APPENDIX A

MONITORING SITE LOCATIONS

Table A1. Surface water site locations

Gwic Id	Site Name	Latitude	Longitude (NAD 83)	Ground Surface Altitude *	Township Range Section	Quarter Section	Site Type	River Miles
Musselshell River Monitoring Sites								
309280	MUSSELSHELL R. X ROUNDUP FAIRGROUND-W. BRIDGE	46.43930	-108.53662	3186	08N 25E 24	ABB	STREAM	0
309281	MUSSELSHELL R. X NO. 4 ROAD BRIDGE	46.44648	-108.51243	3170	08N 26E 18	DBA	STREAM	2
309282	MUSSELSHELL R. X E. PARROT CR. ROAD BRIDGE	46.47138	-108.39232	3118	08N 27E 7	ABB	STREAM	14
309283	MUSSELSHELL R. X GOFFENA ROAD OLD BRIDGE	46.49152	-108.28757	3077	09N 27E 35	DCC	STREAM	23
304661	MUSSELSHELL R. X DELPHIA RD BRIDGE	46.50854	-108.21590	3048.46	09N 28E 28	CCC	STREAM	30
304662	MUSSELSHELL R. X S. MUSSELSHELL RD BRIDGE	46.52015	-108.09153	2998.96	09N 29E 28	BBC	STREAM	40
304663	MUSSELSHELL R. X QUEENS PT. ROAD BRIDGE	46.55881	-107.97749	2947.72	09N 30E 8	CAA	STREAM	51
304664	MUSSELSHELL R. X HARVEY ROAD BRIDGE	46.57085	-107.90086	2906.56	09N 30E 1	CCB	STREAM	59
304665	MUSSELSSHELL R. X MELSTONE - CUSTER RD BRIDGE	46.58193	-107.85810	2883.63	09N 31E 5	BBB	STREAM	64
304666	MUSSELSHELL R. X BRIDGE ROAD BRIDGE	46.71993	-107.82223	2761.61	11N 31E 16	ACC	STREAM	82
Canal, Reservoir, and Stream Monitoring Sites								
307593	DELPHIA-MELSTONE CANAL * DELPHIA CANAL	46.50956	-108.18897	3040.40	09N 28E 27	CDA	CANAL	
304690	DELPHIA-MELSTONE CANAL *MELSTONE CANAL	46.58772	-107.79983	2946.86	10N 31E 34	DAC	CANAL	
308447	FEEDER CANAL OF THE D-M CANAL AT DELPHIA	46.50877	-108.18964	3039.01	09N 28E 27	CDB	CANAL	
305267	HORSE CREEK * AT ADAMS ROAD CULVERT	46.58832	-107.79677	2914.60	10N 31E 34	DAA	STREAM	
305268	ADAMS, RAYMOND * HORSE CREEK COULEE RESERVOIR POND	46.59213	-107.79793	2906.39	10N 31E 34	ADA	RESERVOIR	
310296	DEADMAN BASIN RES. OUTLET **	46.33955	-109.40767	3884	07N 18E 25	ADB	RESERVOIR	

* Elevations reported to the nearest foot were determined using digital elevation maps. Elevations reported to the nearest 0.01 foot were determined by Survey GPS.

** All sites are in Musselshell County with the exception of Deadmans Basin (310296) which is in Wheatland County

Table A2. Groundwater monitoring well site locations

Gwic Id	Site Name	Latitude	Longitude (NAD 83)	Ground Surface Altitude	Township Range Section	Quarter Section	Site Type	Aquifer	Total Depth (ft)
Groundwater Monitoring Wells* **									
Melstone Focus Area Wells									
301883	MBMG ACU * FIELD A CANAL UPPER	46.58636	-107.79833	2951.47	10N 31E 34	DA	WELL	Fox Hills/Bearpaw	45
301861	MBMG ACLD * FIELD A CANAL LOWER DEEP	46.58799	-107.79967	2939.77	10N 31E 34	DA	WELL	Bearpaw	160
301868	MBMG ACLM * FIELD A CANAL LOWER MIDDLE	46.58794	-107.79964	2940.45	10N 31E 34	DA	WELL	Fox Hills/Bearpaw	39
301866	MBMG ACLS * FIELD A CANAL LOWER SHALLOW	46.58794	-107.79970	2941.33	10N 31E 34	DA	WELL	Fox Hills/Bearpaw	22
303593	MBMG BCL * FIELD B CANAL LOWER	46.58595	-107.83003	2950.94	10N 31E 33	CD	WELL	Fox Hills/Bearpaw	27
303537	MBMG BCU * FIELD B CANAL UPPER	46.58609	-107.82907	2958.30	10N 31E 33	CD	WELL	Fox Hills/Bearpaw	30
303539	MBMG CCL * FIELD C CANAL LOWER	46.58002	-107.83868	2957.32	09N 31E 5	AA	WELL	Fox Hills	29
303538	MBMG CCU * FIELD C CANAL UPPER	46.57951	-107.83852	2960.04	09N 31E 5	AA	WELL	Fox Hills	30
303621	MBMG MRD * MELSTONE RIVER DEEP	46.58381	-107.85624	2868.64	10N 31E 32	CC	WELL	Bearpaw	30
303622	MBMG MRS * MELSTONE RIVER SHALLOW	46.58381	-107.85617	2868.21	10N 31E 32	CC	WELL	Alluvium	15
303623	MBMG MUD * MELSTONE UPPER DEEP	46.58314	-107.82922	2966.73	10N 31E 33	CD	WELL	Fox Hills/Bearpaw	60
Delphia Focus Area Wells									
303536	MBMG DUD * DELPHIA UPPER DEEP	46.51412	-108.19217	3073.68	09N 28E 27	CB	WELL	Fort Union	108
303465	MBMG DCD * DELPHIA CANAL DEEP	46.50958	-108.18846	3038.28	09N 28E 27	CD	WELL	Fort Union	50
303471	MBMG DCS * DELPHIA CANAL SHALLOW	46.50956	-108.18849	3038.01	09N 28E 27	CD	WELL	Alluvium	21
303461	MBMG DRD * DELPHIA RIVER DEEP	46.50421	-108.18555	3029.93	09N 28E 24	AB	WELL	Fort Union	50
303456	MBMG DRS * DELPHIA RIVER SHALLOW	46.50427	-108.18556	3030.31	09N 28E 34	AB	WELL	Alluvium	18
Melstone Field A nearby monitoring wells (not included the interpretation presented in this report)									
301884	MBMG FENCE1	46.58951	-107.80039	2926.95	10N 31E 34	AD	WELL	Fox Hills/Bearpaw	35
301891	MBMG FENCE2	46.58947	-107.79944	2924.43	10N 31E 34	AD	WELL	Fox Hills/Bearpaw	30
301859	MBMG POND1	46.59150	-107.79783	2913.29	10N 31E 34	AD	WELL	Alluvium	21
301892	MBMG POND2	46.59146	-107.79778	2913.31	10N 31E 34	AD	WELL	Alluvium	21

*** Monitoring wells were installed in June, September and October of 2019.

APPENDIX B

MUSSELSHELL RIVER FLOW RATES

Table B1. Musselshell River Flow Rates

GWIC ID	Bridge Name	River miles	Date	time	Flow rate (CFS)	Standard Deviation	%StdDev/ Ave	Method*	Notes
304661	Delphia Rd.	30	9/10/2020	12:15	191.18	2.52	1.32	ADCP	
304662	Musselshell Rd.	40	9/10/2020	13:19	202.41	6.26	3.09	ADCP	
304665	Melstone-Custer Rd.	64	9/10/2020	14:47	144.69	7.34	5.07	ADCP	
304666	Bridge Rd.	82	9/10/2020	16:26	151.01	4.45	2.95	ADCP	
309280	Roundup Fairground	0	11/20/2020	10:30	75.55	4.03	5.34	ADCP	
309282	Parrot Rd	14	11/20/2020	11:30	80.71	3.91	4.84	ADCP	
309283	Goeffina Rd.	23	11/20/2020	12:43	78.80	4.23	5.36	ADCP	
304661	Delphia Rd.	30	11/20/2020	13:43	81.43	2.86	3.52	ADCP	
304662	Musselshell Rd.	40	11/20/2020	14:30	89.13	2.49	2.79	ADCP	
304662	Musselshell Rd.	40	11/19/2020	11:10	97.99	3.49	3.56	ADCP	
304663	Queens Rd.	51	11/19/2020	12:09	93.80	3.09	3.29	ADCP	Oxbow tributary estimated <30 gpm
304664	Harvey Rd.	59	11/19/2020	12:50	94.53	4.28	4.53	ADCP	Oxbow tributary estimated <30 gpm
304665	Melstone-Custer Rd.	64	11/19/2020	13:35	92.95	5.45	5.87	ADCP	
311712	Melstone Hwy 12 Br.	70	11/19/2020	15:33	92.85	4.12	4.44	ADCP	
309280	Roundup Fairground	0	8/17/2021	9:10	29.30	2.14	7.31	ADCP	USGS gage 35 falling to 30 cfs
304661	Delphia Rd.	30	8/17/2021	10:54	21.52	0.85	3.97	ADCP	Delphia canal is dry
304662	Musselshell Rd.	40	8/17/2021	11:54	22.79	1.06	4.66	ADCP	USGS gage 21 cfs
304663	Queens Rd.	51	8/17/2021	16:00	5.8			Swoffer	Irrigation pump in river is on
304664	Harvey Rd.	59	8/17/2021	15:00	4.7			Swoffer	
304665	Melstone-Custer Rd.	64	8/17/2021	13:00	2.6			Swoffer	Melstone canal is dry
304666	Bridge Rd.	82	8/17/2021	14:00	1.5			estimated	Too shallow for Swoffer

*ADCP: Teledyne StreamPro Acoustic Doppler Current Profiler

Swoffer: handheld, propeller-driven, current velocity meter. Swoffer error is generally considered to be approximately 5 percent; however, in these poor conditions, stage was generally less than 0.5 feet, the error should be considered to be approximately 10 percent (Sauer and Meyer, 1992).

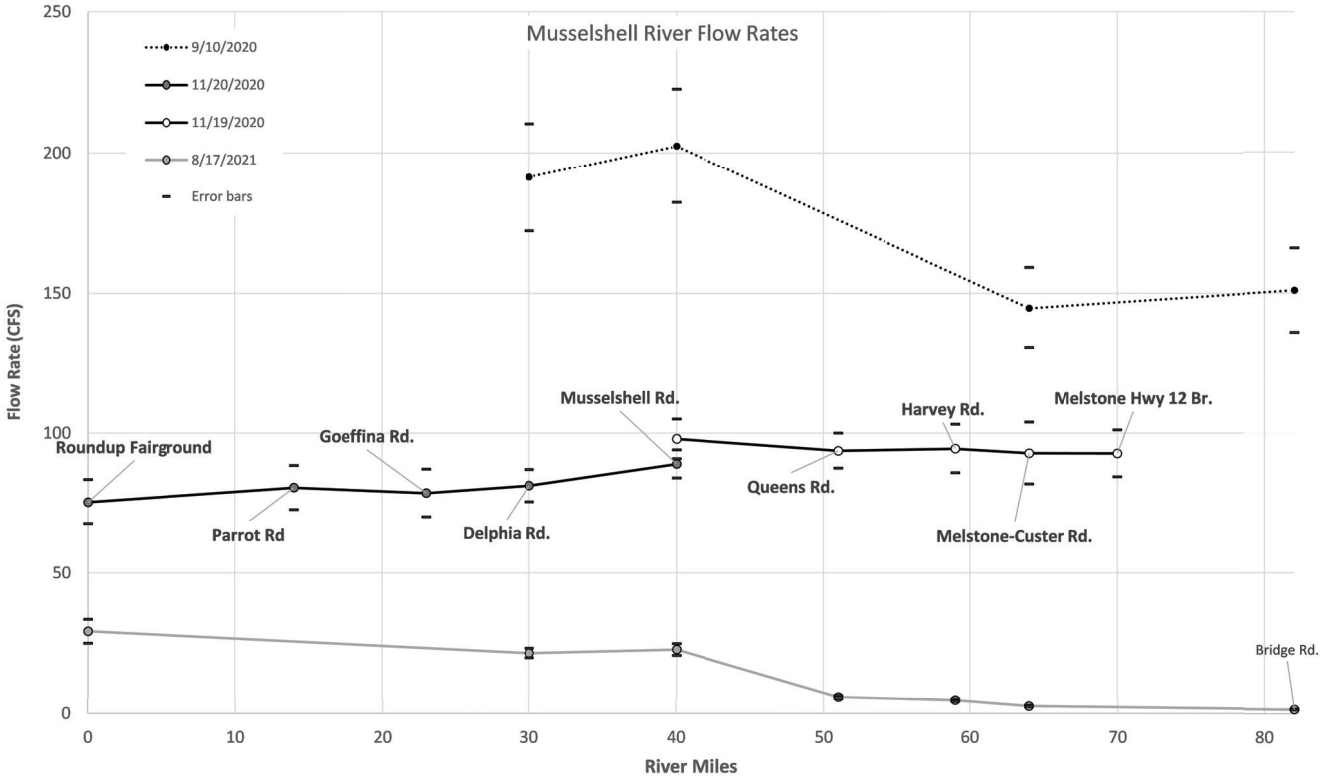

Figure B1. Synoptic flow rate measurements of the Musselshell River found gain and loss to be within measurement error. Additionally, not all withdrawals, including irrigation pumps pulling water directly from the river, could be quantified.

