SUPPLEMENTARY INFORMATION

Evidence for water of condensation: A third source of water in shale gas wells

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Figure S1. Daily water to gas production ratio (15 day moving average) vs. TDS concentration vs. days producing for Well A, B, and C time-series data and 230 produced water samples from Marcellus shale gas wells sampled once each in Susquehanna County.

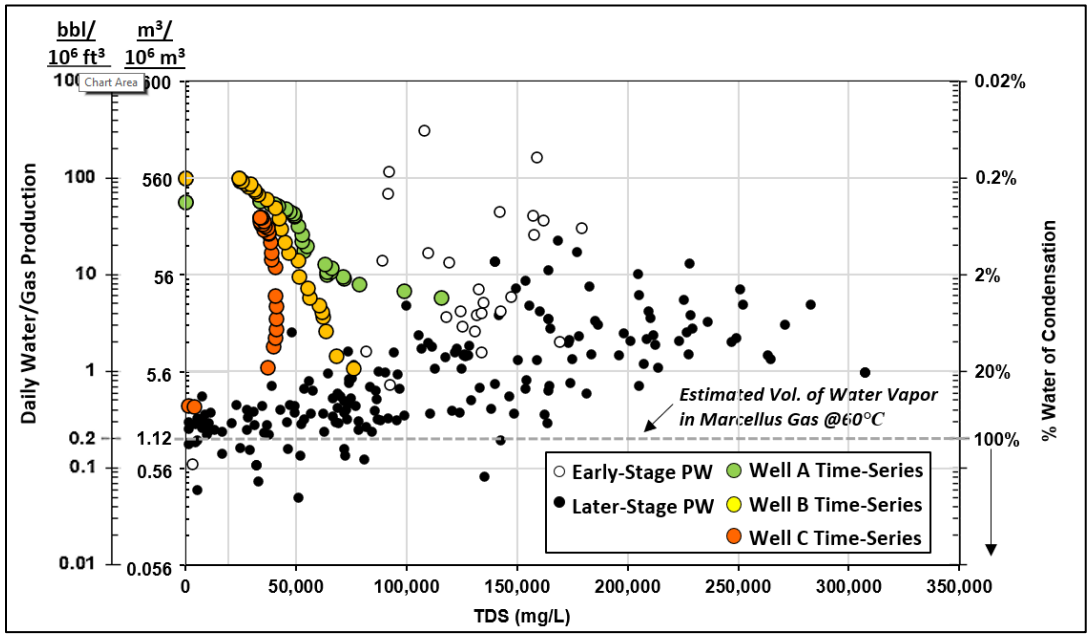


Figure S2. Hypothetical mixing line C-C' (navy), where Point C is defined as downhole fluid with chloride = 60,000 mg/L, $\delta^{18}O$ = -2.6‰, $\delta^{2}H$ = -43.5‰, and Point C' is calculated based on the isotopic composition of water vapor assumed to be in isotopic equilibrium with downhole fluid at typical reservoir temperature (60°C). Water $\delta^{2}H$ vs. $\delta^{18}O$ values are also shown for 230 produced water samples from Marcellus shale gas wells sampled once each in Susquehanna County.

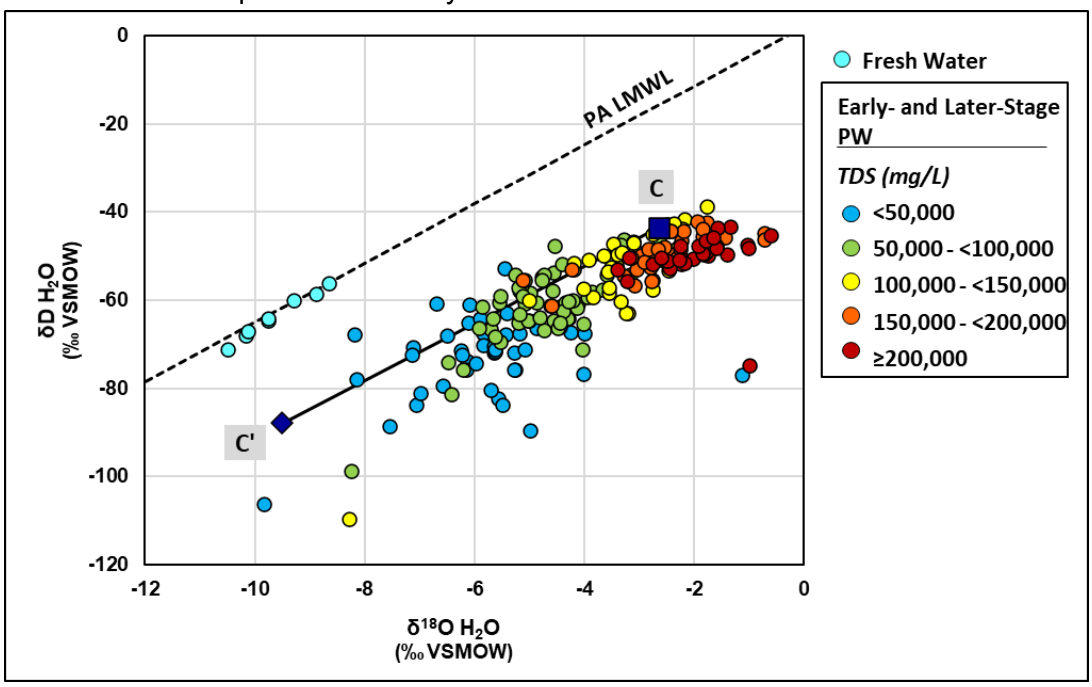


Figure S3. Estimated percentages of formation fluids based on A) the daily ratios of water-to-gas production and B) conservative Cl concentrations, versus the $\delta^{18}O$ and $\delta^{2}H$ composition of produced water using endmember mixing model C-C' in Figure S2. Values with negative proportions removed for plotting purposes. Due to variability in downhole fluid composition, in rare instances, the calculated percentage of downhole fluid based on the $\delta^{18}O$ and $\delta^{2}H$ composition and Cl concentration was greater than 100%.

