Supporting Information Cover Sheet

Naturally Occurring Contamination in the Mancos Shale

Stan J. Morrison,[1,2] Craig S. Goodknight,[2] Aaron D. Tigar,[2]
Richard P. Bush,[3] and April Gil[3]

[1]Corresponding author phone: (970) 248-6373; fax (970) 248-7628; email Stan.Morrison@lm.doe.gov.
[2]Environmental Sciences Laboratory, 2597 Legacy Way, Grand Junction, Colorado 81503; Operated by SM Stoller for the U.S. Department of Energy Office of Legacy Management.
[3]U.S. Department of Energy Office of Legacy Management, 2597 Legacy Way, Grand Junction, Colorado 81503.

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“Natural Contamination” Defined

We use “natural contamination” to mean a process by which constituents are transferred from geologic materials (in this case, rock of the Mancos Shale) to groundwater in concentrations that could be harmful to human health or the environment. For this definition, the source of the groundwater may be anthropogenic, but the water must be of high quality prior to contacting the geologic source of the natural contamination. Contaminants are considered to be constituents with concentrations that exceeded regulated standards; uranium, selenium, and nitrate were notable because their concentratons commonly exceeded standards by more than 10-fold. Additional results and discussion for this project are presented in the DOE report (1).

Geology

Mancos Shale Geology in the Study Regions. Mancos Shale nomenclature varies significantly across the Colorado Plateau in the six study regions, as shown in Figure S1. In general, during marine transgressions, shale, mudstone, claystone, and limestone were deposited, whereas sandstone was typically deposited during regressions. Bordering the Western Interior Seaway on the west was the Sevier orogenic belt. As thrusting in the orogenic belt progressed eastward, the west part of the seaway filled, and the sea migrated to eastern Colorado and adjoining states, depositing Pierre Shale.

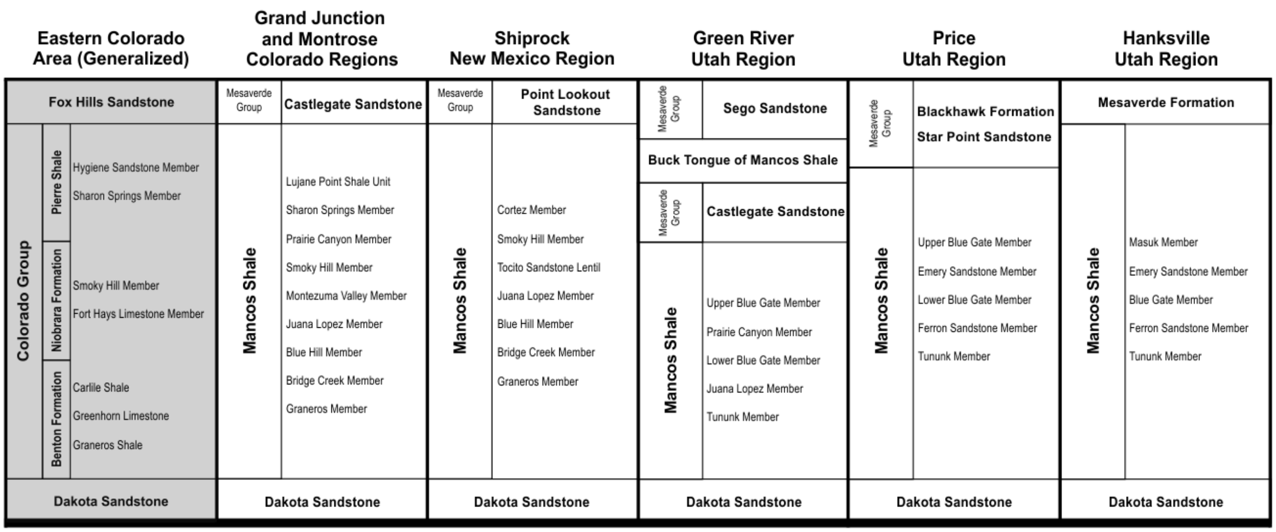

FIGURE S1. Mancos Shale nomenclature for the six sampled regions and eastern Colorado.

Other Black Shale Provinces. In the eastern U.S., a similar depositional environment to that of the Mancos Shale occurred in the shallow epicontinental Appalachian sea during Devonian time. The black shales of the Marcellus Formation and the Chattanooga Shale were deposited in this seaway and may contribute to natural contamination of groundwater similar to that of the Mancos Shale. It would be of value to investigate the occurrence of natural contamination in these other black shale terranes.

Sampling Locations

The following sections contain descriptions of some of the sampling locations within each of the six study regions. The regions and sampling locations are shown in Figure S2. Coordinates and descriptions of all sampling locations are provided in Table S1.

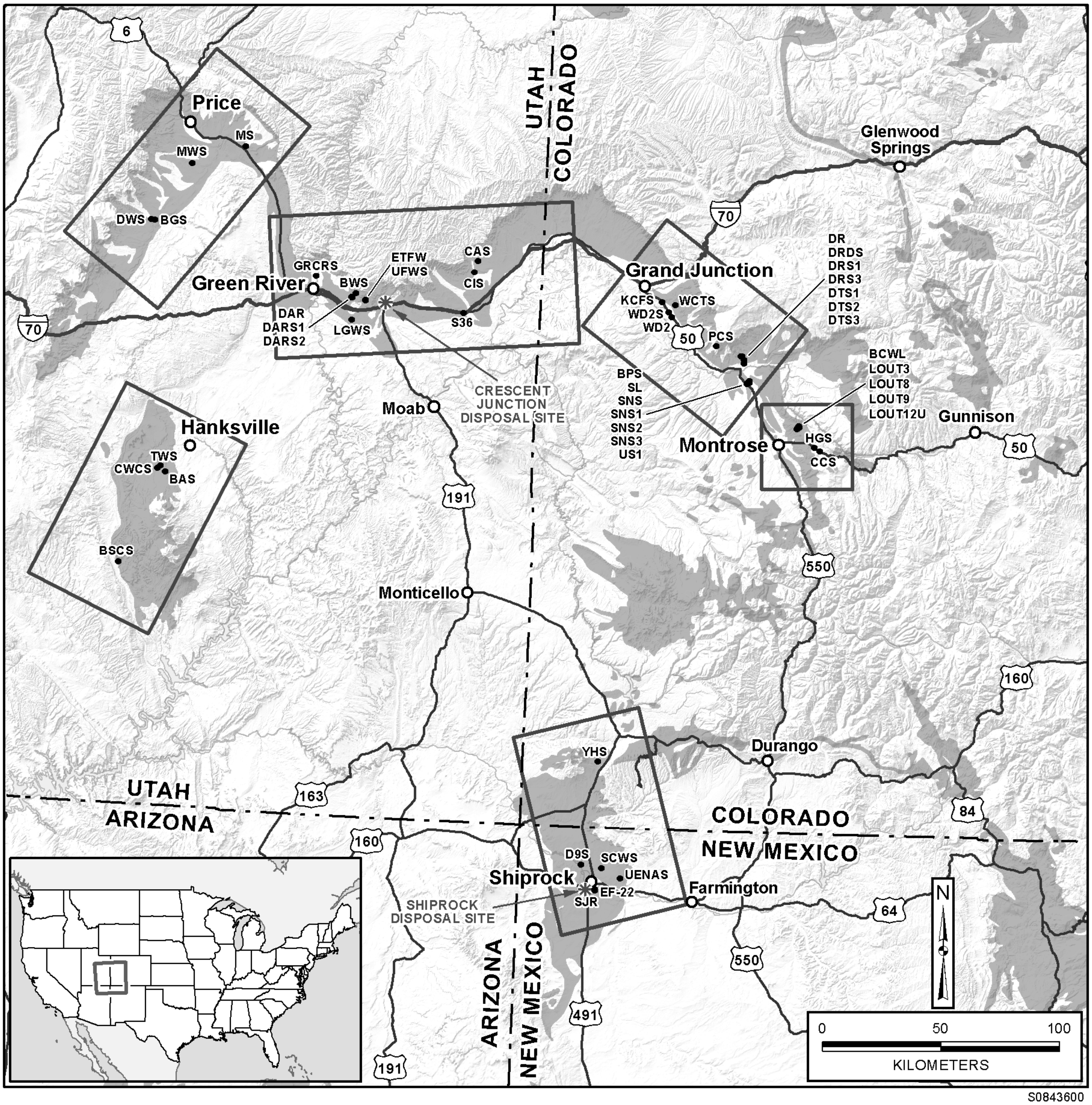

FIGURE S2. Sampling regions (rectangles), sampling locations (dots), and Mancos Shale outcrop (dark shade).

Grand Junction, Colorado, Region. Sampling locations in the Delta Reservoir area are shown in Figures S3 and S4. Delta Reservoir (DR) occupies 1.3 hectares and is fed by pristine water from highlands of the nearby Grand Mesa. Seepage through the reservoir dam was sampled 40 m downgradient at DRDS. Seeps DRS1 and DRS3 are about 440 m hydraulically downgradient of the reservoir. To reach the seeps, groundwater in the Mancos Shale beneath Delta Reservoir migrates laterally through fractures and along bentonite beds.