APPENDIX C

DELPHIA–MELSTONE CANAL LOSS MEASUREMENTS

Table C1. Delphia-Melstone Canal Flow Rate Measurement Locations

	Site	Latitude	Longitude	Canal Miles	Description
Delphia	D1	46.510058	-108.199823	0	Where the canal crosses under HWY 12 west of Teton Road
	D2	46.509760	-108.188917	0.56	Where farm road crosses canal by wells DCD and DCS
	D2'	46.508933	-108.189200		Feeder canal takeout for flood irrigated field above wells DRD and DRS
	D3	46.513465	-108.188110	0.85	Where Teton Road crosses canal
	D4	46.514786	-108.178045	1.57	Cement lined canal before syphon that brings canal under HWY 12 and river, east of Teton Road
Melstone	M1	46.573619	-107.853299	0	West of culvert where canal crosses Melstone Custer Road
	M2	46.578617	-107.846284	0.60	At Field C pivot near parking and grain silos
	M3	46.579445	-107.838969	0.99	At Field C pivot near wells CCU and CCL
	M4	46.586348	-107.829059	1.70	At Field B pivot near wells BCU and BCL, at west culvert
	M5	46.588897	-107.821037	2.14	At Field B pivot near soil moisture meter and east culvert
	M6	46.587586	-107.800251	3.42	At Field A near ACL wells, west of syphon

Table C2. Delphia-Melstone Canal Flow Rate Measurements

		Site Number	Method*	Flow Rate	Std. Dev.	Notes
Delphia	8/5/2020	D1	ADCP	10.0	4.2	
		D2	Swoffer	5.9		Field is being flood irrigated
		D3	Swoffer	4.5		Headgate gauge reads 900 gpm (2 cfs)
		D4	Swoffer	4.0		
	9/14/2020	D1	Swoffer	7.6		
		D2	not measured			The flow rate was changed after D1 and D3 were measured. This site would not have been representative.
		D2'	Swoffer	2.7		This value is for the takeout for flood irrigation between D1 and D2.
		D3	Swoffer	2.5		
		D4	not measured			Depth was too shallow for Swoffer
	5/25/2021	D1	ADCP	11.0	1.0	
		D2'	estimate	see note		Feeder ditch is full, approximately 12 cuts seeping <1 gpm, 1 cut seeping 2-3 gpm. Very small flow past end, no diversion to lower fields. Estimated 30-50 gpm, too shallow for Swoffer.
		D3	ADCP	6.774	0.5	Entire flow is diverted east of Teton Road to the lower fields and to pump. Measurement taken on west side of Teton Road.
		D4	not measured			No flow
Melstone	8/7/2020	M1	not measured			Flood irrigation being taken out between M1 and M2
		M2	ADCP	43.2	3.8	
		M3	ADCP	43.9	2.1	Canal is overflowing through gate to ephemeral channel east of M3.
		M4	ADCP	30.9	3.3	
		M5	ADCP	31.7	1.8	
		M6	ADCP	29.5	1.2	
	9/14/2020	M1	ADCP	23.2	2.4	
		M3	ADCP	20.3	1.5	
		M4	ADCP	20.9	0.8	
		M6	ADCP	24.0	1.8	
	5/25/2021	M1	ADCP	32.606	1.5	
		M3	ADCP	30.991	1.5	Field C pivot on, meter reads ~1150 gpm
		M4	ADCP	31.321	1.4	Field B pivot on, meter hard to see ~1000 gpm
		M6	ADCP	30.714	1.2	

*ADCP: Teledyne StreamPro Acoustic Doppler Current Profiler. Standard Deviation is generated automatically.

Swoffer: handheld, propeller-driven, current velocity meter. Swoffer error is generally considered to be approximately 5 percent under good conditions; however, in poor conditions such as these low flows with significant vegetation the error is consider 8 percent or higher (Sauer and Meyer, 1992).

Delphia Area Measurements

August 2020 summary:

D1–D2: Takeout for the flooded field could not be accurately measured, so the loss between these two sites does not represent seepage loss.

D2–D3: The flood irrigation headgate gage at D3 read 900 gpm (2 cfs). Calculated gain between these sites is unlikely because fields above the canal between these two locations is unirrigated. The compounding error of the flow measurements and the gage on the takeout exceeds what can be learned about loss (or gain).

D3–D4: The canal lost 0.5 cfs along this reach of approximately 0.72 mi. However, only 0.46 mi is unlined—the final length before the syphon under the river is cement lined. Assuming the whole amount was lost over the unlined portion, this results in 0.5 cfs/0.46 mi = 1.1 cfs/mi. This will be an upper limit because the lined portion most likely also leaks to some degree.

September 2020 summary:

D1–D3: The field by D2 was not being actively flood irrigated, but there was flow through the feeder canal. This appeared to be the only takeout between D1 and D3 aside from some small leaking through the headgate at D3. Accounting for the takeout for the field at D2, the loss between D1 and D3 is ([7.6-2.7]-2.5) = 2.4 cfs over a distance of approximately 0.87 mi or 2.7 cfs/mi. This is likely an overestimate because the feeder canal leaks quite a bit through shovel cuts.

May 2021 summary:

D1–D3: The feeder canal by D2 was full and leaking approximately 15 gpm through shovel cuts in the bank. Additionally, there was approximately 50 gpm leaving the feeder canal. Accurate loss to the feeder canal between D1 and D3 could not be determined. Initial estimates of approximately 0.2 cfs loss to the feeder canal results in a loss of 4.0 cfs over 0.85 mi or 4.7 cfs /mi, which is nearly twice the next highest loss measurement. We presume our initial estimates were too low and this loss calculation is not accurate.

Melstone Area Measurements

August 2020 summary:

Both pivots were off, but flood irrigation was occurring between sites M1 and M2.

M2–M3: Not significantly different.

M3–M4: The 13 cfs loss is likely from the overflow from the canal to the ephemeral drainage to the east of M3. Visual verification was difficult, but flow through the headgate could be clearly heard.

M4–M5: Not significantly different.

M5–M6: Not significantly different. Within error this is 2.2 cfs /1.28 mi or 1.7 cfs/mi.

September 2020 summary:

Both pivots were off, no flood irrigation was occurring.

M1–M3: Not significantly different. Within error the loss of 2.9 cfs occurred over approximately 0.99 miles, or 2.9 cfs/mile.

M3–M4: No significant difference. The overflow by M3 could still be heard.

M4–M6: The gain of 3.1 cfs could not be explained by visual inspection of the canal. No obvious sources of gain could be identified.

May 2021 summary:

Both pivots were on, no flood irrigation.

M1–M3: Not significantly different. Within error the loss of 1.6 cfs occurred over approximately 0.99 mi, or 1.6 cfs/mi.

M3–M4: No significant difference; M4–M6: No significant difference.

Figure C1. Delphia area canal flow-rate measurement locations.

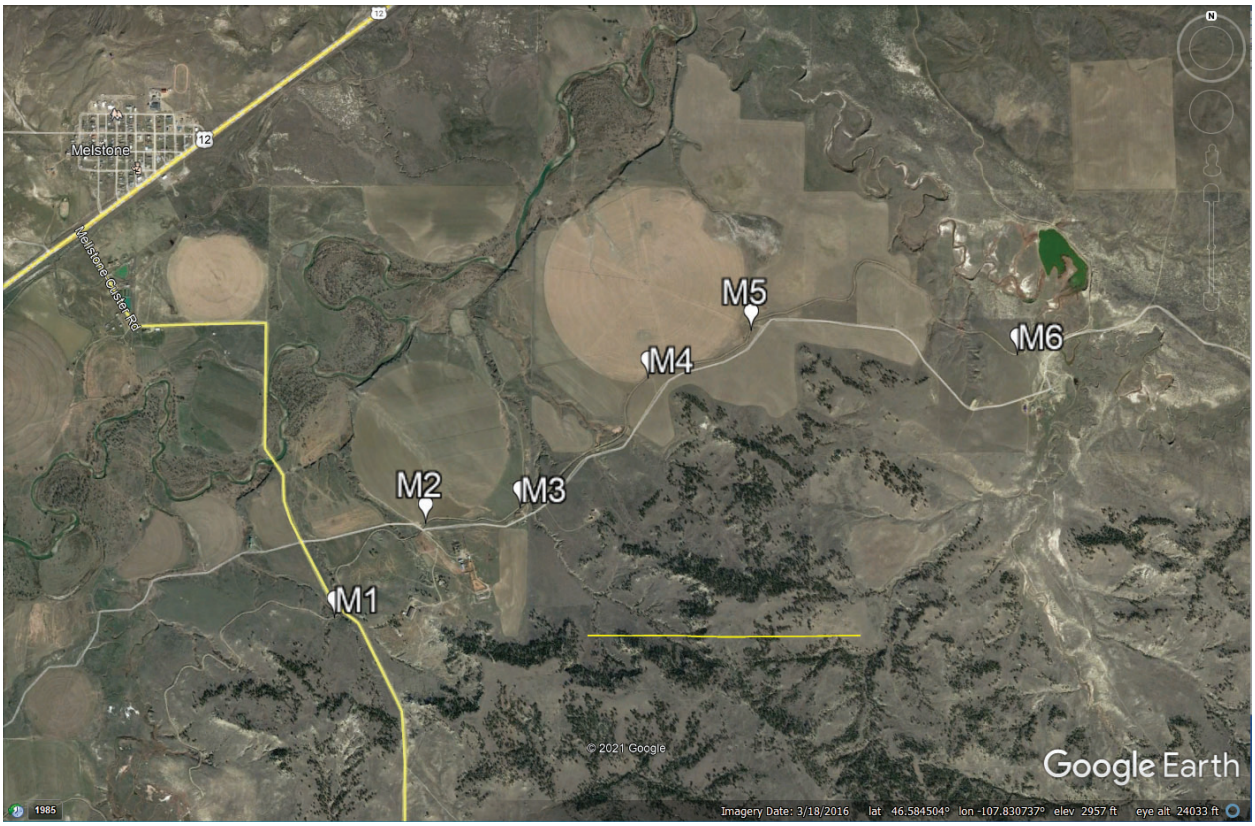

Figure C2. Melstone area canal flow-rate measurement locations.

APPENDIX D

GROUNDWATER QUALITY

Table D1. Groundwater inorganic chemistry. See excel file, downloadable online.

Table D2. Groundwater oxygen and hydrogen isotope ratios. See excel file, downloadable online.