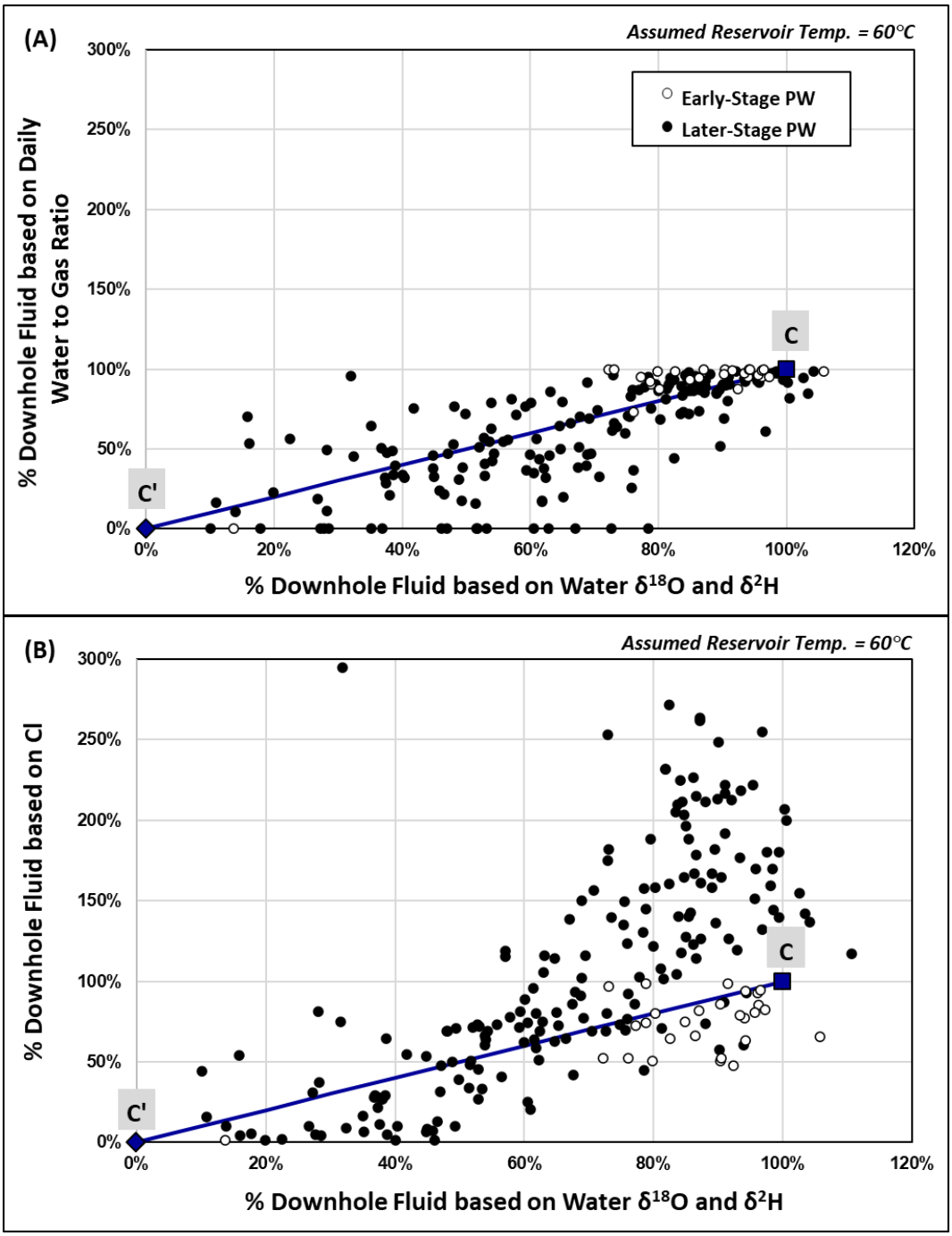


Exhibit S1. Temperature-dependence of estimated water content of natural gas and isotopic composition of water vapor end-member assuming downhole water $\delta^{18}O$ and $\delta^{2}H$ values of -0.9‰ and -39.9‰, respectively.

			Vapor End-member	
Reservoir Temp. (°C)	**bbls water/ 10^6 ft^3 gas**	**m^3 water/ 10^6 m^3 gas**	**$\delta^{18}O$ (‰ VSMOW)**	**$\delta^{2}H$ (‰ VSMOW)**
45	0.1	0.6	-8.8	-94.4
60	0.2	1.1	-7.8	-84.5
70	0.3	1.7	-6.7	-76.3

Notes:
1. Water content of natural gas at different reservoir temperatures is estimated using the chart for the water content of natural gases provided in McKetta and Wehe, 1958.
2. Isotopic composition of water vapor is calculated from the downhole water isotopic composition using the temperature-dependent equilibration fractionation factors provided in Majoube, 1971, and incorporated in Beaudoin and Therrien, 2021.

Figure S4. Differences in hypothetical mixing line A-A' (purple) based on a range of reservoir temperatures (45°C, 60°C, and 75°C), as compared to water $\delta^{2}H$ vs. $\delta^{18}O$ values for 230 produced water samples from Marcellus shale gas wells sampled once each in Susquehanna County.

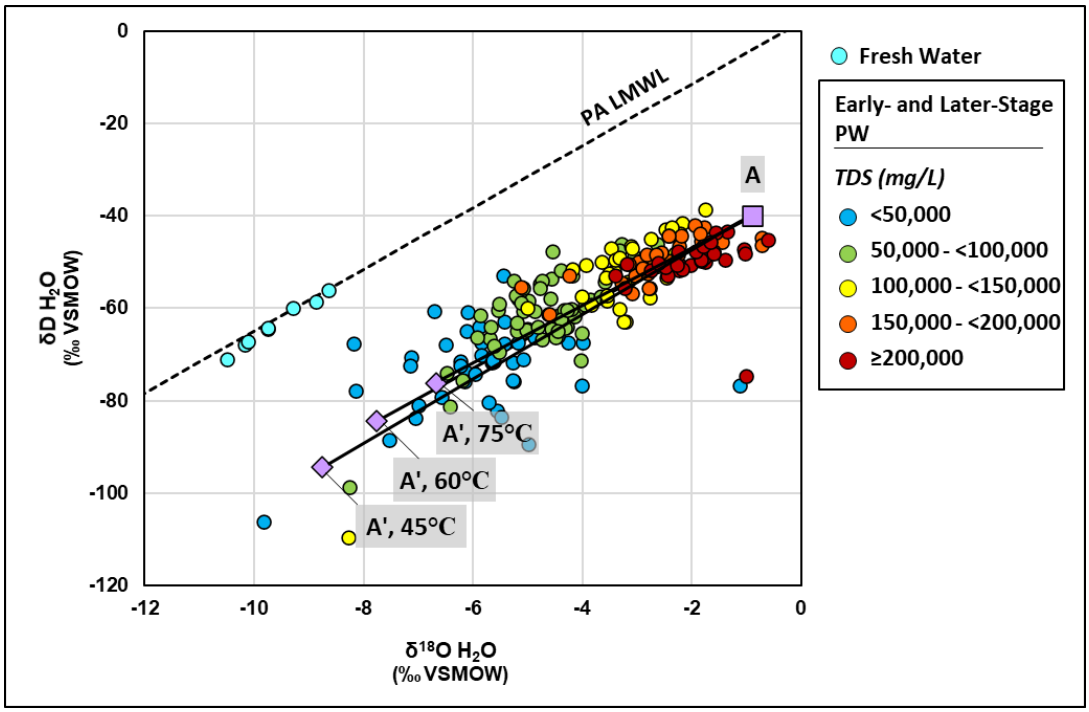


Figure S5. Estimated percentages of formation fluids based on A) the daily ratios of water-to-gas production and B) conservative Cl concentrations, versus the $\delta^{18}O$ and $\delta^{2}H$ composition of produced water using endmember mixing model A-A' with A' calculated assuming a reservoir temperature of 45°C. Values with negative proportions removed for plotting purposes. Due to variability in downhole fluid composition, in rare instances, the calculated percentage of downhole fluid based on the $\delta^{18}O$ and $\delta^{2}H$ composition and Cl concentration was greater than 100%.