FIGURE S3. Sampling locations in the north part of the Delta Reservoir area. Inset is a photo of DRS3 Seep.

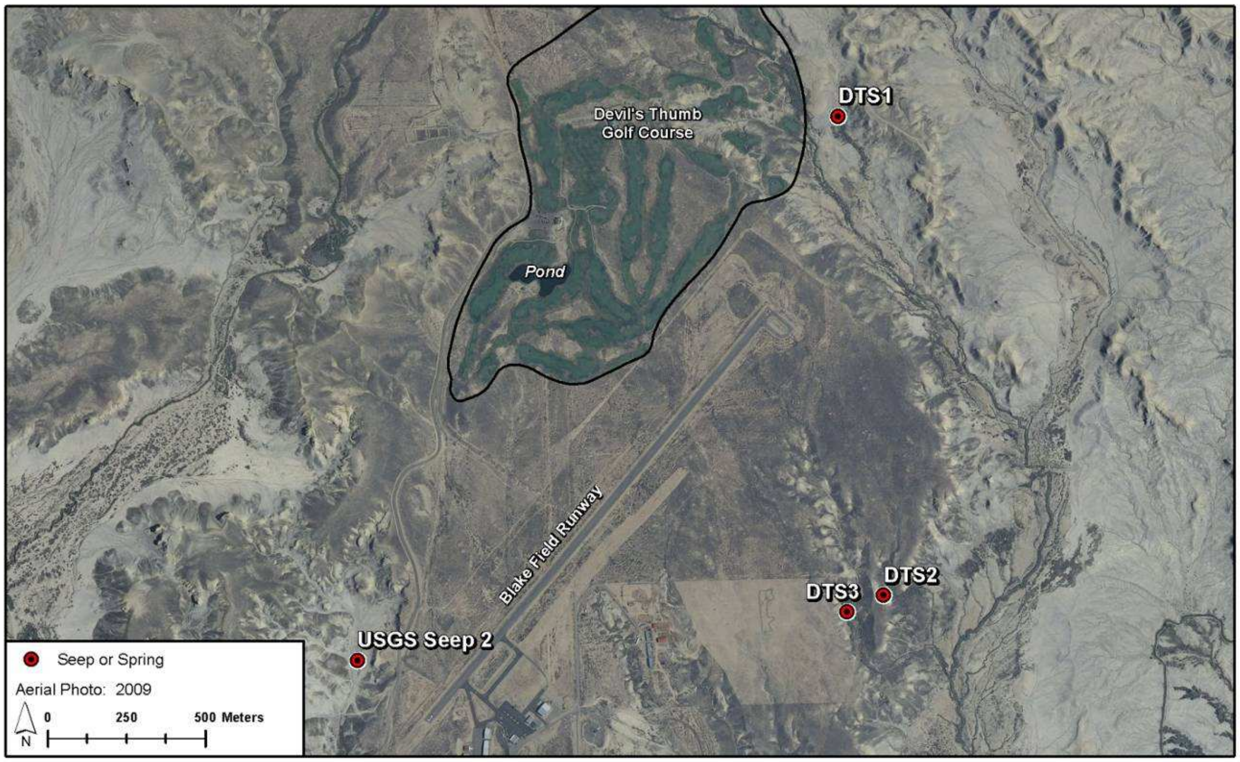

FIGURE S4. Sampling locations and location of USGS Seep 2 in the south part of the Delta Reservoir area around Devil's Thumb Golf Course.

Water is conveyed 1.6 km through a pipe from Delta Reservoir to ponds on the Devil's Thumb Golf Course. Shortly after the golf course ponds were filled, groundwater seeps appeared in nearby areas such as USGS Seep 2, DTS1, DTS2, and DTS3. In November 2001, U.S. Geological Survey personnel sampled USGS Seep 2 about 1280 m from the golf course ponds (4). Using the time period from the filling of the ponds to the first documented seepage, we estimated a minimum flow velocity through the shale of 2.4 m per day. The pond was later lined, causing the seep to dry up, confirming that the pond was the source of the seep water and that groundwater can move at high velocity through the Mancos.

South of the Delta Reservoir area, Sweitzer Lake (SL) has nearby seeps (BPS, SNS, and SNS3) that flow from Mancos Shale, as shown in Figure S5. Northwest of the Delta Reservoir area, Point Creek Seep (PCS) flows from the Mancos in an isolated area with no nearby surface water.

In the north part of the Grand Junction region around Whitewater (Figure S6), Kannah Creek Flowline Spring (KCFS) emerges from the Mancos and flows into a drainage. Also, water that seeps from the bank (WD2S) of U.S. Highway 50 originates in an irrigation canal (WD2) and migrates about 500 m through the Mancos.

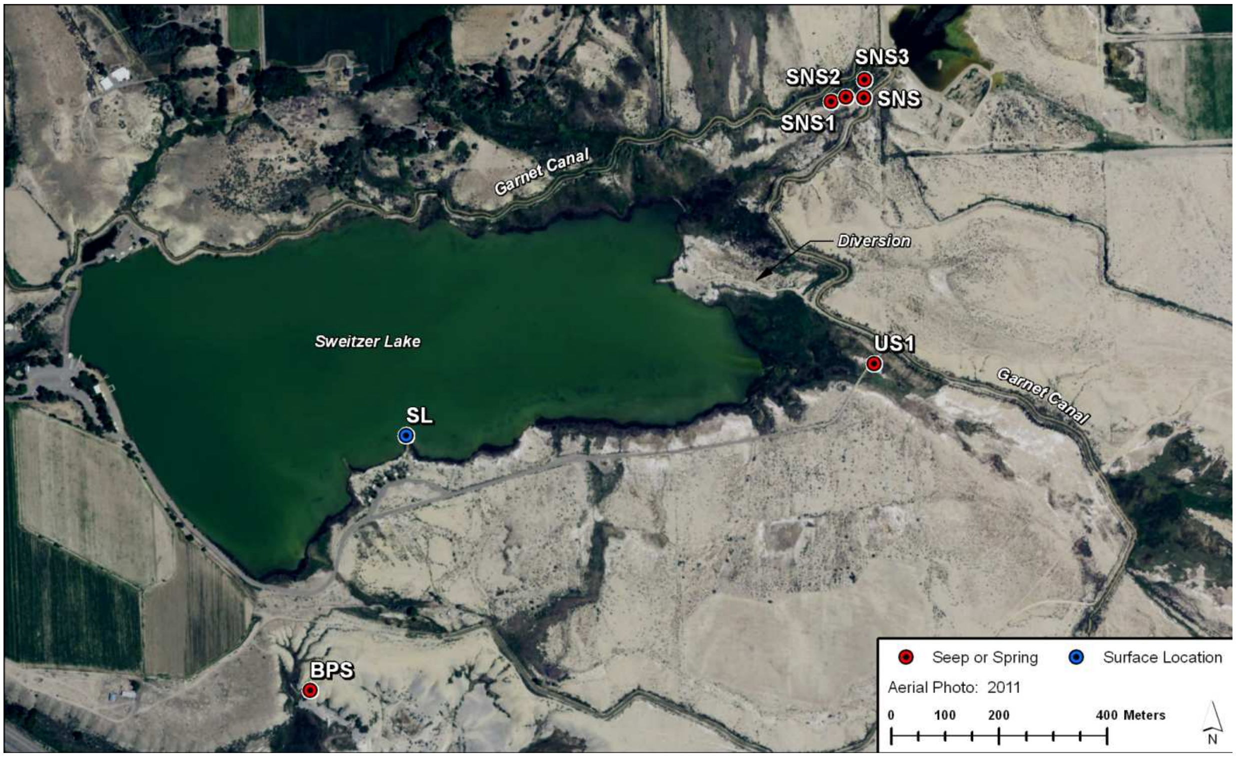

FIGURE S5. Sampling locations in and near Sweitzer Lake.