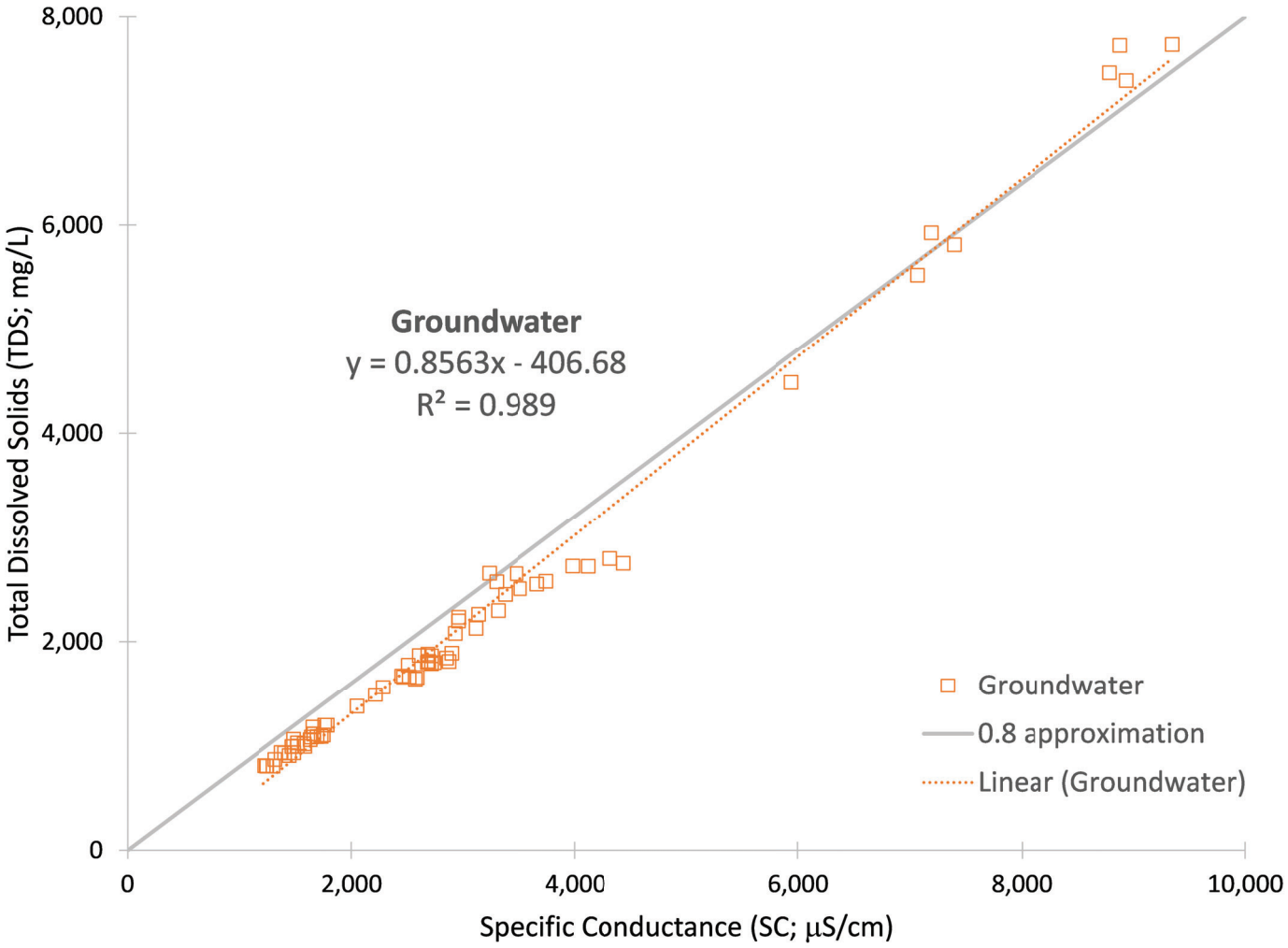

Figure D1. Linear correlation between total dissolved solids and specific conductance. The least-squares linear relationship is presented in the chart. A simplified approximation of a slope of 0.8 is also presented. In general, for groundwater sampled collected for this project, the total dissolved solids in mg/L is approximately 8/10 the value of specific conductance in µS/cm.

APPENDIX E

SURFACE-WATER QUALITY

Table E1. Surface-water inorganic chemistry. See excel file, downloadable online.

Table E2. Infrequent detections for trace metals in surface-water samples. See excel file, downloadable online.

Table E3. Surface-water oxygen and hydrogen isotope ratios. See excel file, downloadable online.

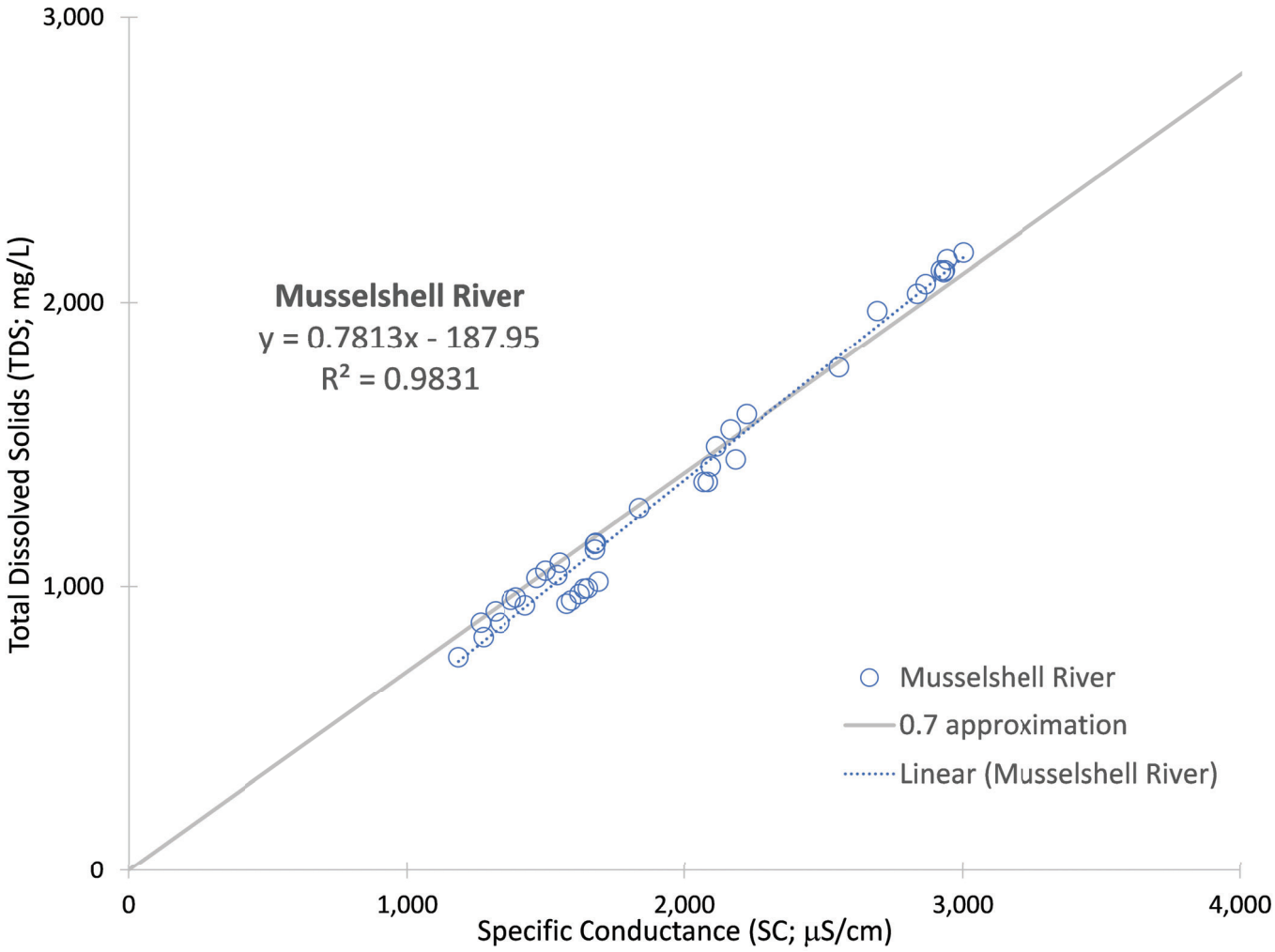

Figure E1. Linear correlation between total dissolved solids and specific conductance. The least-squares linear relationship is presented in the chart. A simplified approximation of a slope of 0.7 is also presented. In general, for the Musselshell river samples collected for this project, the total dissolved solids in mg/L is approximately 7/10 the value of specific conductance in µS/cm.

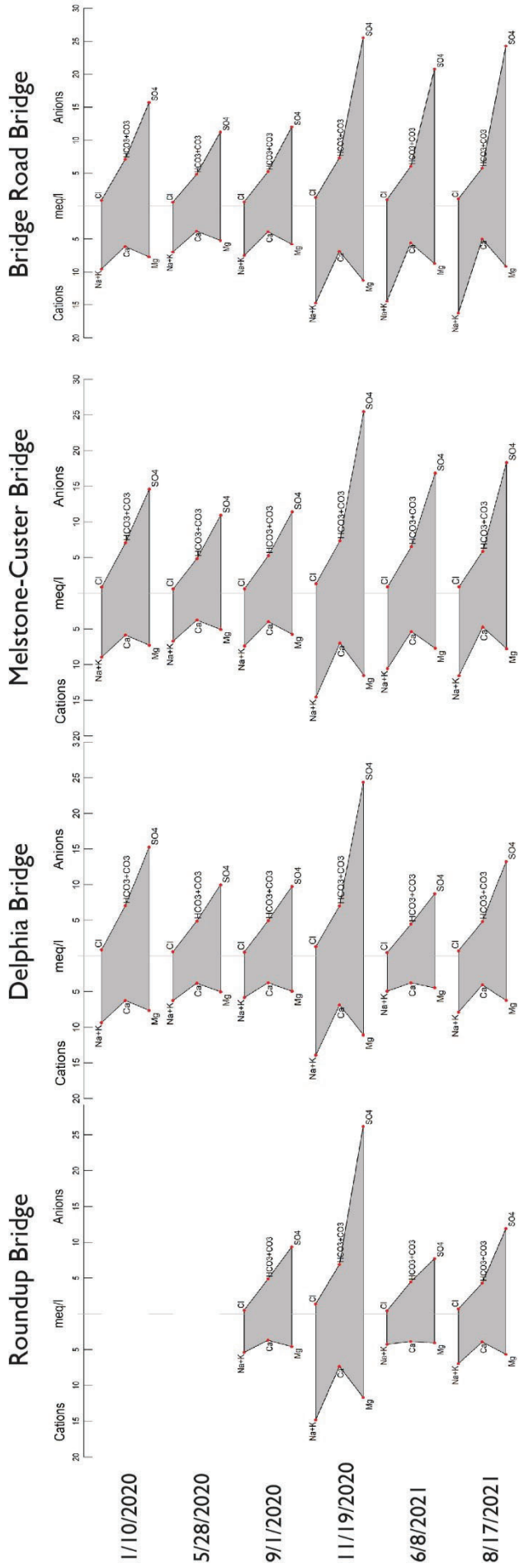

Figure E2. Major ion chemistry of the Musselshell River is balanced-cation–sulfate or sodium–magnesium-sulfate and varies in total concentration throughout the year. Major ion composition tends to be consistent from upgradient (Roundup) to downgradient (Bridge Road) seasonally. The exceptions to this are the samples collected in June and August of 2021. On these dates the river flow rate was below average and the presence of sodium–sulfate groundwater-return flows had a greater influence on the downgradient samples.