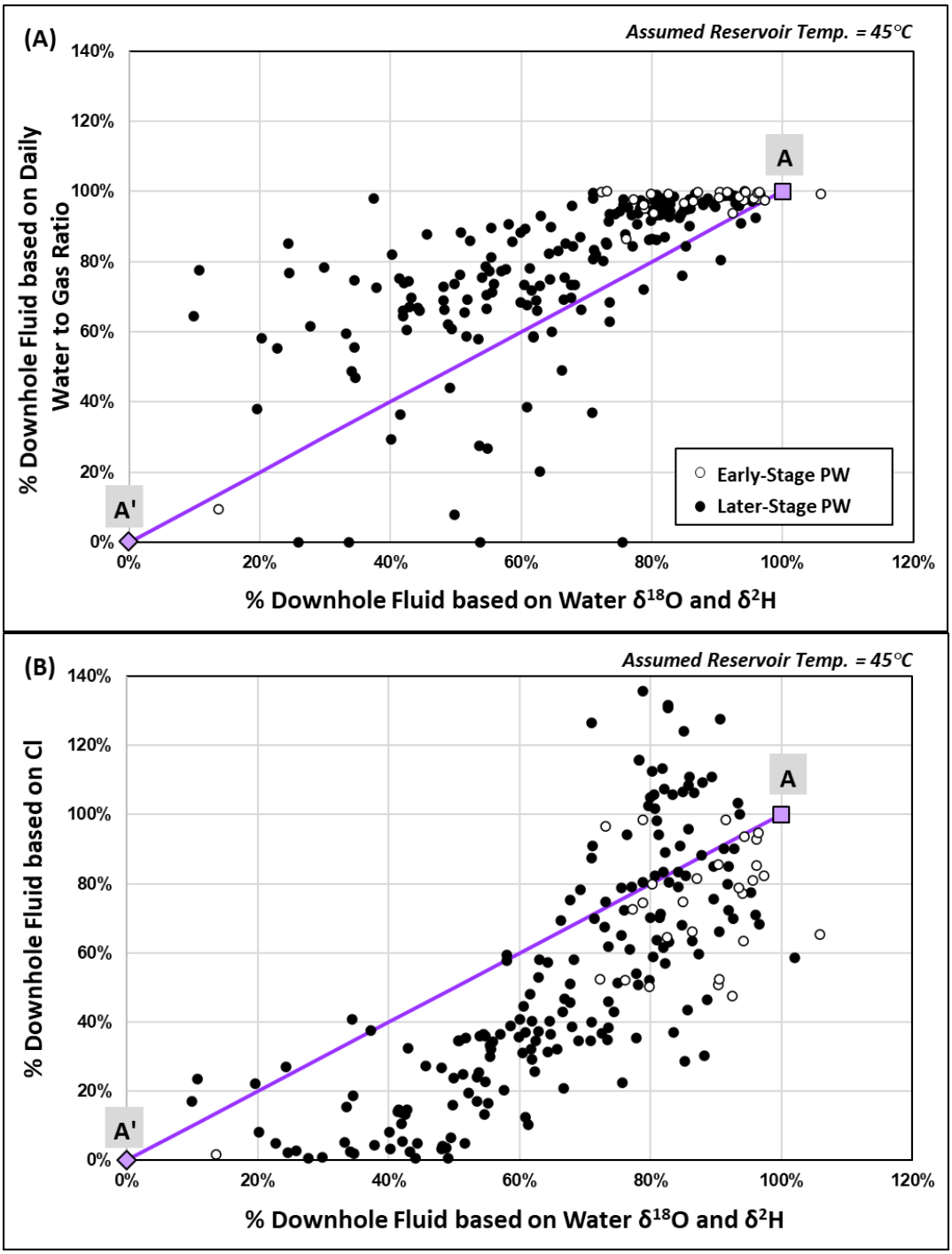
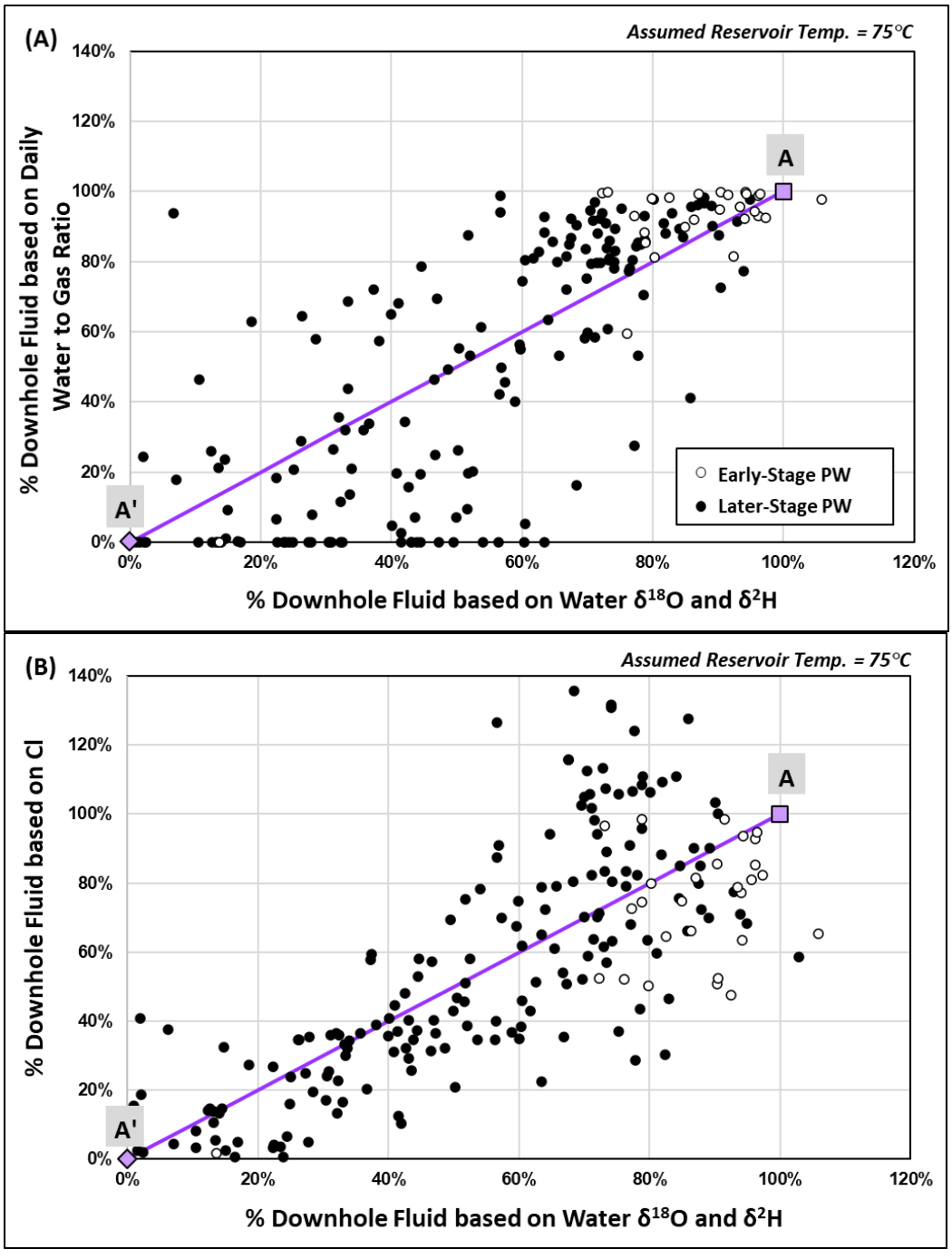


