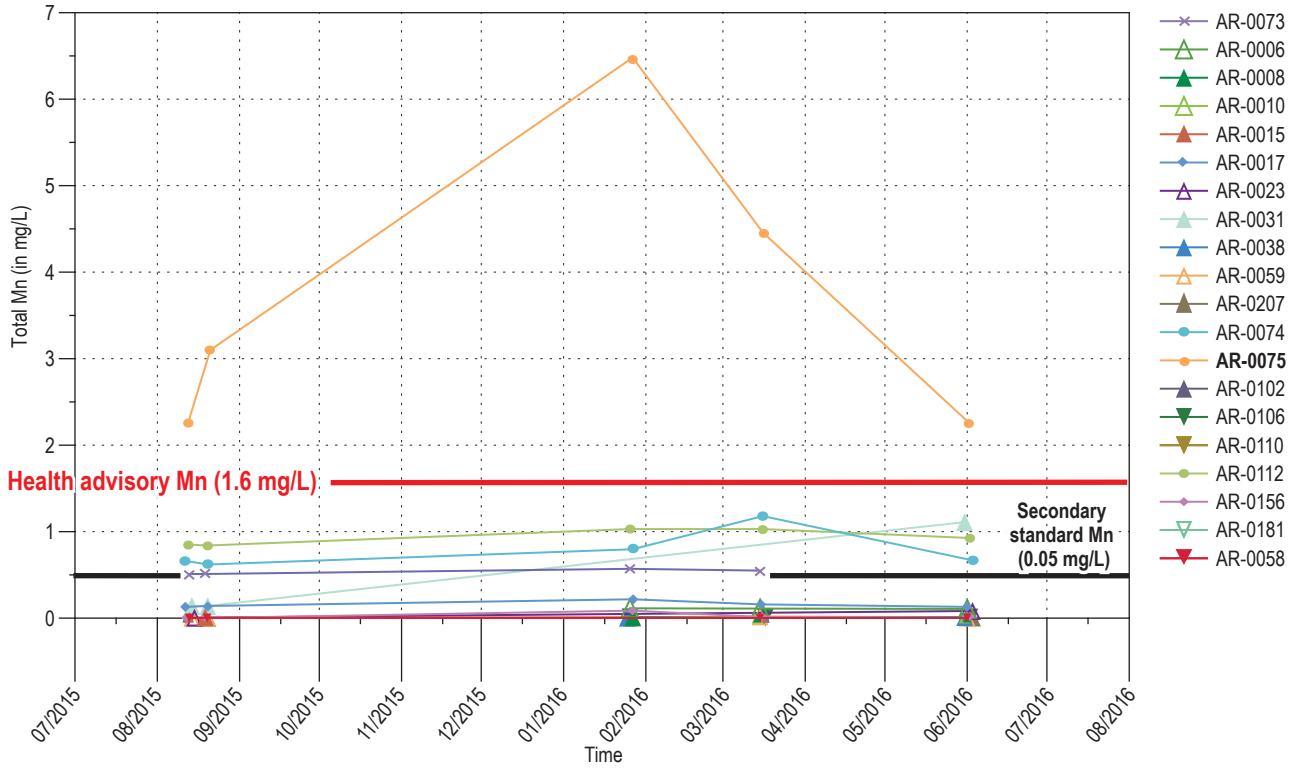


Figure 10. Total manganese (Mn) from from repeat sampled wells, showing trends with time. Samples collected in August are U.S. EPA results; samples from January, March and May-June, 2016 are NMBGMR results. Similar to Fe, we see higher Mn levels in the winter (January) sample period, which decrease in March and May-June as irrigation and snowmelt season begins. The health advisory level for Mn is indicated, as well as the secondary MCL. Many wells are above the secondary level, and one is well over the health advisory level (AR-0075).