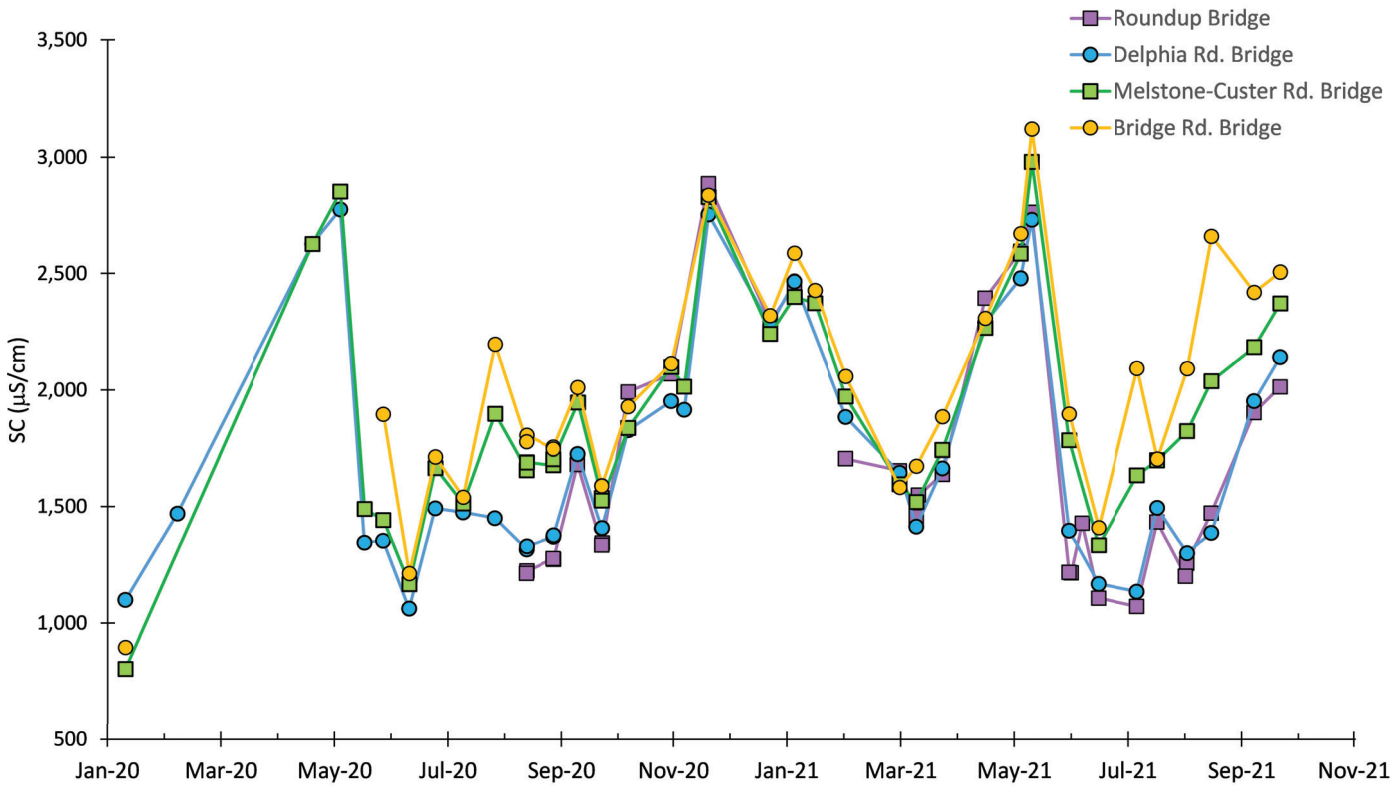

Figure E3. Salinity of the Musselshell River from Roundup to Bridge Road Bridge. The largest downgradient change in salinity is between Delphia and Melstone, with the exception of the extreme low-flow conditions during the 2021 drought. During the low, at times discontinuous, flows in late summer 2021, a similar increase in SC was found between Melstone and Bridge Road.

APPENDIX F

STRONTIUM ISOTOPE RATIOS FOR GROUNDWATER AND SURFACE WATER

Appendix F, Table F1a. Strontium isotope and concentration results for surface water samples

Sample Name	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)
Date	1/10/2020				5/28/2020				9/10/2020			
Number 4 Rd. Br.									0.707991	0.0008	0.000015	1.22
Delphia Br.*	0.708415	0.0008	0.000015	2.07	0.708217	0.0008	0.000015	1.06	0.708185	0.0007	0.000015	1.28
Musselshell Br.					0.708285	0.0008	0.000015	1.08	0.708314	0.0008	0.000015	1.34
Queens Road Br.					0.708275	0.0007	0.000015	1.09	0.708393	0.0006	0.000015	1.34
Harvey Road Br.	0.708627	0.0009	0.000015	1.94	0.708305	0.0008	0.000015	1.11	0.708440	0.0008	0.000015	1.42
Custer-Melstone Rd. Br.	0.708596	0.0009	0.000015	1.96	0.708301	0.0006	0.000015	1.11	0.708440	0.0006	0.000015	1.43
Bridge Road Br.	0.708580	0.0009	0.000015	1.98	0.708289	0.0008	0.000015	1.12	0.708424	0.0009	0.000015	1.44
D-M Canal at Delphia					0.708219	0.0008	0.000015	1.18	0.708053	0.0006	0.000015	1.24
D-M Canal at Melstone					0.708258	0.0007	0.000015	1.09	0.708331	0.0009	0.000015	1.31
Deadman's basin												
Date	3/6/2020								8/17/2020			
Horse Creek	0.708961	0.0009	0.000015	1.54					0.708945	0.0007	0.000015	1.77
Horse Creek Reservoir	0.708858	0.0008	0.000015	2.17					0.708842	0.0008	0.000015	1.38

$^{87}Sr/^{86}Sr$ data are relative to 0.710250 for NBS 987, 2σ = 0.000015, n =25

Internal precision (%SE) for each analysis is better than the reproducibility of the standard.

Use the uncertainty of the standard as the uncertainty of your samples (2-sigma abs).

*Duplicate sample collected	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)
5/28/2020:	0.708223	0.0006	0.000015	1.07

Appendix F, Table F1b. Strontium isotope and concentration results for surface water samples

Sample Name	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)
Date	11/19/2020				6/8/2021			
Number 4 Rd. Br.	0.708393	0.0008	0.000011	2.41	0.707945	0.0007	0.000010	0.80
Delphia Br.	0.708624	0.0007	0.000010	2.35	0.708085	0.0008	0.000011	0.87
Musselshell Br.	0.708718	0.0007	0.000010	2.52	0.708172	0.0007	0.000010	0.91
Queens Road Br.	0.708821	0.0006	0.000009	2.48	0.708329	0.0007	0.000009	0.96
Harvey Road Br.	0.708822	0.0006	0.000009	2.42	0.708600	0.0008	0.000011	1.16
Custer-Melstone Rd. Br.	0.708827	0.0007	0.000010	2.45	0.708831	0.0007	0.000009	1.51
Bridge Road Br.	0.708910	0.0008	0.000011	2.43	0.708476	0.0007	0.000009	0.16*
D-M Canal at Delphia					0.708035	0.0007	0.000010	0.86
D-M Canal at Melstone					0.708305	0.0008	0.000011	0.97
Deadman's basin								
Date					3/5/2021			
Horse Creek					0.708981	0.0007	0.000010	0.78
Horse Creek Reservoir					0.708908	0.0007	0.000010	0.88

$^{87}Sr/^{86}Sr$ data are relative to 0.710250 for NBS 987, 2σ = 0.000015, n =25

Internal precision (%SE) for each analysis is better than the reproducibility of the standard.

Use the uncertainty of the standard as the uncertainty of your samples (2-sigma abs).

*Bridge Road Bridge sample from 6/8/2021 was not considered in the evaluation of the results because of a discrepancy in the concentration results from the TIMS (0.16 mg/L) and the ICPMS (2.25 mg/L) that could not be resolved.

Appendix F, Table F2a. Strontium isotope and concentration results for groundwater samples

Sample Name	Date	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)	Date	$^{87}Sr/^{86}Sr$	%Std Err	Abs Err 2-sigma	[Sr] (ppm)
ACU	3/2/2020	0.707850	0.0009	0.000015	5.96	8/13/2020	0.707852	0.0006	0.000015	8.59
ACLS						8/13/2020	0.708903	0.0008	0.000015	1.55
ACLM	3/2/2020	0.708083	0.0008	0.000015	1.15	8/13/2020	0.708082	0.0007	0.000015	1.84
ACLD	3/5/2020	0.707822	0.0008	0.000015	0.336	8/13/2020	0.707753	0.0008	0.000015	0.536
BCU	3/2/2020	0.707833	0.0008	0.000015	3.42	8/12/2020	0.707866	0.0008	0.000015	4.22
BCL	3/5/2020	0.708363	0.0006	0.000015	0.764	8/12/2020	0.708326	0.0008	0.000015	1.35
CCU	3/6/2020	0.708592	0.0007	0.000015	0.974	8/12/2020	0.708549	0.0008	0.000015	1.46
CCL	2/26/2020	0.708668	0.0008	0.000015	2.03	8/12/2020	0.708779	0.0007	0.000015	2.26
MUD	3/5/2020	0.707882	0.0006	0.000015	0.633	8/12/2020	0.707872	0.0007	0.000015	0.900
MRD	3/6/2020	0.707745	0.0006	0.000015	0.158	8/10/2020	0.707810	0.0008	0.000015	0.329
MRS	3/6/2020	0.708408	0.0008	0.000015	1.99	8/10/2020	0.708416	0.0006	0.000015	3.20
DUD	3/6/2020	0.710850	0.0006	0.000015	0.718	8/10/2020	0.710971	0.0008	0.000015	1.20
DCD	2/26/2020	0.711103	0.0007	0.000015	1.45	8/10/2020	0.711084	0.0008	0.000015	2.20
DCS	2/26/2020	0.709338	0.0006	0.000015	1.05	8/10/2020	0.709131	0.0006	0.000015	1.54
DRD	2/26/2020	0.711120	0.0008	0.000015	2.53	8/10/2020	0.711126	0.0008	0.000015	3.92
DRS	2/26/2020	0.708851	0.0007	0.000015	1.89	8/10/2020	0.708898	0.0007	0.000015	2.80
Fence well 1	3/2/2020	0.707863	0.0007	0.000015	3.84	8/13/2020	0.707876	0.0006	0.000015	4.17
Fence well 2	3/2/2020	0.708090	0.0007	0.000015	0.693	8/13/2020	0.708097	0.0008	0.000015	2.07
Pond well 1	3/5/2020	0.708830	0.0008	0.000015	8.29	8/17/2020	0.708818	0.0006	0.000015	8.91
Pond well 2	3/5/2020	0.708800	0.0009	0.000015	9.03	8/17/2020	0.708823	0.0009	0.000015	8.45

$^{87}Sr/^{86}Sr$ data are relative to 0.710250 for NBS 987, 2σ = 0.000015, n =25

Internal precision (%SE) for each analysis is better than the reproducibility of the standard.

Use the uncertainty of the standard as the uncertainty of your samples (2-sigma abs).