Figure S6. Estimated percentages of formation fluids based on A) the daily ratios of water-to-gas production and B) conservative Cl concentrations, versus the $\delta^{18}O$ and $\delta^{2}H$ composition of produced water using endmember mixing model A-A' with A' calculated assuming a reservoir temperature of 75°C. Values with negative proportions removed for plotting purposes. Due to variability in downhole fluid composition, in rare instances, the calculated percentage of downhole fluid based on the $\delta^{18}O$ and $\delta^{2}H$ composition and Cl concentration was greater than 100%.



References

Beaudoin, G., and Therrien, P., 2021, AlphaDelta Stable Isotope Fractionation Calculator, http://www2.ggl.ulaval.ca/cgi-bin/alphadelta/alphadelta_4alpha.cgi.

Majoube, M., 1971, Fractionnement en oxygene-18 et en deuterium entre l'eau et sa vapeur: Journal of Chemical Physics, p. 1423–1436, doi:10.1051/jcp/1971681423.

McKetta, J.J., and Wehe, A.H., 1958, Use this chart for the water content of natural gases: Petrol. Refine. (Hyd. Proc), v. 37.

Data tables:

Table S1. Chemical analyses of 230 produced water samples from Marcellus shale gas wells sampled once each

Table S2. Chemical analyses of Well A injection fluid and time-series produced water samples

Table S3. Chemical analyses of Well B injection fluid and time-series produced water samples

Table S4. Chemical analyses of Well C injection fluid and time-series produced water samples

Table S5. Chemical analyses of freshwater samples

Table S1. Chemical analyses of 230 produced water samples from Marcellus shale gas wells sampled once each

Well	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
			$bbl/10^6ft^3$	$m^3/10^6m^3$				
1V	9/22/2020	4393	0.0	0.0	-3.06	-48.8	44300	79700
2V	9/22/2020	4393	0.0	0.0	-1.76	-38.7	70400	122200
3V	9/22/2020	4084	0.0	0.0	-5.09	-60.6	38400	67200
4V	9/22/2020	4408	13.7	76.8	-2.18	-41.6	82000	139800
5V	12/14/2017	3373	0.0	0.0	-8.28	-109.6	63000	113800
6V	9/22/2020	4163	0.0	0.0	-3.11	-46.6	71500	119200
7	12/6/2017	2760	1.0	5.5	-8.51	-156.2	189000	307200
8V	12/19/2017	3156	0.0	0.0	-3.48	-47.1	76000	128100
9	12/6/2017	3029	0.0	0.0	-6.48	-74.0	44900	76500
10	11/29/2017	3158	0.2	0.9	-7.06	-83.7	26600	46100
11V	9/22/2020	4076	3.5	19.7	-1.77	-42.4	93000	163700
12V	9/22/2020	4180	0.0	0.0	-3.28	-46.1	36200	66600
13	12/12/2017	2867	0.1	0.6	-4.00	-67.4	19000	31900
14	12/14/2017	2915	0.0	0.0	-3.20	-62.9	71300	128400
15V	11/28/2017	2956	0.0	0.0	-1.44	-45.6	90700	155300
16	10/21/2020	3849	0.1	0.4	-1.13	-76.8	18400	32700
17V	11/29/2017	2976	4.9	27.4	-1.00	-74.7	177000	282500
18	12/6/2017	3004	0.5	3.0	-8.25	-98.6	44500	74500
19	12/13/2017	2858	0.4	2.5	-7.54	-88.6	28200	49200
20	11/21/2017	2754	0.2	1.3	-5.57	-82.2	5840	9600
21	11/29/2017	2864	0.3	1.8	-3.86	-58.1	51500	86800
22	11/29/2017	2805	0.4	2.0	-4.12	-60.8	57500	98800
23	11/21/2017	2773	0.4	2.3	-2.31	-48.2	81700	138100
24	11/21/2017	2734	0.3	1.6	-4.98	-89.4	20400	36800
25	12/19/2017	1842	0.2	1.0	-5.84	-67.5	785	1300
26	3/13/2019	3191	1.0	5.7	-3.33	-47.5	52200	87300
27	12/13/2017	1870	0.1	0.3	-5.20	-65.0	30400	51000
28	10/14/2020	3814	1.3	7.4	-1.95	-42.0	85200	150300
29	11/29/2017	2722	1.6	8.8	-2.91	-49.5	68400	121600
30	9/29/2020	3645	0.9	4.8	-5.87	-61.5	42900	75000
31	11/29/2017	2636	0.8	4.5	-5.53	-69.5	32700	55800
32	11/21/2017	2296	0.2	1.1	-3.56	-58.3	83200	142400
33	11/30/2017	2355	0.2	0.9	-5.28	-71.8	17500	28900
34	11/18/2017	2352	0.2	1.4	-4.88	-60.5	48200	84100
35	10/28/2020	3306	0.3	1.7	-5.85	-70.1	5860	10300
36	11/8/2018	2329	0.3	1.8	-3.59	-54.2	55200	95200
37	11/18/2017	2235	0.4	2.2	-3.84	-59.3	68600	120500
38	11/18/2017	2235	0.4	2.1	-3.56	-57.2	69600	123700
39	11/28/2017	2346	0.4	2.1	-4.44	-61.4	37300	62300
40	11/28/2017	2346	0.1	0.5	-2.46	-53.3	78100	135000