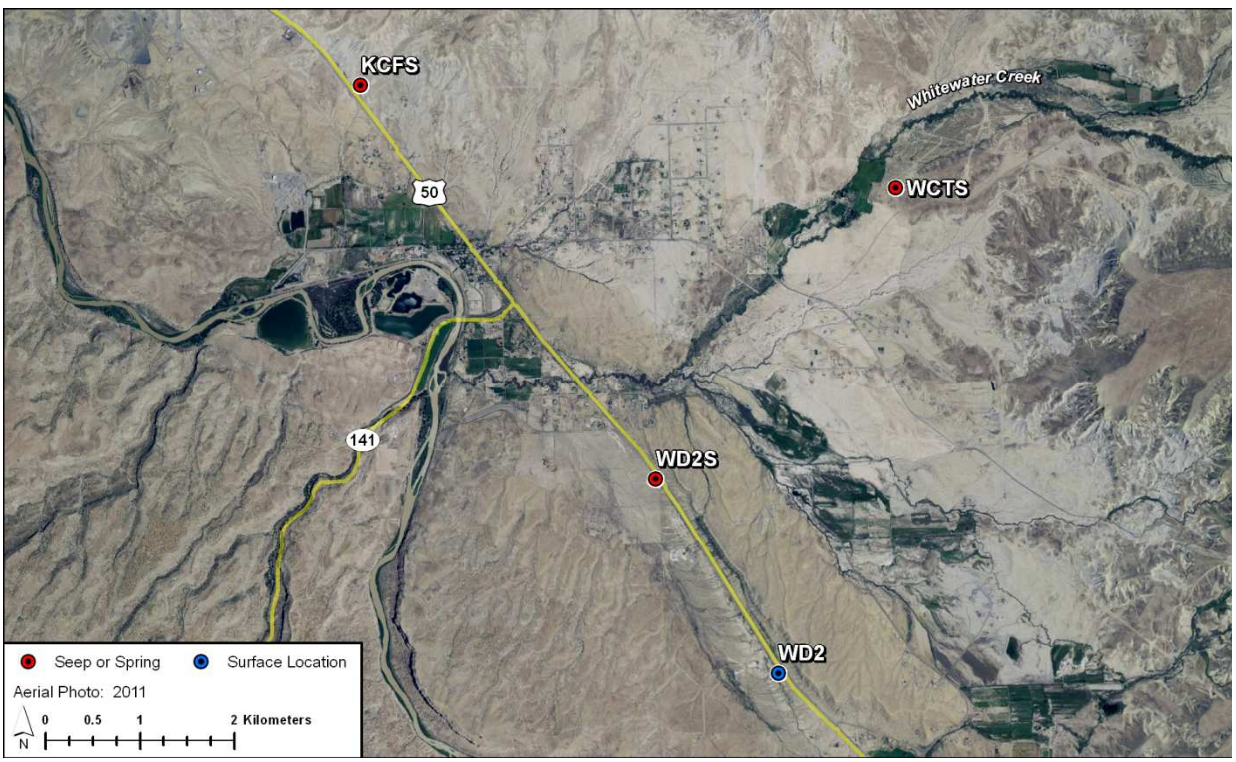

FIGURE S6. Sampling locations near Whitewater.

Green River, Utah, Region. Groundwater from Cato Springs (CAS) issues from a stream bank underlain by Mancos Shale. Section 36 Seep (S36) is in a drainage containing seepage that originates in the Mancos. Browns Wash Seep (BWS) is in an arroyo bordered by Mancos Shale; seepage is associated with Mancos and alluvium.

Seep LGWS was sampled on the bank of Little Grand Wash and flows from alluvium and Mancos Shale. Green River Canal Return Seep (GRCRS), referred to as SP-3 (5), is on the bank of an irrigation canal. This seep flows from alluvium and Mancos Shale and may be influenced by irrigation

Daly Reservoir (DAR) was built as a range improvement in April 1983. Seeps DARS1 and DARS2 (Figure S7) are fed from the water in DAR and are 70 and 110 m downstream, respectively. These seeps flow from a slope of gray shale in the Mancos into an arroyo.

FIGURE S7. Sampling locations in the Daly Reservoir area.

Hanksville, Utah, Region. Town Wash Spring (TWS), Cottonwood Creek Spring (CWCS), and Bert Avery Spring (BAS) issue from sandstone of the Ferron Sandstone Member of Mancos Shale.

Montrose, Colorado, Region. Cedar Creek Seep (CCS) is at the highest-elevation portion of a broad seepage area west of Cerro Summit (Figure S8). At Houston Gulch Seep (HGS), red groundwater seeps from shale of the Mancos.

All seeps with the prefix LOUT are in the Loutsenhizer Arroyo area (Figure S9). Location LOUT8 is at the farthest upstream portion of a seepage area and is referred to as "Lower Seep" by the USGS (4). LOUT9 is another seepage area about 1 km upstream of LOUT8 and is referred to as "Upper Seep" by the USGS (4). LOUT3 and LOUT12U seep from bedded gray shale on a gentle grassy slope and a steep Mancos hillside, respectively. The West Lateral of Bostwick Canal (BCWL) runs above Loutsenhizer Arroyo in Bostwick Park and is the source of water for the seeps.

FIGURE S8. Sampling locations west of Cerro Summit. Inset is a photo of Cedar Creek Seep.

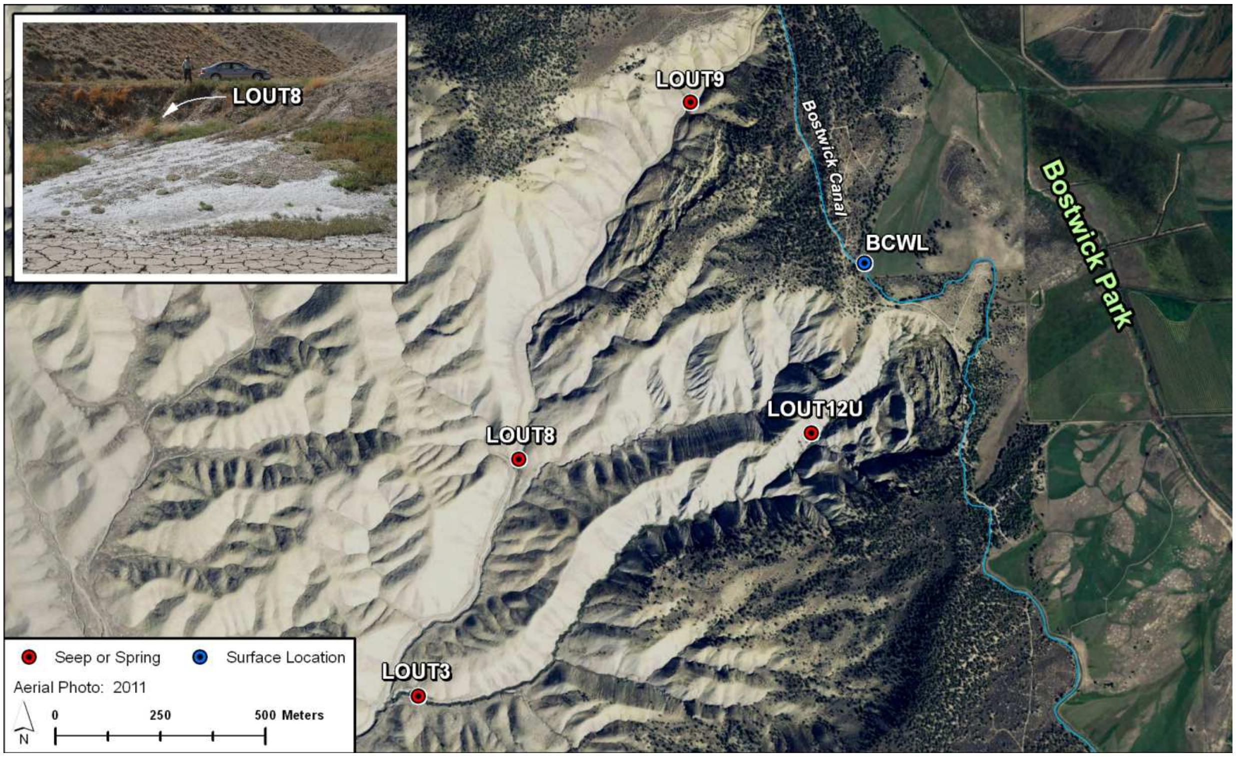

FIGURE S9. Sampling locations in the Loutsenhizer Arroyo area. Inset is a photo of LOUT8 Seep.

Price, Utah, Region. At Mud Spring (MS), clear water flowing from a vertical pipe is fed by groundwater seepage at the base of an alluvial fan overlying Mancos Shale. Dutchmans Wash Seep (DWS) is in a large, flat area covered by pervasive efflorescence. Blue Gate Spring (BGS) issues from dark gray shale of the Blue Gate Member of the Mancos.

Shiprock, New Mexico, Region. Ditch 9 Spring (D9S) is in a marsh along the base of a steep shale hill of Mancos. Salt Creek Wash Seep (SCWS) is at the farthest upstream appearance of seepage in a wash that is incised into Mancos Shale. At Upper Eagle Nest Arroyo, a seep (UENAS) issues from the bank of an arroyo also incised into the Mancos. No apparent sources of surface water are near SCWS or UENAS.

Yucca House Spring (YHS) is in Yucca House National Monument where Wright (6) reported specific conductivity values ranging from 1260 to 2050 µS/cm and uranium concentrations from 7.46 to 13.1 µg/L for water sampled four times from September 2002 to September 2003. The spring originates in sandstone of the Juana Lopez Member of the Mancos. During the irrigation season, groundwater is supplemented by water from the Ute Mountain Ditch.