Appendix F, Table F3a. Strontium Mixing Calculations

			Groundwater Mixing						
			Upgradient bedrock		Introduced / River	Canal	Downgradient mixed groundwater		
	Upgradient/ introduced/ mixed samples	Sample date	$^{87}Sr/^{86}Sr$	[Sr] mg/L	$^{87}Sr/^{86}Sr$	[Sr] mg/L	$^{87}Sr/^{86}Sr$	[Sr] mg/L	***f*** (canal/river)
Field A	ACU / canal at Melstone / ACLM	3/2/2020	0.707850	5.96	0.708298	1.12	0.708083	1.15	99%
		8/13/2020	0.707852	8.59	0.708298	1.12	0.708082	1.84	90%
		3/4/2021	0.707843	6.77	0.708298	1.12	0.708106	1.34	96%
								average	**95%**
Field B	BCU/ canal at Melstone / BCL	3/2/2020	0.707833	3.42	0.708298	1.12	0.708363	1.16[+]	98%
		8/12/2020	0.707866	4.22	0.708298	1.12	0.708326	1.35	93%
		3/2/2021	0.707836	4.73	0.708298	1.12	0.708391	1.59	87%
								average	**93%**
Field C	CCU/ canal at Melstone / CCL	3/6/2020	0.708592	0.974	0.708298	1.12	0.708668	2.03	708%
		8/12/2020	0.708549	1.46	0.708298	1.12	0.708779	2.26	-235%
		3/2/2021	0.708567	1.25	0.708298	1.12	0.708579	2.36	-905%
Melst. alluvium	MRD / River at Melstone / MRS	3/6/2020	0.707745	0.158	0.708827	2.45	0.708408	1.99	80%
		8/10/2020	0.707810	0.329	0.708827	2.45	0.708416	3.20	135%
		3/8/2021	0.707810	0.245	0.708827	2.45	0.708385	2.17	87%
								average*	**84%**
Delphia Field	DCD / canal at Delphia / DCS	2/26/2020	0.711103	1**	0.708102	1	0.709338	1	59%
		8/10/2020	0.711084	2.20	0.708102	1.09	0.709131	1.54	60%
		3/4/2021	0.711087	2.37[+]	0.708102	1.09	0.709163	1.83[+]	43%
Delphia alluvium	DRD / River at Delphia / DRS	2/26/2020	0.711120	2.53	0.708305	1.53	0.708851	1.89	64%
		8/10/2020	0.711126	3.92	0.708305	1.53	0.708898	2.80	47%
		3/8/2021	0.711104	2.90	0.708305	1.53	0.708903	2.06	61%
								average	**56%**

[+] *value from MBMG analytical laboratory ICPMS*

** Average of the 3/6/2020 and 3/8/2021 samples.*

*** (numerals in red) In situations where the concentrations are very similar, within 10%, the concentrations were assumed to be equal.*

Appendix F, Table F3b. Strontium Mixing Calculations

	Musselshell River Mixing													
			Upriver		Introduced groundwater baseflow		Downriver							
	Upriver/ groundwater baseflow/ downriver	Sample date	$^{87}Sr/^{86}Sr$	[Sr] mg/L	$^{87}Sr/^{86}Sr$	[Sr] mg/L	$^{87}Sr/^{86}Sr$	[Sr] mg/L	*f* (baseflow)	River cfs	Baseflow cfs	River Miles	Baseflow cfs/mile
Musselshell River	Delphia/ DRD/ Harvey	1/10/2020	0.708415	2**	0.710360	2	0.708627	2	11%	64	7.0	29	0.24
	Harvey/ BCU+ACU/ Bridge Rd		0.708627	1.94	0.707846737	5.61	0.708580	1.98	1.1%	64	0.70	23	0.03
	Roundup/ DRD/ Queen	9/10/2020	0.707991	1.22	0.710360	2.91	0.708393	1.34	7.1%	144	10	51	0.20
	Roundup/ DRD/ Queen	11/19/2020	0.708393	2	0.710360	2	0.708821	2	22%	90	20	51	0.38
	Roundup/ DRD/ Queen	6/8/2021	0.707945	0.80	0.710360	2.91	0.708329	0.96	7.7%	330	25	51	0.50

[+] *value from MBMG analytical laboratory ICPMS*

*** (numerals in red) In situations where the concentrations are very similar, within 10%, the concentrations were assumed to be equal.*

APPENDIX G

SOIL COLUMN SATURATED PASTE EXTRACTION ANALYSIS

Table G1. Saturated paste chemistry from soil cores

Field	Depth	mid-depth	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L)	Bicarb. (mg/L)	Conductivity (mS/cm)
DUD	0-1	.5	169.3	48.6	9.9	20.3	11	50	180	219	1.3
	1-3	2.0	479.0	550.4	157.0	5.1	123	3420	108	132	4.2
	3-5	4.0	468.9	3353.4	2345.0	15.6	1740	17200	81	99	12
	5-8	6.5	481.0	1421.6	1518.5	15.6	1380	8250	63	77	9.3
	8-10	9.0	302.6	549.2	843.7	7.8	563	3860	64	76	5.8
	10-13	11.5	485.0	456.8	471.3	8.2	202	3650	72	88	4.9
	13	13.0	519.0	458.1	492.0	6.6	261	3650	87	106	5
	13-15	14.0	416.8	373.0	459.8	8.2	252	2910	53	64	4.4
	15-17.5	16.0	509.0	358.4	347.1	5.1	111	3050	68	83	4.2
	17.5-20	19.0	114.2	93.4	209.2	7.8	84	872	61	74	1.9
	20-21	20.5	134.1	106.4	199.3	10.9	67	1010	92	112	2
Delphia Flood	0-2	1.0	128.9	69.5	116.6	15.2	33	325	191	232	1.6
	2-5	3.5	75.6	37.8	119.8	5.1	19	369	161	196	1.1
	5-6	5.5	67.3	33.8	113.8	7.0	18	339	159	194	1
	6-7	6.5	59.7	31.8	108.7	6.3	16	351	131	160	1
	7-10	8.5	61.1	31.3	109.0	6.3	18	369	119	146	1
	10-13	11.5	51.3	28.3	100.9	6.6	20	293	135	165	1
	13-15	14.0	54.9	29.0	106.0	5.5	16	354	112	137	1
	15-16	15.5	77.8	90.6	148.7	14.5	19	621	178	217	1.6
	18-20	19.0	68.3	36.6	122.1	6.6	20	418	113	137	1.1
MUD	0-2	1.0	55.1	38.9	29.7	7.8	19	51	261	319	0.7
	2-3	2.5	456.9	411.9	827.6	12.1	41	4590	142	173	5.4
	4	4.0	412.8	781.2	2459.9	18.4	110	9460	71	86	9.5
	4-10	7.0	360.7	981.7	3149.6	23.1	205	11900	65	79	11
	8	8.0	418.8	1174.9	3517.5	23.5	243	13600	67	82	11.9
	12-16	14.0	416.8	828.6	2942.7	22.7	262	10900	55	67	10.6
	16	16.0	420.8	756.9	2850.8	18.8	238	10100	61	74	10.4
	16-20	18.0	426.9	760.6	2566.8	21.1	194	10500	64	78	10
	20	20.0	414.8	579.6	2016.2	15.2	115	7880	66	81	8.6
Field C - Pivot	0-2	1.0	240.5	118.0	340.3	16.0	77	1120	230	280	2.8
	2-3	2.5	168.7	120.8	310.4	4.3	63	1360	112	136	2.5
	3-4	3.5	92.8	112.0	275.9	5.1	22	1120	149	182	2.1
	4-6	5.0	79.0	153.1	228.3	7.0	10	1160	157	191	2.1
	6-7	6.5	39.9	158.0	217.5	7.0	5	1090	132	161	1.9
	7-8	7.5	29.9	130.0	184.4	7.8	4	806	159	194	1.7
	8-9	8.5	17.2	76.4	149.9	5.1	6	506	160	196	1.2
	9-10	9.5	15.0	54.8	120.5	4.7	9	315	182	222	1
Field B - Pivot	0-4	2.0	91.2	50.8	169.2	10.9	39	434	180	220	1.5
	4	4.0	89.2	95.0	298.9	5.9	33	1050	117	142	2.1
	4-8	6.0	164.5	281.9	446.0	10.2	88	2720	95	116	3.6
	8	8.0	121.0	133.7	264.4	10.2	47	1270	102	125	2.3
	8-12	10.0	66.1	70.6	220.7	9.8	46	929	108	131	1.7
	12	12.0	61.5	39.5	317.3	7.8	79	769	117	143	1.8
	12-16	14.0	177.8	111.3	450.6	9.8	220	2030	81	99	3
	16	16.0	192.4	111.5	347.1	7.8	154	1410	76	93	2.7
	16-20	18.0	99.8	58.8	195.9	6.6	62	811	85	104	1.6
	20	20.0	302.6	160.4	586.2	12.5	16	2550	75	92	3.7

Carbonate as CO_3 was non-detect for all samples.

Figure G1. Major ion chemistry of the soils cores collected from unirrigated fields on Fort Union (DUD) and Fox Hills/Bearpaw (MUD) and flood- and pivot-irrigated fields at Delphia and Field B, show soluble salt is primarily sulfate based. Core locations shown in figs. 9 and 10.

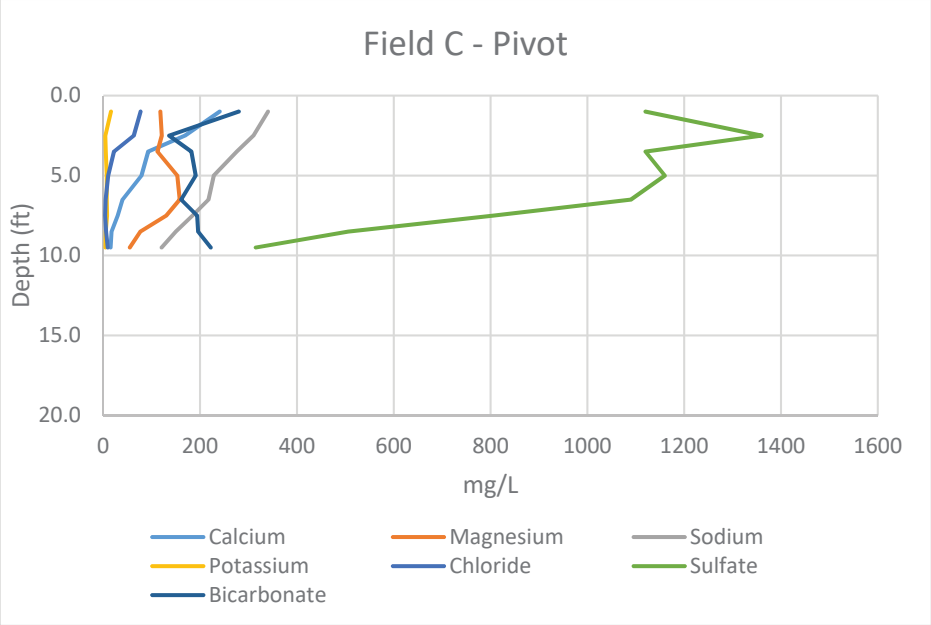

Figure G2. A core to 10 ft collected from the pivot-irrigated Field C shows high-sulfate concentrations near the surface that quickly drop with depth.

Table G2. Laboratory reporting criteria

Analyte	Reporting limit	Unit	Method
Calcium, sat. paste	1.002	mg/L	SW6010B
Magnesium, sat. paste	0.972	mg/L	SW6010B
Potassium, sat. paste	1.173	mg/L	SW6010B
Sodium, sat. paste	0.9196	mg/L	SW6010B
Chloride	1	mg/L	E300.0
Sulfate	1	mg/L	E300.0
Alkalinity, Total as $CaCO_3$	4	mg/L	ASA10-3
Bicarbonate as HCO_3	4	mg/L	ASA10-3
Carbonate as CO_3	4	mg/L	ASA10-3
Conductivity, sat. paste	0.1	mS/cm	ASA10-3

Laboratory reports cations as meq/L; these values were converted to mg/L.
Laboratory reports conductivity as mmhos/cm which is equivalent to mS/cm.