Note: V = Vertical wellbore

Table S1. Continued

Well	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
			$bbl/10^6ft^3$	$m^3/10^6m^3$				
41	11/21/2017	2472	0.8	4.6	-3.04	-53.0	86800	153800
42	11/18/2017	2516	0.3	1.9	-4.28	-64.1	38400	66400
43	11/21/2017	2381	1.5	8.3	-2.44	-50.1	113000	195900
44	11/21/2017	2472	0.8	4.3	-2.38	-49.7	100000	173900
45	9/30/2020	3193	1.1	6.0	-3.24	-62.9	69300	124700
46	11/21/2017	2504	2.3	13.0	-1.84	-45.5	102000	177600
47	9/29/2020	3020	0.3	1.9	-3.67	-57.5	54700	91300
48	12/14/2017	2215	0.3	1.8	-4.34	-60.4	30700	53600
49	12/5/2017	2395	0.2	1.3	-5.49	-83.6	9600	16300
50	11/21/2017	2272	1.1	6.2	-1.35	-43.4	120000	213400
51	9/23/2020	3334	1.5	8.2	-2.54	-50.3	76400	127700
52	12/12/2017	2319	1.0	5.3	-4.31	-64.2	36100	64100
53	3/13/2019	2303	0.5	2.8	-4.77	-54.6	43900	71800
54	11/20/2017	1825	0.4	2.0	-6.13	-73.7	5180	8500
55	11/30/2017	1835	0.3	1.5	-5.43	-67.7	4250	7400
56	9/29/2020	3160	0.8	4.7	-5.70	-66.6	41400	73800
57	10/29/2018	2305	0.2	1.4	-5.55	-60.4	35100	62500
58	10/29/2018	2305	0.2	1.1	-6.15	-75.8	2810	5000
59	10/23/2018	2226	0.5	2.6	-6.70	-60.6	12300	22700
60	10/23/2018	2226	0.3	1.8	-8.19	-67.7	3790	6600
61	11/28/2017	1744	0.4	2.1	-2.76	-57.6	90200	148500
62	9/21/2020	3163	22.6	126.6	-5.12	-55.4	105000	168200
63	11/28/2017	2073	0.7	4.2	-2.61	-50.8	84300	139700
64	11/21/2017	2132	4.2	23.4	-4.24	-53.0	94700	160000
65	10/23/2018	2226	0.6	3.3	-4.98	-58.4	38500	68800
66	10/23/2018	2226	1.2	6.6	-5.25	-54.1	41900	75700
67	12/13/2017	2119	0.2	1.3	-5.25	-75.7	22300	37600
68	11/9/2020	2897	2.5	14.2	-5.45	-52.8	26900	47900
69	10/22/2018	2148	0.3	1.7	-4.24	-61.2	44400	78100
70	9/23/2020	3079	1.5	8.1	-2.65	-50.6	70500	126200
71	9/23/2020	3079	0.3	1.5	-6.58	-79.3	686	1200
72	10/12/2020	2865	0.8	4.3	-5.14	-56.5	41500	73900
73	10/22/2018	2144	0.1	0.8	-4.01	-65.3	29000	51800
74	10/22/2018	2144	0.2	1.4	-4.87	-66.2	5850	10100
75	10/14/2020	2756	1.4	7.9	-5.01	-59.9	69700	117200
76	11/20/2017	1880	0.3	1.7	-3.09	-56.7	93900	163300
77	11/20/2017	1880	3.3	18.5	-1.75	-49.9	136000	236100
78	11/20/2017	1880	1.5	8.3	-1.40	-49.5	157000	263200
79	9/21/2020	2916	10.1	56.9	-3.18	-50.3	122000	204500
80	12/13/2017	1712	0.5	3.0	-5.67	-64.0	39700	66600

Table S1. Continued

Well	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
			$bbl/10^6ft^3$	$m^3/10^6m^3$				
81	10/12/2020	3003	0.2	1.1	-5.28	-75.6	2380	4300
82	11/21/2017	1950	0.3	1.8	-4.14	-61.7	48800	88100
83	9/14/2020	2630	0.7	3.9	-4.39	-62.4	46800	83200
84	11/30/2017	1669	1.2	6.8	-2.20	-50.9	126000	207200
85	10/29/2018	1944	0.5	2.5	-5.42	-62.8	24400	46800
86	11/20/2017	1806	0.2	1.4	-4.02	-76.6	6050	10500
87	11/20/2017	1806	0.4	2.2	-5.09	-71.1	17400	30400
88	12/13/2017	1876	0.1	0.8	-4.57	-64.5	43100	72000
89	9/28/2020	2716	0.7	3.8	-4.58	-57.8	55900	96600
90	12/13/2017	1884	0.3	1.7	-4.03	-71.2	38800	67700
91	12/13/2017	465	0.5	2.6	-5.02	-64.6	43700	73400
92	10/14/2020	2770	0.4	2.1	-4.26	-67.3	28600	49000
93	11/30/2017	1673	0.6	3.3	-2.78	-55.7	109000	181300
94	11/8/2018	2088	0.1	0.7	-4.21	-60.1	44800	80600
95	11/28/2017	1510	0.3	1.9	-5.18	-64.5	16000	28000
96	12/13/2017	1626	0.3	1.8	-4.49	-66.2	42600	72900
97	9/7/2017	1490	0.4	2.4	-4.74	-66.8	41400	68500
98	10/28/2020	2637	0.4	2.4	-6.99	-81.0	2610	4600
99	10/12/2020	2621	1.1	6.0	-3.41	-51.9	64700	112800
100	9/7/2017	1490	0.5	2.9	-2.75	-44.9	79400	129200
101	12/12/2017	1499	0.3	1.6	-4.28	-60.3	41400	69200
102	12/21/2017	1672	0.7	3.8	-6.42	-81.2	32300	53600
103	12/12/2017	1499	4.8	26.9	-2.97	-49.9	85500	155400
104	11/29/2017	1642	2.4	13.4	-4.02	-57.4	61300	105100
105	12/12/2017	1295	13.2	74.1	-1.04	-47.3	127450	227700
106	12/21/2017	1672	1.9	10.4	-3.40	-49.6	73800	128100
107	12/12/2017	1492	0.3	1.4	-5.18	-67.4	7900	13100
108	12/7/2017	1471	0.1	0.3	-5.71	-80.4	3150	5400
109	12/20/2017	1518	0.6	3.1	-2.76	-55.5	83900	146400
110	12/20/2017	1518	0.6	3.6	-2.80	-52.4	94950	163900
111	12/20/2017	1518	0.4	2.1	-3.33	-60.2	63400	110400
112	9/21/2020	2547	2.2	12.5	-2.23	-51.8	139000	248800
113	9/30/2020	2322	3.6	20.2	-2.02	-50.6	127000	210200
114	11/28/2017	1410	0.4	2.3	-4.45	-65.0	43000	72500
115	12/21/2017	1369	1.5	8.5	-3.17	-54.3	74200	126100
116	10/28/2020	2412	11.3	63.2	-2.43	-44.3	95700	163700
117	11/28/2017	1116	0.3	1.7	-5.64	-70.3	775	1400
118	11/28/2017	1116	0.4	2.1	-5.62	-71.4	6550	11200
119	9/21/2020	2473	3.1	17.2	-2.17	-51.5	163000	271100
120	10/14/2020	2166	0.4	2.5	-5.19	-63.2	43800	77000