East Fork (EF-22) is in a tributary about 30 m from its confluence with Many Devils Wash. Many Devils Wash is about 0.8 km from DOE's Shiprock uranium mill tailings disposal site, and DOE is responsible for remediating the wash. EF-22 is the only sampling location that is near a known source of anthropogenic uranium contamination. Remediation efforts in Many Devils Wash include construction of a collection drain, surface water catchment dam, and riprap cover downstream of sampling location EF-22. The groundwater system at EF-22 was not affected by the remediation activities. A sample was collected from the San Juan River (SJR) 35 m upstream of the Many Devils Wash confluence.

Methods

Notes on Methods, Precision, and Accuracy of Chemical Analyses. Uranium concentrations were determined by kinetic phosphorescence analysis (KPA), and these values were used for all results and discussions. Uranium isotopes were measured by alpha spectrometry on some samples. Total uranium determined from the alpha spectrometry results provide an independent check on the KPA results. Results from the two methods matched reasonably well. For uranium concentrations more than 20 µg/L, the average difference between KPA and alpha spectrometry was 1.5%, although a few analyses differed by as much as 10% and one was nearly 20%. For uranium concentrations less than 20 µg/L, the concentrations determined by the two methods varied considerably, probably because of the imprecision of the alpha spectrometry with the counting times used (Table S2).

For the ion chromatograph (IC), all samples were analyzed at least twice and many were analyzed three or four times at different dilution factors to ensure concentrations of chloride, nitrate, and sulfate were within the standard curves and to evaluate dilution or interference effects. Also, some samples were run multiple times at the same dilution factor to determine precision. Agreement between dilutions and between duplicate samples was generally within 10%. Standard additions were done on every fifth sample. Recoveries ranged from 95 to 110%. External standards were also analyzed and ranged from 90 to 110%. Most of the dilution factors ranged from 1 to 100 with some at 200 or 500. As an example of analytical precision on a high salinity sample, IC analyses of sulfate on sample HGS gave a relative standard deviation (RSD) of 2.3% for 8 analyses of the same sample. For the IC, external standards were run at the beginning and end of each run and results ranged from 95 to 110%.

Argon chloride (ArCl) is a polyatomic species which can form in the argon plasma of an inductively-coupled-plasma mass spectrometer (ICP-MS) when analyzing high-concentration chloride samples. Because ArCl has the same masses as arsenic (75 amu) and selenium (77 amu), the mass spectrometer can not differentiate between ArCl and the elements of interest. Therefore, high concentrations of chloride can interfere. An Agilent 7700 ICP-MS equipped with a collision cell was used for the analysis. Collision cell ICP-MS is advantageous because it is virtually free of the polyatomic interferences that affect arsenic and selenium analyses. Use of this instrument minimizes chloride interferences. In addition, to ensure removal of interferences, matrix spikes, serial dilutions, and interference check solutions were run. Serial dilution checks were run on six of the samples and all dilutions were within 10% of each other. Replicate precision and duplicate precision were within 10% and calibration verification standards ranged from 90 to 110%.

Results

Constituent Concentrations by Sampling Location. Concentrations of five constituents in groundwater are shown in Figure S10 for 36 of the sampling locations—the locations that had analyses of all five constituents. A comprehensive set of chemical data is provided in Table S2.

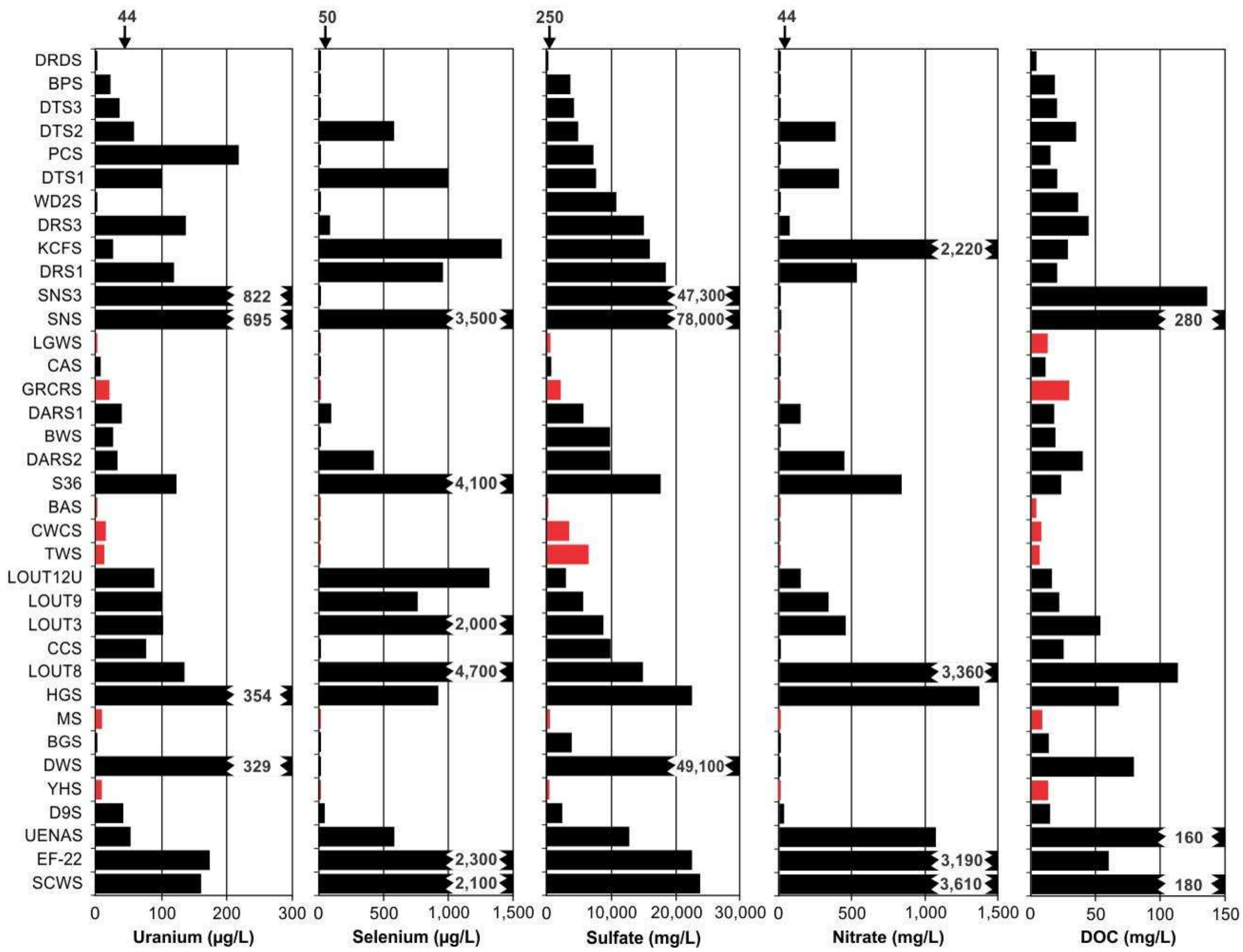

FIGURE S10. Concentrations of selected chemicals in groundwater samples. Values that exceeded the graph maximums are indicated. Red bars are samples of groundwater from sandstone; all others are from shale. Arrows at top indicate drinking water standards (7).

Water Isotopes. In most cases, seeps were flowing at less than 1 L/min and there was concern that atmospheric exposure during sampling could cause evaporative concentration. Water isotopes were analyzed to help determine if samples had been evaporated prior to or during sampling. Most of the water isotopic signatures plot to the right (^{18}O enrichment) of the local meteoric water line (LMWL) for the Colorado Plateau (8) as shown in Figure S11. There was no obvious difference in the water isotopic signatures among samples collected at various sampling rates.

Water samples with specific conductivity values more than 20,000 µS/cm generally plot farther to the right (^{18}O enriched) than those with specific conductivity values less than 20,000 µS/cm (Figure S11), suggesting that some water samples were affected by evaporation. From these data, we surmise that most of the evaporation signature observed in carefully collected (those that avoided recent surface exposure) groundwater samples occurred during recharge and are representative of in situ Mancos groundwater conditions.

Water from BCWL and seeps in the Loutsenhizer Arroyo area were isotopically lighter than those in other areas (Figure S12). Water in BCWL comes from the Cimarron River draining part of the San Juan Mountains, which receive isotopically light rainout from clouds moving east. Lighter isotopic signatures are known to occur in high elevation areas from Raleigh fractionation effects (9). The isotopic signature of BCWL is similar to that of the Loutsenhizer Arroyo area seeps, supporting the field observation that BCWL is the source of recharge.

Isotopic signatures in Delta Reservoir and related seeps are light owing to water piped from 3,000 m elevation on Grand Mesa. The similarity of isotopic signatures of Delta Reservoir water and the nearby seeps suggests that the reservoir is the source of the seeps (Figure S12). In contrast, isotopic signatures are heavier in the Daly Reservoir area.