APPENDIX H

SUMMARY OF MUSSELSHELL WATERSHED COALITION VOLUNTEER MONITORING DATA

Monitoring site location and program summary can be found here: https://www.arcgis.com/apps/MapSeries/index.html?appid=6e45af0d62e44f989354121cdd32db78

Salinity and temperature data can be found here: https://django.msu.montana.edu/msuewq/musselshell/

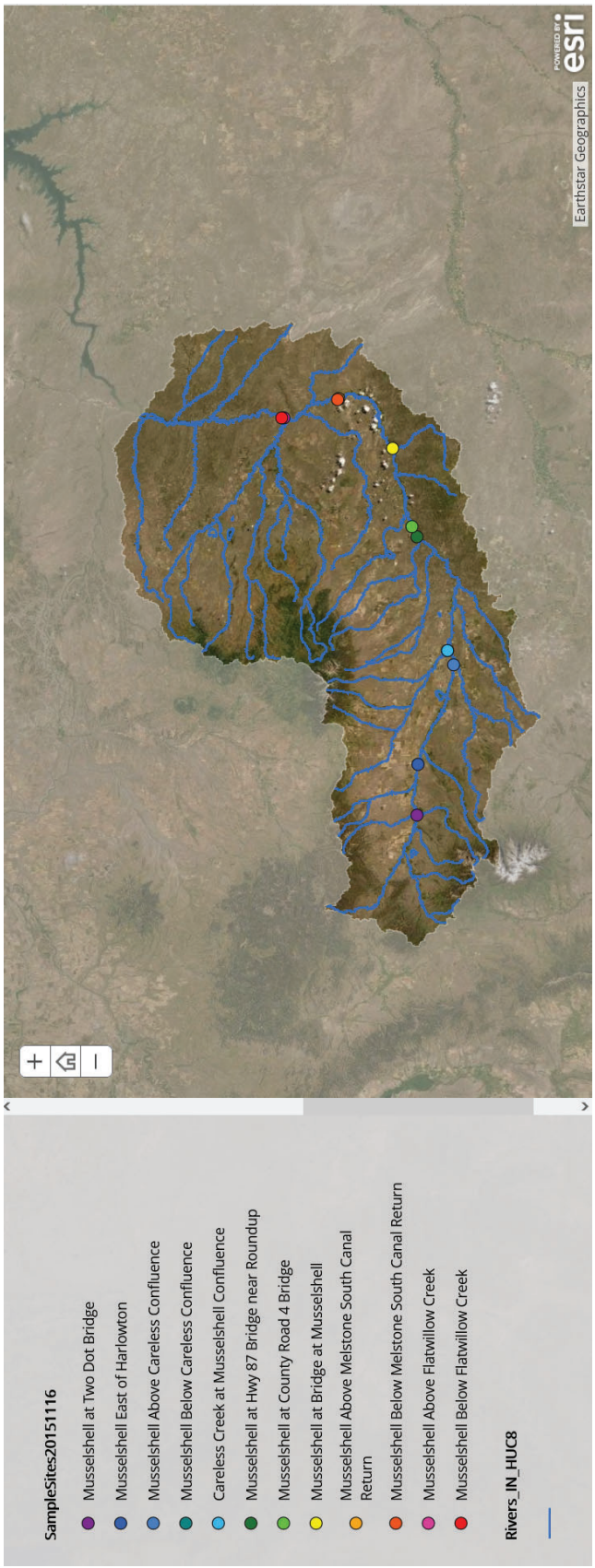

Figure H1. MWC volunteer monitoring locations along the Musselshell River extend from Two Dot to Flatwillow Creek.

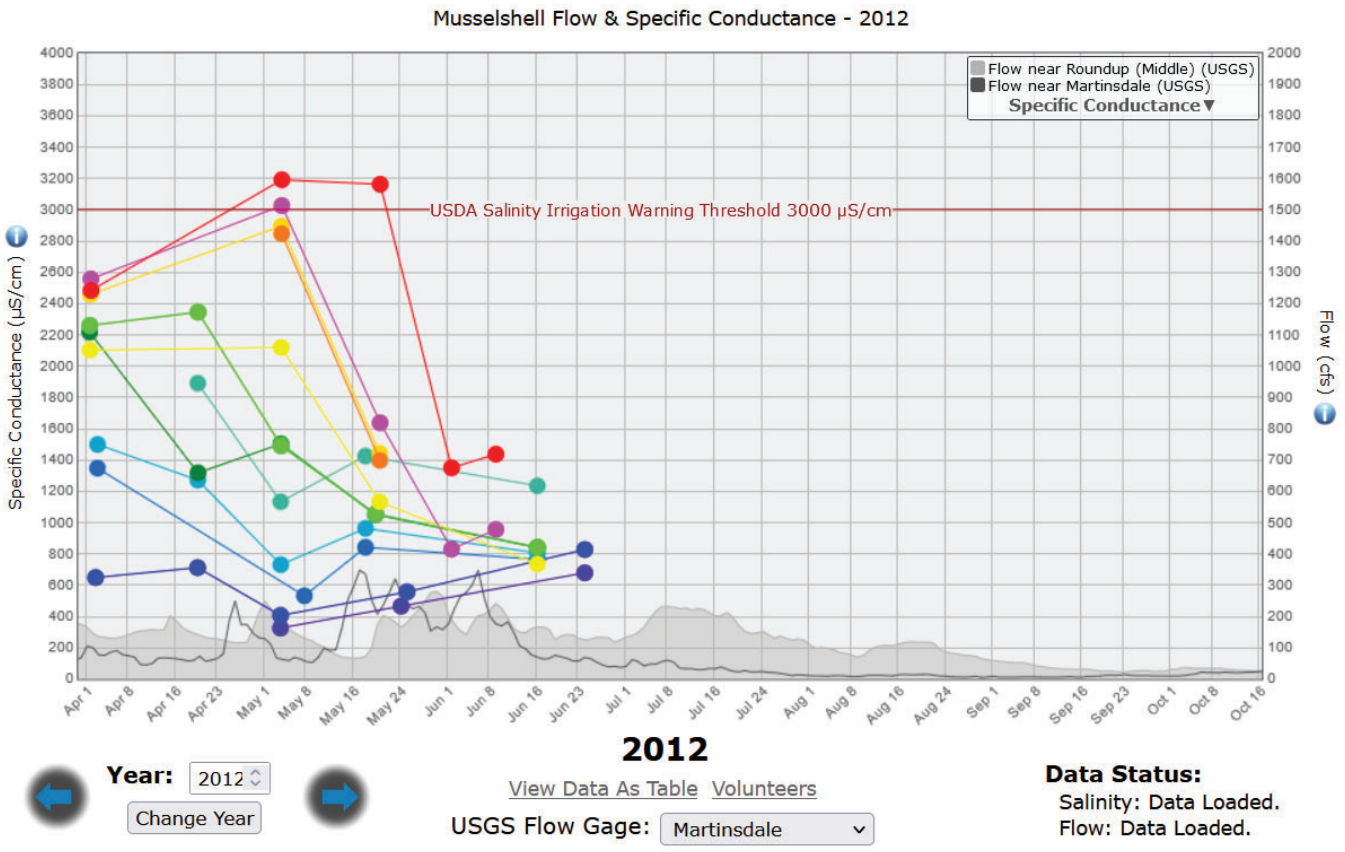

Figure H2. Volunteer monitoring data from 2012; a drought year with no high spring river flow rates.

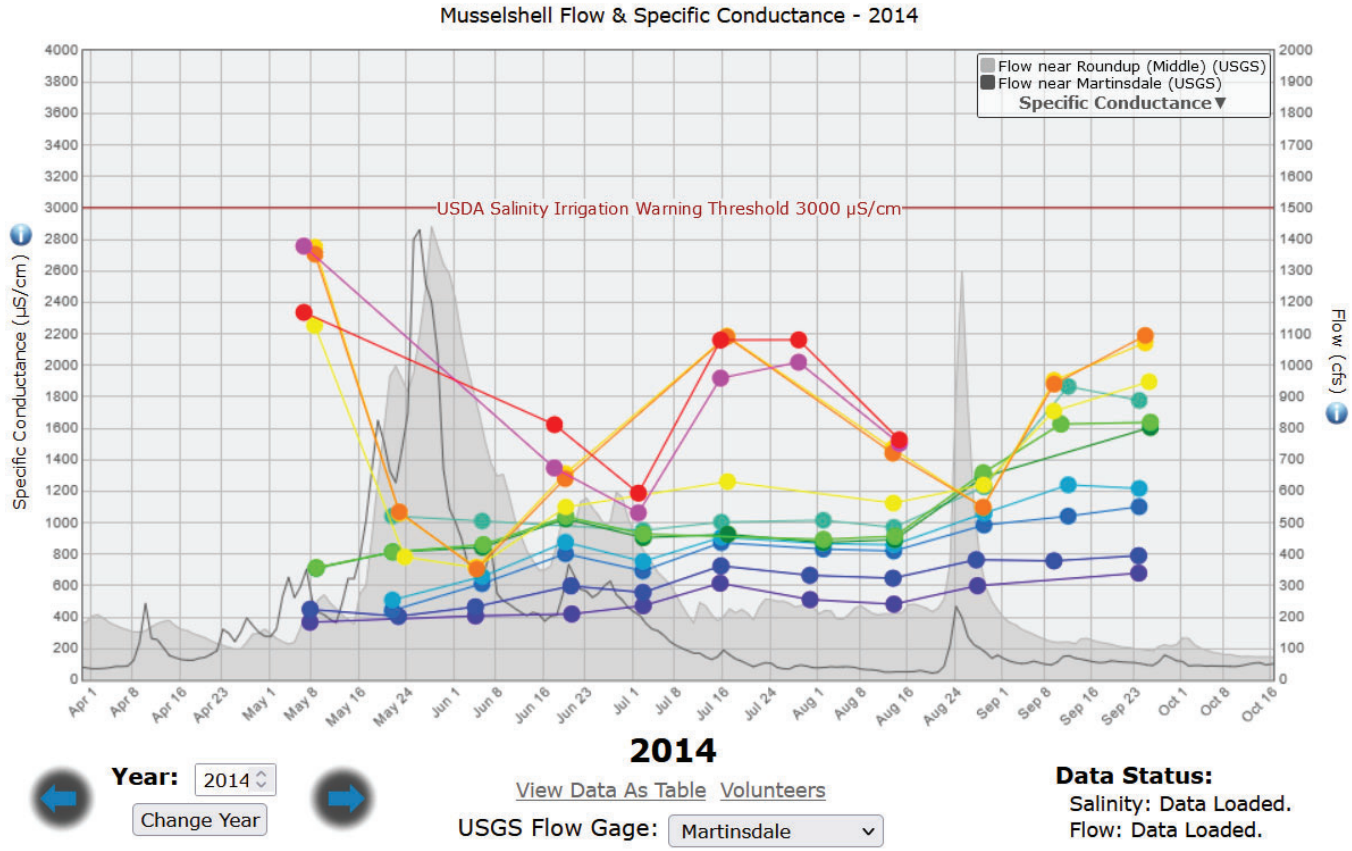

Figure H3. Volunteer monitoring data from 2014; high spring river flows dilute the river salinity.

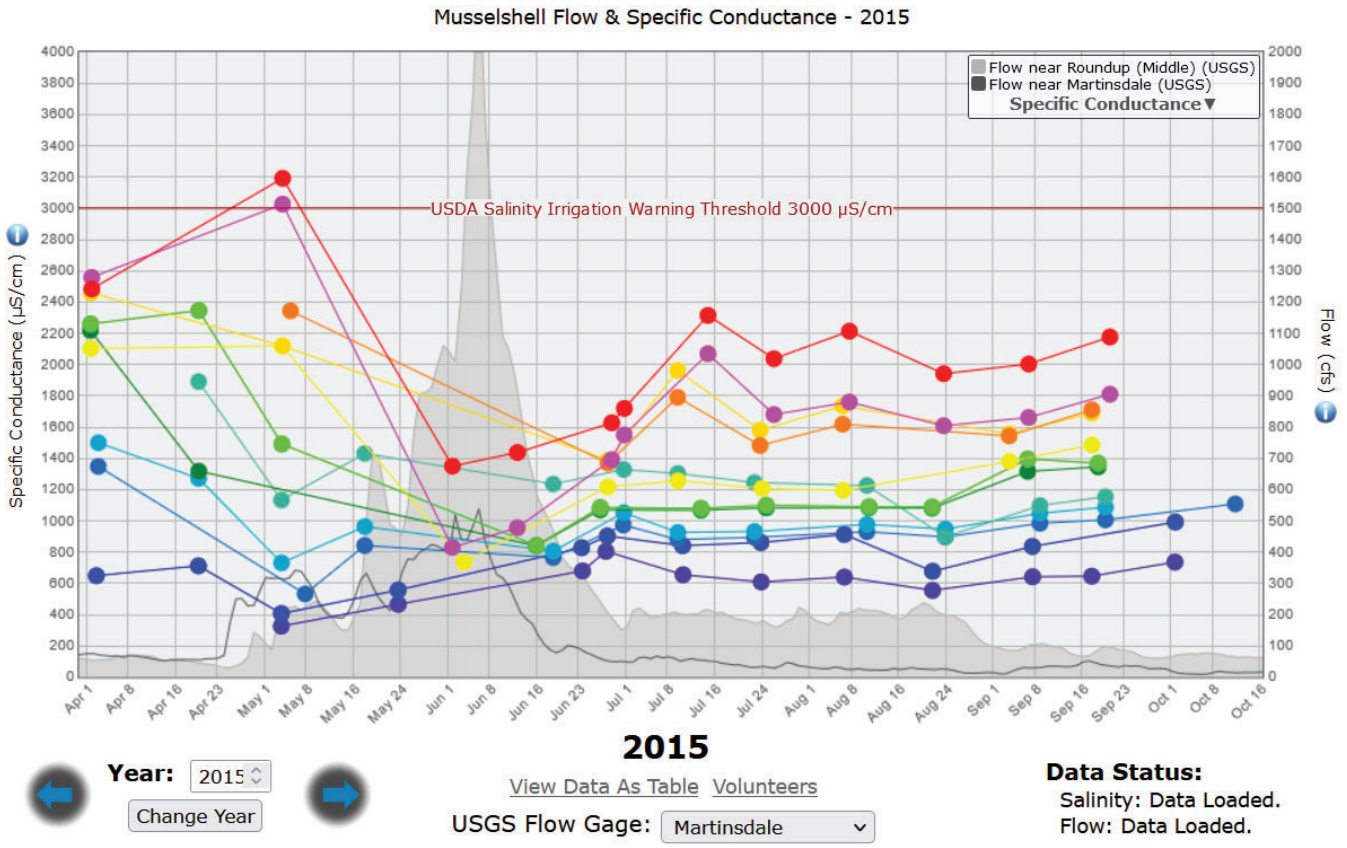

Figure H4. Volunteer monitoring data from 2015; high spring river flows dilute the river salinity.