Table S1. Continued

Well	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
			$bbl/10^6ft^3$	$m^3/10^6m^3$				
121	9/30/2020	2322	2.1	11.8	-2.45	-52.8	113000	201100
122	11/20/2017	1249	2.0	11.5	-1.02	-48.2	149000	247000
123	11/20/2017	1249	1.5	8.5	-1.83	-49.7	129000	227300
124	12/20/2017	1319	0.7	4.0	-2.49	-51.0	122959	204900
125	10/6/2020	1945	1.5	8.3	-3.52	-52.4	73100	125400
126	10/28/2020	1554	0.3	1.6	-6.24	-71.4	16700	31000
127	9/30/2020	2122	0.2	1.3	-6.12	-65.0	20400	35200
128	9/23/2020	2261	1.0	5.5	-3.95	-59.2	48400	90200
129	12/7/2017	1240	0.3	1.7	-5.01	-64.5	27100	45800
130	10/14/2020	2165	0.7	4.0	-4.45	-66.0	23300	38900
131	12/12/2017	908	0.7	3.9	-3.23	-54.6	80900	133000
132	9/29/2020	2283	3.8	21.4	-3.65	-49.9	84200	141600
133	9/30/2020	1886	6.2	34.7	-1.78	-49.0	127000	204800
134	9/30/2020	2127	3.8	21.4	-2.75	-51.7	139000	228000
135	9/23/2020	2104	0.4	2.2	-6.20	-75.6	48800	85200
136	3/13/2019	1544	0.6	3.6	-4.54	-47.6	34400	57300
137	11/29/2017	946	0.7	3.7	-3.29	-54.5	89800	153400
138	11/29/2017	635	2.2	12.1	-1.60	-47.7	130000	208200
139	11/29/2017	635	3.0	17.0	-1.85	-43.8	108000	186300
140	11/29/2017	635	2.4	13.5	-1.57	-43.5	124000	211500
141	9/30/2020	1668	5.6	31.2	-2.28	-50.7	135000	225000
142	11/29/2017	632	1.9	10.7	-1.60	-48.2	128000	212200
143	9/29/2020	2040	1.4	7.6	-1.84	-49.4	158000	264600
144	12/21/2017	316	0.4	2.1	-5.62	-68.1	32100	56600
145	12/12/2017	1028	0.6	3.1	-6.23	-72.4	4020	7400
146	3/13/2019	1483	0.4	2.3	-5.65	-71.8	16800	27800
147	9/23/2020	2044	0.3	1.6	-9.83	-106.2	2480	4200
148	10/28/2020	1885	7.0	39.4	-0.61	-45.2	153000	250500
149	10/14/2020	1768	7.5	42.2	-2.22	-44.6	108000	182500
150	11/30/2017	865	2.1	11.6	-1.93	-47.6	133000	222800
151	9/30/2020	1900	5.0	27.9	-3.23	-55.7	152000	252100
152	10/14/2020	1933	0.2	0.9	-6.10	-60.9	15000	24700
153	11/20/2017	363	0.3	1.6	-5.63	-71.5	12800	20600
154	11/20/2017	363	0.3	1.4	-5.63	-71.2	16000	27500
155	11/20/2017	363	0.4	2.1	-4.82	-63.9	41300	71500
156	11/29/2017	388	2.1	12.0	-2.75	-49.5	107000	173600
157	11/29/2017	388	2.0	11.0	-2.55	-47.8	98700	173100
158	11/29/2017	388	2.8	15.6	-2.72	-49.2	96500	164700
159	9/16/2020	1587	4.2	23.5	-2.26	-47.6	115000	209400
160	11/29/2017	388	2.5	14.0	-2.31	-50.3	118000	198100

Table S1. Continued

Well	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
			$bbl/10^6ft^3$	$m^3/10^6m^3$				
161	11/28/2017	96	0.0	0.0	-3.95	-48.4	50700	86400
162	11/28/2017	96	1.6	9.0	-4.05	-47.6	47600	81300
163	11/29/2017	388	3.3	18.7	-2.24	-46.5	106000	184900
164	11/30/2017	326	1.3	7.4	-2.83	-48.4	94800	158800
165	12/20/2017	126	4.3	23.9	-3.18	-46.3	85250	142400
166	12/20/2017	126	5.2	29.1	-3.30	-46.5	80900	134500
167	11/21/2017	394	2.5	14.2	-1.79	-46.5	131000	226600
168	11/21/2017	394	2.8	15.7	-1.65	-45.7	133000	228900
169	11/21/2017	394	0.4	2.0	-2.91	-51.4	96400	162100
170	12/21/2017	27	26.2	146.9	-2.83	-46.4	92900	157600
171	12/20/2017	69	3.9	21.7	-3.38	-47.1	77150	131600
172	12/20/2017	69	7.0	39.4	-3.64	-47.3	78900	132200
173	12/4/2017	131	1.6	9.0	-3.83	-52.3	79900	133600
174	12/20/2017	418	1.4	7.7	-2.66	-48.4	100000	174700
175	12/20/2017	418	0.7	4.0	-3.15	-50.3	98800	164300
176	11/20/2017	254	0.3	1.6	-5.92	-66.2	29900	52100
177	11/20/2017	239	0.4	2.3	-5.18	-57.8	25100	42900
178	9/16/2020	131	2.1	11.5	-3.44	-52.9	98500	168900
179	12/12/2017	196	0.6	3.6	-5.21	-57.1	46250	85700
180	12/12/2017	189	1.6	8.8	-4.57	-53.6	51400	94000
181	9/30/2020	804	0.9	5.3	-4.62	-61.3	53400	95700
182	10/23/2018	198	0.3	1.5	-4.73	-54.1	45900	81600
183	10/23/2018	198	0.6	3.1	-5.53	-59.1	37600	69700
184	10/23/2018	198	0.2	0.9	-5.09	-55.5	41400	71800
185	10/23/2018	198	0.5	2.9	-4.78	-55.5	48000	86300
186	10/23/2018	198	0.2	1.4	-5.12	-58.9	43600	78300
187	10/22/2018	43	13.4	75.1	-3.32	-42.6	65400	119200
188	10/15/2018	56	2.6	14.5	-4.16	-52.8	74500	130700
189	10/15/2018	56	3.7	20.5	-4.09	-49.9	66000	117600
190	10/15/2018	56	4.2	23.8	-4.66	-53.3	72600	124200
191	3/13/2019	185	1.8	9.8	-3.32	-49.1	75800	122500
192	10/23/2018	198	1.8	10.2	-3.93	-50.7	62600	111200
193	10/12/2020	918	7.3	41.1	-2.21	-43.8	83900	149300
194	10/23/2018	198	2.0	11.1	-4.19	-51.6	61000	109400
195	9/28/2020	759	0.4	2.5	-5.89	-64.1	19900	34600
196	10/21/2020	733	1.5	8.6	-2.25	-48.3	109000	183200
197	10/5/2020	428	8.7	48.6	-2.19	-44.2	86700	153400
198	9/14/2020	628	1.7	9.8	-3.58	-53.4	61600	106500
199	9/10/2020	768	4.9	27.3	-2.64	-46.0	55800	99400
200	9/23/2020	267	0.3	1.7	-6.50	-67.9	5020	8700