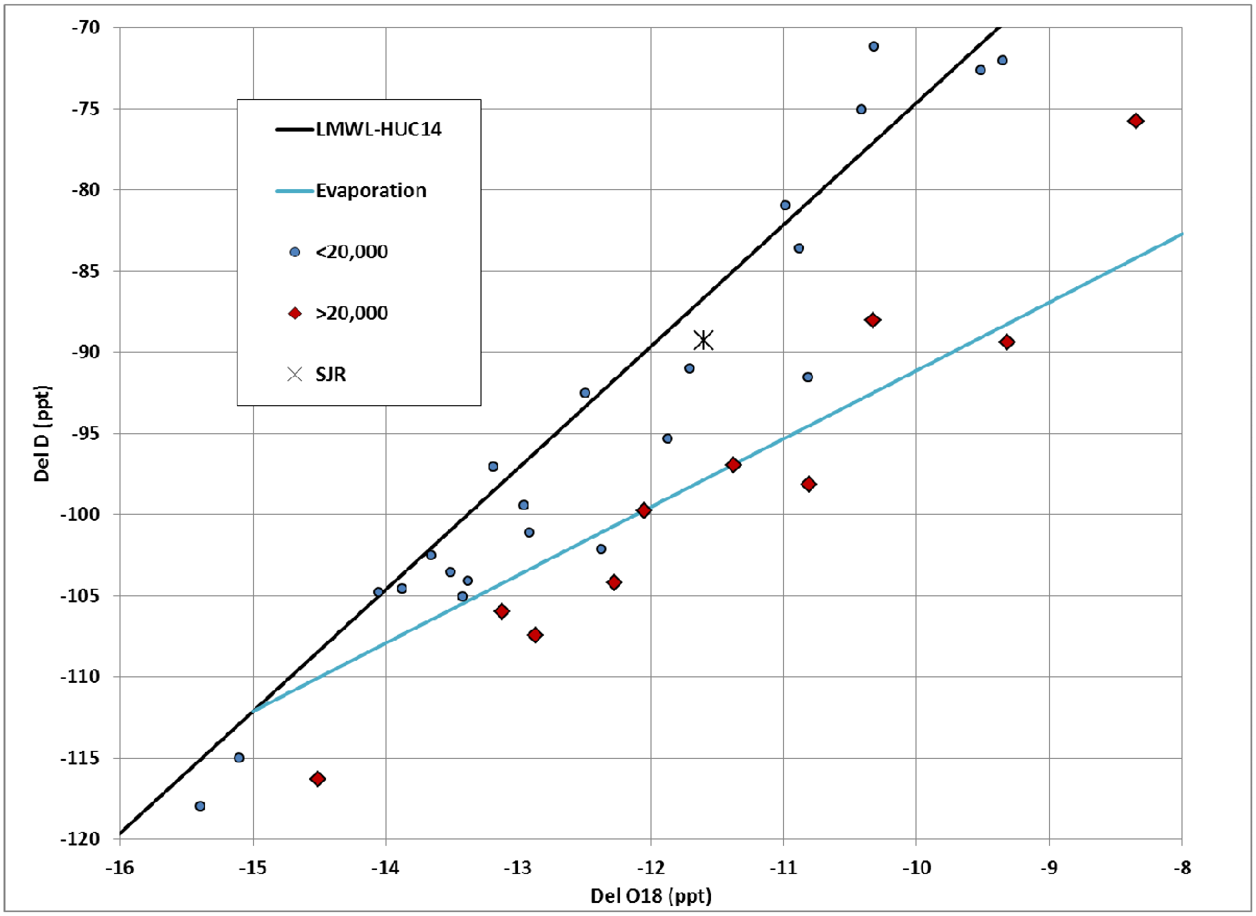

FIGURE S11. $\delta^{18}O$ (Del O18) and $\delta^{2}H$ (Del D) results for groundwater samples. Samples are divided into two groups based on a specific conductivity of 20,000 µS/cm. LMWL-HUC14 = local meteoric water line for Colorado Plateau (8). SJR = San Juan River. ppt = parts per thousand. Evaporation line is drawn for 25% humidity.

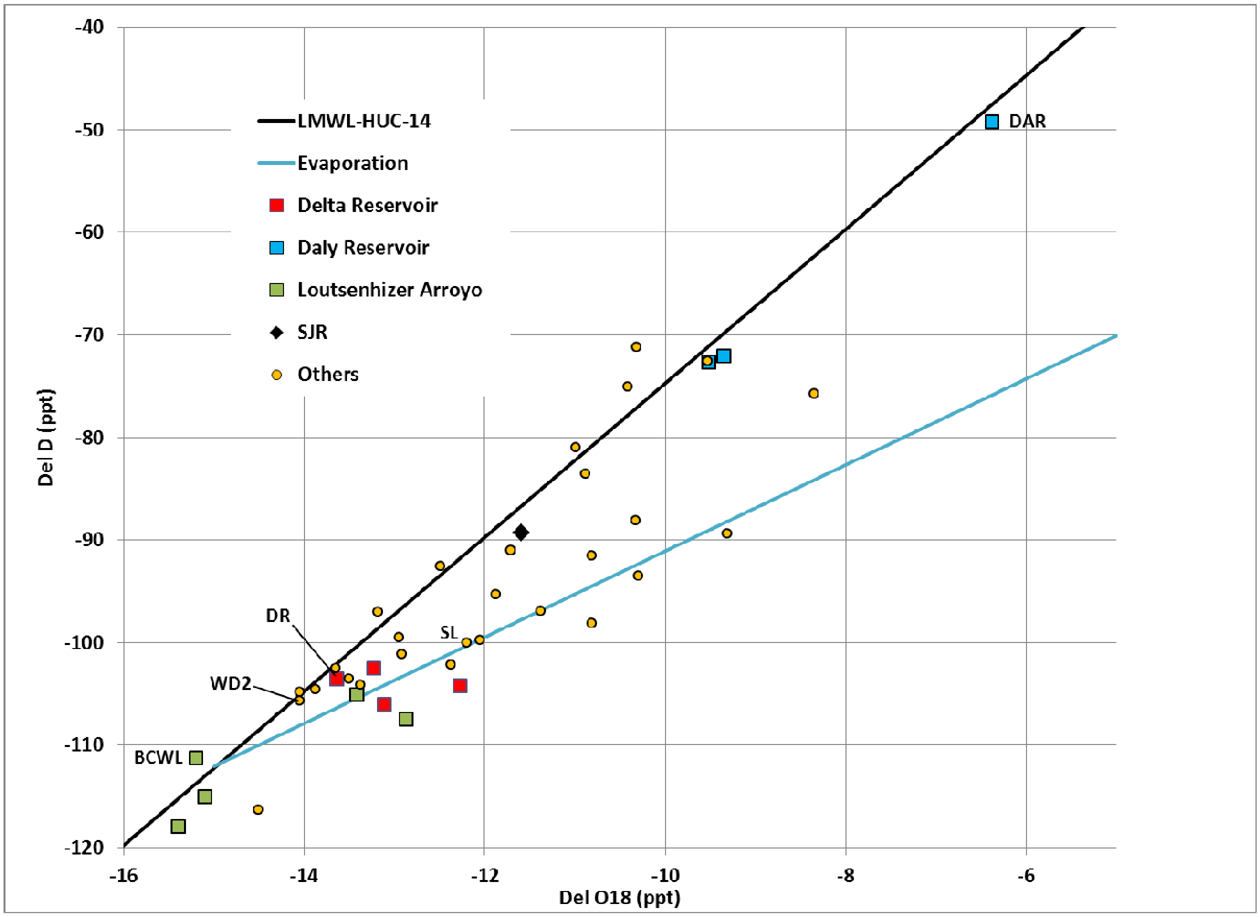

FIGURE S12. $\delta^{18}O$ (Del O18) and $\delta^{2}H$ (Del D) results. Surface water samples are labeled, all others are seeps. Samples are color coded by sampling area. LMWL-HUC14 = local meteoric water line for Colorado Plateau. SJR = San Juan River. ppt = parts per thousand. Evaporation line is drawn for 25% humidity.