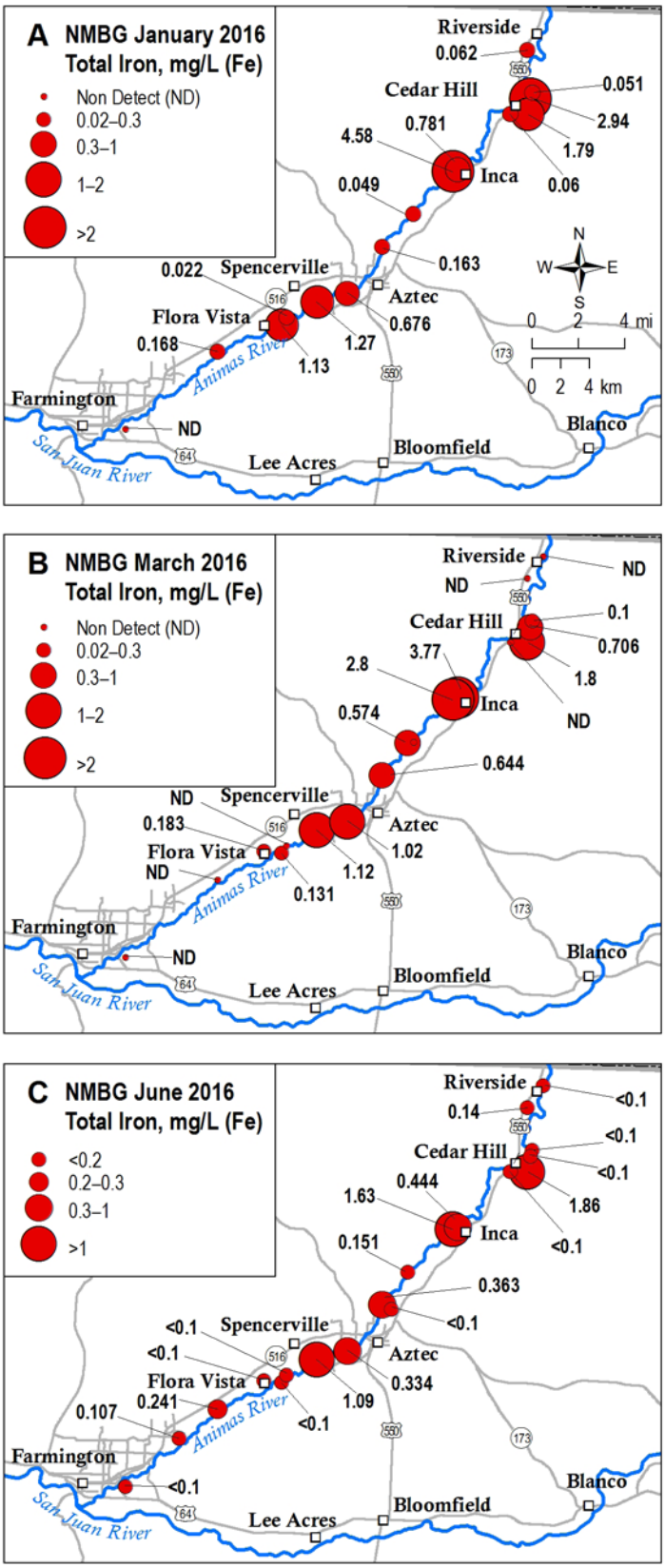


Figure 11. Total iron concentration maps by sample period. Total Fe is in mg/L, with symbol size proportional to the Fe concentration (larger symbol = higher level). **A**—January 2016. **B**—March 2016. **C**—May-June 2016. Regions with consistently elevated levels of iron are apparent with clusters of larger symbols.