Table S1. Continued

Well	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
			$bbl/10^6ft^3$	$m^3/10^6m^3$				
201	5/2/2019	5	68.0	381.7	-5.32	-55.1	52400	91500
202	7/25/2019	7	115.0	645.0	-3.75	-48.4	52400	91700
203	7/25/2019	7	16.7	93.8	-4.48	-51.3	64400	109700
204	7/25/2019	7	305.9	1716.1	-3.59	-47.0	63300	107700
205	7/19/2019	67	30.7	172.2	-3.15	-48.1	98400	179100
206	12/18/2019	116	36.1	202.3	-3.16	-46.2	94600	161600
207	12/18/2019	116	40.5	227.5	-3.34	-47.0	93700	156900
208	10/14/2020	417	17.3	97.2	-2.42	-44.2	102000	177000
209	11/18/2020	495	0.3	1.9	-7.13	-70.6	2890	5000
210	11/18/2020	495	0.5	2.6	-8.14	-77.9	1130	2000
211	11/18/2020	495	0.1	0.8	-7.15	-72.3	9760	16500
212	9/10/2020	426	1.6	9.1	-4.40	-51.7	42500	73500
213	11/19/2020	496	1.4	7.7	-4.19	-53.0	49800	90200
214	11/19/2020	496	2.9	16.2	-3.10	-46.9	59200	103900
215	10/28/2020	108	0.1	0.6	-7.02	-77.1	1610	2800
216	10/12/2020	92	5.9	33.0	-3.26	-48.6	85600	147100
217	7/30/2020	18	13.9	77.8	-5.01	-52.5	50300	89000
218	7/30/2020	18	44.6	250.0	-3.74	-49.8	81600	141800
219	11/19/2020	496	5.7	32.0	-2.49	-42.9	67300	114700
220	10/12/2020	351	0.3	1.8	-5.97	-74.2	1160	2200
221	10/12/2020	351	7.7	43.2	-2.37	-42.5	76700	130100
222	12/18/2019	116	4.0	22.7	-3.65	-46.0	82200	133700
223	12/18/2019	116	3.0	16.6	-4.25	-50.6	74800	125100
224	2/17/2020	12	162.6	912.4	-4.99	-55.0	96600	159000
225	9/21/2020	229	0.4	2.5	-4.60	-61.3	96400	164600
226	9/16/2020	206	16.5	92.8	-2.61	-50.2	137000	241200
227	9/16/2020	206	1.7	9.3	-3.39	-53.0	118000	214300
228	9/30/2020	73	0.7	4.1	-4.48	-53.9	52100	92300
229	12/7/2017	1541	25.9	145.1	-0.72	-44.8	120000	192300
230	9/23/2020	2562	115.8	649.8	-0.72	-46.2	118000	186000

Table S2. Chemical analyses of Well A injection fluid and time-series produced water samples

Well	Matrix	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
				$bbl/10^6ft^3$	$m^3/10^6m^3$				
A	Injection Fluid	5/7/2019	--	--	--	-7.67	-57.3	17400	30000
A	Produced Water	7/12/2019	0	57.1	320.1	-5.32	-48.8	19600	33500
A	Produced Water	7/13/2019	1	53.5	300.3	-5.17	-49.1	22300	38600
A	Produced Water	7/13/2019	1	53.5	300.3	-4.85	-47.9	23300	40200
A	Produced Water	7/14/2019	2	50.7	284.6	-4.84	-48.7	24200	42000
A	Produced Water	7/14/2019	2	50.7	284.6	-4.80	-47.5	22900	40300
A	Produced Water	7/15/2019	3	48.2	270.2	-4.67	-47.2	26600	45200
A	Produced Water	7/16/2019	4	46.1	258.4	-4.77	-47.8	26100	44800
A	Produced Water	7/17/2019	5	44.2	248.2	-4.58	-48.1	26800	46900
A	Produced Water	7/18/2019	6	42.5	238.6	-4.56	-46.8	27500	48700
A	Produced Water	7/19/2019	7	40.9	229.7	-4.42	-46.3	28400	49200
A	Produced Water	7/20/2019	8	39.6	222.4	-4.45	-46.1	28700	49200
A	Produced Water	7/22/2019	10	31.9	179.0	-4.67	-47.9	29700	51000
A	Produced Water	7/24/2019	12	26.1	146.3	-4.18	-46.8	29900	52500
A	Produced Water	7/26/2019	14	22.2	124.6	-4.24	-46.7	30000	52600
A	Produced Water	7/28/2019	16	19.7	110.4	-4.25	-45.9	30000	54600
A	Produced Water	7/30/2019	18	17.7	99.4	-4.24	-47.9	30700	53500
A	Produced Water	8/8/2019	27	12.8	71.5	-4.05	-45.9	36000	62900
A	Produced Water	8/15/2019	34	11.6	65.1	-3.93	-46.1	37900	66100
A	Produced Water	8/22/2019	41	10.6	59.6	-4.02	-45.5	37600	65400
A	Produced Water	8/22/2019	41	10.6	59.6	-3.95	-46.5	38500	63800
A	Produced Water	8/29/2019	48	10.0	55.9	-3.90	-45.9	39800	63900
A	Produced Water	9/5/2019	55	9.5	53.6	-3.84	-46.4	40600	71100
A	Produced Water	9/12/2019	62	9.2	51.5	-3.74	-44.8	42000	71600
A	Produced Water	10/9/2019	89	8.0	45.1	-3.51	-45.2	46800	78300
A	Produced Water	9/9/2020	425	6.8	38.3	-2.85	-44.8	56900	98900
A	Produced Water	11/19/2020	496	5.8	32.4	-2.79	-43.5	65900	115400