TABLE S1. Sampling Location Data

Seeps and Springs

No.	Location	ID	Latitude	Longitude	USGS Site No.	Geologic Unit*	Region	Area
1	Bert Avery Spring	BAS	38.26847466	–110.8225768	381603110491901	Ferron Sandstone	Hanksville	
2	Blue Gate Spring	BGS	39.2207617	–110.9513918	391315110570301	Blue Gate	Price	
3	Buen Pastor Spring	BPS	38.70697125	–108.0353522		middle Smoky Hill	Grand Junction	
4	Bitter Spring Creek Spring	BSCS	37.91682206	–111.0217921	375458111011901	Emery Sandstone	Hanksville	
5	Browns Wash Seep	BWS	38.98516015	–109.9522626	385906109570601	Upper Blue Gate	Green River	
6	Cato Springs	CAS	39.13246669	–109.3674558	390758109220201	Upper Blue Gate	Green River	
7	Cedar Creek Seep	CCS	38.458021	–107.673677		upper or middle Mancos	Montrose	
8	Cisco Springs	CIS	39.08870947	–109.3822425	390519109230001	Prairie Canyon	Green River	
9	Cottonwood Creek Spring	CWCS	38.27976	–110.861307	381639110513801	Ferron Sandstone	Hanksville	
10	Ditch 9 Spring	D9S	36.85511911	–108.7483559		Cortez	Shiprock	
11	Daly Reservoir Spring 1	DARS1	38.97021006	–109.9710173		upper Prairie Canyon	Green River	Daly Reservoir
12	Daly Reservoir Spring 2	DARS2	38.97056543	–109.9711552		upper Prairie Canyon	Green River	Daly Reservoir
13	Delta Reservoir Dam Spring	DRDS	38.809687	–108.069081		Prairie Canyon	Grand Junction	Delta Reservoir
14	Delta Reservoir Seep 1	DRS1	38.810393	–108.063758		Prairie Canyon	Grand Junction	Delta Reservoir
15	Delta Reservoir Seep 3	DRS3	38.808375	–108.064455		Prairie Canyon	Grand Junction	Delta Reservoir
16	Devil's Thumb Seep 1	DTS1	38.79759965	–108.0544136		upper Smoky Hill	Grand Junction	Delta Reservoir
17	Devil's Thumb Seep 2	DTS2	38.78388498	–108.053317		middle Smoky Hill	Grand Junction	Delta Reservoir
18	Devil's Thumb Seep 3	DTS3	38.78344064	–108.0546702		middle Smoky Hill	Grand Junction	Delta Reservoir
19	Dutchmans Wash Seep	DWS	39.22153704	–110.9688968		Blue Gate	Price	
20	EF–22 Seep	EF–22	36.759505	–108.678292		Cortez	Shiprock	
21	East Tributary Floy Wash	ETFW	38.96177	–109.904612		upper Blue Gate	Green River	
22	Green River Canal Return Seep	GRCRS	39.04252778	–110.1511944	390233110090401	upper Blue Gate	Green River	
23	Houston Gulch Seep	HGS	38.471966	–107.700601		upper or middle	Montrose	

No.	Location	ID	Latitude	Longitude	USGS Site No.	Geologic Unit*	Region	Area
						Mancos		
24	Kannah Creek Flowline Spring	KCFS	39.006019	–108.462288		lower Smoky Hill	Grand Junction	
25	Little Grand Wash Seep	LGWS	38.88477648	–109.9658041		lower Blue Gate	Green River	
26	Loutsenhizer 12 Upper	LOUT12U	38.545237	–107.776984		upper or middle Mancos	Montrose	Loutsenhizer Arroyo
27	Loutsenhizer 3	LOUT3	38.5399	–107.787952		upper or middle Mancos	Montrose	Loutsenhizer Arroyo
28	Loutsenhizer 8	LOUT8	38.544899	–107.784986	383242107470401	upper or middle Mancos	Montrose	Loutsenhizer Arroyo
29	Loutsenhizer 9	LOUT9	38.55241793	–107.7799697	383307107454701	upper or middle Mancos	Montrose	Loutsenhizer Arroyo
30	Mud Spring	MS	39.51934353	–110.5325294	393103110315901	middle Mancos	Price	
31	Mathis Wash Seep	MWS	39.44309801	–110.7881307		Blue Gate	Price	
32	Point Creek Seep	PCS	38.84549654	–108.1921318	385043108112901	upper Prairie Canyon	Grand Junction	
33	Section 36 Spring	S36	38.93193402	–109.4255796		middle Blue Gate	Green River	
34	Salt Creek Wash Seep	SCWS	36.84469614	–108.6501375		Cortez	Shiprock	
35	Sweitzer NE Seep	SNS	38.71654655	–108.0231702		upper Smoky Hill	Grand Junction	
36	Sweitzer NE Seep 1	SNS1	38.71649529	–108.0238606		upper Smoky Hill	Grand Junction	
37	Sweitzer NE Seep 2	SNS2	38.71656063	–108.0235525		upper Smoky Hill	Grand Junction	
38	Sweitzer NE Seep 3	SNS3	38.71684347	–108.0231466		upper Smoky Hill	Grand Junction	
39	Town Wash Spring	TWS	38.28946022	–110.84917	381721110505401	Ferron Sandstone	Hanksville	
40	Upper Eagle Nest Arroyo Spring	UENAS	36.80853481	–108.560075		Cortez	Shiprock	
41	Upper Floy Wash Spring	UFWS	38.96103007	–109.9056714	385738109541901	upper Blue Gate	Green River	
42	USGS Seep 1	US1	38.71211716	–108.02314	**	upper Smoky Hill	Grand Junction	
43	Whitewater Creek Tributary Seep	WCTS	38.99507784	–108.3979729		Smoky Hill	Grand Junction	
44	Whitewater Ditch No. 2 Seep	WD2S	38.96777266	–108.4276475		Blue Hill	Grand Junction	
45	Yucca House Spring	YHS	37.250161	–108.686194	371500108410801	Juana Lopez	Shiprock	

* Member of Mancos Shale or position within the Mancos
**Thomas (2)

Surface Locations

No.	Location	ID	Latitude	Longitude	Geologic Unit*	Region	Area
1	Bostwick Canal West Lateral	BCWL	38.54883569	–107.7753634	upper Mancos	Montrose	Loutsenhizer Arroyo
2	Daly Reservoir	DAR	38.96965	–109.970598	upper Prairie Canyon	Green River	Daly Reservoir
3	Delta Reservoir	DR	38.810042	–108.068961	Prairie Canyon	Grand Junction	Delta Reservoir
4	San Juan River	SJR	36.764259	–108.676992	Cortez	Shiprock	
5	Sweitzer Lake	SL	38.711165	–108.033135	upper Smoky Hill	Grand Junction	
6	Whitewater Ditch No. 2	WD2	38.948979	–108.413333	Blue Hill	Grand Junction	

*Member of Mancos Shale or position within the Mancos.

Deep Wells

No.	Location	Latitude	Longitude	Geologic Unit*	Region	Area	Hole Depth or Screened Interval (m)**
1	Crescent Junction 201	38.9685639	–109.8102278	Lower Blue Gate	Green River		91.7
2	Crescent Junction 202	38.9598794	–109.8099280	Lower Blue Gate	Green River		91.4
3	Crescent Junction 203	38.9668125	–109.8043174	Lower Blue Gate	Green River		91.7
4	Crescent Junction 204	38.9631214	–109.8042658	Lower Blue Gate	Green River		91.4
5	Crescent Junction 205	38.9585650	–109.8029977	Lower Blue Gate	Green River		91.4
6	Crescent Junction 210	38.9667029	–109.7862156	Lower Blue Gate	Green River		92.0
7	Shiprock Floodplain 860	36.775196	–108.684971	Cortez	Shiprock		25.8–26.5
8	Shiprock Floodplain 861	36.775218	–108.684990	Cortez	Shiprock		41.3–42.1
9	Shiprock Floodplain 862	36.772236	–108.681055	Cortez	Shiprock		27.1–27.9
10	Shiprock Floodplain 863	36.772258	–108.681063	Cortez	Shiprock		41.2–41.9
11	Shiprock Terrace 820	36.774237	–108.685650	Cortez	Shiprock		45.4–46.2
12	Shiprock Terrace 822	36.774239	–108.685686	Cortez	Shiprock		60.7–61.4
13	Shiprock Terrace 823	36.771788	–108.681681	Cortez	Shiprock		29.7–30.5
14	Shiprock Terrace 824	36.771786	–108.681646	Cortez	Shiprock		60.5–61.3
15	Shiprock Terrace 825	36.771812	–108.681660	Cortez	Shiprock		45.0–45.8
16	Delta Landfill 11 ***	38.780934	–108.061472	Smoky Hill	Grand Junction	Delta Reservoir	57.3–58.8

*Member of Mancos Shale or position within the Mancos.