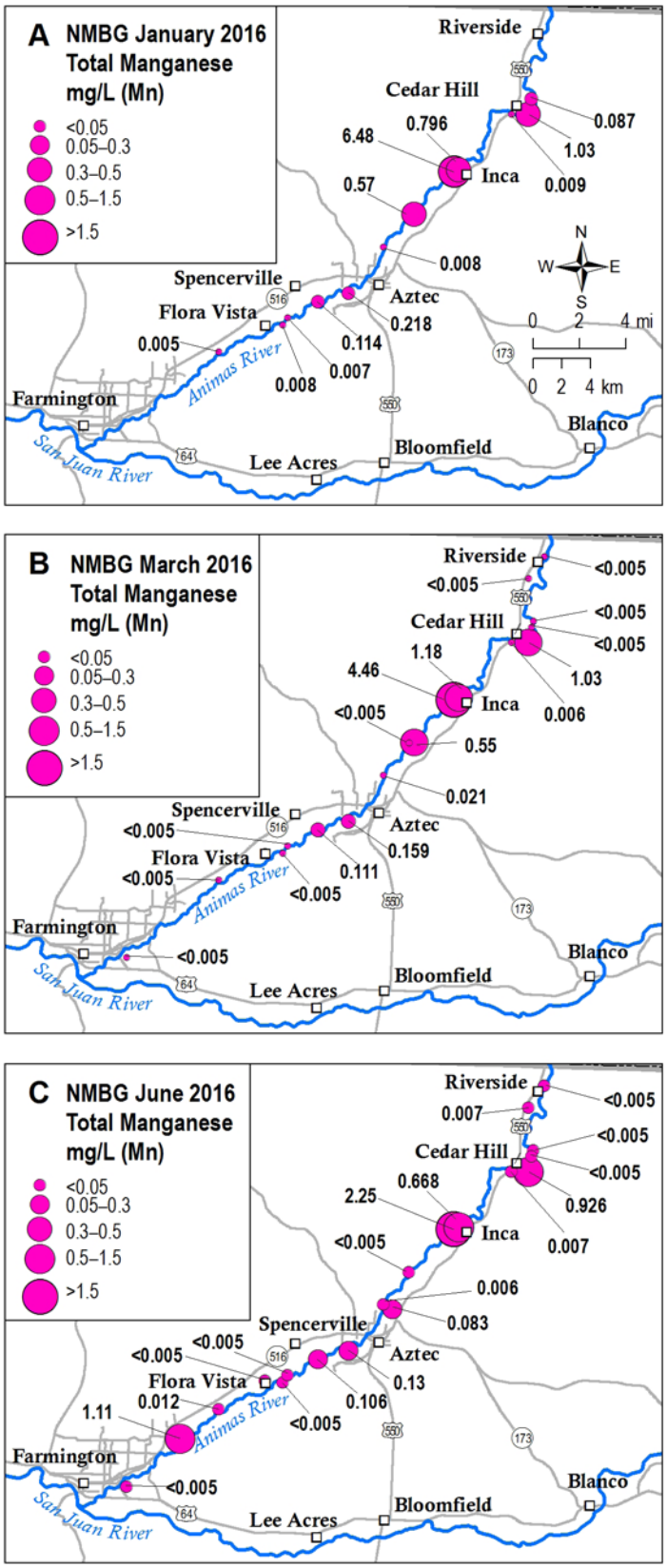


Figure 12. Total manganese concentration maps by sample period. Total Mn is in mg/L, with symbol size proportional to the Mn concentration (larger symbol = higher level). **A**—January 2016. **B**—March 2016. **C**—May-June 2016. Regions with consistently elevated levels of manganese are apparent with clusters of larger symbols.

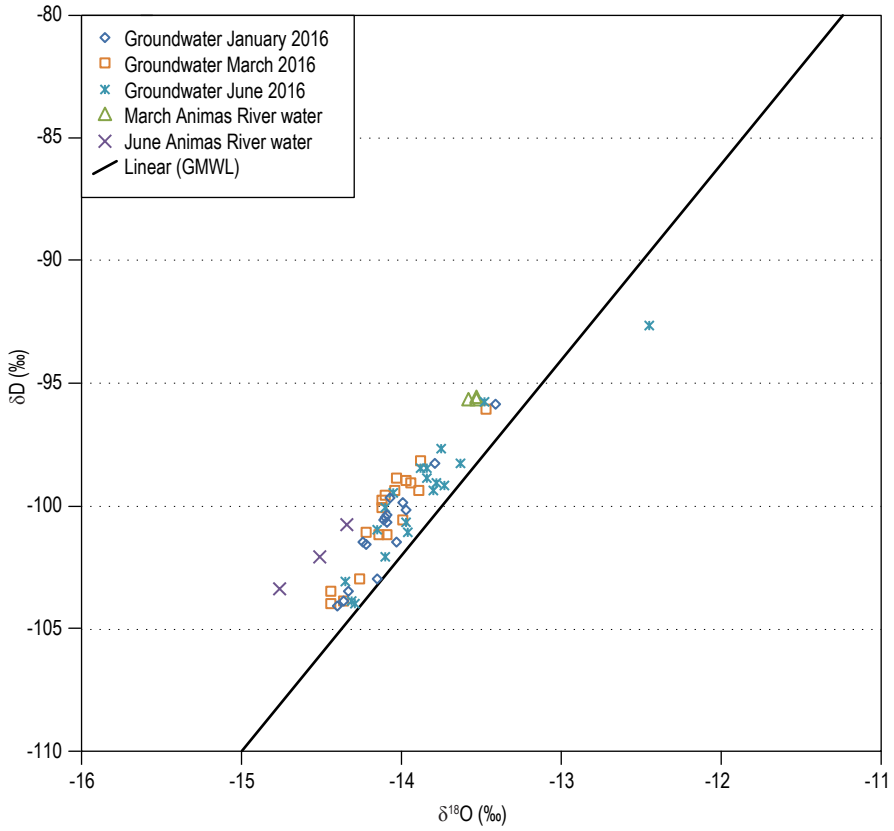


Figure 13. Plot of stable isotopes of oxygen ($\delta^{18}O$) vs. hydrogen (δD) with the Global Meteoric Water Line (GMWL). Groundwater samples are shown clustered data, except for two sites, AR-0006 and AR-0031. AR-0006 is plotted adjacent to March Animas River samples (green triangles). The June Animas River samples are lighter, reflecting snowmelt water.