Table S3. Chemical analyses of Well B injection fluid and time-series produced water samples

Well	Matrix	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
				$bbl/10^6ft^3$	$m^3/10^6m^3$				
B	Injection Fluid	5/2/2019	--	--	--	-8.33	-58.7	9670	16000
B	Produced Water	7/12/2019	0	99.9	560.7	-6.84	-55.2	13700	24100
B	Produced Water	7/13/2019	1	93.1	522.5	-6.45	-53.3	14000	24600
B	Produced Water	7/13/2019	1	93.1	522.5	-6.46	-53.2	15200	25300
B	Produced Water	7/14/2019	2	87.1	488.4	-6.39	-51.8	15700	27300
B	Produced Water	7/14/2019	2	87.1	488.4	-6.30	-52.7	17000	29300
B	Produced Water	7/15/2019	3	81.0	454.5	-6.39	-52.6	16600	28300
B	Produced Water	7/16/2019	4	75.8	425.2	-6.21	-52.7	18700	31100
B	Produced Water	7/17/2019	5	71.5	401.1	-6.20	-52.3	18100	31400
B	Produced Water	7/18/2019	6	67.5	378.8	-6.34	-53.3	18800	32700
B	Produced Water	7/20/2019	8	60.3	338.4	-5.92	-51.5	21200	36500
B	Produced Water	7/22/2019	10	49.0	275.0	-5.76	-49.9	23100	40500
B	Produced Water	7/24/2019	12	38.1	213.6	-5.62	-50.0	24500	42300
B	Produced Water	7/26/2019	14	29.4	165.0	-5.62	-51.2	25400	43200
B	Produced Water	7/28/2019	16	21.6	121.4	-5.24	-49.9	25100	45000
B	Produced Water	7/30/2019	18	17.0	95.3	-5.37	-50.5	26100	46400
B	Produced Water	8/1/2019	20	13.9	78.0	-5.42	-51.8	30100	50700
B	Produced Water	8/8/2019	27	9.5	53.2	-5.23	-49.8	29200	51500
B	Produced Water	8/15/2019	34	7.3	40.7	-5.16	-50.0	31600	55100
B	Produced Water	8/22/2019	41	5.8	32.7	-5.04	-49.1	33100	56200
B	Produced Water	8/29/2019	48	4.9	27.3	-4.92	-49.4	35400	60200
B	Produced Water	9/5/2019	55	4.1	23.2	-4.83	-48.8	35600	61500
B	Produced Water	9/12/2019	62	3.6	20.4	-4.87	-49.3	36300	62000
B	Produced Water	10/9/2019	89	2.6	14.7	-4.79	-50.3	36800	63600
B	Produced Water	9/9/2020	425	1.4	8.1	-4.90	-56.3	40800	68400
B	Produced Water	11/18/2020	495	1.1	6.1	-4.71	-54.6	42700	75900

Table S4. Chemical analyses of Well C injection fluid and time-series produced water samples

Well	Matrix	Sample Date	Days Producing	Daily Water/Gas 15 Day Moving Avg.		$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
				$bbl/10^6ft^3$	$m^3/10^6m^3$				
C	Injection fluid	5/17/2019	--	--	--	-8.84	-63.3	7760	13200
C	Produced water	7/13/2019	1	38.6	216.7	-6.24	-54.1	19200	34600
C	Produced water	7/13/2019	1	38.6	216.7	-6.14	-52.7	18500	33600
C	Produced water	7/13/2019	1	38.6	216.7	-6.46	-53.4	19000	33800
C	Produced water	7/14/2019	2	35.9	201.3	-6.18	-53.2	19100	33700
C	Produced water	7/14/2019	2	35.9	201.3	-6.16	-52.5	20200	35400
C	Produced water	7/15/2019	3	33.5	187.9	-6.01	-52.6	19700	33900
C	Produced water	7/15/2019	3	33.5	187.9	-6.16	-52.3	20000	35000
C	Produced water	7/16/2019	4	31.7	177.7	-6.06	-52.9	20300	35700
C	Produced water	7/17/2019	5	30.1	169.1	-6.04	-51.3	21000	37000
C	Produced water	7/18/2019	6	28.7	161.0	-6.16	-52.3	20200	35400
C	Produced water	7/19/2019	7	27.4	153.6	-6.06	-51.3	21600	37500
C	Produced water	7/20/2019	8	26.3	147.3	-6.04	-51.5	21600	37600
C	Produced water	7/22/2019	10	21.4	120.0	-5.85	-50.9	22100	38500
C	Produced water	7/24/2019	12	16.8	94.3	-5.86	-52.0	22100	38800
C	Produced water	7/26/2019	14	14.2	79.6	-4.81	-49.8	22100	39000
C	Produced water	7/28/2019	16	11.9	67.0	-5.81	-51.0	23800	40300
C	Produced water	8/8/2019	27	6.1	34.3	-5.58	-50.3	23100	40600
C	Produced water	8/15/2019	34	4.7	26.5	-5.60	-50.5	23400	41200
C	Produced water	8/22/2019	41	3.5	19.8	-5.53	-50.3	23800	41200
C	Produced water	8/29/2019	48	2.8	15.5	-5.58	-51.1	23500	41100
C	Produced water	9/5/2019	55	2.2	12.6	-5.59	-52.1	23000	40700
C	Produced water	9/12/2019	62	1.8	10.3	-5.63	-52.8	22800	39700
C	Produced water	10/9/2019	89	1.1	6.2	-5.91	-54.1	20900	37000
C	Produced water	9/9/2020	425	0.4	2.5	-7.77	-73.5	2070	3700
C	Produced water	11/18/2020	495	0.4	2.5	-7.56	-74.0	716	1400

Table S5. Chemical analyses of freshwater samples

Source	Sample Date	$\delta^{18}O$ (‰ VSMOW)	$\delta^{2}H$ (‰ VSMOW)	Chloride (mg/L)	TDS (mg/L)
1	6/6/2019	-8.88	-58.6	12	50
2	6/6/2019	-8.65	-56.1	7	49
3	3/14/2019	-9.30	-59.9	11	44
4	3/14/2019	-10.17	-67.9	18	69
5	3/14/2019	-10.49	-71.1	30	126
6	3/14/2019	-9.76	-64.5	22	76
7	3/14/2019	-10.12	-67.1	17	66
8	3/14/2019	-9.75	-64.2	25	79