**Wells at Crescent Junction are open–hole (not screened).

***Golder Associates (3)

TABLE S2. Analytical Data

No	Location	Type	ID	Sample	Temp	pH	Sp Cond	ORP	DO	Alkalinity	Cl	NO3	SO4	NH3-N	U	Fe	Ca	Na	Mg	K	DOC	Color	Se	As	B	V	222Rn	U233+234	U235	U238	Total U	AR	$\delta^{18}O$	$\delta^{2}H$
				Date/Time	(deg C)		(µS/cm)	(mV)	(mg/L)	(mg/L as CaCO3)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(µg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)		(µg/L)	(µg/L)	(µg/L)	(µg/L)	(pCi/L)	(pCi/L)	(pCi/L)	(pCi/L)	(ug/L)			
	SEEPS																																	
1	Bert Avery Spring	Seep	BAS	11/17/10 14:00	10.75	7.29	418	-28	2.4	129	11.7	<0.50	67.5		0.19	1.6	48	26	9.8	1.4	4.4	81	0.18	0.94	16	0.28	144	<0.284	0.246	0.322	1.08		-10.88	-83.59
2	Blue Gate Spring	Seep	BGS	11/16/10 11:30	7.68	6.87	6203	-30	7.2	58	287	2.3	3910		<1.0	0.57	410	780	400	15	9.1	<25	0.37	0.33	860	0.16	53.0	0.637	<0.159	<0.0810	0.317		-12.38	-102.17
3	Buen Pastor Spring	Seep	BPS	11/30/10 14:14	4.61	7.49	5639	33	7.1	365	62.3	1.9	3710		22.6	<2.0	380	1200	210	16	12	59	3.8	0.36	570	0.37	130	18.2	<0.168	7.98	23.9	2.28	-10.82	-91.54
4	Bitter Spring Creek Spring	Seep	BSCS	11/18/10 13:40	8.58	7.05	2037	307	0.45						65.3																			
5	Browns Wash Seep	Seep	BWS	11/12/10 10:20	4.78	7.74	10800	245	2.8	359	267	15.0	9850		26.6	<1.0	470	3000	720	1.2	20	65	25	0.48	240	0.47	316	16.0	0.484	8.54	25.8	1.87	-10.41	-75.05
6	Cato Springs	Seep	CAS	11/11/10 10:25	10.97	7.58	2184	-65	0.34	625	21.5	1.7	762		7.6	2.0	73	360	140	3.6	11	160	0.14	4.5	79	0.56	417	4.25	<0.0641	1.83	5.50	2.32	-13.65	-102.53
7	Cedar Creek Seep	Seep	CCS	11/3/10 10:30	10.85	6.55	16410	228	4.3	644	1430	2.9	9930		76.7	<1.0	450	3300	1000	27	25	<25	12	0.23	1200	<0.15	1620	38.9	1.44	23.5	70.9	1.66	-13.51	-103.55
8	Cisco Springs	Seep	CIS	11/11/10 12:18	9.28	7.56	3947	68	1.5						13.5																			
9	Cottonwood Creek Spring	Seep	CWCS	11/17/10 13:12	7.18	7.07	5965	-92	0.89	390	137	1.7	3530		15.4	0.79	390	870	210	4.1	7.8	130	1.3	0.58	320	0.54	266	6.98	0.484	3.64	11.1	1.92	-10.99	-80.95
10	Ditch 9 Spring	Seep	D9S	12/2/10 15:45	13.28	7.01	4045	174	1.7	329	33.3	38.5	2460		42.0	<0.20	480	310	200	13	9.8	34	54	0.20	730	0.24	793	30.0	0.783	14.8	44.6	2.03	-12.50	-92.53
11	Daly Reservoir Spring 1	Seep	DARS1	11/12/10 11:40	14.40	7.88	9187	149	0.47	305	97.4	150	5730		39.7	<0.20	360	1900	250	24	17	200	110	0.36	570	0.52	715	24.9	1.12	12.5	37.9	1.99	-9.51	-72.65
12	Daly Reservoir Spring 2	Seep	DARS2	11/12/10 11:40	16.06	7.71	15380	124	0.8	335	175	449	9860		33.2	<0.20	360	3600	320	34	41	430	400	0.37	560	0.59	442	22.7	0.565	11.5	34.6	1.97	-9.35	-72.06
13	Delta Reservoir Dam Spring	Seep	DRDS	11/8/10 11:44	14.58	7.97	793	145	5.6	101	1.1	8.2	312		3.2	<0.20	150	9.3	9.0	1.2	2.9	<25	0.41	1.3	24	0.66	311	1.31	<0.0306	1.07	3.21	1.22	-13.24	-102.47
14	Delta Reservoir Seep 1	Seep	DRS1	11/8/10 14:01	10.37	7.16	27250	174	1.8	925	1270	534	18500		119	<1.0	380	7600	600	27	16	170	950	0.20	550	0.35	233	108	1.90	41.5	125	2.60	-12.28	-104.22
15	Delta Reservoir Seep 3	Seep	DRS3	11/8/10 15:02	15.18	7.25	22840	198	3.6	1040	798	76.5	15100		137	<1.0	410	5900	600	35	44	350	100	3.0	690	0.84	353	98.6	3.74	47.9	145	2.06	-13.12	-105.99
16	Devils Thumb Seep 1	Seep	DTS1	12/7/10 10:26	1.86	7.11	13500	227	1.8	407	388	413	7700		101	<0.20	330	3000	440	20	20	140	990	0.26	380	0.56	792	69.7	1.47	30.5	91.9	2.29	-13.38	-104.12
17	Devils Thumb Seep 2	Seep	DTS2	12/7/10 14:11	11.59	7.25	8724	166	5.2	492	387	389	4900		58.4	<0.20	420	1500	440	32	23	180	600	0.43	760	1.2	208	44.9	1.26	19.1	57.7	2.35	-11.88	-95.32
18	Devils Thumb Seep 3	Seep	DTS3	12/7/10 12:57	8	6.99	6576	172	0.40	338	146	6.1	4270		36.5	<0.20	390	820	420	18	13	95	12	0.24	550	0.34	1050	29.5	0.693	13.9	41.9	2.12	-12.92	-101.11
19	Dutchmans Wash Seep	Seep	DWS	11/16/10 12:05	3.57	8.45	48520	108	8.1	882	1030	2.9	49100		329	<2.0	430	15000	2200	72	81	380	10	1.2	430	1.4	<1.0	253	5.74	101	305	2.50	-10.33	-88.07
20	EF-22 Seep	Seep	EF-22	12/2/10 17:02	8.15	7.45	37060	230	0.57	662	1920	3190	22600		174	0.40	360	9200	1300	34	59	210	2300	0.91	510	3.3	407	139	2.87	57.0	172	2.44		
21	East Tributary Floy Wash	Seep	ETFW	11/11/10 14:00	10.05	7.87	21320	139	2.2						38.1																			
22	Green River Canal Return Seep	Seep	GRCRS	11/12/10 8:32	6.92	7.24	3847	191	5.6	370	44.7	1.9	2210		21.1	0.24	530	400	100	7.2	28	140	3.6	0.69	310	0.64		13.0	<0.0813	7.38	22.1	1.76	-11.71	-91.03
23	Houston Gulch Seep	Seep	HGS	11/3/10 12:10	19.45	7.36	22790	136	2.4	690	102	1370	22500	1	354	<8.0	450	2600	3300	47	67	580	890	1.8	940	1.4	119	201	8.97	135	408	1.49	-14.51	-116.33
24	Kannah Creek Flowline Spring	Seep	KCFS	11/2/10 12:00	10.90	7.22	26250	221	3.3	417	927	2220	16000	1	26.6	<0.20	400	7200	520	36	24	140	1400	0.15	500	0.20	544	37.1	0.744	9.09	27.5	4.08	-10.81	-98.17
25	Little Grand Wash Seep	Seep	LGWS	11/12/10 14:15	3.87	7.25	1637	10	0.98	75	20.1	9.2	616		1.5	<0.20	160	96	6.2	14	12	49	16	0.39	41	0.62	<1.0	2.02	<0.157	0.895	2.75	2.26	-10.32	-71.18
26	Loutsenhizer 12 Upper	Seep	LOUT12U	11/3/10 15:00	13.36	6.13	5190	281	6.7	310	176	151	3010		89.1	<0.40	410	640	230	9.9	16	79	1300	0.24	810	0.65	452	48.3	1.48	27.2	82.0	1.78	-15.39	-117.96
27	Loutsenhizer 3	Seep	LOUT3	11/3/10 17:30	11.97	7.03	15330	228	2.6		818	459	8820		103	<2.0	480	3700	420	29	53	310	2000	0.66	1100	3.1	107	59.8	1.97	35.0	106	1.71	-13.42	-105.05
28	Loutsenhizer 8	Seep	LOUT8	11/4/10 10:15	11.74	7.91	22130	250		428	928	3360	14900	1	135	<2.0	450	6700	720	37	110	600	4700	0.60	990	1.1	433	68.5	2.08	36.6	110	1.87	-12.87	-107.47
29	Loutsenhizer 9	Seep	LOUT9	11/4/10 11:15	15.65	7.54	8844	197		633	79.0	342	5700		102	<0.40	430	1200	680	29	21	170	730	0.22	1200	0.36	455	58.1	2.01	34.0	103	1.71	-15.10	-115.00
30	Mud Spring	Seep	MS	11/16/10 14:50	10.51	7.41	1650	66	3.8	351	52.7	3.9	553		9.7	<0.20	72	170	110	1.8	5.8	71	17	0.35	230	2.3	947	5.65	<0.0582	4.06	12.2	1.39	-14.05	-104.79