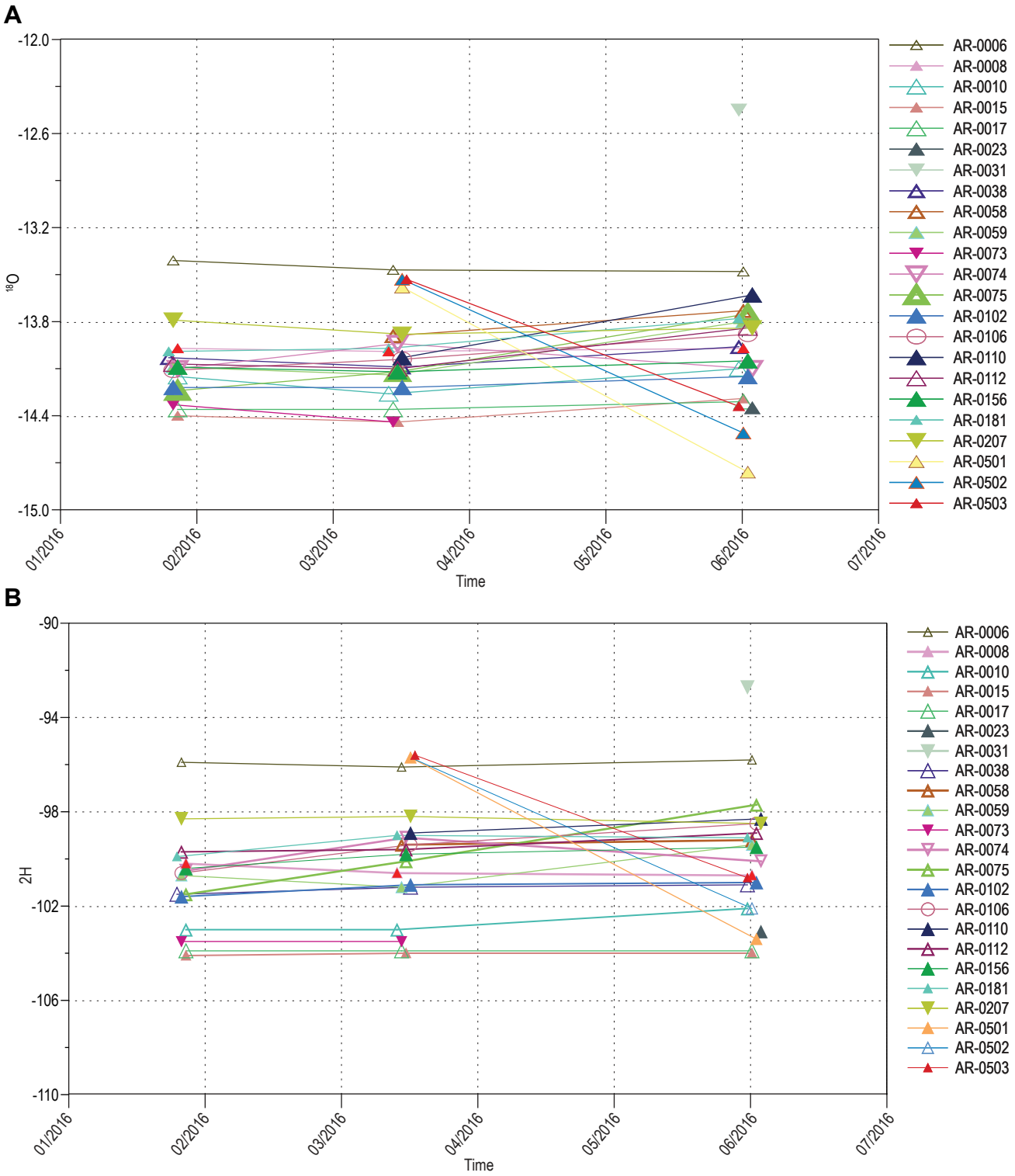


Figure 14. Plots of **A**—oxygen ($\delta^{18}O$) and **B**—hydrogen (δD) samples over time. The dominant observed change occurs in the river samples, AR-0501, AR-0502, and AR-0503, where they become lighter due to the snowmelt input to the Animas River in June.

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