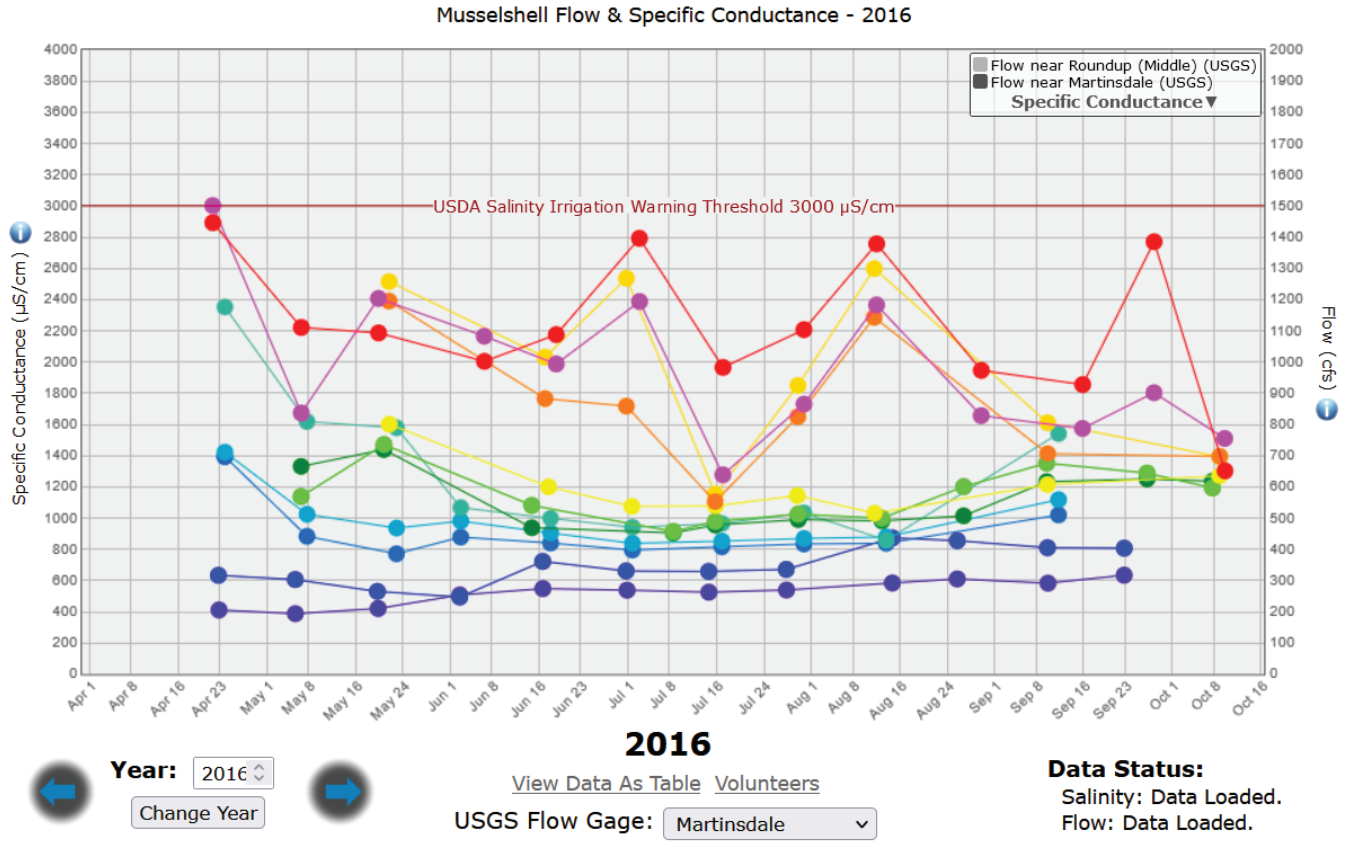

Figure H5. Volunteer monitoring data from 2016; chart rendering did not include river flow rates in 2016.

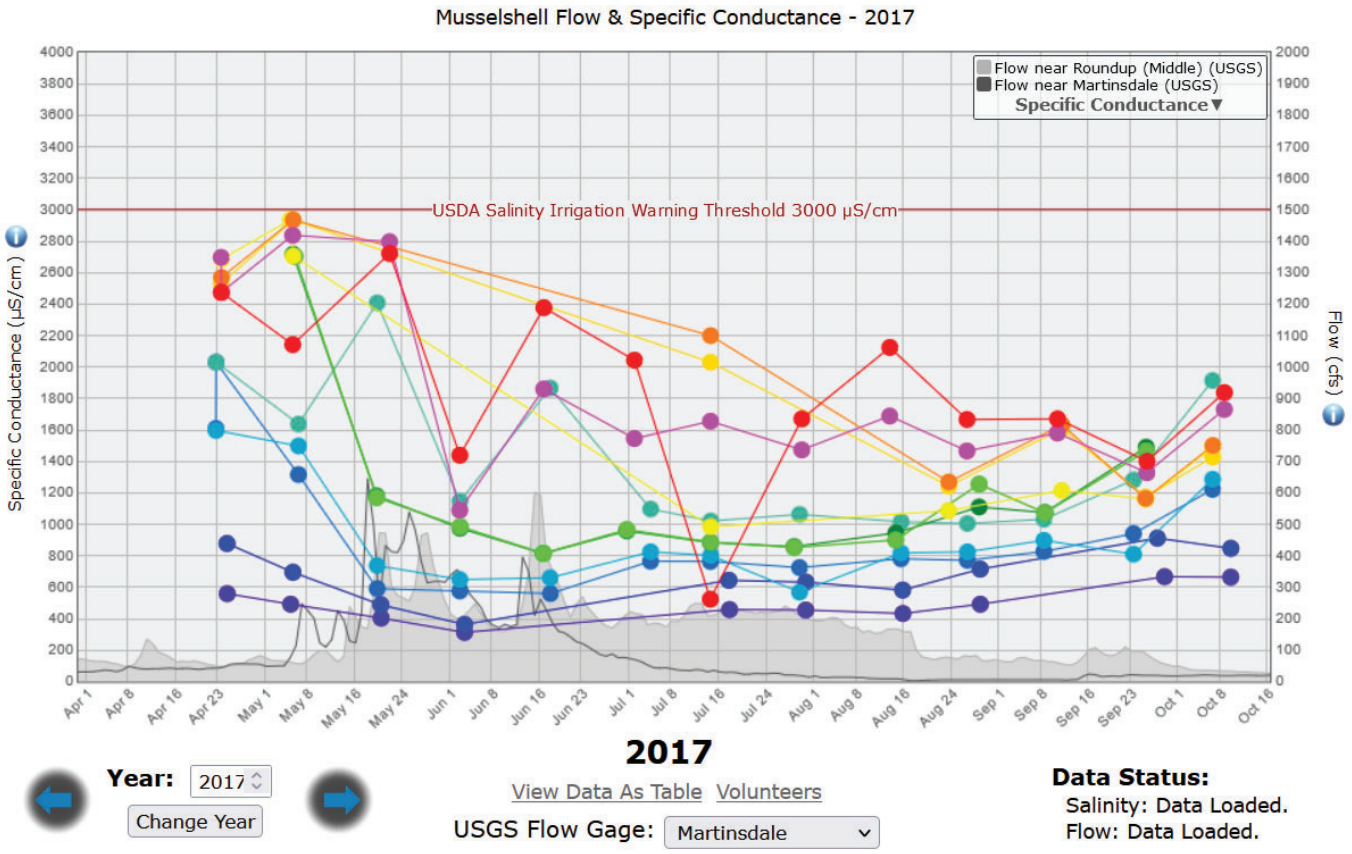

Figure H6. Volunteer monitoring data from 2017; a drought year with no high spring river flow rates.

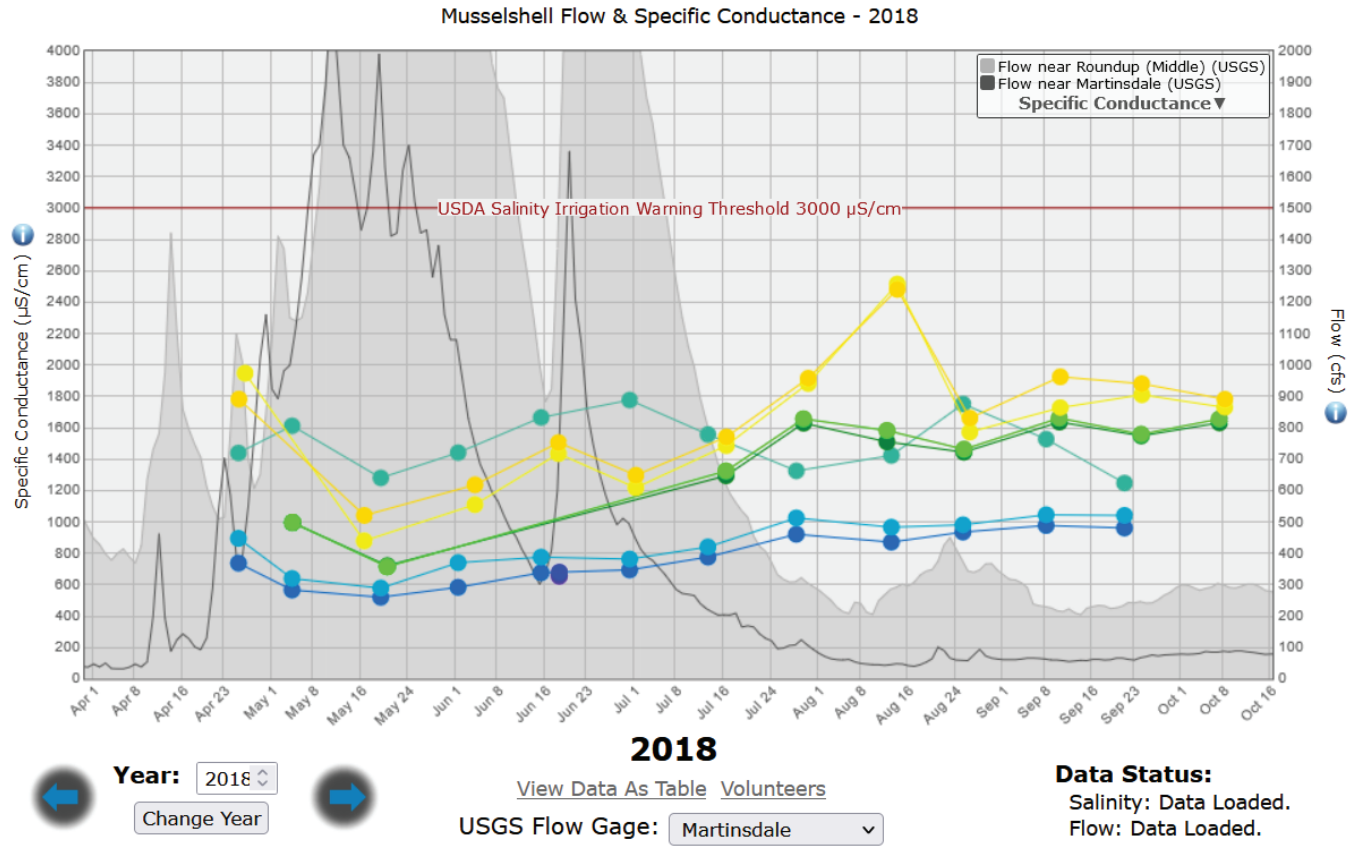

Figure H7. Volunteer monitoring data from 2018; high flows began before the typical peak in river salinity.