31	Mathis Wash Seep	Seep	MWS	11/16/10 13:35	7.69	7.77	70000	255	3.0	1300	3380	33.5	76900		480	0.53	600	23000	7000	14	260	2000											-9.32	-89.40
32	Point Creek Seep	Seep	PCS	11/8/10 8:46	9.82	7.56	10740	277	2.6	610	250	<0.50	7280		218	<1.0	440	1700	640	29	15	60	1.5	0.75	1400	0.24	217	114	2.88	72.4	218	1.57	-13.88	-104.59
33	Section 36 Spring	Seep	S36	11/11/10 14:00	12.41	7.67	24520	164	2.6	479	436	841	17700		123	<1.0	400	6500	840	24	24	84	4100	0.36	260	0.47	256	79.2	1.13	35.9	108	2.21	-11.38	-96.97
34	Salt Creek Wash Seep	Seep	SCWS	12/7/10 11:33	1.97	7.39	48640	238	1.6	1090	7100	3610	23800		160	<0.40	450	15000	1400	62	180	460	2100	0.68	800	1.1	258	150	2.58	53.3	161	2.81		
35	Sweitzer NE Seep	Seep	SNS	11/4/10 14:35	8.09	8.45	68110	126			1980	18.1	78000	3	695	<2.0	520	25000	1950	45	280	2600	3500	12	2000	19		468	15.0	243	733	1.93		
36	Sweitzer NE Seep 1	Seep	SNS1	11/30/10 11:25	3.44	7.56	53320	239	1.2						985																			
37	Sweitzer NE Seep 2	Seep	SNS2	11/30/10 12:18	4.23	8.30	33490	197	4.4						1920																			
38	Sweitzer NE Seep 3	Seep	SNS3	11/30/10 11:54	2.11	7.44	55960	190	0.6	1730	1590	4.1	47300		822	<2.0	480	19000	2700	20	130	520	13	5.3	3200	3.7	193	489	14.4	280	844	1.75	-12.05	-99.78
39	Town Wash Spring	Seep	TWS	11/17/10 11:25	3.36	7.34	10020	-19	1.4	293	171	2.4	6520		13.2	0.31	370	1300	700	6.2	6.6	76	1.7	0.62	89	0.28	221	7.34	0.354	2.61	7.97	2.81	-9.52	-72.55
40	Upper Eagle Nest Arroyo Spring	Seep	UENAS	12/2/10 10:00	8.42	7.3	26610	224	2.7	368	4170	1070	12800		53.0	0.30	470	5900	1000	22	160	<25	540	0.23	700	0.30	403	31.3	0.794	14.7	44.3	2.13		
41	Upper Floy Wash Spring	Seep	UFWS	11/11/10 0:00	9.46	7.64	6514	100	3.1						9.5																			
42	USGS Seep 1	Seep	US1	11/30/10 15:23	2.85	8.35	41620	127	6.4						362																			
43	Whitewater Creek Tributary Seep	Seep	WCTS	12/7/10 16:22											700						260	1500											-10.30	-93.48
44	Whitewater Ditch No. 2 Seep	Seep	WD2S	11/2/10 13:20	11.33	4.15	14280	258	4.1	0	171	<0.50	10800		<1.0	17	380	3000	720	20	36	270	5.6	2.8	1500	0.19	317	<0.249	<0.00	<0.190	<0.568		-12.95	-99.46
45	Yucca House Spring	Seep	YHS	12/1/10 13:30	9.92	7.00	1442	130	1.9	317	28.6	2.0	463		9.4	<0.20	160	92	56	0.89	8.9	<25	5.9	0.20	150	1.0	811	7.21	<0.105	2.93	8.81	2.46	-13.19	-97.05
	SURFACE LOCATIONS																																	
1	Bostwick Canal West Lateral	Surf	BCWL	11/4/10 12:30		8.53	197	201		64	0.90	1.7	27.1		0.40	<0.20	22	5.8	4.6	2.4	3.3	<25	0.18	0.37	<3.1	0.98	1.2	0.472	<0.00	0.296	0.885	1.59	-15.20	-111.24
2	Daly Reservoir	Surf	DAR	11/12/10 11:40	6.39	8.27	1720	168	9.6	55	24.1	3.7	941		0.75	<0.20	260	120	16	12	7.1	<25	2.5	0.41	89	0.15	0.9	0.864	<0.0314	0.282	0.858	3.06	-6.38	-49.24
3	Delta Reservoir	Surf	DR	11/8/10 11:24	9.77	8.71	114	193	7.8	47	2.8	<0.50	4.1		<0.20	<0.20	14	2.4	4.1	1.5	12	<25	0.058	0.34	<3.1	1.4	<1.0	0.210	<0.00	<0.131	<0.392		-13.64	-103.50
4	San Juan River	Surf	SJR	4/14/11 0:00	11.63	8.22	954	72	9.6	109	15.0	2.2	159		1.7	<0.20	62	62	11	2.9	24	<25	0.75		53			1.39	0.0404	0.905	2.71	1.54	-11.60	-89.27
5	Sweitzer Lake	Surf	SL	11/4/10 15:45	12.94	8.63	1728	-62		124	15.4	2.3	892		11.3	<0.20	140	170	50	5.6	8.5	<25	8.9	0.88	170	1.4	8.1	6.54	<0.195	4.36	13.1	1.50	-12.20	-100.02
6	Whitewater Ditch No. 2	Surf	WD2	11/2/10 14:10	8.13	6.57	2185	234		221	17.8	2.5	1080		24.3	<0.20	270	140	92	4.5	7.9	<25	15	0.69	310	0.63	12.6	10.2	0.526	6.39	19.3	1.60	-14.05	-105.68
	DEEP WELLS																																	
1	Crescent Jct 201	Well	CJ201	9/6/06 0:00	17.58	7.08	54530	263		994	20000	0.36	2200	9.3	2.7	0.51	160	11000	150	57			8.9	<2.0	1500									
2	Crescent Jct 202	Well	CJ202	9/7/06 0:00	19.48	7.15	54950	465		410	22000	0.10	<100	19	5.3	0.62	200	11000	96	54			5.4	<1.7	1100									
3	Crescent Jct 203	Well	CJ203	9/7/06 0:00	18.73	6.93	43330	11		1500	15000	0.080	5500	9.8	<0.24	1.3	140	9800	110	53			<1.4	<3.8	1600									
4	Crescent Jct 204	Well	CJ204	9/7/06 0:00	17.18	6.85	64260	202		472	26000	0.13	<100	22	<0.23	1.5	300	13000	130	64			<2.9	<1.9	1200									
5	Crescent Jct 205	Well	CJ205	9/7/06 0:00	16.95	7.24	66120	56		440	27000	0.22	<100	15	<0.77	0.70	370	13000	140	64			<1.6	<1.9	1100									
6	Crescent Jct 210	Well	CJ210	9/11/06 0:00	17.11	7.08	62430	15		534	5300	<0.040	6100	8.1	20	0.47	70	5700	56	27			<0.67	<0.86	1500									
7	Shiprock FP 860	Well	SHP860	1/23/08 0:00	13.20	7.42	25300	92		544	7540	26	2600	1.1	18.1		140	4000	54	36	170		2.7	<0.40				9.40		3.90		2.41		
8	Shiprock FP 861	Well	SHP861	1/23/08 0:00	13.50	7.34	30540	-5		440	8320	28	5570	18	3.2	6.6	210	6900	84	63	220													
9	Shiprock FP 862	Well	SHP862	1/23/08 0:00	11.60	7.27	28500	65		628	7640	9	3960	2.8	4.4	0.20	200	6300	76	17	190		4.2	<1.9										
10	Shiprock FP 863	Well	SHP863	1/23/08 0:00	12.30	7.44	26210	-7		495	7360	10	5040	7.9	<0.40	2.9	200	6500	74	33	160		0.72	<1.5		<1.7								
11	Shiprock Terrace 820	Well	SHP820	9/2/10 0:00	19.22	7.18	31000	-41		428	9000	17	4200	0.23	72	0.20	190	6400	85	36	150		1.0	<1.0		0.60								
12	Shiprock Terrace 822	Well	SHP822	9/2/10 0:00	16.47	7.35	26230	-37		374	6000	42	6100	0.10	88	0.70	160	5300	70	100	120		1.3											
13	Shiprock Terrace 823	Well	SHP823	2/15/01 0:00	13.70	7.29	17030	246		360	3700	236	3170	4.4	133		100	4700	53	19														
14	Shiprock Terrace 824	Well	SHP824	2/15/01 0:00	18.18	7.03	27700	6		170	5200	1510	5500	26	270	0.10	160	4600	89	170			2.8	1.6		0.60								
15	Shiprock Terrace 825	Well	SHP825	2/15/01 0:00	19.55	6.84	29700	22		189	6700	108	6500	4	41	0.20	250	5800	92	120	140		0.98											
16	Delta Landfill 11*	Well	DLF11	1/19/04 0:00	15.00	8.00	26400			3270	6400	<1.0	5530				20	6800	40	14	47		17										-8.52	-78.04

*Golder Associates (3). Some values estimated from earlier analyses.

References for Supporting Information

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