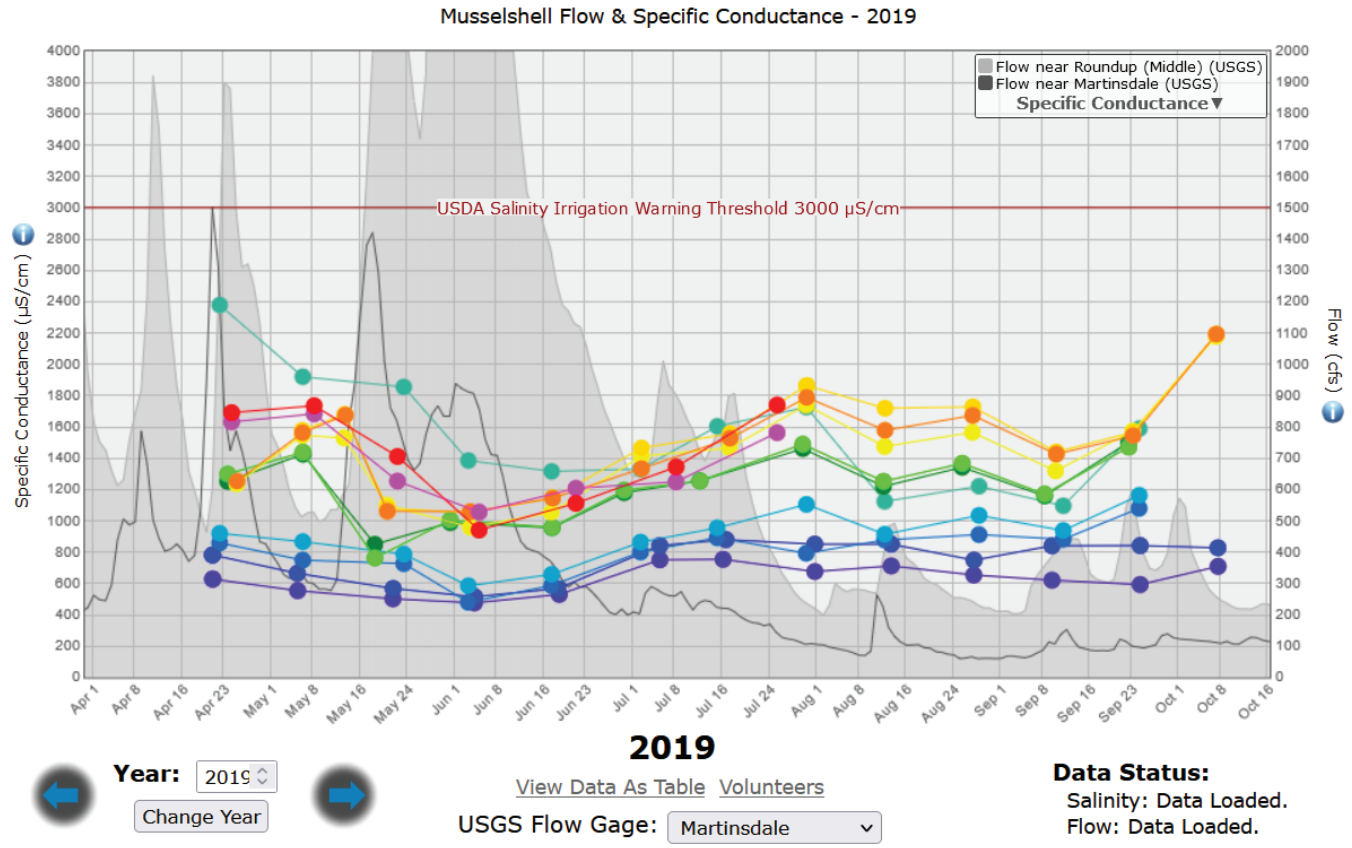

Figure H8. Volunteer monitoring data from 2019; high flows began before the typical peak in river salinity.

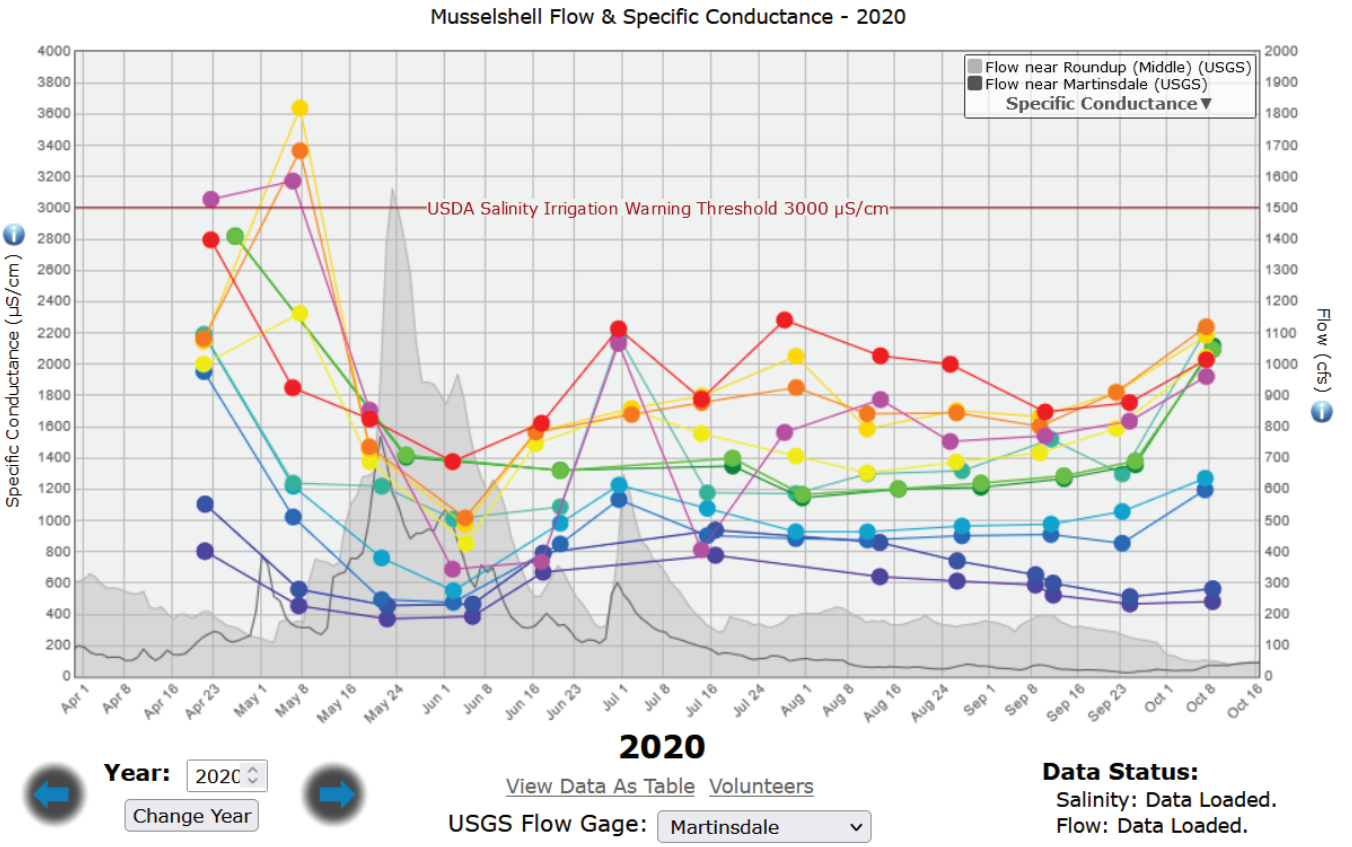

Figure H9. Volunteer monitoring data from 2020; high spring river flows dilute the river salinity.

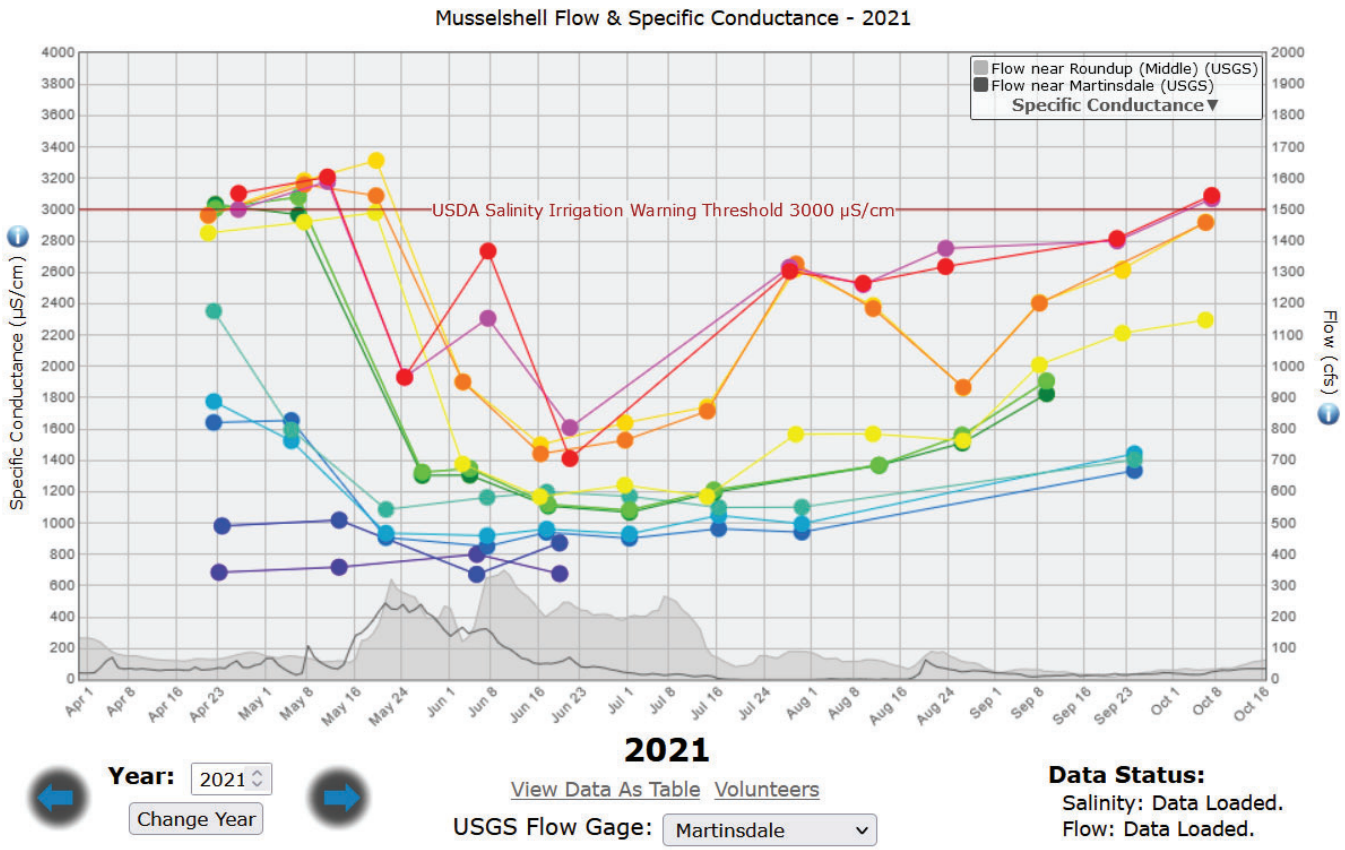

Figure H10. Volunteer monitoring data from 2021; a drought year with no high spring river flow rates.